Guiding start-ups in the Development of a Bio-based Non-structural Closed Façade Building Product

Thesis MSc Civil Engineering (Building Engineering track)

I.I.G. (Isabel) Koopman

Delft University of Technology
ABT Consulting Engineers

May 19th 2025

Supervision
Daily company supervisor from ABT B.V.: ir. D. (Diana) de Krom
Committee chair: Dr.ir. H.R. (Roel) Schipper
University supervisor: Dr.ir. S. (Sander) van Nederveen
University supervisor: Dr.-Ing. M (Marcel) Bilow

This page intentionally left blank.

Executive Summary

The construction industry faces an urgent need to reduce its environmental footprint, in which the adoption of bio-based materials is a valuable step. However, the use of such materials in façades remains limited. This thesis, conducted within the MSc Civil Engineering (Building Engineering track) program at Delft University of Technology, in collaboration with ABT Consulting Engineers, uncovers the experienced challenges and addresses them by developing an information product for start-ups aspiring to bring bio-based non-structural closed façade products to market.

The research focuses on the knowledge and performance aspects necessary for start-ups lacking access to expert consultancy. Through a combination of literature research and interviews with start-ups and industry stakeholders, the study identifies key barriers: difficulties in product testing, difficulties navigating certification and regulatory frameworks, lack of standards tailored to bio-based materials, unfamiliarity with the use of bio-based materials, and difficulty with guarantees on supply, quality and production. Literature was reviewed on bio-based materials (e.g., flax, hemp, straw, cork, mycelium), façade design principles, façade performance (structural, fire, water, air, thermal, moisture, and acoustic), testing methods, and the legislative framework surrounding building products in the Netherlands.

The research methodology involved three phases: (1) expert dialogues to capture industry insights, (2) product development, using the state-of-the-art and results from the expert dialogues, and (3) validation through a feedback questionnaire with the target audience. The expert dialogues, taking place with start-ups, bio-based experts, and building (physics) experts, revealed advice from experience: certification should not be the main focus, but a means to help sell products, and adopt a go-to-market strategy that starts in an accessible market. The experts also gave insight in the useful knowledge from the state of the art, such as information on design tools such as UBAKUS or simple Excel models, testing methods such as compressive and flexural strength, bonding, UV, freeze, and fire resistance checks, how to comply with relevant standards by testing, and sustainability measurement tools such as LCA, MPG, BCI.

The final product is an interactive information guide designed specifically for start-ups. It navigates users through early-stage product development phases, including material selection, performance requirements, indicative testing strategies, and certification (including CE marking). The guide's format follows practices for user engagement: visual, intuitive navigation, and different layers of depth.

In conclusion, the thesis successfully creates a practical, targeted resource that empowers bio-based product start-ups to bridge critical knowledge gaps, increase their market readiness, and contribute to the sustainable transition of the built environment. The findings stress the importance of flexible certification frameworks, simplified early-stage testing, and stakeholder involvement to enable broader acceptance of bio-based innovations in construction.

Table of Contents

1. Introduction

One of the biggest challenges for actors in the built environment is the highly necessary reduction of the sector's environmental footprint. Materials with limited to no harmful emissions (from harvest to waste) are in the picture as part of the solution. Additionally, resource depletion should be avoided wherever possible, either through discontinuation of the use of a resource, through the reuse of a resource, or through the use of renewable resources.

Bio-based materials—defined as materials made of renewable biological sources such as plants, animals, and forestry—have emerged as a promising solution. These natural sources are inherently renewable, meaning they can be regenerated within the lifespan of a building. The sources typically originate from horticulture, agriculture, livestock farming, and forestry. Because these materials can be grown naturally, harmful emissions are limited or not even requisite at all. In many cases, they also act as carbon sinks during their growth and use phase, further contributing to carbon reduction efforts in the building sector. These bio-based materials might be the answer to the challenges the building sector is facing.

Despite their advantages, the integration of bio-based materials into mainstream construction practices remains limited. In history, the construction of shelters, homes, and larger buildings initially did rely heavily on bio-based materials due to their widespread availability and low cost. However, in time, these materials were often recognized as less durable and more vulnerable to environmental factors such as moisture, fire, and pests. As a result, with the development of early building regulations—many of which focused primarily on fire safety and mandated minimum distances between buildings—non-combustible materials such as stone, metals, and, later, industrial materials like concrete and plastics began to dominate and bio-based materials seemed to be forgotten. As of now, in The Netherlands, a mere 0,1% of used building materials is a bio-based material (excluding timber) (Oever, 2024). Unfortunately, the number of bio-based building products in the National Environmental Database (NMD) is very limited (61 out of more than 3000 products) (Dijk, 2022). A report by the Wageningen Food & Biobased Research department notes that in the Netherlands, materials that are not included in the NMD are the less obvious choice (Dam & Oever, 2019). Other barriers that hinder widespread adoption include unfamiliarity with new building materials and methods or increase of expenses that come with small scale production and labour-intense installations (Dam & Oever, 2019). Moreover, bio-based materials require a different design approach because they are 'alive', and are thus more vulnerable to damage by moisture, fire, and UV exposure. To top it off, many bio-based materials and their characteristics are not yet incorporated into existing construction standards and regulations, resulting in unclarity on possibilities and rules.

While numerous innovative companies are actively working to overcome these obstacles and work with bio-based materials, the path to widespread adoption is riddled with mentioned challenges that demand strategic navigation. To accelerate the transition to a more sustainable built environment, it is essential to address these challenges and facilitate the broader application of bio-based materials.

1.1. Research goal

During an interest session for building with bio-based at the Stichting Nederlands Normalisatie Instituut (NEN), the current state of building with bio-based materials was discussed: there is a large ambition, but there are many challenges in scaling up, of which one is knowing what is relevant and which connections should be made (Verslag Interessebijeenkomst Biobased Bouwen, 2024). Start-ups are often innovative by nature and could be the perfect parties to adopt bio-based materials for their products, but the challenges of scaling up and making the right connections are even more difficult for these actors. Since they are having a more difficult time figuring out how to go about their product development process and they do not have the capital yet to request technical advice, this could be experienced as a threshold for entering the market. The application of this clouded material category requires experience and expert knowledge, two things start-up companies often lack. To boost the use of bio-based materials, it is important to first define which experience and knowledge start-ups are missing. Next, a strategy to collect and share this information with them should be developed.

In a research to evaluate challenges and opportunities for upscaling bio-based materials in construction projects, Dams et al. (2023) nominated three challenge categories: finance, knowledge and policy. In this thesis, the focus is on the knowledge category, and finance and policy are touched upon. Challenges include missing or unavailable knowledge of the emerging bio-based materials and a lack of a sufficient number of case studies (Dams et al., 2023). These challenges are taken on in this thesis. Barriers that hinder widespread use of bio-based materials are addressed in the factsheet of Wageningen University & Research (Trip et al., 2023), and are the following six: regulation and standardization, higher initial costs, farmlands and land use change, supply chain challenges, limited awareness and knowledge, and performance concerns. Of these barriers, this thesis focuses mostly on the latter two.

Based on the information unfolded above, the following research goal was formulated for this thesis.

*The **Research goal** is to create a guiding product for bringing a bio-based façade building product to the market, with a focus on knowledge and performance and helps understand the development process in general.*

1.1.1. Scope

According to Patil et al. (2017), the process of product design and development contains the following phases, of which this thesis focuses on phase 2 and 3 (also see Figure 1: Product design and development phases):

1. Analysing market and customers' needs

2. **Product concept generation**
3. **Product design specifications**
4. Design for manufacturing
5. Development of concept and prototype
6. Detailed design
7. Design evaluation and review
8. Product launch

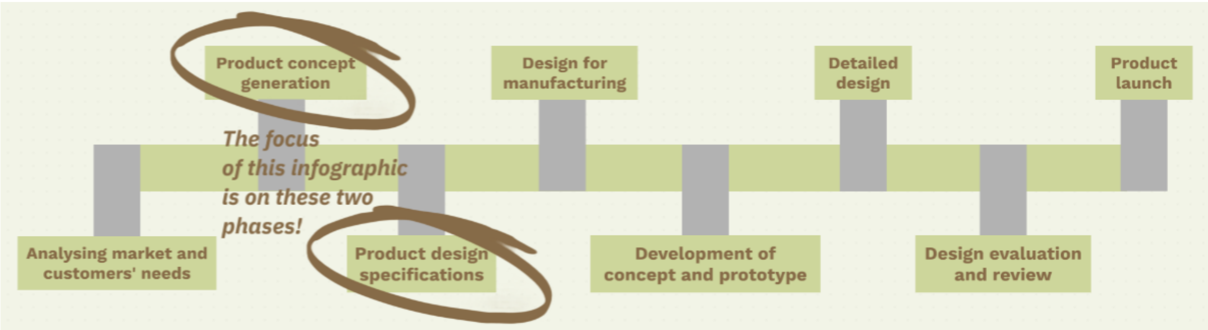


Figure 1: Product design and development phases

In this thesis, the focus is on phase 2 and 3, with an outlook on phase 4. The end-product of this thesis should provide with a guide for start-ups through the steps of these two phases, and be specific to developing a bio-based façade product.

In a WUR factsheet (Trip et al., 2023), the stakeholders in the value chain of bio-based construction materials in the building sector and the housing system in Europe are identified: suppliers of raw materials, manufacturers, distributors, builders, architects, engineers, regulators, and end-users. This thesis focuses on the façade building product supplier, who is identified as the manufacturers that transform these raw materials into useable products. A standard construction supply chain can be found in Figure 2: A typical construction supply network (Dainty et al., 2001).

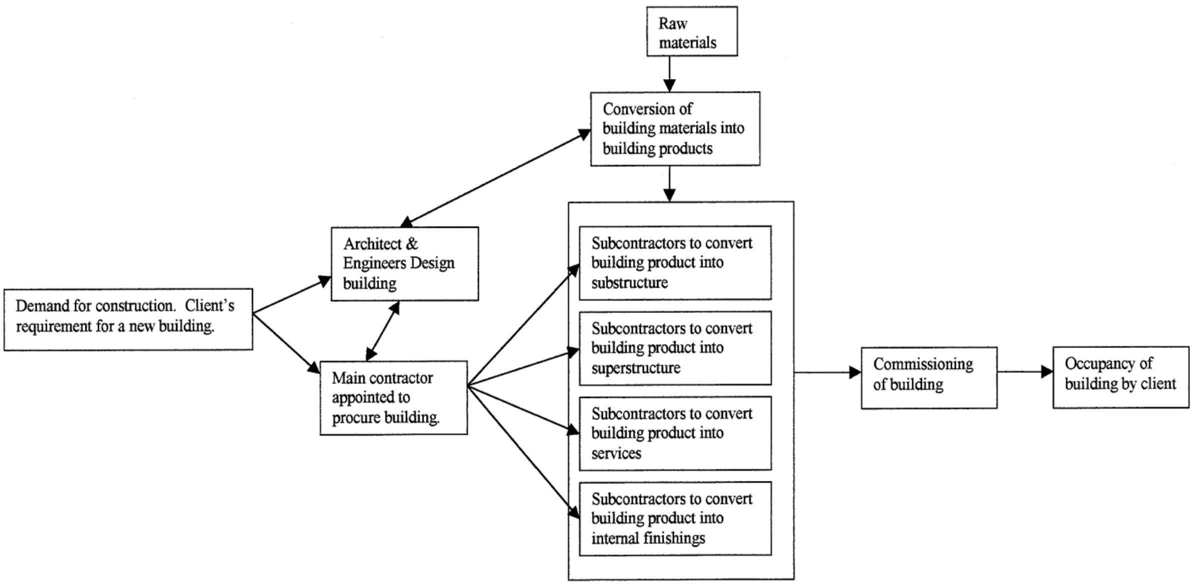


Figure 2: A typical construction supply network (Dainty et al., 2001)

This thesis focuses on the actor 'Conversion of building materials into building products'. This actor is connected to the three other network actors:

- Raw materials actor
- Architect & Engineers: design building
- Subcontractors: convert building product into substructure, superstructure, services, or internal finishings.

In this thesis, the actor of 'Conversion of building materials into building products' is called the 'façade product supplier'. It is important for this supplier to be aware of what the raw materials actor will provide them with. This information is vital as input for the process of converting a building material into a building product. To create a successful building product, the product supplier also needs to know what the architects, engineers and subcontractors require from them and their product. As described by Konstantinou et al. (2015), the focus of the product supplier should generally be on the architect and the general contractor, who will decide which products to use in their design. Konstantinou et al. (2015) also state that the general contractor often has direct relations to suppliers. Emmitt (2006) suggests that architects have a strong tendency to use products that are already known to them because they have limited time to make decisions. However, it is the façade builder who eventually buys and installs them (Klein, 2013). Klein (2013) also suggests that it is the goal of the system supplier to have their product explicitly inquired in the tender document, to ensure its eventual use. Guarantees of quality and durability, which are most common in the shape of a certificate, play an important role in the persuasion. It is critical for a product supplier to be aware of relations between actors, the power of each individual actor, and the most successful way to convince them to use their product.

The following stakeholders are considered in this thesis:

1. Bio-based façade building product suppliers
2. Other façade building product suppliers (traditional materials)
3. Raw material suppliers
4. Licensing labs
5. NEN (standards and guidelines institute)
6. Contractors
7. Architect & engineers
8. Subcontractors
9. Builders
10. Building owners
11. End users (clients)
12. Local governments
13. Financing partners (e.g. banks)

Scope boundaries

The end-product of this thesis will take the shape of an informative product on façade product design using an unspecified bio-based material. The following list sums up the aspects that limit the scope of this thesis.

- The end user is a bio-based façade product supplier. They are an innovative start-up (or scale-up) that has chosen a material but has no bio-based product development knowledge yet.
- The bio-based façade product is created for application in a closed, non-structural façade (e.g. thermal insulative layer, sheet material, fire retardant layer, etc.).
- The focus of this thesis' end-product is determined by the current challenges experienced by start-ups (from the 'State of the Art' interviews). These are the following:
    - Design aspects that differ from traditional building materials.
    - Simplified testing methods and suggestions for further testing.

1.1.2. Research questions

To achieve the research goal (*to create a guiding product for bringing a bio-based façade building product to the market, with a focus on knowledge and performance and helps understand the development process in general*), research questions are formulated. The main research question is supported by three research questions (including subquestions). These three research questions will help answer the main research question, which in turn, will lead to achieving the research goal. The main research question is as follows.

***Main research question**: What information could help start-up companies developing a bio-based façade building product and how could this information be conveyed in a fitting way?*

The three research questions are as follows, including subquestions.

Research question 1: What are the current challenges for start-ups creating a bio-based façade product?

Research question 2: What knowledge is available for developing a bio-based façade product?

a.) What are the tests available for developing a bio-based façade product?
b.) How does a product comply to current legislations, regulations and standards?
c.) What advice would current actors in the sector give to newcomers?

Research question 3: What should the information product for bringing a bio-based building product to the market be?

a.) What information is most relevant (focused on performance and testing)?
b.) What should the interface of the information product look like?
c.) How does the relevant information fit in the interface?

The following chapter, the State of the Art, will answer research question 1 and will give input to answer research questions 2 and 3. The methodology chapter will describe how research questions 2 and 3 are answered, and the results chapter will give the answers to these questions, as well as the answer to the main research question.

2. State of the Art

This chapter explains what the current state of affairs is for the sector in which bio-based façade product suppliers have to work their ways. It consists of a literature review that was carried out and interviews that were conducted. The literature review will give useful input for answering research questions 2 and 3. In the interviews section, the current challenges are discovered, answering research question 1.

2.1. Literature review

In the literature review, the knowledge required to develop a bio-based façade product (research question two) is gathered, including a review on existing bio-based materials, façade design and performance, available tests and legislation. Furthermore, theory on information products is analysed, which is used as input to design the end-product of this thesis that eventually will give answer to research question three.

2.1.1. Bio-based materials

In this section, input for research question 2 is given, 'What knowledge is available for developing a bio-based façade product?'. The aim of this section is to understand which materials exist and figure out possible applications, in order to get a general understanding of bio-based materials.

Bio-based materials are, conform NEN-EN 16575:2014, derived from biomass, processed physically, mechanically, chemically or biologically. A bio-based product is a product entirely or partly derived from biomass. Below, some of the more popular bio-based materials are listed along with their characteristics and possible applications. Note that this list is not complete, but is illustrative for the variety, characteristics and applications of bio-based materials.

Flax

Flax is a flowering plant cultivated for its fibre. The most valued properties of flax are its tensile strength, absorptivity and biological activity. Flaxboards are used in dry environments in fire-check doors, door partitions and cores (Yadav & Agarwal, 2021). Flax fires are used as additives in cement and plaster and in insulators (Brischke & Jones, 2017).

Hemp

Hemp is a plant cultivated for its useful bast fibre. Hemp insulation is becoming a popular eco-friendly alternative to traditional insulation materials.

Hempcrete is an insulation substitute to subfloors, attics, walls, providing it is not exposed to large quantities of moisture/water. It is fire-resisting and mildew resistant (Yadav & Agarwal, 2021).

The fibres can be used for the production of hemp wool (Bourbia et al., 2023). The shives can be used to create construction products like mortar, plaster and concrete (Bourbia et al., 2023).

Straw

Straw is an agricultural byproduct consisting of the dry stalks of cereal crops, after the grain and chaff have been removed. According to Jones & Brischke (2017) straw is durable, load-bearing, long-lasting, and insulant. It does need to be protected from the moisture.

According to (Bourbia et al., 2023), straw bales are used as insulation, plaster support, straw concrete, and as fibres in mud bricks.

Cork

Cork is the bark of the Cork Oak tree. Cork has a wide range of uses, such as floor and wall covers, and loft, floor and roof insulation (Bourbia et al., 2023). When it comes to thermal insulation, cork oak or recycled cork is often used.

Mycelium

Mycelium is a root-like structure of a fungus consisting of a mass of branching, thread-like hyphae (Soon et al., 2024). Mycelium bricks are made from from plant and animal leftover (Yadav & Agarwal, 2021). The bricks can be used as a robust, fire-resistant, water and mould artefact mature to a producer's specifications (Yadav & Agarwal, 2021). Low in density and thermal phenomenon, high acoustic captivation and hearth safety show specific promise as acoustic and thermal insulation foams (Yadav & Agarwal, 2021).

Biocomposites

Biocomposites are materials that contain two or more raw materials, of which at least one is naturally derived. The bio-based content should be measured for promotion purposes. In the USA, this is done using ASTM D6866, expressing the content of bio-based organic carbon as a percentage of the total amount of organic carbon. In Europe, certification standards are NEN-EN 16640 (this one is similar to the code in the USA, but taking into account both organic and inorganic carbon) and EN 16785-1 (measuring the total bio-based content of a material, including bio-based oxygen, nitrogen, hydrogen, and carbon) (Willemse & Zee, 2018).

2.1.2. General façade design

To understand how bio-based materials can be used in a façade product, it is necessary to understand how façades are built up in general. This section treats these aspects, giving input for answering research question 2, 'What knowledge is available for developing a bio-based façade product?'

A façade 1.) prevents water intrusion, 2.) limits air infiltration, 3.) admits and controls sunlight, 4.) controls thermal transfer, 5.) controls acoustics, 6.) performs for a long period of time with minimal maintenance and repair (Boswell, 2013).

Primary functions of the façade (Boswell, 2013)

1. Structural function
2. Weathertightness
3. Energy efficiency

4. Accommodating building movements

The layers of a ventilated façade are the following:

1. Covering or external facing;
2. Anchoring structure;
3. Air gap;
4. Insulating layer;
5. Perimeter or curtain wall;
6. Anchoring elements.

A waterproof membrane might need to be added (between the insulating layer and the perimeter, depending on the waterproofness of layers 1 till 4).

A building product fulfils one or multiple functions in a façade. A product can be used as A building product can help to improve any of these performances of a façade. It can be a cladding, structural support, fire retarding layer, water or air impermeable layer, or thermal / acoustic insulator. Some products can fulfil more than one function. It is important to decide which function(s) a product will fulfil. Any of these functions bring along different required material characteristics. General performance indicators to consider when designing a standard façade are, according to (Kültür et al., 2019):

- Structural Performance
- Fire Performance
- Water-related Performance
- Air Permeability-related Performance
- Thermal Performance
- Moisture-related Performance
- Acoustic Performance

These performance indicators will be further described in the next chapter, chapter 2.1.3. Façade performance.

Types of façades

There are closed and open systems, and mixed-mode systems. Moghtadernejad et al. (2018) give a helpful description of different façade types found in buildings, see Figure 3: Façade types and characteristics (Moghtadernejad et al., 2018).

Façade types	Characteristics
Masonry and brick façades	Used in low-rise residential and commercial buildings; ordinary or decorative with color and shape variety; easily molded; inexpensive; minimal repair costs
Wooden façades	Used in low-rise residential buildings; unique colors; susceptible to aging and aggressive environments; should be treated to prevent decay
Stone façades	Used in prestigious buildings; unique textures and colors; durable; high compressive strength; lack of construction flexibility
Concrete façades	Various shapes, colors, textures, and finishes; usually prefabricated; appropriate fire resistance, energy efficiency, acoustics, and vibration control; construction flexibility; have higher weight and durability problems
Metal façades	Various forms, design, and construction flexibility; usually made from composite metals or stainless steel with high strength and corrosion resistance; remain shiny and stain-free for a long time; higher initial costs but lower maintenance costs
Glass façades	Used in modern, high-rise buildings; desirable for architects; allow natural light and heat to enter; availability of folded glass façades and high-performance glazing products with minimum energy consumption (Zelenay et al. 2011)
Double-skin façades	Consists of two skins with a void in the middle through which air flows; single or double glazing; natural, fan supported, or mechanical ventilation; enhance building energy performance; higher costs and lower usable space (Poirazis 2004)
Photovoltaic-integrated façades	Can be used as supplementary source of electric power; improved building energy performance by use of a hybrid design (generating both heat and electrical energy) (Clarke et al. 1997)
Fiber-reinforced polymer (FRP) composite façades	Have higher stiffness and strength, lower density and weight; high corrosion resistance and manufacturing flexibility; durable and cost effective; have poor fire resistance [can be improved by using phenol-based composites, but these are costly (Nguyen et al. 2013)]; moisture effects and susceptibility to high temperatures, ultraviolet (UV) radiation and exposure to light
Sandwich panel façades	Made of two thin layers (e.g., FRPs, stainless steel, metal composites, concrete) and a low-density core (usually made of different foams); cost efficient and prefabricated; high stiffness with minimum weight; can be used in industrial and commercial buildings, sports facilities, and warehouses

Figure 3: Façade types and characteristics (Moghtadernejad et al., 2018)

Functional requirements

Examples of factors describing what aspects are important in the application of a product are also called functional requirements. The functional requirements of a façade are the following (Boswell, 2013):

- Building use
- Program
- Owner/user specifics
- Weathertightness
- Energy efficiency
- Durability

Other points of attention for a façade design, aside from performance indicators, are the following: manufacturability, order of assembly, connections, materials, tolerances, durability, environmental impact and risks. These factors are not functions of a building product, but they do need to be considered in the design process, because they will have impact on a product and can improve its attractiveness to potential buyers.

2.1.3. Façade performance

This section treats façade performance aspects, giving input for answering research question 2, 'What knowledge is available for developing a bio-based façade product?' A facade has to fulfil its established functions. These functions can be checked against performance indicators, which are also mentioned in chapter 2.1.2. It is important to know what functions a façade should fulfil to be able to figure out which of these could be fulfilled by bio-based materials. In the following section, the performance indicators (structural, fire, water-related, air permeability-related, thermal, moisture-related, and acoustic performance) are further addressed.

A façade is a combination of building products. This combination of products should fulfil the functions mentioned. This means that each individual product can fulfil one or more of the functions. A watertight foil will fulfil water-related performance as a thermal insulation layer will generate thermal performance. All layers should be in working order, interact with one another properly, and together fulfil all necessary functions of a façade.

2.1.3.1. Structural Performance

A façade will need to be self-load bearing and must also resist the present mechanical and environmental loads, such as wind and rain load. It must also allow for differential movements (Boswell, 2013). If a facade product aims at adding to the façade's structural integrity, it is important to consider the following aspects.

The stiffness design criterion is as follows.

$$d = \frac{l}{n}$$

$$d = deflection$$
$$l = span$$
$$n = number\ dependent\ on\ cladding\ material\ support$$

The depth to span ratio is important for deflection as well.

Forces that can affect the façade include wind, water/precipitation, infiltration/exfiltration, temperature, sunlight, seismic, blast, condensation, noise/acoustics (Boswell, 2013).

Vertical loads and horizontal loads

Vertical loads include dead loads (incl. own weight), imposed loads, snow loads. Horizontal loads include wind loads and impact loads. Restraint forces are caused by thermal or moisture induced changes in volume/shape. In Figure 4: Standing and suspended façade (Herzog et al., 2021), two different ways to support a façade can be viewed.

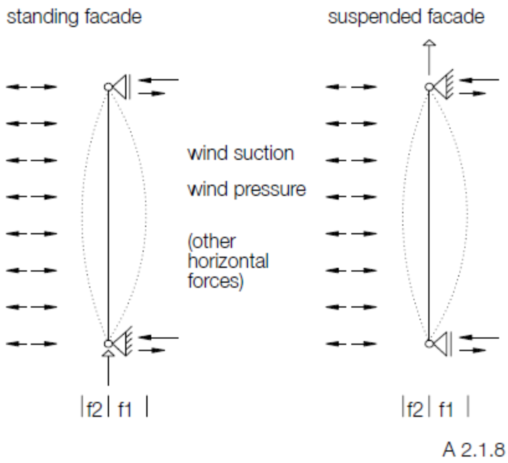


Figure 4: Standing and suspended façade (Herzog et al., 2021)

In a standing façade, the planar/ linear components should be designed for compression and bending and thus also buckling (due to stability problems). In a suspended facade, the planar/ linear components should be designed for tension and bending. The suspended façade is generally used, because it is advantageous over the standing façade, especially in longer spans (Herzog et al., 2021).

Special attention should be paid to the following aspects (Herzog et al., 2021):

- Deformation of the building fabric, e.g., due to dead and imposed loads.
- Production-related tolerances.
- Dynamic, horizontal floor displacements caused by wind drift or seismic actions.
- Differences in length changes due to differing materials and temperatures.
- Vertical displacements cause by floor loads.

2.1.3.2. Water-related and air permeability-related performance

Water that enters the façade must be discharged to the exterior without penetration to the interior or the parts of the façade that are designed to stay dry (Boswell, 2013). The façade system should be designed so it can dry when the water source is removed.

Moisture aspects

Relative humidity (RH) is the relationship between the actual vapour pressure and the maximum possible vapour pressure for a certain temperature. It is a measure of climate control and human health, comfort and safety of a room. It is critical when the RH of the space surrounding a bio-based material is too high, since it can affect material properties due to their viscoelastic and hygroscopic nature (Perruchoud et al., 2024).

Hygroscopic moisture is the naturally present moisture in a material. The amount of present moisture depends on the relative humidity of the surrounding air. The moisture content equilibrium is, for a certain relative humidity, the amount of moisture associated with the material (Linden et al., 2016). A higher RH usually accounts for a higher moisture content equilibrium. A higher moisture content equilibrium has a stabilizing effect on the RH, since more moisture can be absorbed and later released.

For the entire façade, the following circumstances are relevant:

- The moisture content stimulating fungal growth is estimated at 22 to 24%, depending on material type, so it is advised to stay well below that. For timber, building experts recommend 19% as the upper limit of the moisture content of untreated wood (Sandak et al., 2019).
- Relative air humidity and temperature affect the development of moulds. Water vapour flows from high vapour pressure to low vapour pressure. If, at the same time, temperature drops below dew point, then the water condensates. This leads to a risk of mould growth.
- Low surface temperatures can cause mould and fungus if hygroscopic moisture levels are high enough. Mould is a health issue and should be avoided, and fungi can destroy the material.
- It is critical to limit moisture exposure to bio-based products during construction.

Façade design should allow for water to escape. Forces that move water are gravity, wind, surface tension, capillary action, pressure difference and kinetic energy (Boswell, 2013). These forces should be considered when designing a façade, as they can lead to water entering a façade, but can be used to drive water *out* of the façade as well.

Vapour tight and vapour open

Materials in the façade are either weatherproof or porous. Effective moisture management is critical to ensure durability, energy efficiency, and indoor comfort in buildings. Traditionally, moisture entry is avoided, moisture should be able to escape, and indoor comfort should be regulated. Following these principles, vapour tight facades are the goal. They can be created by choosing materials that allow for the right (for climate and building use) vapour flow. The vapor permeability of a building material can be distinguished using the following classes (determined by the ASTM E96 desiccant method): Class I vapor barrier (0.1 perm or less), Class II vapor Retarder (0.1 < perm < 1.0 perm), and Class III Vapor Retarder (1.0 perm < perm < 10 perm). The climate zone in which a building is in determines which vapor barrier class should be used. Vapour open barriers are the alternative, but are still underexposed in research and adoption.

Vapour tight facades prevent the warm, moist indoor air from penetrating the insulation. Vapour tightness can be obtained by "using a vapour-tight insulation material or, alternatively, by coupling a vapour barrier to a vapour-open material. Particular caution is always required when a vapour barrier is adopted, as any disconnection or perforation of the barrier determines a possible vapour penetration, thus a significant decrease in the system performance" (*RIBuild - Guideline for Selecting an Internal Insulation System*, n.d.). The vapour barrier should be placed at the correct point in the structure to prevent internal condensation. In a traditional, vapour-tight façade, the following design aspects should be considered. Porous materials should be backed up with a weatherproof layer, and either the porous material must allow for water storage (to be released to the exterior) or the façade must contain drainage to discharge water.

Vapour open facades are generally obtained by using a vapour-open insulation material that "also enables capillary suction (*capillary-active* insulation material). The capillary activity of the material, in fact, allows the moisture transport through the insulation material towards the indoor air if the inner surface of the existing wall gets wet, for instance due to interstitial condensation" (RIBuild - Guideline for Selecting an Internal Insulation System, n.d.).

Vapour barriers were introduced to prevent assemblies from getting wet. However, moisture does not only come from the exterior, but also from the interior (from activities such as cooking, breathing, sweating, etc.). And thus, vapour barriers could end up trapping moisture in the assembly. The most important ability an assembly should have is that it can dry if it becomes wet. Viable strategies (vapour tight or open) are dependent on climate, exposure, cladding type, structure material, and by occupancy and operation of the building.

A vapour open façade allows water vapour to diffuse through the assembly, reducing the risk of trapped moisture. This approach might be particularly suitable for bio-based materials due to their hygroscopic (moisture-absorbing and releasing) properties. A vapour-open insulation material enables capillary suction. The capillary activity of the material allows moisture to travel through the insulation material towards the indoor air if the inside of the wall gets wet (*RIBuild - Guideline for Selecting an Internal Insulation System*, n.d.). Vapour open construction is best suited for climates with low to moderate humidity.

The direction of the vapour drive impacts the placement of materials in a wall assembly. A psychrometric chart can help calculate vapour pressure differentials.

Condensation

Condensation occurs when the dew point of water is reached. This can happen within a material, or on a material surface. The progression of temperature throughout the entire façade is required, in addition to the dew point, T_s.

$$T_s = \frac{b \times \alpha(T, RH)}{a - \alpha(T, RH)}$$

$$T_s = Dew\ point\ [°C]$$

$$T = Temperature\ [°C]$$

$$RH = Relative\ humidity\ [\%]$$

$$a, b = Magnus\ coefficients, a = 17.625, b = 243.04\ °C$$

$$\alpha(T, RH) = \ln\left(\frac{RH}{100}\right) + \frac{aT}{b + T}$$

Systems that prevent for condensation use a vapour barrier to disable vapour transfer from the room side into the construction, condensate-limiting insulation systems contain a vapour brake, and condensate-tolerating insulation systems contain a capillary active insulation material (*RIBuild - Guideline for Selecting an Internal Insulation System*, n.d.).

The locations of thermal bridges are generally also weak spots for moisture control. Condensation can take place in spots with large temperature differences. Condensation should be prevented because it (Linden et al., 2016) attracts dirt and mold, and enlarges the chance of cracks during frost. To avoid condensation, the moisture-retardant layer should be put in the right spot in the façade: the calculated vapour pressure should stay below the maximum vapour pressure at every point in the façade. Rule of thumb: place the moisture-retardant layer on the warm side of the construction (Linden et al., 2016).

The Glaser method is a simple calculation method in MS Excel to calculate the hygrothermal performance of building components and building elements and check for condensation risks. However, the Glaser method is a static method and has some limitations. According to BS EN ISO 13788, the method "assumes built-in water has dried out and does not take account of a number of important physical phenomena". Alternatively, WUFI® software is the state-of-the-art tool for simulating coupled heat and moisture transfer. It provides realistic simulation of hygrothermal conditions in building components and considers actual climate conditions.

Design principles

For a vapour open façade, a weather-resistant barrier (WRB) must be included that is vapour-permeable in addition to an exterior cladding that protects against rain. A vapour-open façade can be design as a ventilated cavity in order to allow airflow and reduce the risk of mold and rot.

Some real-life examples of vapour open façades exist, for example in Sundby School in Denmark and Wally Farms in New York State, the USA (Logan, 2024). However, there are design challenges that come with vapour-open design, especially since many contractors and architects/engineers are not used to designing vapour-open constructions.

Vapour-tight façades should be designed with eye for detail, such that leaks are prevented. Design principles of vapour-tight facades include the following. Biobased materials should never be put in between two vapour-tight layers, because water will not be able to escape and the material will rot. Adding indoor insulation will result in a dew point shift in the façade, the position of the vapour barrier is important for possible drying possibilities for the biobased material towards the inside. *NPR 2652 (nl) Vochtwering in gebouwen - Wering van vocht van buiten en wering van vocht van binnen - Voorbeelden van bouwkundige details* is a document that can help get an idea of proper moisture-wicking design. Vapour-open facades should be analysed thoroughly (perhaps through experiments), to ensure that the façade can 'breathe' properly, so rotting and/or moulding does not occur.

Exterior walls should be designed in such a way that condensation does not occur on the cool surfaces of the exterior wall assembly, the inner surface of the exterior walls, or within the interior wall (Moisture Control Guidance for Building Design, Construction and Maintenance, 2013). Moisture prevention, found in BBL Art. 4.118, has to be treated according to NEN 2778. Watertightness is, according to this standard, required in spaces adjacent to toilet or bathrooms and crawl space.

Water absorption, found in Art. 4.120, has to be treated according to NEN 2778 to avoid mold growth and rot. It is stated that walls up to 1,2 meters above the floor can only have an average water absorption of maximum 0,01 kg/(m².s ½), and in no place larger than 0,2 kg/(m².s½). A bathroom has to be water-resistant for a length of at least 3 m and a height of 2.1 m above the floor of that space.

2.1.3.3. Thermal performance

The insulation value of a façade (R_c) describes its insulation performance, important for maintaining a comfortable indoor temperature and lowering heating (and cooling) demand.

The thermal conductivity (λ) of a material describes how well a material conducts heat. The overall R_c-value of a façade assembly is represented by the summation of the R_d-values of each individual layer. In Table 1: Important thermal parameters, these three characteristics are summarized. In case a cavity is present in the facade, the heat resistance of this cavity should be calculated (according to NPR 2068) and added to reach the final R_c-value.

Table 1: Important thermal parameters

Most important parameters	**Explanation**	**Note**
λ-value	Thermal conductivity of material	low = better insulation
R_d-value	Insulation value of product ($R_d = \frac{d}{\lambda}$)	high = better insulation
R_c-value	Insulation value of entire façade ($R_c = R_{d,1} + R_{d,2} + \ldots$)	Minimum of R_c = 4,7m^2·K/W

Of influence on the thermal performance of a layer are its mass/density (ρ), the material's thermal conductivity (λ), and its heat capacity (c). Many biobased materials have, compared to traditional building materials, a lower ρ and λ and a comparable c. The lower the thermal conductivity, the better the insulation property of the material. The higher the heat capacity, the smaller the thermal diffusivity, meaning that the heat will move more slowly through the material. The relationship between thermal performance and density is complex for plant fibers. The thermal performance initially decreases with increasing density. When it reaches a critical point (dependent on the manufacturing process), the thermal performance increases with the density of the fibers (Amziane et al., 2023). According to (Bourbia, Kazeoui, & Belarbi, 2023), plant fibres on itself show better thermal and water performance compared to when they are incorporated in binders. An example is straw concrete, which was found to have the best thermal conductivity of several researched fibres and is also resistant to water vapour.

An energy-efficient façade admits natural light while minimizing heat gain/ loss and maximizing insulation values. It controls temperature and condensation (Boswell, 2013).

1. Heat transfer: thermal energy flows from higher temperatures to lower temperatures, either by means of conduction, radiation or convection. The heat transmittance, U, can be calculated.
2. Water vapour pressure: water vapour flows from high pressure to low pressure. If, at the same time, temperature drops below dew point, then the water condensates. This leads to a risk of mould growth (see chapter 2.1.3.2.
3. Radiation transfer: Radiation on a surface is either reflected, absorbed, or transmitted. Heat radiation affects thermal performance when it is absorbed or transmitted. Transmission does not occur in opaque surfaces.

Dependent on the type of ventilation as well. Natural ventilation should be enabled whenever possible.

Thermal performance

Heat transfer takes place between the inside and outside of a façade, due to several physical principles such as heat flow, water vapour pressure, or radiation transfer. Thermal conductivity depends on the material and density, and affects thermal performance.

The Rc-value [K/W] gives the thermal resistance of a material. The higher the Rc-value, the more the material functions as a thermal buffer. Less heat transfer will take place between the one side of the material and the other. High-value materials are good insulators, and the thicker the material, the higher this Rc-value. It is a material property, and can be found in literature for common building materials. The overall Rc-value of a façade assembly is represented by the summation of the Rc-values of each individual layer.

$$R_c = \frac{d}{\lambda}$$

$$R_c = thermal\ resistance\ of\ facade\ layer\ [m^2K/W]$$

$$d = thickness\ [m]$$

$$\lambda = thermal\ conductivity\ of\ material\ [W/mK]$$

The location in the façade (on the inside or outside) of the thermal insulation influences its impact on the indoor situation, too (Van der Linden, Kuijpers-Van Gaalen, Zeegers, & Erdtsieck, 2013).. When insulation is placed on the outside, more energy is stored in the walls, making the indoor temperature more stable. However, when the building has cooled down and needs to be heated up again, the walls *also* need to be heated, which costs a lot of energy. When the inside is insulated, the heating has to be able to respond quickly, but it costs less energy to heat up the room (since the walls do not need to be heated, too).

The key to success for thermal performance is not just in having a thick, high Rc-value insulative layer, but also in overall optimization of frames and connections. In the design of a façade, thermal weak links and thermal bridges should be eliminated. Design solutions to cover these leaks (in insulation) could help improve the applicability of a building product. Cold bridges negatively affect a building's thermal performance. A cold bridge is a break in the insulation with an area outdoors larger than the area indoors.

When insulation is placed on the outside, more energy is stored in the walls, making the indoor temperature more stable. However, when the building has cooled down and needs to be heated up (or in summer, cooled down) again, the walls also need to be heated (or cooled), which costs a lot of energy. When the inside is insulated, the heating has to be able to respond quickly, but it costs less energy to heat up the room (since the walls do not need to be heated, too).

Thermal inertia

Thermal inertia is the tendency of a material to resist changes in temperature. Materials with a high thermal inertia van store more heat and at a slower pace. The thermal phase shift (or, in Dutch 'faseverschuiving') of a material refers to the time it takes for heat to penetrate it, and thus get to the other side. A high thermal inertia leads to a longer thermal phase shift, something that is beneficial for insulation of buildings.

In winter, a good thermal phase shift is useful because it keeps heat *inside* for a longer period of time, and thus the inside cools down less quickly. In summer, it is exactly reversed: a material with high thermal inertia keeps the heat *out* longer.

Now, it is the case that bio-based flexible insulation materials specifically theoretically have better thermal phase shift when compared to mineral wools and synthetic insulation, due to high density and thermal capacity values (Amziane et al., 2023, p356). As a result, bio-based insulation materials have longer phase shifts, which is suggested to be beneficial.

Temperature progression

In a façade, temperature progression analysis can help get an idea of the effect of the thermal insulation.

- Temperature progression in multi-layer walls can be calculated for each layer as follows.
  - Known parameters: thickness [d], heat conduction coefficient [lambda].
  - Calculate: R_n, ΔT_n, T_n for each layer. Table 2: Temperature progression analysis should be filled out

Table 2: Temperature progression analysis

Layer	Thickness of layer [d]	Heat conduction coefficient [λ]	$R_n = \frac{d}{\lambda}$	$\Delta T_n = \frac{R_n}{R_1} * \Delta T$	T_n
Outside air					

Heat transfer resistance outside r_e			See NTA 8800		
Layer 1					
Layer 2					
...					
Heat transfer resistance inside r_i			See NTA 8800		
Inside air					

The parameters $r_e = 0.4$ and $r_i = 0.13$ are used for a completely insulated cavity wall.

2.1.3.4. Sound reduction performance

Another function of a façade is to “keep out” sound to reduce indoor noise. This is achieved by having sound absorbing elements in a façade, but can also be achieved by having mass in the facade. In this section, the aspects of sound reduction are discussed.

It is important to address the difference between sound absorption panels and sound reduction panels. Sound absorption (or acoustic) panels aim at improving acoustic quality, e.g. by reducing reverberation, and by using materials that are light and porous so they trap and convert sound waves. Sound reduction panels aim to prevent sound from entering or leaving a space, using high density materials to block sound transmission (Acoustical Surfaces, 2024). In this section, we look at sound reduction panels.

Sound reduction performance is dependent on the frequency of the sound. Required acoustic performance depends on the function of a building. Denser materials usually provide better sound insulation, which can yield a dual purpose with thermal insulation. For standard porous materials, high tones are better absorbed than lower tones. In general, the thicker the insulation, the lower the frequencies that are absorbed best. The following terms are useful:

- Characteristic insulation index for airborne sound (karakteristieke lucht-geluidniveauverschil, $D_{nT,A,k}$) is used to compare structures (NEN 5077) and gives a realistic description of the insulation provided by the seperating structure. Flanking transmission and the construction of joints can result in the decrease of the actual sound insulative value of a wall.
- Characteristic façade sound reduction index (karakteristieke gevelgeluidwering, $G_{a;k}$) is used to analyse the reduction of noise from an outdoor to indoor space.
- Sound Reduction Index (SRI, or R): the sound insulation effectiveness of an individual product (measured a real sized sample).

In Table 3: Most relevant sound parameters, the relevant parameters are summarized.

Table 3: Most relevant sound parameters

Most important parameters	Explanation	Note

SRI or R [dB] / R_w (ISO 10140)	Sound reduction index of a product	high = better sound reduction
$G_{a;k}$ [dB(A)] (NEN 5077)	Karakteristieke gevelgeluidwering (Dutch sound reduction parameter)	high = better sound reduction (BBL-requirement of $G_{a;k} > 20dB$

Following NEN 5077, the sound reduction parameter of a façade ($G_{a;k}$) can be determined.

Design principles

Ways to improve sound insulation: increase mass of components, provide efficient seal, use of cavity (with walls of two unequal masses to avoid passing through natural frequency). Additionally, even the tiniest gaps and holes reduce the sound insulation significantly: in a wall of 10m2 with a sound reduction value of 50 dB(A), a hole of 0,01m2 (with sound insulation value of 0 dB(A) yields in a reduction of sound insulation by 20 dB(A).

The sound insulation value of a single wall can be determined using the plateau method. There are rules of thumb for various traditional materials, but not yet for bio-based. It is important that a single wall functions as a single mass, so any layers must be bonded together well to avoid a very narrow cavity with unfavorable resonance frequency. Adding a cavity can significantly improve the acoustic insulation value, for example in light walls where the sound insulation cannot be derived from mass. The cavity leaves must not have any joints between them to prevent vibration transmissions between the leaves.

The sound insulation value of a cavity wall is hard to predict due to resonance. It is important to figure out at which frequency resonance (f_0) occurs. If the f_0 is larger than 80Hz, it is important it is reduced. This can be done by either widening the cavity or increasing the masses. The insulative performance can also be improved by inserting a porous absorbing material (such as sheep's wool) in the cavity.

Flanking transmission and the construction of joints can result in the decrease of the actual sound insulative value of a wall. This is one of the largest issues in timber buildings.

Calculations and simulations

The sound insulation value of a single wall can be determined using the plateau method. There are rules of thumb for various traditional materials, but not yet for bio-based. It is important that a single wall functions as a single mass, so any layers must be bonded together well to avoid a very narrow cavity with unfavorable resonance frequency.

The sound insulation value of a cavity wall is hard to predict due to resonance. It is important to figure out at which frequency resonance (f_0) occurs. If the f_0 is larger than 80Hz, it is important to suppress this. This can be done by inserting sheep's wool in the cavity.

NPR 5070 can help find a suitable dwelling partitioning wall for the desired sound insulation value. At certified testing laboratories, tests can be run on façades to obtain sound transmission class (STC) rating levels.

Methods, according to Linden et al. (2016):

- Revised calculation method for sound proofing in façades and Calculation method for Sound Proofing in large Municipalities (GGG calculation method).
    1. Determine the sound insulation of the composite façade (R_A) per octave band.
    2. Determine the sound proofing of the external partitioning structure (G_A).
    3. Determine the typical sound proofing of the external partitioning structure ($G_{A;k}$).
- Determine the resonance frequency, f_0.
- Plateau method.

2.1.3.5. Fire performance

Fire performance of façades is important for the safety of the building. This is especially the case for taller buildings, since evacuation and firefighting is more difficult here. There are strict fire regulations for tall buildings, sometimes complicating the use of biobased materials since these are often not as fire retardant as some artificial façade materials.

Bio-based materials often have a different fire behaviour compared to traditional materials. For example, they may ignite faster or develop more smoke. The fire behaviour of the façade is affected by these fire characteristics. To get the highest fire safety, use materials with the highest fire class (according to EN13501-1), also see Table 4: Fire performance classes. Fire classes can apply to a building product (individual), but also to an entire façade (composite structure).

Table 4: Fire performance classes

Most important parameters	Explanation	Note
A to F	Fire behaviour (combustibility)	A = non-combustible F = highly combustible
S1 to 3	Smoke Development	S1 = little or no smoke S3 = substantial/heavy smoke
D0 to 2	Formation of Flaming Droplets/Particles	D0 = no droplets D2 = quite a lot of droplets

A horizontal cavity barrier is typically included to avoid fire from spreading further in vertical direction through the cavity void of a ventilated façade. In other types of façades, a fire barrier can be applied in the insulation layer.

There are several ways of fire spread and ways to limit them (Martin, 2017):

- On the cladding surface: take measures to limit the reaction to fire of the façade cladding.

- From floor to floor (internally or externally via windows): ensure the fire resistance of the junction (between the floor and the façade) and that of the façade element at floor level, Non-combustible stone wool fire barriers if positioned above the window opening can delay fire spread.
- Through the façade system, e.g. via the air cavity or thermal insulation: add non-combustible or low-combustible elements, protect the combustible element (panels with K2 10 or K2 30 protection classes), or interrupt the combustible layer/ cavity.

Prevention differs per way of fire spread. Since this thesis focuses on elements in a curtain wall façade, it is important to pay attention to spread through the ventilation cavity or through the thermal insulation (or other flammable materials in the façade).

It is necessary to provide fire testing certificates that adhere to the set regulations. If not in possession of these certificates, fire testing needs to be done to get them. In The Netherlands: NEN-EN 13501-1 guides to the right class, depending on height and façade application.

Product characteristics

WBDBO: Weerstand tegen BrandDoorslag (resistance to fire penetration) en BrandOverslag (resistance to fire spread), according to NEN 6068. In practice, most façades have to comply with fire class B (new construction) or fire propagation class 2 (existing construction). The WBDBO is a characeristic of a wall, and is measured in the minutes it is able to resist fire. Holes and openings can affect the fire resistance of the product and might need to be fitted with fire-resistant elements, or a fire flap.

Requirements

It is clear that a building should be built to *not* collapse in the case of a fire. According to BBL §4.2.2, the parts of a structure that are above or below the escape route cannot collapse within 30 minutes. A table indicates up to 120 minutes of non-collapse for other parts of the building.

Fire traveling along the façade requirements: up to 2.5 meters and above 13 meters have to have fire class B according to NEN-EN 13501-1 and for other façades applications class C of D. The application of the façade product defines its required fire class. Fire class requirements apply to the composite structure of the façade, and thus the façade should be tested in its entirety, to see if it meets the demands.

2.1.4. Testing a façade product

In this section, input for answering research subquestion 2a, 'What are the tests available for developing a bio-based façade product?', is given. This input is later used in the expert dialogues, as a base for discussion on which tests are of value for a bio-based façade product supplier.

The aim of testing is to establish functionality, compare variations, and eventually check a concept design's readiness to go to the market. The process of designing a building product is iterative. It loops between analysis, synthesis and appraisal. Or, in other words, research, design and functional testing (Markus, 1970). Functional testing gives the information required to improve research areas and focus topics and tweaks to the design, all to improve the concept product. This concept is tested again, improved again, etc., until deemed ready for being put on the market. Other aspects affecting a product's successful launch into the market include the required certificates, alternative existing products in the market, user demand rates, and the company's production plans and strategy.

Below, in Table 5: Available tests for each performance factor, both indicative tests and certified tests (according to NEN-standards) can be found. The indicative tests are mostly found in research by Konijnenberg (2024), who performed their indicative tests on rammed earth.

Table 5: Available tests for each performance factor

Indicative tests	Tests from EN-standards
Structural	
Three-point bending test (House & House, 2020) Supplies: - 2 200mm pieces of 1×2 wood - 2 finishing nails (50mm long) - Metal coat hanger - Bucket or bag - Weight: e.g. sand or flour Steps: 1. Assemble the structure using the blueprints. 2. Put the weight in the bucket/bag in small (depending on the estimated sample strength) increase steps until it breaks. Goal: To get an impression of the product's bending strength.	*NEN-EN 12179:2000 Curtain Walling - Resistance to Wind Load – Test Method* - Positive pressure test: three pulses of air pressure of 50% of design wind load or 500 Pa, whichever is greater. - Negative pressure test: same procedure as positive pressure test, but with negative test pressures. - Increased load test (optional) Results: Frontal displacements, frontal deflections, as functions of test pressure. Residual deformations. Damage. Pass: Compare with maximum values specified in prEN 13116:1997

Impact test (Houben & Guillaud, 1994)
Try to damage the samples with different objects.
Goals:
- To understand the response from a material to impact
- Get a sense of possibilities and limitations of altering your product (for example when changing the shape or puncturing a hole)
	NEN-EN 14019:2016 Curtain Walling - Impact resistance - Performance requirements
	- Impact loads at different positions
	  - Impact of 100mm drop height, increase until failure
	  - Ranges of 5-30°C and 25-75% RH.
	Results: Inspection of test piece after each impact
	Pass: No part exceeding a mass of 50g falls down, no holing bigger than an ellipse of (400+-2)mm x (300+-2)mm

	shall occur, the test sample or any infill panels shall not detach or dislodge,
Moisture	
Wetting and drying test (Houben & Guillaud, 1994) Supplies: - Container for water submerging - Container as drip tray - Weighted steel brush - Low-temperature oven (50-110 C) - Scales Steps: 1. Prepare the test sample. 2. Place the test sample in the container for water submerging, and fill it with water (T0). 3. Move the test sample to the dry tray (T0+5h). 4. Place the test sample in the oven at 110C (T0+7h). 5. Place the test sample in the oven at 110C (12h). Results: Weigh the test sample at certain times, take pictures and note changes. Goal: To understand how the sample responds to moisture	*EN 12155:2000 Curtain walling - Watertightness - Laboratory test under static pressure* - Three pulses of positive pressure equal to 500 Pa or 110% of maximum test pressure (from EN 12154:1999, chapter 6) - After 15 minutes of spraying, apply the test pressure as specified in EN 12154:1999 Results: Check for water leakages and record test pressure, time and location of any leaks. Pass: There shall be no water leakage to the maximum test pressure throughout the sequence of test pressure and times specified in 12154:1999.
Freeze and thaw test (Houben & Guillaud, 1994) Supplies: - Freezer - Container - Spray bottle - Absorbent towel - Scale According to a time schedule, freeze, thaw and dry the test sample. Results: A comparison before and after the test, noting the weight reduction and visual changes over time. Goal: To get an indication of the level of frost resistance, predicting damage behaviour.	*NEN-EN 13050:2011 Curtain Walling - Watertightness - Laboratory test under dynamic condition of air pressure and water spray* - Watertightness test as mentioned above. - Wind generator with air velocity of 20 m/s at 20mm, moving it at 2.5+-0.5m/min, moving it back and upwards and traverse. Results: Inspection of inside surfaces for water leakage, record of the details of leakages and the total time from start of spraying to completion of movement of the wind generator.
Moisture absorption test (Norton, 1997) Supplies: - Container for water submerging - Scales - Measuring tape Steps:	*NEN-EN 12153:2023 Curtain Walling - Air Permeability - Test Method* - Apply test pressures in increments of 50 Pa upto 300 Pa and with increments of 150 Pa up to maximum test pressure.

1. Place sample in container and fill container with water. 2. Check at preset intervals. Results: Note results and take pictures at the intervals. Weigh the sample at start and end. Take size measurements. Goal: To figure out how much water is absorbed by the sample and how it changes its shape and dimensions.	- Positive pressure test - Negative pressure test Results: Determine the air permeability, $Q_f = Q_{fc} - Q_c$, and calculate the air permeability per unit length of fixed panels and plot a graph against the test pressures. Pass: According to NEN-EN 12152:2023, the air permeability is classified per Table 1 and 2.
Fire	
Cone calorimeter test According to according to ISO 5660:1050. Burns up a 100x100 mm material. Goal: To determine the heat release, smoke production and mass loss rate. (this information can be used to get an estimate of the fire class).	*NEN 6069:2022 nl Determination and classification of resistance to fire of building elements and building products* - Creating the sample - Creating the test piece, with size according to A.5.2 (NEN-EN 1364-3), with a RH of 50+-10% at 20+-5C. - Oven test: stick to the temperature progression as shown in A.2.2: $\theta - \theta_0 = 345 \times \log(8 \times t + 1)$ If the determination considers the fire resistance from outside to inside of outer walls, then follow A.2.3: $\theta - \theta_0 = 345 \times \log(8 \times t + 1)$ voor $t \leq 10$ min en $\theta - \theta_0 = 659$ °C voor $t > 10$ min Results: Note time, place and type of tears, cracks, or other openings, keep track of test piece area temperature, and possible failure of test piece. Pass: Flame density requirements (no flames constantly visible for 10 sec, cotton wools glow or ignite, opening calibers should be put in the oven without exerting force) , surface temperature maximum (140C and 180C), no failure of the test piece.
	NEN-EN 1364-1:2025 Fire resistance tests for non-loadbearing elements - Part 1: Walls - In accordance with NEN-EN 1363-1:2020, heating curve according to: $T = 345 \log_{10}(8t + 1) + 20$ Results: record temperatures of all thermocouples together with the time,

	and note furnace pressure, deflection of the test sample, the integrity (cotton wool pad ignition and flaming). Pass: limiting deflection, integrity, insulation (maximum unexposed face temperature increase)
	NEN-EN 13501-1:2019 Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests - *EN ISO 1182 Non-combustibility test* - *EN ISO 1716 Heat of combustion test* - *EN 13823 Single Burning item test* - *EN ISO 11925-2 Ignitability test* - *EN ISO 9239-1 Determination of the burning behaviour of floorings, using a radiant heat source*
Thermal	
AAMA 501.5-23 Test Method for Serviceability of Exterior Fenestration After Thermal Cycling Heating and cooling of a material or product between temperature extremes for a certain duration. Results: Evaluation of permanent damage caused by thermic cycling. Goal: To evaluate a material's defects and/or product's design after facing varying temperatures.	*NEN-EN12667:2001 Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Products of high and medium thermal resistance* - Guarded hot plate apparatus measurements, or: - Heat flow meter apparatus measurements Results: Thermal resistance of product
Acoustic	
Impedance tube test Quantifying the sound absorption performance according to ISO 10534-2 → this test is for sound absorption, so it is not applicable to sound insulation, but to acoustic performance.	*NEN-EN ISO 717-1 rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation* - NEN-EN-ISO 10140-2:2021 en Acoustics - Laboratory measurement of sound insulation of building elements - Part 2: Measurement of airborne sound insulation - NEN-EN-ISO 16283-1:2014/A1:2018 en Acoustics - Field measurement of sound insulation in buildings and of

	building elements - Part 1: Airborne sound insulation Results: Sound Reduction Index (R) Pass: Compare with curve of reference
Durability	
Accelerated aging test Uses extreme heat, humidity, oxygen, sunlight, vibration conditions to speed up the normal aging processes of a sample. Goal: Get an estimate of the long-term effects of expected levels of stress	*NEN-EN 113 1-3 Durability of wood and wood-based products* - Part 1: Assessment of biocidal efficacy of wood preservatives - Part 2: Assessment of inherent or enhanced durability - Part 3: Assessment of durability of wood-based panels Results: Durability parameters
Abrasion test (Houben & Guillaud, 1994) Supplies: - Clamp to secure test sample - Weighted steel brush - Scales Steps: 1. Prepare test sample and secure in place. 2. Place the weighted brush on the sample. 3. Move the brush from left to right and back. This is one cycle. Repeat 50x. Results: Weigh the sample before and after the test, take photos and note changes. Goal: To determine a sample's vulnerability against contact damage.	
Penetration test (Houben & Guillaud, 1994) Supplies: - Point-ended object - Measuring stick - Scales Steps: 1. Prepare the test sample. 2. Put down measuring tool. 3. Penetrate the sample with the pointed object, with a force of about 1.5kg. Repeat 5 times. 4. Penetrate the sample with the pointed object, with maximum force Repeat 5 times. Results: Note results and take pictures. Goal: To determine a sample's vulnerability against impact damage.	

2.1.5. Standards, legislation and regulations

In this section, input for answering research subquestion 2b, 'How does a product comply to current legislations, regulations and standards?', is given. This input is later used in the expert dialogues, as groundwork for discussion on which regulations and standards are important for a bio-based façade product supplier.

There is legislation every building needs to conform to. These legislative rules are established in the Decree on construction works in the living environment (Besluit bouwwerken leefomgeving, BBL). All other requirements set by potential buyers are usually based on market agreements. These are standards put forward by the market, and usually significantly higher than the legal requirements.

For building products, certification is not required by law, with the exception of CE marking (discussed below). However, customers often demand proof for a certain quality and durability in order to ensure the complete building conforms to the BBL requirements and it complies with their own or their client's requirements as well.

2.1.5.1. BBL requirements and testing methods

BBL requirements are set for the complete façade of a building. It is required by law to conform to the standards. This is the responsibility of the architect and contractor. Below, the BBL requirements for façades are listed in Table 6: Decree on construction works in the living environment (BBL) for façades.

Table 6: Decree on construction works in the living environment (BBL) for façades

Performance	BBL requirement	Testing method	BBL
Structural			
Water	Separation construction of a living area, a toilet room, or a bathroom must be waterproof.	NEN 2778 Moisture Control in Buildings and ISO 12572 Hygrothermal performance of building materials and products - Determination of water vapour transmission properties - Cup method	4.118
Thermal	RC min. 4,7m²·K/W	NEN-EN 12667 Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods	4.152
Acoustic	min. 20 dB	NEN 5077 Noise control in buildings - Determination methods for performances concerning airborne sound insulation of façades, airborne sound insulation and impact sound insulation, sound levels caused by technical services	4.3.1
	Minimum difference between external noise load and internal sound level: (33 / 35 dB)	NEN 5077 Noise control in buildings - Determination methods for performances concerning airborne sound insulation of façades, airborne sound insulation and impact sound insulation, sound levels caused by technical services	4.3.1

Fire	The interior side of the façade must comply with the fire class and smoke class s2 specified in Table 4.42.	NEN-EN 13501-1 Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests	4.43
	The exterior side of the façade must comply with the fire class specified in Table 4.42 (=D), unless it is situated lower than 2.5 m or higher than 13 m above the adjacent terrain, in which case it must comply with fire class B.	NEN-EN 13501-1 Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests	4.44

2.1.5.2. Declaration of performance

Per regulation (EU) nr. 305/2011, a declaration of performance (DoP) is mandatory for all construction products placed on the market in Europe, see Figure 5: Declaration of Performance (Commission Delegated Regulation (EU) No 574/2014, 2014). In this DoP, product characteristics are established. By drawing up this Declaration of Performance, the manufacturer assumes responsibility for ensuring that the product complies with the declared values. Subsequently, a CE marking is a required label. If the building product does not fall under an existing harmonised standard, CE marking is not required. Obtaining the label anyway is done by drafting a EAD/ETA via the European Organisation for Technical Assessment. The full CE marking contains, in addition to the familiar logo, the indication of the unique code for the product type. This should make it possible to find the Declaration of Performance that belongs to the product.

DECLARATION OF PERFORMANCE

No

1. Unique identification code of the product-type:
2. Intended use/es:
3. Manufacturer:
4. Authorised representative:
5. System/s of AVCP:

6a. Harmonised standard:

Notified body/ies:

6b. European Assessment Document:

European Technical Assessment:

Technical Assessment Body:

Notified body/ies:

7. Declared performance/s:
8. Appropriate Technical Documentation and/or Specific Technical Documentation:

The performance of the product identified above is in conformity with the set of declared performance/s. This declaration of performance is issued, in accordance with Regulation (EU) No 305/2011, under the sole responsibility of the manufacturer identified above.

Signed for and on behalf of the manufacturer by:

[*name*]

At [*place*] on [*date of issue*]

[*signature*]

Figure 5: Declaration of Performance (Commission Delegated Regulation (EU) No 574/2014, 2014)

2.1.5.3. Standards

A list of browsed standards can possibly give newcomers a start on what to search for. Possibly useful standards for bio-based façade products include the following:

- NPR_CEN TR 16208 2011 Biobased producten _ Overzicht van normen
- EN 16751 Biobased producten – Duurzaamheidscriteria
- NEN2891 Façade elements - Terms, definitions and rules for modular location and dimensioning
- NEN EN 1364-1 Fire resistance tests for non-loadbearing elements - Part 1 Walls
- NPR 6112 Fire safety of buildings - Practical examples of façades with pedestrian doorsets and openable windows with fire-resistant characteristics
- NPR 5272 C1 Geluidwering in gebouwen - Aanwijzingen voor de toepassing van het rekenvoorschrift voor de geluidwering van gevels op basis van NEN-EN 12354-3
- NPR 2068 (nl) Thermische isolatie van gebouwen - Vereenvoudigde rekenmethoden
- NPR 2652 (nl) Vochtwering in gebouwen - Wering van vocht van buiten en wering van vocht van binnen - Voorbeelden van bouwkundige details

- NPR 1090 (nl) Ventilatie van schoolgebouwen - Voorbeelden van oplossingen voor schoolgebouwen
- ISO 17738-1 Thermal insulation products - Exterior insulation finish systems - Part 1: Materials
- ISO 17738-2 Thermal insulation products - Exterior insulation and finish systems (EIFS) - Part 2: Installation
- ISO 17738-3 Thermal insulation products - Exterior insulation and finish systems (EIFS) - Part 3: Design requirements
- IWA 42 2022 en net zero guidelines
- NEN-EN 16935 (en) Biobased producten - B2C-rapportage en - communicatie - Eisen aan claims
- NEN EN 16785-1 Bio-based products - Bio-based content - Part 1 Determination of the bio-based content using the radiocarbon analysis and elemental analysis
- EN ISO 18134-1 & 2 2022 bepaling vochtgehalte van vaste bio brandstoffen

Sustainability

Sustainability is an important aspect of bio-based products. It is useful to be able to quantify the sustainability aspect of a product. Well-known sustainability certificates include:

- Environmental Product Declaration (EPD): reports comparable, objective and third-party verified data that show the good, the bad and the evil about the environmental performance of their products and services.
- Forest Stewardship Council (FSC): indiactes that trees are harvested responsibly so there is no net loss of forest over time, workers are provided with proper training, adequate safety protocols, and fair wages, plant and animal species are protected and local communities living in and around forest areas are consulted, and their legal and cultural rights to land and forest resources are respected.
- Natureplus label: independant environmental label which ist fully compliant to ISO 14024. It demonstrates compliance with high standards of quality for all areas relevant to sustainability (recources, production, health).
- Nationale Milieu Database (NMD): official product database in The Netherlands, containing official Life Cycle Assessments (LCAs) of registered products.

Other certifications, that are specific to green building products (National Institute of Building Sciences, 2024), concerning façade products specifically:

- SCS Global Services: claims for recycled content, biodegradable liquid products, and no-added formaldehyde products
- Cradle to Cradle Certified^{CM}: assesses a product's safety to humans and the environment and design for future life cycles
- International Green Mark (IGM): assessing and verifying the sustainable attributes of products, IGM presents an impartial statement on whether a product is less harmful to the environment than another similar yet unlabeled product

- GREENGUARD Certification Program: GREENGUARD certifies that a product meets thresholds for formaldehyde, total aldehydes, total volatile organic compounds (VOCs), and one-tenth of the threshold limit value (a regulatory benchmark) for many other compounds.
- Health Product Declarations (HPD): provide a full disclosure of the potential chemicals of concern in products by comparing product ingredients to a wide variety of "hazard" lists published by government authorities and scientific associations. To achieve third-party verification, the HPD must have 100% disclosure of known ingredients and/or 100% disclosure of known hazards down to 1000 ppm.
- Declare: platform for manufacturers of ecologically sound products to demonstrate market leadership and secure a competitive advantage.

2.1.6. Creating an informative product

The end-product of this thesis will be an information product. It is important to find out what informative products could look like and which design aspects are important to consider. This section gives input to answer subquestion 3b, 'What should the interface of the information product look like?'

The Gestalt principles touch upon visual aspects specifically as important aspects of an infographic, which can be found in Figure 6: Gestalt Principles (Principles of Data Visualization - What We See in a Visual, 2016).

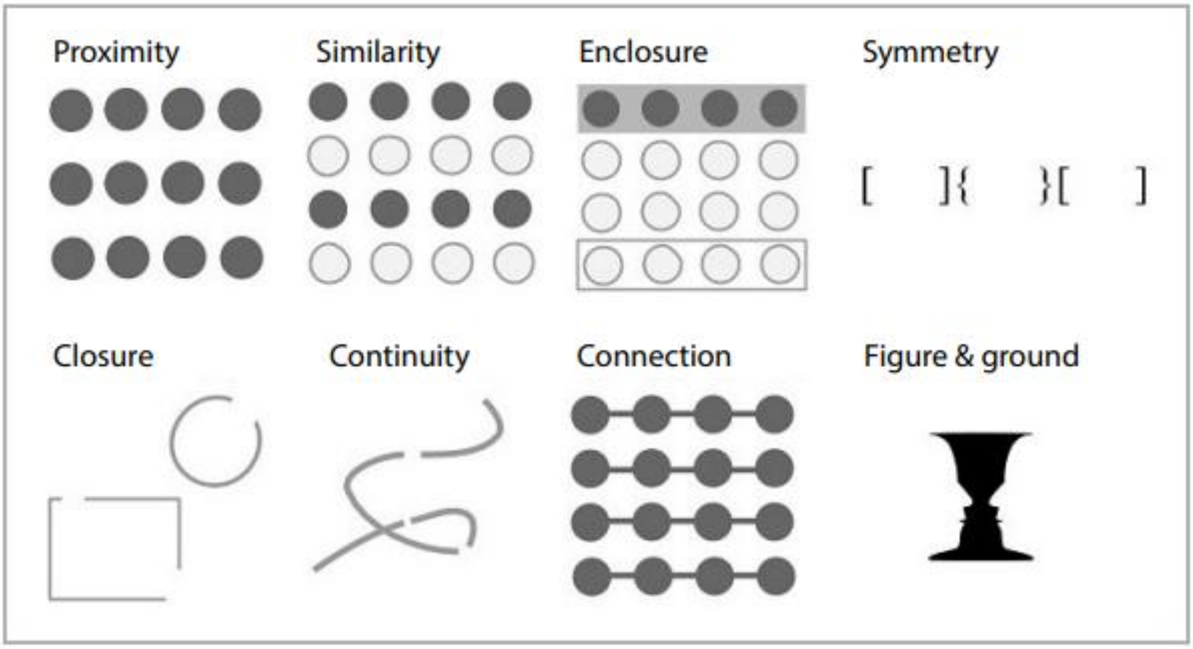


Figure 6: Gestalt Principles (Principles of Data Visualization - What We See in a Visual, 2016)

The five principles of Design theory are the following:

- Alignment
- Repetition
- Contrast
- Hierarchy

- Balance

Both the Gestalt principles and the principles of Design theory could be applied to the design of the information product.

Infographic design

What qualities constitute an effective infographic (Dunlap & Lowenthal, 2016)?

- Immediacy
- Malleability
- Compellingness
- Resonance
- Coherence

Key ingredients for an engaging infographic include the following (Scott et al., 2017):

- Factors such as age, gender and education level of the consumer have been found to influence the ability of an infographic to capture attention.
- Seek advice from the population group the infographic is designed for.
- Strike a balance between visualisations, images and text.
- Text should be used sparingly in an infographic and should provide clarity and understanding of the concepts that are presented visually.
- Apply the 'no text test'. Ask yourself is the infographic comprehensible when the text is removed.
- Use no more than three different font type and use a colour palette of 3–5 colours that complement one another.

According to a publication by Public Health England (Stones & Gent, 2015), guidelines for designing public health infographics (which could be considered similar to other types of infographics) are the following:

G: Get to Know Your Audience
R: Restrict Colour
A: Align Elements
P: Prioritise Parts
H: Highlight the Heading
I: Invest in Imagery
C: Choose Charts Carefully

When it comes to getting to know your audience, factors such as age, gender and education level influence the ability of an infographic to capture attention (Harrison et al., 2015). Below, in Figure 7: Questionnaire for an engaging infographic (Harrison et al., 2015), the questionnaire used in this research can be found. This questionnaire can be used as example of the type of questions that could be asked in the rating of an infographic.

In your own words, why do you think people like this infographic?

Related to *immediacy* component:
1. The infographic creates a sense of urgency. [Yes or No] How does this infographic create a sense of urgency? Or how does it not?
2. The infographic creates a sense of excitement. [Yes or No] How does this infographic create a sense of excitement? Or how does it not?
3. The infographic encourages users to take action. [Yes or No] How does this infographic encourage users to take action? Or how does it not?

Related to *malleability* component:
4. The infographic enables users to apply the content in various ways. [Yes or No] How does this infographic enable users to apply the content in various ways? Or how does it not?
5. The infographic allows users to determine their own personal meaning and relevance. [Yes or No] How does this infographic allow users to determine their own personal meaning and relevance? Or how does it not?
6. The infographic allows users to explore the content. [Yes or No] How does this infographic allow users to explore the content? Or how does it not?

Related to *compellingness* component:
7. The infographic grabs users' attention. [Yes or No] How does this infographic grab users' attention? Or how does it not?
8. The infographic holds users' attention. [Yes or No] How does this infographic hold users' attention? Or how does it not?
9. The infographic shares a provocative idea or problem. [Yes or No] How does this infographic share a provocative idea or problem? Or how does it not?
10. The infographic shares a novel idea or problem. [Yes or No] How does this infographic share a novel idea or problem? Or how does it not?
11. The infographic uses storytelling to deliver the message. [Yes or No] How does this infographic use storytelling to deliver the message? Or how does it not?
12. The infographic uses unexpected design elements. [Yes or No] How does this infographic use unexpected design elements? Or how does it now?

Related to *resonance* component:
13. The infographic helps users see how the content is relevant to them. [Yes or No] How does this infographic help users see how the content is relevant to them? Or how does it not?
14. The infographic helps users see connections (e.g., past, present, and future; existing and new ideas and perspectives; theory and practice). [Yes or No] How does this infographic help users see connections? Or how does it not?
15. The infographic evokes users' emotions and memories. [Yes or No] How does this infographic evoke users' emotions and memories? Or how does it not?
16. The infographic is credible (e.g., includes reliable content from trusted sources). [Yes or No] How is this infographic credible? Or how is it not?

Related to *coherence* component:
17. The infographic presents a complete message. [Yes or No] How does this infographic present a complete message? Or how does it not?
18. The infographic presents a well-formed message. [Yes or No] How does this infographic present a well-formed message? Or how does it not?
19. The infographic is logically structured. [Yes or No] How is this infographic logically structured? Or how is it not?
20. The infographic's message is clear. [Yes or No] How is this infographic's message clear? How is it not?
21. The infographic includes relevant text and images. [Yes or No] How does this infographic include relevant text and images? Or how does it not?
22. The infographic includes consistent design elements. [Yes or No] How does this infographic include consistent design elements? Or how does it not?

Additional comments or insights about this infographic?

Figure 7: Questionnaire for an engaging infographic (Harrison et al., 2015)

2.2. Interviews: challenges of the innovation

Interviews were held to find an answer to research question 1, 'What are the current challenges for start-ups creating a bio-based façade product?'. The goal of this thesis is to create an information product containing all information *relevant* to bio-based façade product start-ups. These interviews help understand what the challenges for these start-ups are of this moment in time and the outcome will be necessary to discover what information is required to tackle these challenges. The full notes to the interviews can be found in Appendix A. Interviews: Challenges of the Innovation.

To figure out what the biggest challenges are at this moment in time when it comes to bringing the innovation of a biobased façade product to the market, eight interviews were scheduled with people from the following groups. Three biobased façade companies with experience (1, 2, 6), two biobased startups (in the process of starting up) (3, 4), one startup that did not fall through and with a lot of follow-up experience in the field (5), one expert on standards (7), one expert on technical (biobased) innovation (8). These people were deemed to be a good small-scale representation of people with the required experiences and knowledge.

A semi-structured interview was held with each of the respondents, in which the following questions were asked (in Dutch):

1. What challenges do you encounter in the process of designing a building product up to its sale (examples: gathering raw materials and information, finding the perfect application, designing with bio-based materials, production (and scaling up), bringing it to market (with certifications), acquiring customers)?
2. What information is needed to better understand how to design and apply your bio-based building product in a façade (examples: production methods, assembly, technical aspects, building physics aspects, connections, sustainability aspects such as disassembly)?
3. What type of product could help a company bring an (innovative) bio-based façade product to the market (example: a guide that covers all phases and steps). What is the most important aspect?

During the interviews, interesting follow-up topics or side tracks were followed through.

2.2.1. Summary: challenges of the innovation

Below, a summary of the interviews results is shown per question. Numbers mentioned between brackets refer to the different interviews, so it is easy to check how many people noted the same and also make sure different opinions were voiced.

Question 1: What challenges do you encounter in the process of designing a building product up to its sale (examples: gathering raw materials and information, finding the perfect application, designing with bio-based materials, production (and scaling up), bringing it to market (with certifications), acquiring customers)?

Respondents brought up the **traditional building sector** as an issue, including the following examples. Dutch contractors are not used to keeping structures dry (1), unfamiliarity leads to fear (2), profit margins in construction are so minimal that competing with new materials is nearly impossible (3), scaling is a major challenge and can only be done with prefab (which means relying on existing half products) (3).

Many respondents brought up **testing**: Existing test methods are not designed for approval (3), testing is vital to a good product (6) current tests are not suitable for bio-based materials, e.g., assumptions about vapour-tightness (7) fire testing is extremely expensive and complex, making it nearly impossible (7), testing remains a challenge (8).

Some respondents brought up **certification** as well. Standards either do not exist or are not aligned with bio-based materials (3), what standards apply? (4), what materials are being used in the market? What tests/certificates do they have? Customers set requirements (4).

The **bio-based material itself** was also seen as the challenge: Bio-based production yields different results each time—how do you determine quality and meet quality standards? (3), raw material quality is crucial—each batch must be tested (4), material availability is critical → it is not easily supplied, especially in the early stages of a startup (6).

The **zero-series production** was also seen as a challenge. TRL (Technology Readiness Level): Levels 0-2 involve lab testing, while levels 5-6 mark the pilot phase. Many startups get stuck at levels 5-6 (5). Producing the first zero-series is a challenge (8).

Question 2: What information is needed to better understand how to design and apply your bio-based building product in a façade (examples: production methods, assembly, technical aspects, building physics aspects, connections, sustainability aspects such as disassembly)?

Respondents highlighted **regulations** as a challenge. Regulations can be restrictive, especially for vapour-open and passive construction (1). The NENnovation funnel and NEN Webtool were mentioned as useful resources (7). Companies should ask construction firms what certification is required—whether it concerns testing, compliance with NEN standards, or full certification (5). Many NEN standards are market-driven, with only a small portion being legal requirements found in the BBL (7). NTA standards offer a more flexible alternative to NEN norms, allowing for quicker development (7).

Design aspects were also considered crucial. Building physics play a significant role, especially regarding fire resistance and moisture distribution throughout the year (1). Moisture is a major challenge (4), and fear of moisture-related consequences leads to concerns (5). If materials are resistant to moisture, detailing and vapour-open layering are essential (5). Fire resistance depends on building height: under 15 meters is less restrictive; above 15 meters requires additional attention (5).

Testing and material selection were also addressed. Companies need to determine which materials to use, their capacity, tolerances, and capabilities (3). The biggest challenge is finding the right application (3). It is also important to consider whether existing material functions are sufficient (4). Some respondents recommended simplified in-house tests, such as lighter tests for fire resistance (4, 5). Durability testing is also key—one winter provides some insight, but five years reveal much more (5). The development of new laboratories and manufacturing facilities is necessary to transition from prototype to production and zero-series manufacturing (8).

Question 3: What type of product could help a company bring an (innovative) bio-based façade product to the market (example: a guide that covers all phases and steps). What is the most important aspect?

Presentation format was frequently mentioned. Visual representation is key—an infographic with a flowchart and chapter references would be the most effective (1). Clear scoping is essential, focusing on what users actually need (3). A clickable format would allow users to navigate to relevant sections (6). Open-source accessibility was also suggested, allowing continuous updates and improvements (6).

Content was another critical point. Respondents emphasized the need for clarity on façade standards and how new materials can comply (4). The best approach is to start with existing materials and align with their requirements (4).

Testing should also be **structured into different phases**, progressing from basic to high-end tests (5):

- Acoustic testing: Ranging from shouting to impedance tube measurements (€100s), followed by full-scale tests (€1,000s).
- Fire testing: From lighter tests to SBI tests (€100s), cone calorimeter tests (measuring burn rate and gas emissions, €100s), and corner fire tests (€5,000).
- Durability testing: Simple exposure tests (e.g., water immersion, outdoor exposure).
- Structural testing: Three-point bending or compression tests, which can be scaled up.
- Insulation testing: Moving beyond simplistic 1D resistance tests to full insulation testing (€1,000s)

Miscellaneous comments

The following comments were made during the discussion of follow-up topics or side tracks.

- Scaling strategy → also requires certification (1): WUFI calculations (to assess condensation risk).
- Circular Reno covers insurance, legal requirements, production, and testing methods. (3).
- Raw material quality, production process, and machinery must be established before certification by a notified body (e.g., TÜV or Lloyd's) (4).
- Go-to-market strategy: Don't aim for high-end applications immediately—start with simpler applications with more accessible markets (4,5). For example, door manufacturers did not have any requirements for standard types of doors, only manufacturability in production is important. start with that as an entry market, then you move on to more complicated applications (4).

- Market connections are crucial (6). Suggested sparring partners include Building Balance, Holland Houtland, Lectoraat Biobased Bouwen (MNext) Avans, Agrodome, Material District, and various trade fairs.

2.3. State of the Art conclusion

In this chapter, the literature review was presented and a summary of the 'challenges' interviews was presented.

In the interviews section, research question 1 'What are the current challenges for start-ups creating a bio-based façade product?' was answered by the responds on interview question 1. The challenges for bio-based start-ups presided mostly in the design and testing stages. This answer is valuable for shaping the end-product of this thesis, because it gives a clear direction to the content of this product.

The literature review gave useful input for answering research question 2 'What knowledge is required to develop a bio-based façade product?'. All the information gathered here is used as input for the expert dialogues. In the expert dialogues, the gathered information is discussed and the result to that discussion should yield the answer to research question 2.

Section 2.1.7. gave input for answering research question 3b 'What should the interface of the information product look like?' by zooming in on on design theory. The interviews gave useful input for answering research question 3a 'What information is most relevant (focus on performance and testing)?' (interview question 2) and also on research question 3b (interview question 3). Relevant information included: regulations, design aspects, testing. The suggestions for the type of information product: flowchart, clickable, open-source.

Through the state of the art, it could be concluded that knowledge gaps are present, because we are dealing with a new and innovative type of material-product combination in a conservative market. These gaps are found in the absence of bio-based specific design guidelines (most evident are the unknowns in vapor-open design), the absence of bio-based specific testing (there is only one experimental paper, which was dedicated to rammed earth, and all tests from NEN-standards were not specifically aimed at bio-based), gaps in information on field experience and the sector-specific product development process. These knowledge gaps should be addressed in this thesis. The method to cover these gaps is expert dialogues and is explained in the next chapter. Once all information is gathered and knowledge gaps addressed (and research question 2 is answered), the final end-product of this thesis can be developed and validated (research question 3). The methods for these steps are explained in the next chapter.

3. Methodology

In this chapter, the used methods for the expert dialogues, product development and validation are described. The aim of the expert dialogues was to get additional knowledge from first-hand experience, filling up the knowledge gaps of the literature review. The goal of the product development was to end up with an attractive information product, containing information deemed relevant for bio-based façade start-ups. The aim of the validation was to figure out if the developed product indeed fulfilled its purpose. The methods described were carried out and the results can be found in the next chapter.

3.1. Expert dialogues method

The expert dialogues were the first step in the development of the final end-product of this thesis. From the State of the Art (literature review & interviews regarding challenges), much information was gathered. The knowledge gaps found in the State of the Art were filled by means of conversing with experts about their knowledge and experience. Specifically, for design and testing, experience with bio-based was valuable. Therefore, the following types of expertise were inquired: start-ups, bio-based experts, and building (physics) experts. A total of 9 experts were spoken with.

The aim of these dialogues was to fully answer research question 2 'What knowledge is required to develop a bio-based façade product?', and subquestion 3a 'What information is most relevant (focused on performance and testing)?'.

The following types of information were required:

1. General bio-based knowledge
2. General start-up process
3. Bio-based design knowledge
4. Testing methods
5. Useful stakeholders in the field
6. Infographic interface design
7. Success stories

The following types of experts were used to obtain these types of information:

- For 1, all players in the bio-based field had valuable information.
- For 2, current/past start-ups and involved parties (such as Building Balance and the Green Village) had useful information.
- For 3, TUD-researchers and ABT-experts were consulted
- For 4, past and current start-ups, The Green Village and TNO were consulted.
- For 5, a current and past start-ups were asked who was valuable in their process and a general analysis of the field was made.
- For 6, design experts were asked and books were further consulted.
- For 7, four start-ups / bio-based businesses were asked to co-write a success story of about 100 words with me.

3.2. Product development method

The product development phase aimed at getting all relevant information from the literature research and interviews and shape it into one infographic, which would need to have an attractive interface, and be intuitive and easy to navigate. The final sub question, 3c 'How does the relevant information fit in the interface?' was addressed in this step. At the end of this step, research question 3 'What should the information product for bringing a bio-based building product to the market be?' had to be answered.

3.2.1. Content

The first step of the product development method was to collect the information that was going to be used as input for the end-product. To determine what the most relevant information from the State of the Art was, interviews were conducted. These interviews aimed at figuring out what the biggest challenges are for start-ups in the process of developing a biobased building product. The conclusion was that design and testing were the most challenging aspects and thus available information from the desk research was collected as a first step in the product development method. An important aspect of this step was to group all available information in logical segments and create easily readable (= both not too long and not too difficult) paragraphs. Before the information product took the shape of a visual product, a long 'guide' was created, which contained *all* possibly useful information. Much of this information was used as input for the eventual information product, the infographic. The information was made more concise, and choices were made on which information was most relevant. A clear example is the choice to include not include structural performance in the Design box. This choice was made because, a. the scope of this thesis was limited to non-structural façade elements and, b. the information that would still be required to design for being self-load bearing, resisting the present mechanical and environmental loads, etc is the same for a bio-based material as for a traditional building material. Thus, this performance factor was not included in Design. Drawings were made to support the building physics aspects, an informative table was created with BBL-requirements and corresponding NEN-standards.

3.2.2. User interface

The second step was figuring out what type of informative product should be chosen. Several options were considered including, but not limited to, an informative guide, a flowchart, an infographic. In order to decide which option fit best with the purpose of the product, the interviewees were asked which option they would prefer. From the interviews, a visual flowchart, with clickable format and clear scoping was suggested, possibly open-source. The infographic was a balanced combination of all these aspects. Additional design choices were made considering the following aspects:

1. audience needs;
2. content complexity and organisation;
3. distribution channels;
4. time and resources;
5. overall goal.

The third and final step in creating the end-product was combining the relevant information with the chosen type of information product. An interface had to be created that would support the content. Requirements for the medium were the following: easy to use (due to the focus of this thesis), clear and attractive design possible (to create something that would invite potential users to read its content), and the possibility to create different levels (to enable users to go in depth or stay on the surface, depending on their prior knowledge and level of interest).

3.2.3. The product

To merge the available information with the infographic, sketches were made, (re)categorizing the available information. After a concept design was created, this design was recreated in the chosen medium, leading to the first concept design. The Gestalt principles and principles from Design theory, such as symmetry, alignment and similarity were used to position, shape and colour the information blocks, lines and arrows in the infographic. Parallel to creating the first concept designs, the expert dialogues took place, providing with confirmation on the importance of gathered information and providing with new information. In the dialogues, the initial concept designs were shown and feedback on the design was considered.

An additional part in this step was fiddling with the interface design. Several colour schemes were tried in order to find the one that fit best, with criteria such as readability, attractiveness, and matching with content.

3.3. Validation method

The validation of the end-product was done by means of presenting it to potential end-users (start-ups and students) and field experts. A set of questions was asked to each of these groups, with the aim to figure out whether the infographic's content was complete and the interface appealing. At the end of the validation step, a conclusion could be drawn on whether the developed product fulfilled its purpose. If not yet, the choice to incorporate feedback could be made to solve or at least improve this.

3.3.1. The test groups

The following groups of people were asked to validate the end-product.

- Bio-based experts (10 individuals): During this thesis, many different experts crossed paths. These experts are defined by their knowledge in the field of bio-based materials in construction, each with their own expertise. One is distinguished by their experience with a bio-based start-up and the challenges that arise, another has seen many start-ups and helped them test their product, a third has knowledge and experience in business and marketing, and more. These varying expertises cover all aspects that are covered in this thesis, and thus is their view on the end-product of this thesis of inestimable value.
- Building (physics) experts (9 individuals): these are researchers from the TU Delft and colleagues from ABT. They will have knowledge about the

design content and about the building process in general. They might also offer additional advice on one of the steps.

- Biobased start-ups (10 start-ups): this group is about to start with, right in the middle of, or (just) finished designing and developing a bio-based façade product. This group will know best which challenges they encountered and what helped them to overcome them. They will have the ultimate view on what information is valuable to others like them, and what information is redundant.

3.3.2. Feedback questionnaire

The questionnaire was sent out to all three test groups and was created using an AidaForm. All possible participants were notified a week before sending out the questionnaire by means of an email. In this email they were updated (or informed) on this MSc-thesis project and called on to fill out the questionnaire once it was sent to them. In the email one week later, containing the link to the questionnaire, they were asked to fill out the questionnaire within one and a half week. This deadline was deemed reasonable but not too far in the future. After one week, another email was sent as a reminder, and each person was addressed individually to create a more personal feeling.

The questionnaire contained to following questions.

Initial questions

1. What is your first / overall impression of the infographic? [1 – terrible, 5 – wow!]
2. How would you naturally navigate through the infographic? [open question]

Design questions

3. What seems to be the target audience? [open question]
4. What do you think of the colour scheme (contrast, attractiveness)? [1 – terrible, 5 – great]
5. Are the elements properly aligned? [Yes or No (please specify)]
6. Which parts draw most attention? [open question]
7. Is the heading clearly visible? [Yes or No (please specify)]
8. Are the images supporting the content? [Yes or No (please specify)]
9. Are the charts and tables supporting the content? [Yes or No (please specify)]

Content questions

Is the content of the guide valuable for the target group; what is most valuable and what is missing?

10. Overview: is it clear what content you can expect? [1 – not at all, 5 – 100%]
11. How would you rate the following information blocks (see the colored demarcations on the image above) of the infographic on their depth?
    a. General overview
    b. Understanding context
    c. Useful to know

    d. Input for you product design
    e. Design
    f. Testing
    g. Output from your final testing
12. Please elaborate! [open question]
13. Dive in [Design block]: Moisture, Fire, Thermal, Sound [open question]
14. Dive in [Testing block]: Structural, Thermal, Moisture, Sound, Fire, Durability [open question]

Ending

15. Is there anything else I need to know? [open question]
16. Your email If you wish to receive the final version of my infographic [not required]

Interface

Below, in Figure 8: Validation questionnaire interface, a screenshot of the interface of the questionnaire can be found.

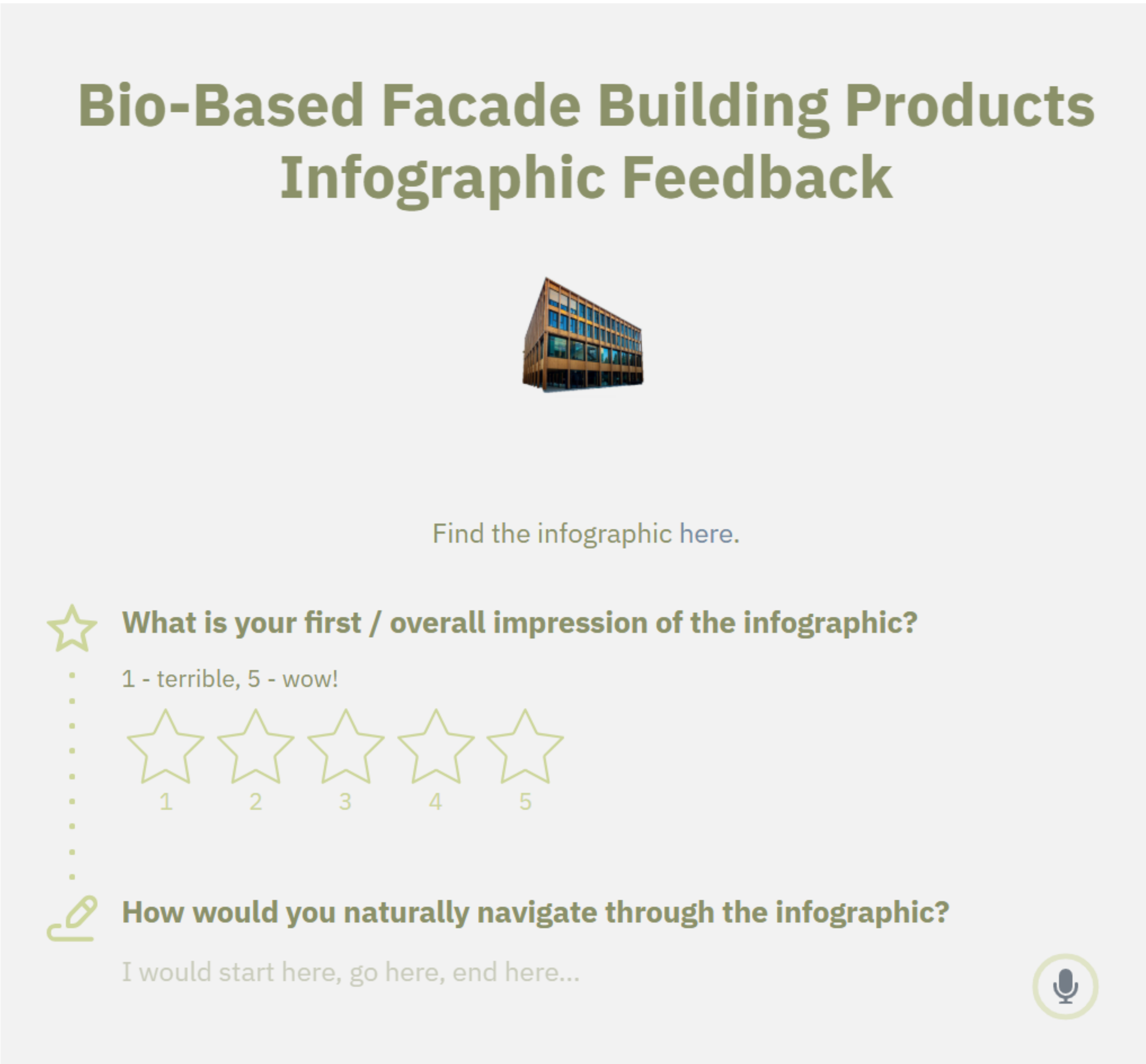


Figure 8: Validation questionnaire interface

3.3.3. Incorporation of feedback

The feedback given in the validation session was of great value. It confirmed or denied the efficiency of the different aspects of the end-product. Some feedback was too large to incorporate. This feedback can be used as input for suggested improvements or for recommendations for further research.

However, there was feedback that could be easily implemented, and/or feedback that was too important to ignore. The changes that arised from these pieces of feedback were made after validation. When the incorporation of this criticism was done, the end-product was finished. This end-product complied with the research goal: to create a guiding product for bringing a bio-based façade building product to the market, which addresses the most prominent questions that arise along this journey.

4. Presentation of Work

The following results were obtained during the execution of this thesis. Acting in accordance with the described methodology, the results of the expert dialogues, product development and those of the validation were acquired. At the closing of this chapter, the final end-product is shown, which also serves as the answer to the main research question: What information could help start-up companies developing a bio-based façade building product and how could this information be conveyed in a fitting way?

4.1. Expert dialogues

The following information was gathered from the meetings with experts. These experts had the following expertise. Standards and legislation (1), bio-based testing and start-ups (2, 4, 6), bio-based state of the art (3, 5), building experience (7). This information is divided into different topics, which are the following. General bio-based knowledge, bio-based design knowledge, testing methods, useful stakeholders and parties, process steps and advice and success stories. For every topic, a summary of the results is given. Numbers mentioned between brackets refer to the different dialogues, so it can be noted how many people noted the same and checked if different opinions were voiced. The full notes from the expert dialogues can be found in Appendix B. Expert Dialogues.

4.1.1. Design with bio-based

Input for the design phase includes the intended function of the end-product: what purpose should it fulfil in a façade? (3). In the design phase itself, working with natural materials calls for different thinking. Experts from TUD and ABT stressed the importance of raw material challenges, moisture and thermal considerations, including the possibility of **vapour-open designs**. Two experts noted that moisture resistance should increase from the interior to the exterior, ensuring healthy building physics (3, 5). Tools like **UBAKUS** or simple **Excel models** help simulate vapour diffusion and condensation risk (3, 5). One expert with experience with building vapour-open buildings explains they are successful in building vapour-open for all parts except for the foundation (7).

Challenges in the material development phase are common. One expert noted: "You have to add glue to your raw material to turn it into a building material. These adhesives are the source of challenges. The process time is too much, and it is possible you need up to 40% glue, which is incredibly expensive an potentially less sustainable as well" (4). Moisture resistance and **thermal considerations** are tightly linked. Insulation should be on the outside, thermal mass on the inside. One expert noted that standard walls do not have long phase shifts, but a 12-hour phase shift is ideal for stable indoor temperatures (5). This could form an opportunity for bio-based.

Fire design is done for an entire façade, and cannot be done for just one product (4). One field expert noted the fire behavior of his favorite material: hempcrete obstructs fire, is thermally insulating and detains heat (7).

Durability is another important aspect that could be seen as a challenge, since bio-based materials may degrade more quickly. It is important to note this aspect remains subject to the current **BBL lifespan requirements** (5).

4.1.2. Testing methods

Start-ups and other actors highlighted possible tests and an essential consideration: perform a number of DIY-tests before starting on the official tests.

Expert (5) suggested that product developers should start off with DIY-tests to get a feeling of their material and product, and to get an idea of the properties and performance of their sample product, yielding improvement possibilities. All other experts agreed with this suggestion. Experts noted different useful types of tests. From simply **breaking a sample** (compressive and flexural strength) (4) to a **burner and lighter** test and the **cone calorimeter** test (fire), **speaker/shout** test (soundproofing), and putting the sample in **freezer**, **outside**, and in a **sunbed** (UV, freeze, durability) checks (4, 5, 6). One expert was of the opinion that **waterproofing** is vital for bio-based materials because they are more prone to moisture-related issues like molding or rotting (5). For acoustic insulation, the following can be used as a test: use three speakers at different frequencies and wrap an insulative layer around them (perhaps putting them in separate boxes might be necessary to neatly pack those boxes in the insulative layer). The tested insulation material can be compared to existing insulation materials, by recording and listening to the results of different material wrappings (4). Fire behaviour can be evaluated both via a basic Bunsen burner setup (4) and advanced **cone calorimeter tests (ISO 5660-1:2015)** (6). When it comes to thermal tests, mid-range ISO testing (€300–900) offers cost-effective insights compared to SBI fire tests costing €25,000 (6).

It must be clear what you are testing and what the purpose of the test is: is it a material, a product, or an entire façade and what do you wish to figure out (6)? For fire behaviour, a basic Bunsen burner setup (4) aims at figuring out how fire-resistant a material is, and an advanced **cone calorimeter test (ISO 5660-1:2015)** (6) aims at describing fire behaviour. For the durability tests, the aim is to figure out material response (e.g. brittleness and density) to different circumstances (4). For the DIY thermal lamp test, the aim is to evaluate thermal mass (6).

One expert stated that a bio-based testing facility at universities (but also available for entrepreneurs) would help with understanding material behaviour and certification (2).

4.1.3. Standards and regulations

Standards form the backbone of any building product's way into the market. An expert on standards emphasized the importance of familiarizing oneself with the **NEN Connect Handbook** to identify relevant standards (1). The **ICS** classification system is useful to search relevant standards per topic. Additionally, standards contain cross-references to other standards, which might be valuable to explore (1). While **BBL requirements are mandatory**, other standards—such as voluntary standards, BRLs, and EADs—serve as crucial additions, particularly in the current absence of standards for bio-based materials (1, 3).

A pragmatic approach was shared: "Start by complying with BBL-mandatory standards, then focus on voluntary ones, and only then look into to BRLs and EADs" (1). For example, a specific BRL already exists for bio-based insulation (1).

Functionality remains key: "What function must your product fulfill?" (3). Without that clarity, compliance with both **government regulations** (5) and **certification requirements** becomes an uphill battle.

Market introduction does not always require testing, but compliance with relevant standards must be demonstrated (3). Contractors prefer certified products for safety and reliability, even if alternatives are permitted (3).

4.1.4. Sustainability aspects

Sustainability is a measurable aspect of a product and it is an important selling point, more so for bio-based materials. One expert highlighted the importance of **Life Cycle Assessment (LCA)** and the **Milieuprestatie Gebouwen (MPG)** framework used in the Netherlands (9). MPG is performed with an expert and according according to EN 15804 (9). Sustainability considerations include end-of-use planning (4). Lifecycle Assessment (LCA) is crucial, and the narrative of reusability vs. renewability is essential for a company's go-to-market strategy (4).

Alba Concepts is a sustainability company who invented the Building Circularity index (BCI). This **BCI** covers more than just environmental impact scores, and takes into account more than MPG (9), such as demountability.

The Corporate Sustainability Reporting Directive (CSRD) is a future legal requirement to hold companies accountable for their environmental, social and governance (ESG) impacts. Biobased materials have a positive effect on these impacts, so they could be a good way for companies to offset emissions (9).

Stakeholders also flagged limitations in current systems like the **Nationale Milieu Database (NMD)**, which can be skewed by dominant sectors like concrete (9).

4.1.5. Useful stakeholders in the field

The following stakeholders were mentioned in addition to the ones already on the list, or a specific usefulness was noted. **NEN** offers guided sessions for standards exploration (1), while **Krimppp** assists with DIY testing. **SHR** certifies wood-based products (4). Wageningen University (**WUR WFBR**) has expertise in bio-based panel materials and can provide advice and conduct projects (4). Design-focused specialists like **Barchi** offers vapour-open expertise (7) and **Woonder** offers international consultation (7).

4.1.6. Other steps and the process

Start-ups and experts with (second-hand) experience with the process provided recommendations.

Material processing knowledge is often overlooked: harvesting times, plant part selection, and glue percentages can make or break product quality (4). The product developer must determine what the product requirements are and how the product fits in the market (3).

Many experts advise a **go to market strategy** that starts in an accessible market with few requirements to gain time, money and experience (6, 8, 9). This makes it possible to further testing (and certify) the product and develop and establish it, and eventually get it ready for a more difficult market like the building product market.

A tangible sample of the product can also play a big role in convincing clients, because they get to experience the material and better imagine what it would look like (9). Including a **user manual** with each product was also emphasized (4).

Finally, it is already necessary early in the process to advocate for biobased materials with potential clients. The focus should be on architects rather than contractors: the product must be integrated into the façade design (9).

4.1.7. Success stories

Four start-ups / bio-based businesses were asked to co-write a success story of about 100 words with me, of which two answered. The two success stories are cowritten by me and the corresponding companies.

Pro Suber

Pro Suber® has successfully pioneered the use of cork as a sustainable building material in The Netherlands. Recognizing cork's natural thermal and acoustic insulation properties, as well as its resistance to moisture and pests, they have introduced products like expanded cork insulation boards and decorative design panels. These offerings not only enhance energy efficiency but also contribute to a healthier indoor environment.

Their journey highlights the value of bio-based materials in construction. They stand for integrating natural, renewable resources (such as cork) because it leads to durable, high-performance, and eco-friendly buildings.

In their experience, it is crucial to create a good architectural design, and have full craftsmanship and devotion by the contractor to realize the mended result to create a durable and successful cork façade.

Their golden tip: put your effort and energy into that of which you are convinced has added value, but don’t get sucked into it, blinding you to all else. Be self-critical and open to feedback from others. Your product is part of a bigger picture.

Lignitec

Lignitec is breaking new ground in the world of bio-based construction by developing innovative sheet materials made from agricultural by-products and natural binders. This start-up is deeply engaged in the material development phase, experimenting with various raw material combinations and processing techniques to identify the optimal mix for performance, durability, and sustainability.

Their work exemplifies the potential of bio-based product design to drive sustainable innovation. By navigating the uncharted territory of renewable material development, Lignitec is contributing to a growing movement that values regenerative practices and circular thinking in construction.

As early advocates for hands-on, DIY material testing, Lignitec encourages other pioneers in the field to try small-scale experiments themselves. These practical trials have proven invaluable in accelerating their own development process and understanding the behavior of bio-based composites under different conditions.

Their golden tip: Don’t wait for perfection—start building and testing early. Be honest about what works and what doesn’t. The field of bio-based design is collaborative by nature—treat feedback, even critical feedback, as a vital resource.

4.1.8. Expert dialogues conclusion

In this section, knowledge gaps were filled using input from experts. With this knowledge, Research question 2 ‘What knowledge is required to develop a bio-based façade product?’ could be answered. Final input for answering research question 3 was gathered to figure out what information was most relevant for helping bio-based façade start-ups, and what interface could work best. The following conclusions were drawn.

It is valuable for a product developer to test their product samples using simple methods. Certification is not required by law (with the exception of CE-marking). The only requirements by law can be found in the Decree on construction works in the living environment (BBL). Three experts advice the façade product supplier to start by putting a new product on the market in a more accessible sector. Useful new knowledge was provided with, too: the use of design tools such as UBAKUS or simple Excel models is valuable, testing methods such as compressive and flexural strength, bonding, UV, freeze, and fire resistance checks are useful, sustainability measurement tools such as LCA, MPG, BCI are good to look into.

4.2. Product development

The aim of the product development phase was to answer research question 3c ‘How does the relevant information fit in the interface?’.

The product development phase resulted in (concise) text pieces, a user interface and a combination of the two. The relevant information from both the literature review and the interviews can be found in the final result of the infographic. The valuable types of information were chosen based on the results of the interviews from the state of the art and the expert dialogues delivered valuable inputs for these topics. The chosen type of information product was an infographic, since it seemed to suit the project aspects best.

The medium that was used for this was Prezi. Prezi is a simple tool that is used to create presentations, but in this case, it was used to create the infographic. Prezi was chosen because it is easy to use, it has a possibility of clear and attractive design, and the possibility to create different layers so in depth information can be visually shown in depth. The only disadvantage of President is that, since its purpose is design for presentations, some features that would be useful for infographic design (such as allignment, order of layers, and navigating through the design) were not available or less convenient in use.

The infographic development is shown below, including all concepts, in chronological order.

The first picture of an initial concept sketch can be found in Figure 9: Initial concept sketch (drawing).

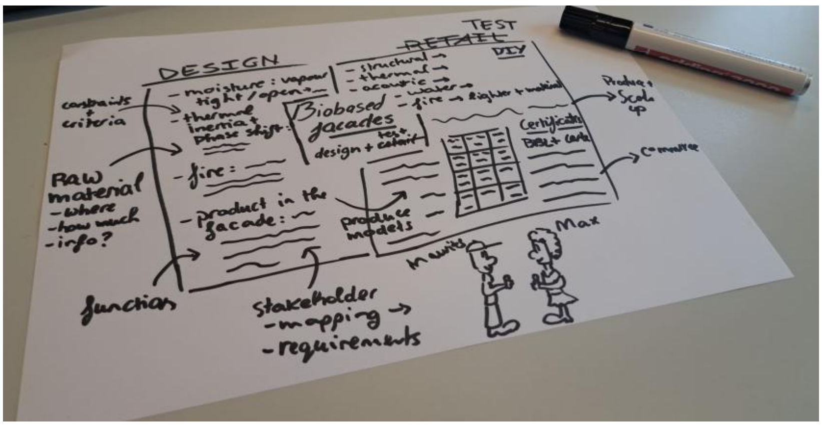


Figure 9: Initial concept sketch (drawing)

The first two concept sketches can be found in Figure 10: Scans of the first two concept sketches.

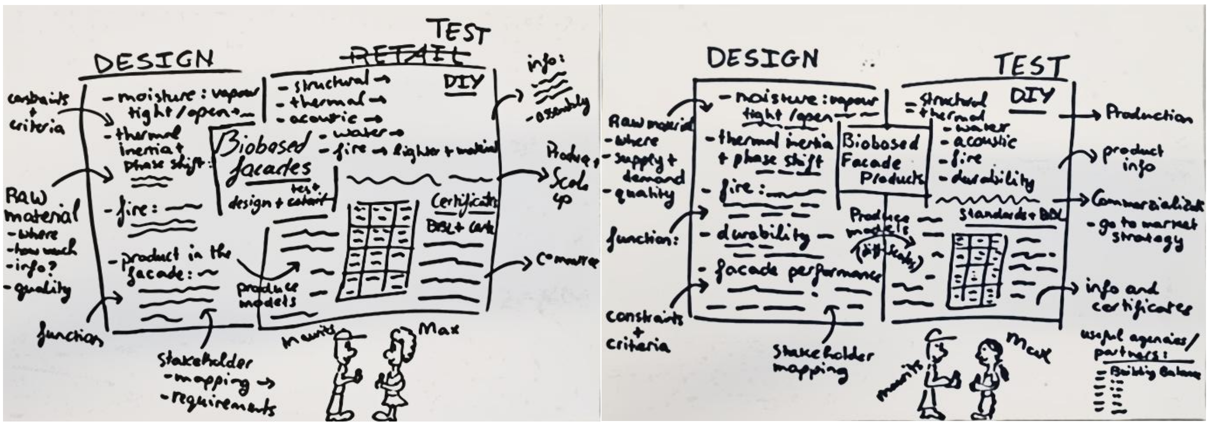


Figure 10: Scans of the first two concept sketches

Then, these concept sketches were translated into the first digital concept in Prezi, which can be found in Figure 11: Initial concept (Prezi).

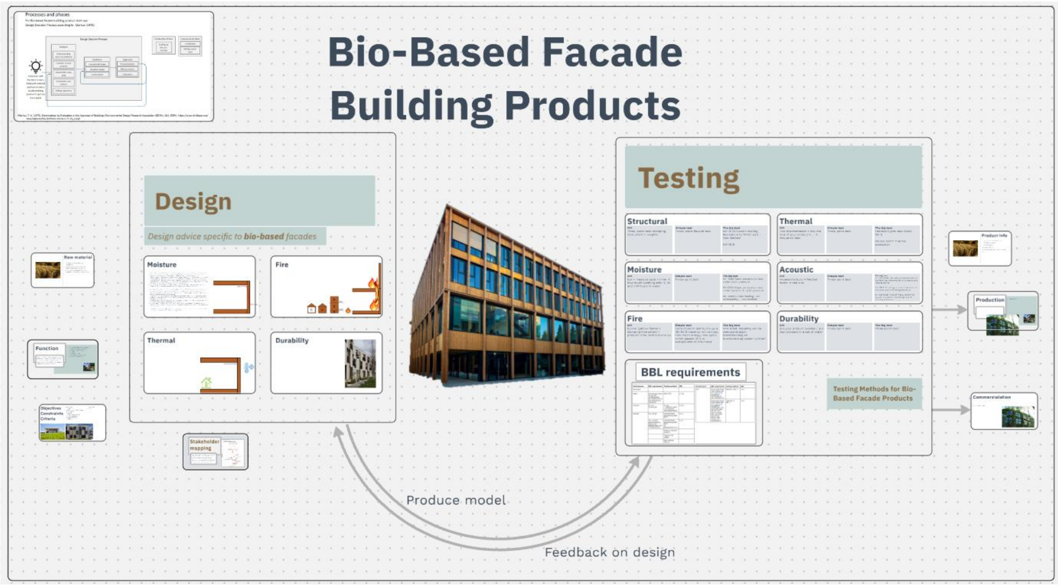


Figure 11: Initial concept (Prezi)

This concept was further developed: text and pictures were added and parts were moved around (Figure 12: Second concept (Prezi)).

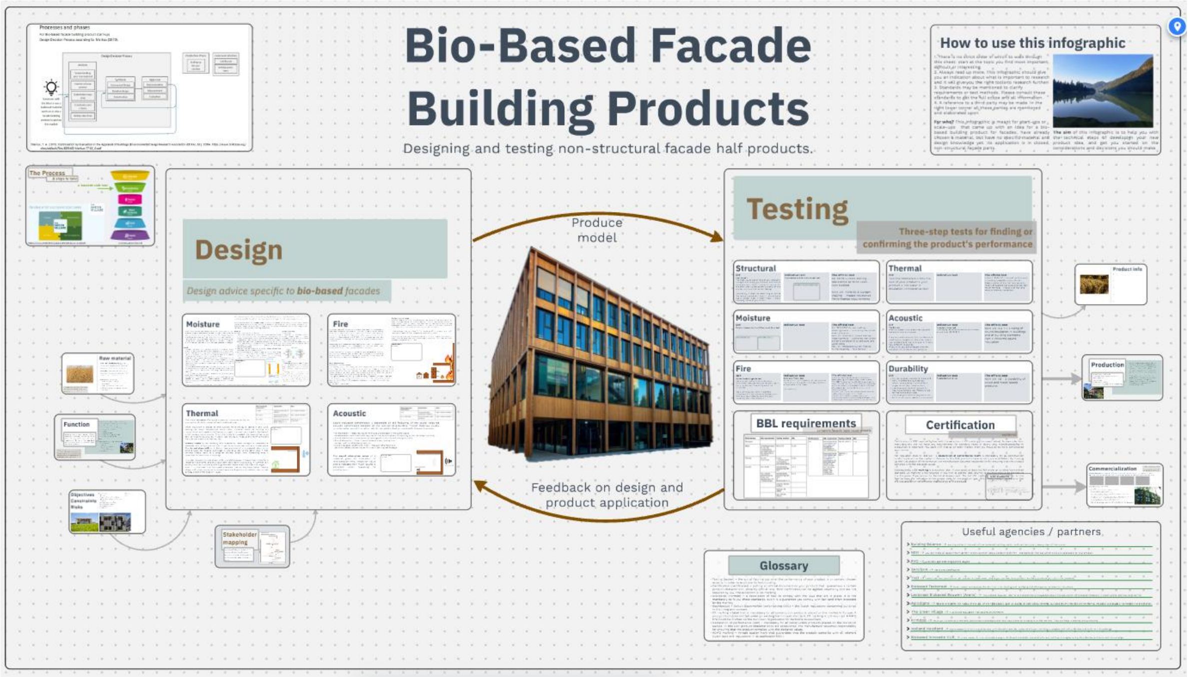


Figure 12: Second concept (Prezi)

Experimenting with different colour and font schemes resulted in the designs as seen in Figures 12 until 16.

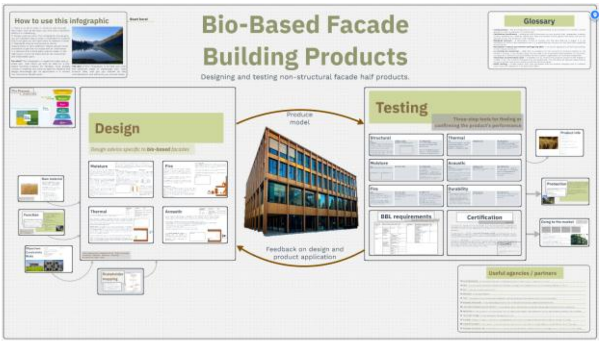


Figure 13: Lime version

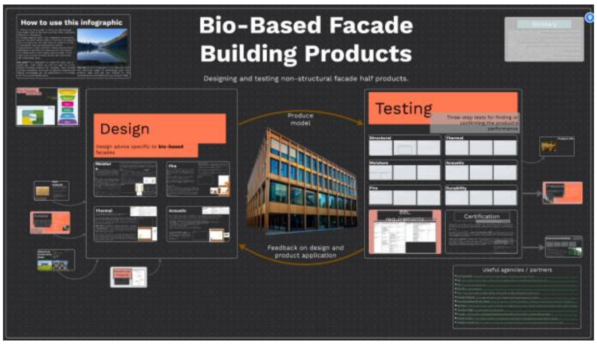


Figure 14: Black-orange version

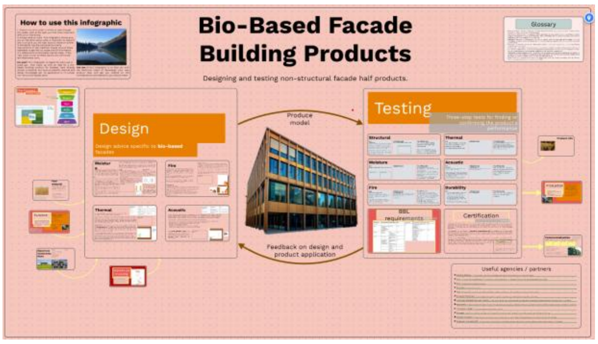


Figure 15: Pastel orange version

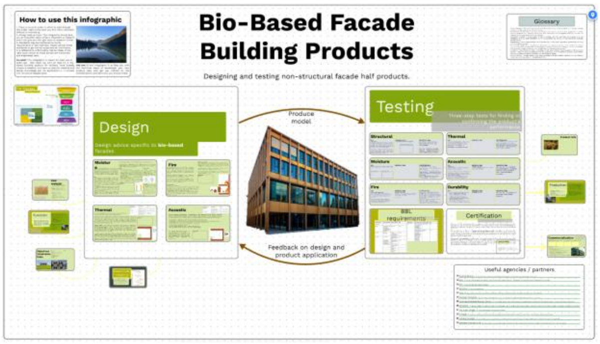


Figure 16: White-bright green version

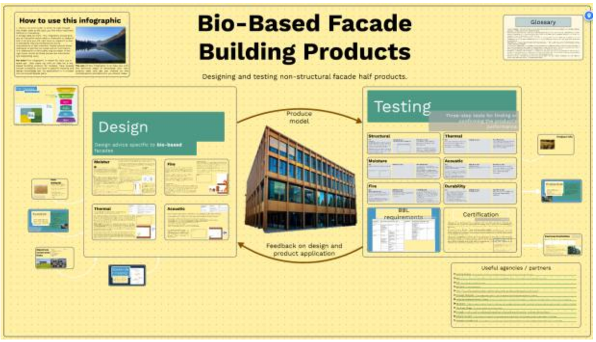


Figure 17: Butter-ocean version

Finally, the moss green and brown colour palette was selected, because it had comfortable readability, is attractive, yet not too bright, and matches with the topic of biobased. This version can be found in Figure 18: Final colours and fonts.

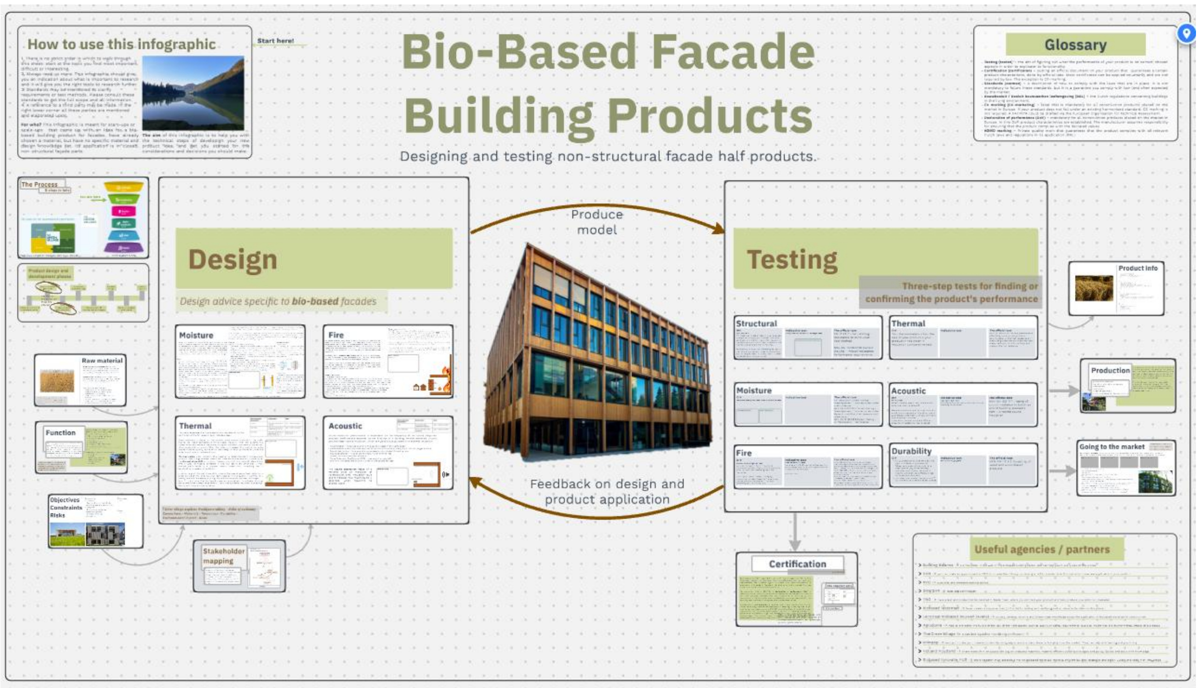


Figure 18: Final colours and fonts

The final large change included improvements in structure and organization, especially considering the guidelines from the literature reviews. The results can be found in Figure 19: Aligned and organised.

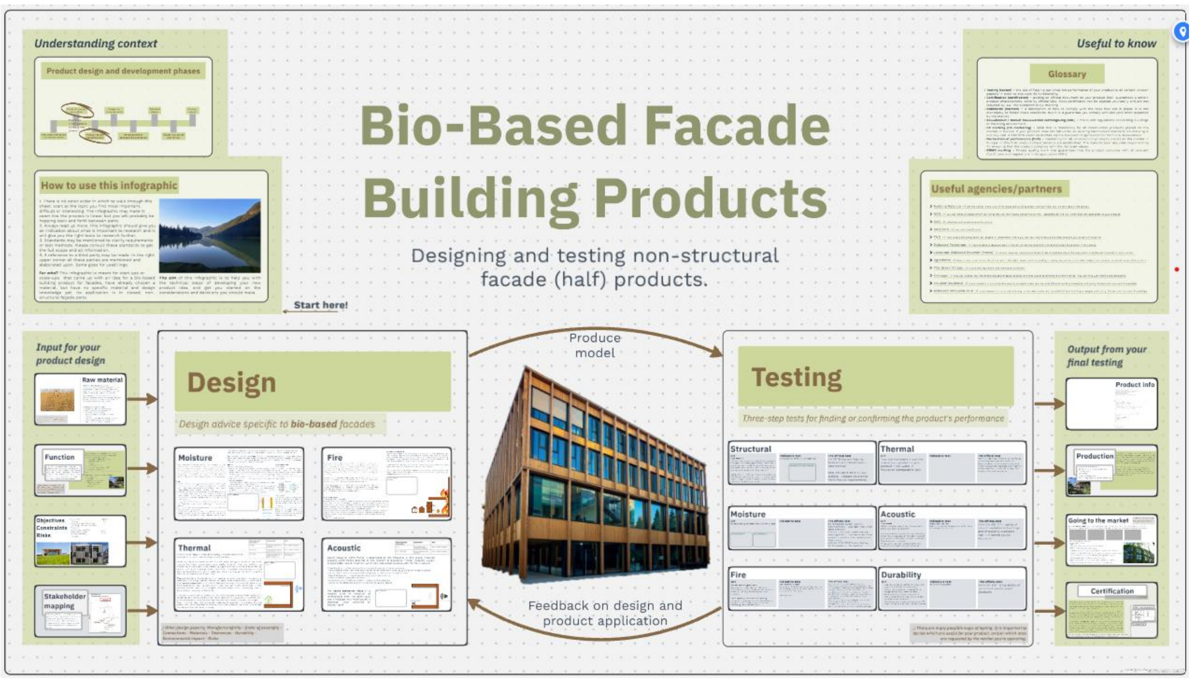


Figure 19: Aligned and organised

The final concept design had some small additional alterations, and can be found in Figure 20: Final concept design.

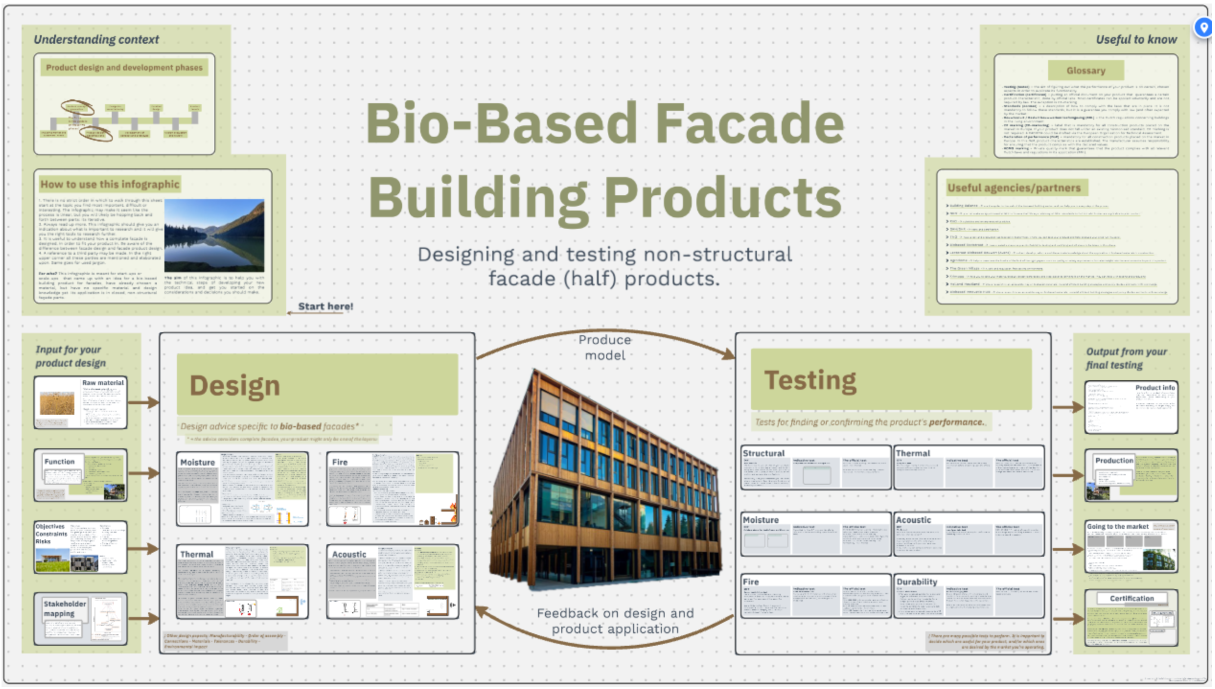


Figure 20: Final concept design

The following link leads to the Prezi version of the final concept design: [Validatieversie]: Guide for Bio-Based Façade Building Products | Prezi. This version was the one that was used for the validation.

4.3. Validation

The results of the validation include the outcomes of the validation sessions with different groups and the incorporation of this feedback on the end-product.

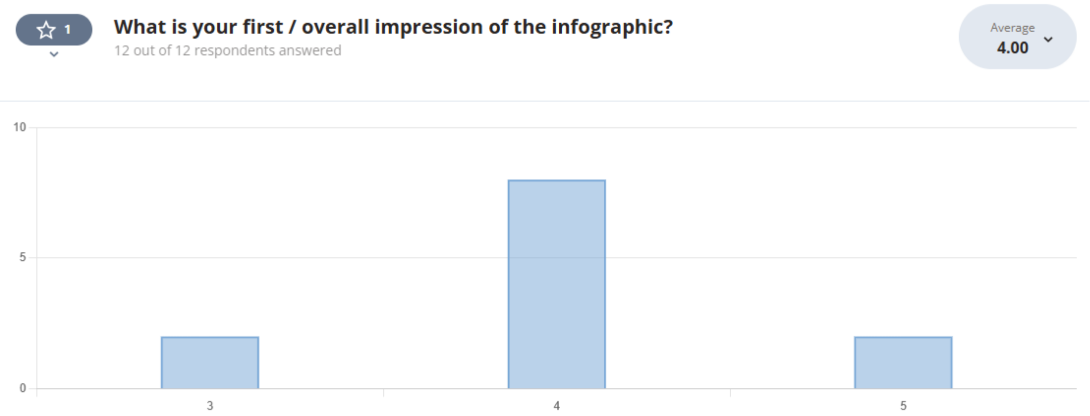
4.3.1. Feedback questionnaire

Below, the summarized answers to the questionnaire are given. A total of 12 responses was collected. Questions in which was asked for a rating show block charts showcasing the ratings that were given. These block charts are taken from the Response Summary in AidaForm.

First questions

1. **What is your first / overall impression of the infographic? [1 – terrible, 5 – wow!]**
   The average rating was 4.00. The largest group of people (8/12) scored a

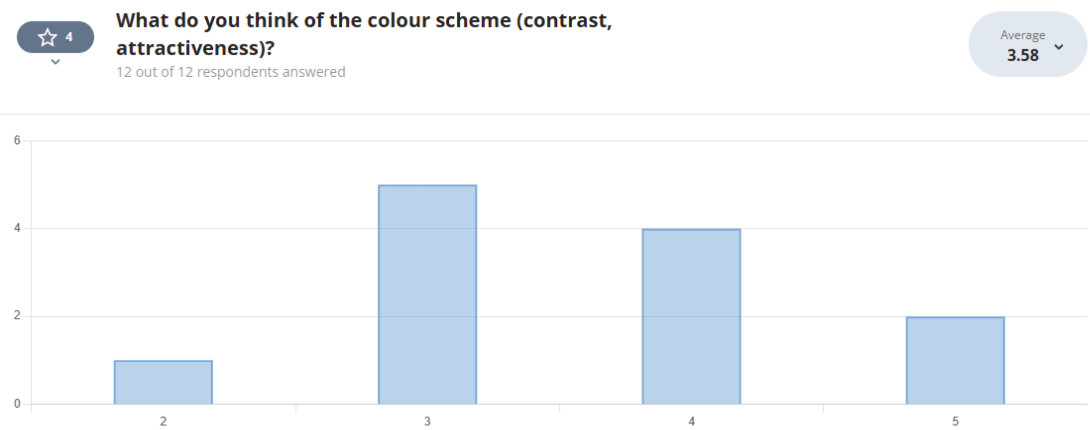
4.



2. **How would you naturally navigate through the infographic? [open question]**
   One respondent (1) said they navigated by clicking on the topics, some (4, 5) focused on the pictures, most (3, 4, 6, 7, 9, 12) navigated from left upper corner, following the arrows to the right. Two respondents (8, 10) noted that it is easy to navigate so the order does not really matter and they liked browsing. One respondent (11) was of the opinion that the infographic contained too much information, but did not contain specific information for specific questions.

Design questions

3. **What seems to be the target audience? [open question]**
   professionals (1), government (1), non-specialist (2, 11), interested in multi aspects of a façade (2), people with a lot of knowledge on façades but no knowledge on bio-based materials (3), students (4, 6, 10), start-ups in bio-based façades (4, 8, 10, 12), designers that wish to implement bio-based façades (5, 6), researchers (6), contractor interested in working with a bio-based façade material (7, 9), producer of bio-based façades (7, 9), architects (9).
4. **What do you think of the colour scheme (contrast, attractiveness)? [1 – terrible, 5 – great]**



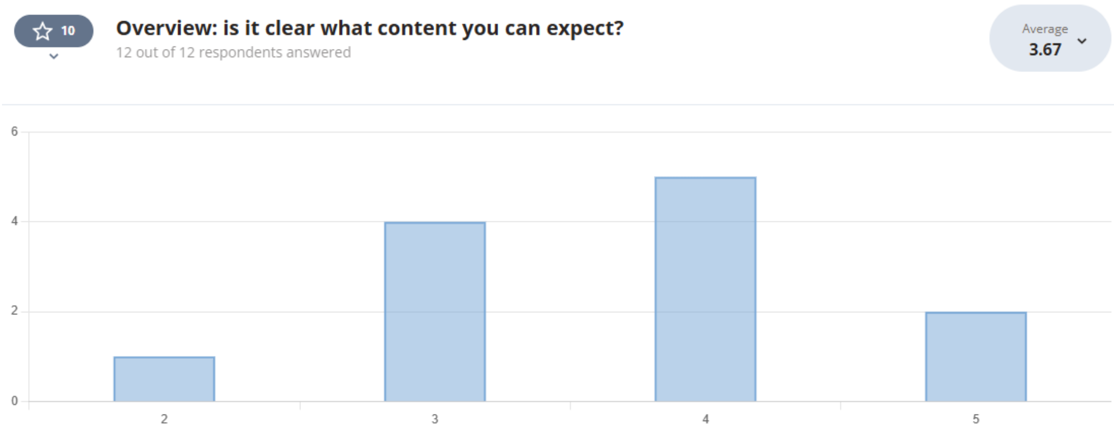
The average rating was 3.58. The largest group of people (5/12) scored a 3.

5. **Are the elements properly aligned? [Yes or No (please specify)]**
   Most respondents (9/12) answered 'Yes'. There were some minor notes.
6. **Which parts draw most attention? [open question]**
   Some respondents (5/12) answered 'Design and Testing' and half noted the large picture in the middle (6/12). One person also noted the large picture did not add anything. Another respondent noted they did not look at the title before seeing the center image and the Design and Testing blocks.
7. **Is the heading clearly visible? [Yes or No (please specify)]**
   Most respondents (10/12) answered 'Yes'. There were two smaller notes.
8. **Are the images supporting the content? [Yes or No (please specify)]**
   Half of the respondents (6/12) answered 'Yes'. There were six notes, mostly noting the images do not add anything, or that they mismatch with the content. One respondent (4) said it would be good to have the images and text support each other, whereas they are loose elements.
9. **Are the charts and tables supporting the content? [Yes or No (please specify)]**
   Most respondents (10/12) answered 'Yes'. There was one note about the length of text in the tables and one respondent said they did not note any supporting charts/tables.

Content questions

Is the content of the guide valuable for the target group; what is most valuable and what is missing?

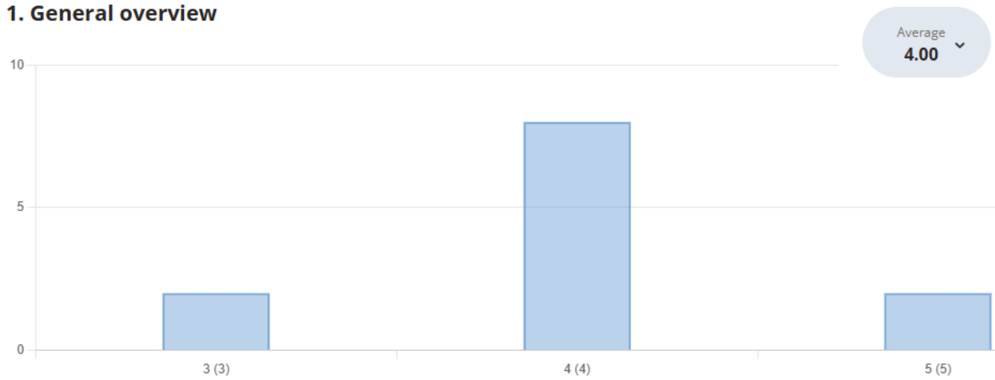
1. **Overview: is it clear what content you can expect? [1 – not at all, 5 – 100%]**



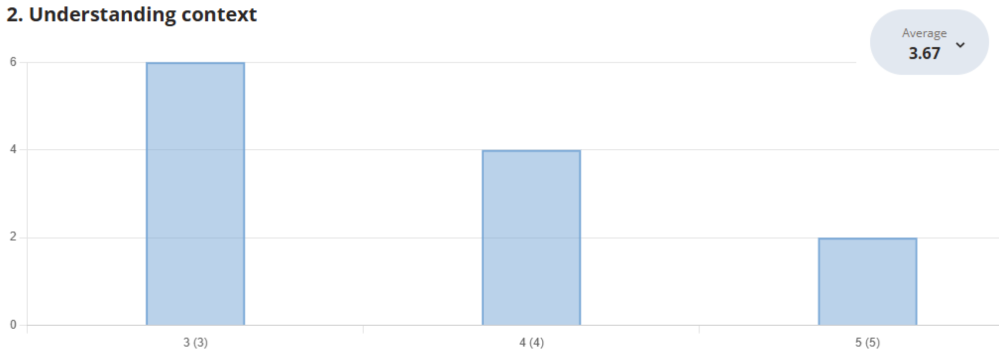
The average rating was 3.67. The largest group of people (5/12) scored a 4.

2. **How would you rate the following information blocks (see the coloured demarcations on the image above) of the infographic on their depth?**

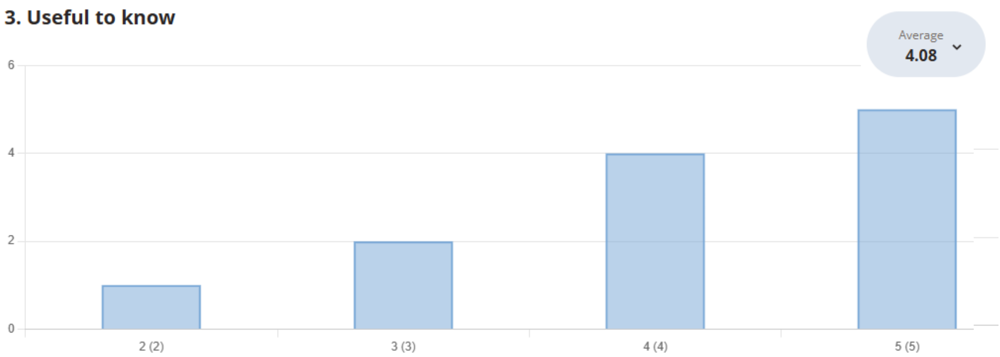
a. General overview: The average rating was 4.00. Most respondents (8/12) scored a 4.



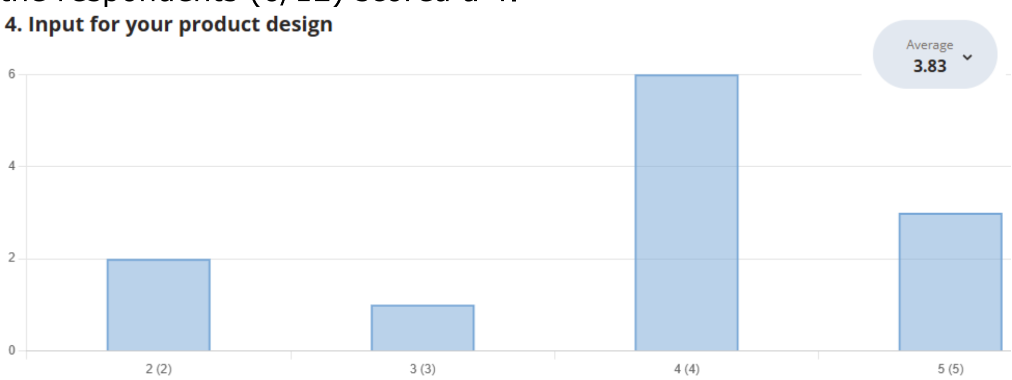
b. Understanding context: The average rating was 3.67. Half of the respondents (6/12) scored a 3.



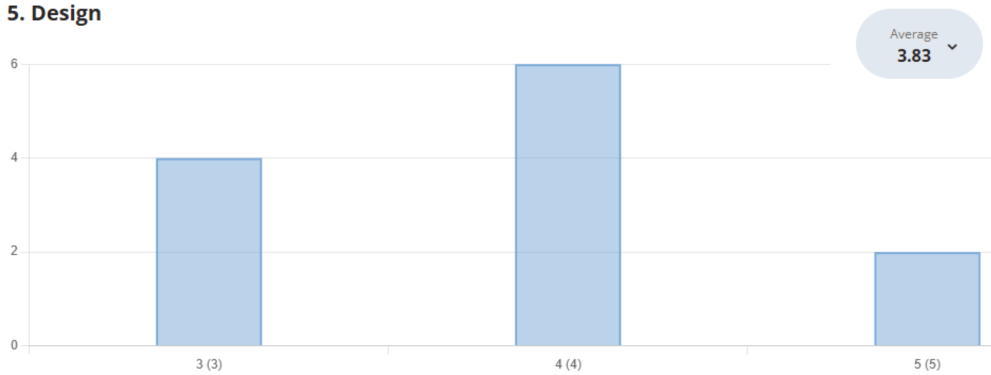
c. Useful to know: The average rating was 4.08. The largest group of respondents (5/12) scored a 5.



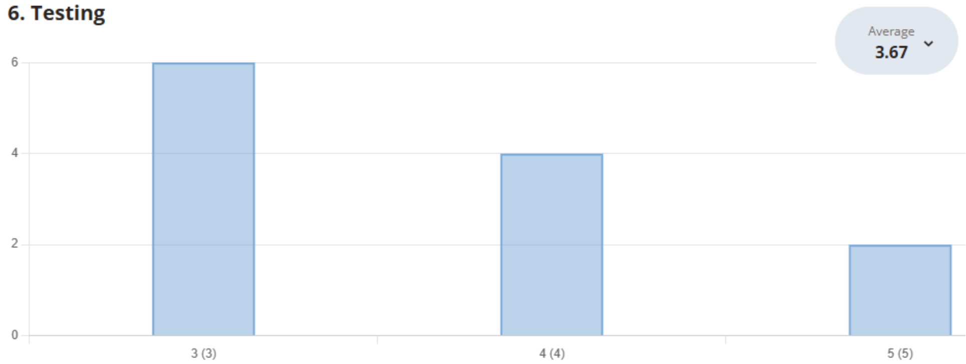
d. Input for you product design: The average rating was 3.83. Half of the respondents (6/12) scored a 4.



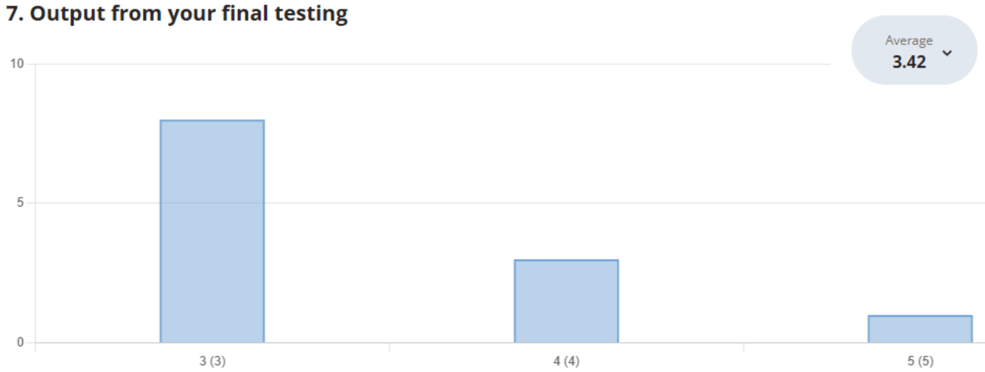
e. Design: The average rating was 3.83. Half of the respondents (6/12) scored a 4.



f. Testing: The average rating was 3.67. Half of the respondents (6/12) scored a 3.



g. Output from your final testing: The average rating was 3.42. Most respondents (8/12) scored a 3.



3. Please elaborate! [open question]

One respondent (1) noted it could do with more practical examples, another respondent (3) noted the infographic assumes you already have your material and it skips the step from raw material into building material; a step that is vital in bio-based design, a third respondent (6) suggested adding an example timeline or planning. Another suggestion (7) was to improve the 'How to Use' by starting with the aim. Respondent (8) noted that the infographic's line of reasoning is based on wood behaviour, but bio-based is more than that, they'd like more information about the market, and the stakeholder mapping is different from their experience. Respondent (10) explained they preferred to be lead by images, even small icons, but that that was also a matter of taste. Respondent (11) noted they did not appreciate the chosen format: they preferred a reference work with chapters covering multiple pages. Respondent (12) suggested that the Testing part could contain more information about what else product developers need to take into account.

4. **Dive in [Design block]: Moisture, Fire, Thermal, Sound [open question]**
   One respondent (5) stated that it was unclear what was being tested and the product was not clearly defined. Respondents (4, 7, 9, 10) were of the opinion most relevant information was there, although (4) noted it might even be too specific. One respondent (8) said an appendix with additional information would be useful. Respondent (1) noted the thermal case only contained 'wrong' details, one 'right' detail would be good to add. Respondent (3) noted the thermal and sound calculations might be too difficult for a layman. Respondent (2) suggested adding info on attachment methods, environmental impact and biodiversity. Respondent (11) did not have an opinion.
5. **Dive in [Testing block]: Structural, Thermal, Moisture, Sound, Fire, Durability [open question]**
   Respondents (1, 4, 7, 9, 10) were of the opinion most relevant information was there. There were some small additional notes (6, 10). One respondent (8) said an appendix with additional information would be useful. A noteworthy question was asked by respondent (5): "*Are there startups that develop bio-based façades? or are there only companies that produce new biobased materials, and companies that are interested in using these in façades. Some tests should be done on the façade, some on the e.g. boards.*". Respondent (2) suggested adding a way to put it in the context of a specific design. Respondent (3) noted the testing block contains 6 parts, whereas the design block only contains 4, and it might be worthwhile to connect the corresponding ones. Respondent (11) did not have an opinion.

Ending

6. **Is there anything else I need to know? [open question]**
   One respondent (2) noted sometimes the examples were Dutch
   Two respondents (2, 4) specifically noted the infographic was comfortable to navigate through! Respondent (11) specifically noted the infographic was very user-friendly. Respondent (4) also noted some improvements could be made graphically: more headings, colors showing what corresponds, combining the information in the top corners in one spot, etc. Respondent (3) suggested to make drawings and pictures bigger. They were also excited to show the infographic to their colleagues. Respondent (6) suggested the following: I would try to make the difference between raw materials, products, and façades clearer. And try to show what can be changed after measuring something, will you change to product (other glue, other plant e,g) or the design of the façade? Respondent (9) suggested to include examples from practice, and respondent (10) suggested linking the useful partners section to their websites and to include examples of spec sheets to provide insight in what information to

collect and how to communicate this info. One respondent (11) stated the infographic should be in Dutch.

4.3.2. Validation conclusion

Below, feedback from the validation is discussed. First, incorporations based on given feedback are addressed. Remaining relevant feedback is summarized in suggested improvements for the infographic.

First off, all the images were replaced, due to the feedback that they did not add anything. The image in the center was replaced with a more relevant picture: the Natural Pavillion, an innovative and bio-based ABT-project. "Pan-and-zoom" frames were used to put a focus on façade parts. Apart from the center image, all other images were replaced by images created by AI, using the initial idea of "Max and Maurits": a comic book duo who are bio-based entrepreneurs aiming to create a bio-based façade product. Furthermore, headings were enlarged and arrows were made thicker to better show the different parts and the connections between them. Content-wise, proposed changes such as additions, clarifications and definition mistakes were incorporated into the infographic. Additional small improvements were also made on own initiative.

Suggested topics for improvement are formulated as well. These suggestions are also used as input for the recommendations at the end of this thesis. A deeper dive could be taken into almost all topics covered in the infographic. It is dependent on the research aim which topic should be explored further. The points of improvement for the infographic resulting from the validation feedback are the following.

So far, timber is the only well-known and used bio-based material, so some of the design guidelines are framed around that material. The information should be expanded to include more on bio-based materials in general (in this thesis mostly in the design guidelines), when this information becomes available.

The sector and market should be analysed further to improve comprehension of stakeholder relations. A start-up could be followed closely in order to find out which parties they get in touch with. This helps understand the workings of the sector better, and which parties should be included in bio-based adoption strategies. This can help improving the infographic in the understanding of almost all steps in the process of developing a bio-based façade product, and will mostly add to the 'Stakeholder Mapping' block and in the 'Useful agencies/partners' block in the infographic.

Suggested topics to add to the infographic are the following. Building assembly aspects (such as attachment methods), environmental impact (not only the sustainability assessment methods, but also how to achieve a lower environmental impact) and biodiversity considerations. A final suggestion is to add more (design) examples from practice.

A relevant conclusion is that, theoretically, a different infographic should be created for each individual situation, because a different situation asks for a different focus. This research aimed at creating a general infographic, merging all points of view into one product. This takeaway was confirmed in the validation. The opinions of the different validators varied greatly. Most of the respondents rated the different components of the infographic with a 3 to 4 (out of 5), which is moderately positive. However, whereas some respondents rated certain aspects with a 5, (because they were of the opinion that these aspects were the most useful) there were others that rated these same aspects with a 3 (and sometimes even commented that they didn't think that part useful). This confirms that people with different points of view preferred different parts and focuses of the guide.

4.4. Final Product

The last iteration, incorporating the feedback from the validation, led to the final end-product of this master thesis. The final product can be found here. A screenshot of the product can be found in Figure 21: Final end-product (screenshot)

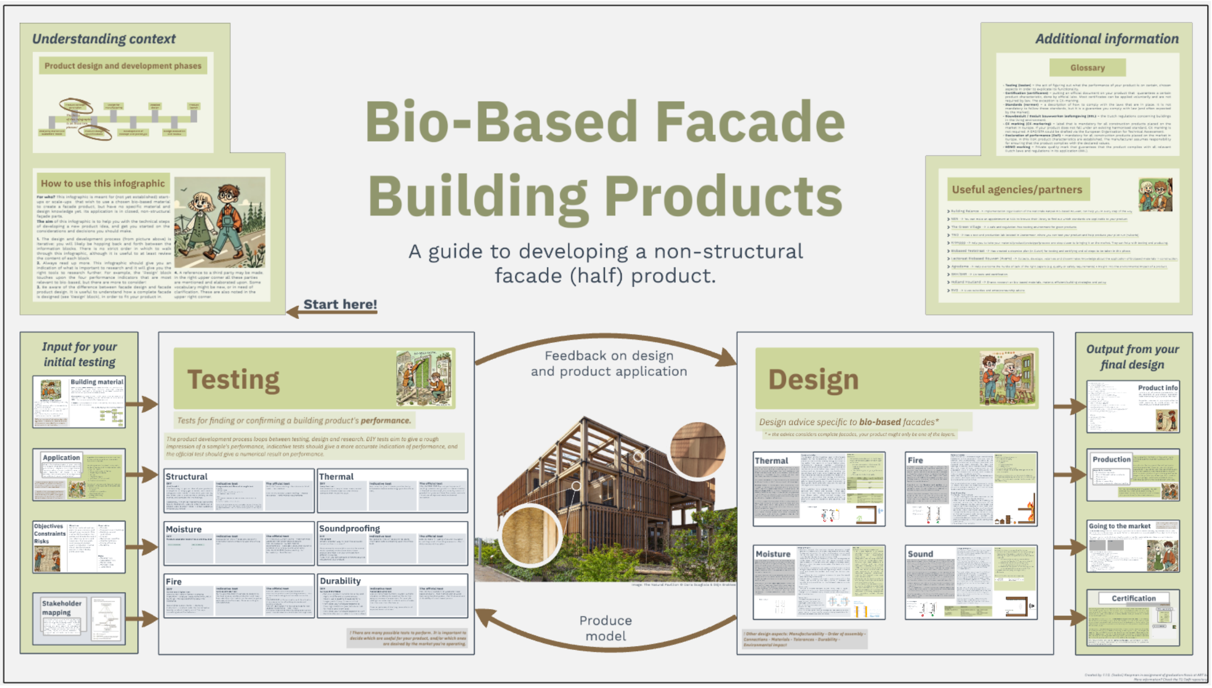


Figure 21: Final end-product (screenshot)

This final product is the answer to the main research question. The focus of the infographic is based on the results of the interviews from the State of the Art, chapter 2.2. These interviews brought forward the conclusion that both design and testing of the façade product were experienced to be most challenging and certification also deserved some explanation. The content of the infographic is taken from both the literature review and the expert dialogues. Information taken from the literature review is about bio-based materials, façade functions, NEN-standards, design (using performance indicators) and testing. Information taken from the expert dialogues is about design, DIY test methods, certification (including what is required and what is voluntarily), useful agencies / partners (and the reason), material development and the success stories. The feedback questionnaire ensured validation of the end-product. Even though there is still plenty room for further improvement, it could be concluded from the validation that both the information and the way it was conveyed were fitting to help start-up companies developing a bio-based façade building product.

The main research question*: What information could help start-up companies developing a bio-based façade building product and how could this information be conveyed in a fitting way?*

5. Discussion

The research conducted for this master thesis explored the development and market introduction of bio-based, non-structural closed façade products. The final product – a guiding infographic - serves as a practical output aimed at bridging knowledge gaps for start-ups. This discussion evaluates its methodology and key findings.

The semi-structured interviews with industry experts provided qualitative depth, allowing the study to capture diverse perspectives on bio-based façades. This methodological approach was appropriate, given the emerging nature of bio-based building products, where limited empirical data is available. However, a limitation of this approach is the potential bias from interviewees. This is due to the fact that there is only a small group of people in this field and they often knew each other and might share experiences and opinions (this is less applicable to newcomers in the sector). Additionally, the number of interviewees (eight people) could be considered too small to yield significant results. Seeing the variety in experiences from start-ups and the other key actors, it would have been good to have, say, roughly double the number of people. The current challenges for start-ups creating a bio-based façade product (the first research question) were found in the interviews. The challenges that were experienced in the sector were regarding testing, design, certification and the bio-based material itself. This is valuable information for understanding the current state of the sector and help with figuring out how to improve its accessibility.

The information and knowledge available for developing a bio-based façade product (research question 2) was found in both the state of the art and obtained from expert dialogues. In the state of the art, several bio-based materials were highlighted and their characteristics researched, leading to a general understanding of bio-based materials in de built environment, and the conclusion that they seem to be suitable for façades. The functions of the different façade parts were captured by performance indicators (structural, fire, water-related, air permeability-related, thermal, moisture-related, and acoustic performance), contributing to the research as the basis for the design guidelines.

The tests that are available for developing a bio-based façade product partially came from NEN-standards and other research reports, and partially from the expert dialogues, resulting in a list of tests with a range from DIY to official.

What the most relevant information is and what the interface should look like (research questions 3a and 3b), was discovered in the expert dialogues and interviews, using the information collected in the state of the art as input. This method was suitable, mainly because there is limited research and are not many (official) design guidelines on building using bio-based materials. Experience is a large part of the current knowledge on this topic. On the other hand, as already explained for the interviews, a limitation of the 'expert dialogues' approach is its subjectivity to bias from the respondents. Since part of the information in the infographic comes from these expert dialogues, it is important to be careful putting it out there as 'the truth'. It is, however, also important to note that none of the published information was ever only from one source, and was always double-checked. Another important note is that there are still remaining knowledge gaps. A good example of these are the proposed indicative tests, taken from a research on rammed earth. These tests might be applicable to bio-based in general, but this should be confirmed. The interviews yielded which types of information would be useful to overcome experienced challenges, necessary to create the correct focus of the infographic. The expert dialogues yielded additional knowledge and advice from experience, valuable because these experts being as close to the sector as one can get. The type of product that would fit with conveying this information was discovered in the interviews, relevant because the interface should fit with the audience needs.

The question of how the relevant information fitted with the chosen interface (research question 3c) lead to the final end-product, which was verified in the validation. The development of the end-product, an infographic created in Prezi, was based on literature research and both the interviews and expert dialogues. This method was fitting because it was based on academic sources and validated by the end-users. The number of validators (twelve) is small, which is a limitation of this thesis. One other limitation is that the respondents delivering input and feedback in the validation did not have any information product design expertise. For further development of this infographic, it would be valuable to further dive into the design side of it, and have experts help design it. Regarding the validation itself, there is a limitation as well. There was feedback that could not be included because of either of the two following reasons. Either the feedback was contradictive with other feedback, or the feedback was too large or deeply rooted. For the first group of feedback, the comments were weighed and the researcher made the call how the feedback was included. For example, one respondent preferred more text and another wanted more images, so the researcher balanced these two aspects. Comments from the latter group of feedback, of which incorporation would cost too much time, were included in suggestions for further improvements. These are discussed in the recommendations.

6. Conclusions

The aim of this master thesis was to create a guiding product for bringing a bio-based façade building product to the market, which addresses the most prominent challenges that arise during this process, especially to those who have no experience in the field yet. In this section, the conclusions are given, grouped per method. These conclusions provide the answers to the research questions posed in chapter 1.1.2. For each conclusion, the number between brackets shows to which research question it corresponds. Finally, the outcome of this thesis is positioned within the industry and academic world.

The interviews yielded the following conclusions.

- Testing was considered expensive and difficult, and was often only seen as a requirement for certification and regulations, instead of a way to understand the tested product and its characteristics (RQ1).
- Regulations were seen as a challenge: they can be restrictive, difficult to comply to, and often, standards for bio-based material use in building applications do not exist and the existing standards cannot be aligned with bio-based materials (RQ1).
- Bio-based material (selection) itself was seen as a challenge: unfamiliarity with the use of bio-based poses design questions and the traditionality of the building sector does not contribute (RQ1).
- Guarantees on supply and quality were pointed out as difficult because there is limited control of the growth process (RQ1).
- Market connections are crucial (RQ2c).
- The preferred type of product was a visual flowchart, with clickable format and clear scoping, possibly open source, although the opinions on this matter varied greatly (RQ3b).

Key takeaways from the expert dialogues are the following.

- It is valuable for a product developer to test their product samples using simple methods: do DIY-tests to figure out even the roughest estimates of the performance indicators of your product to gain a feeling for the product and improve its design (RQ2a).
- Certification is not required by law (with the exception of CE-marking). The façade product supplier's customers set requirements that might make it necessary to conform to NEN-standards. However, the only requirements by law can be found in the Decree on construction works in the living environment (BBL), and it is up to the contractor to comply with those, so they will *prefer* certified products (RQ2b).
- Several (three) experts advice the façade product supplier to start by putting a new product on the market in a more accessible sector, with less difficult market standards and requirements (RQ2c).
- Useful new knowledge (in addition to the information gathered in the state of the art), according to the involved experts (RQ3a):
    - Design tools such as UBAKUS or simple Excel models are useful.

  - Simple testing methods: simply break a sample, burner and lighter test, cone calorimeter test, lamp heat test, speaker/shout test, durability (put sample in freezer, outside, sunbed).
  - Sustainability measurement tools such as LCA, MPG, BCI.

Relevant points of feedback from the validation are the following.

- The relevant information was there, according to most respondents (RQ3a).
- Relevant infographic content conclusions (RQ3a):
  - The infographic's line of reasoning is based on wood behaviour, but bio-based is more than that.
  - The stakeholder mapping is different from their experience.
  - The infographic skips from raw material into building material.
  - The product is not clearly defined: make a distinct difference between materials, products, and façades.
  - Suggestion to add info on attachment methods, environmental impact and biodiversity.
- Navigation through the infographic was considered easy: the interface is user-friendly (RQ3b).
- Each infographic user has different needs concerning the types of relevant information and the way of conveying the information. The 'perfect' infographic differs per user. It is impossible (especially given the scope of a MSc-thesis) to create a perfect general infographic, because the topic is too broad to cover all possible aspects in-depth yet stay concise as well (RQ3c).

The combination of the answers to all three research questions yields the answer to the main research question, 'What information could help start-up companies developing a bio-based façade building product and how could this information be conveyed in a fitting way?'. The conclusion that the end-product contained the right information, conveyed in a good way, can be drawn from the validation, where the average score for every part was between 3 and 4 (out of 5).

One of the key contributions of this thesis is its support in encouraging the use of bio-based materials in façade product development. Unclarity in design methods, ways of testing and rules and regulations obstruct the way for bio-based products, and this thesis aimed to get some clarity in this area. Additionally, it is important to note its policy and building sector implications. The findings suggest that regulatory frameworks need to evolve to accommodate the unique properties of bio-based materials. Current building codes are primarily designed for conventional materials, creating compliance challenges for bio-based products. This is consistent with discussions in both the academic world and the sector itself on the need for additional regulatory measures in sustainable construction. This thesis underscores the importance of collaboration between start-ups, material suppliers, and regulatory bodies. It suggests that strategic partnerships can help mitigate knowledge gaps and facilitate better product design. It is important to note that efforts in research, policy adaptation, and industry collaboration are essential to fully realize the potential of bio-based materials in the built environment.

To conclude, this thesis makes a valuable contribution by addressing the specific challenges start-ups face in developing and launching bio-based façade products. By providing a framework for start-ups, this study takes a step toward mainstreaming bio-based construction.

7. Recommendations

Recommendations flowing from this thesis include spreading the infographic amongst experts and new start-ups (and improving and updating by making it open source) and further researching bio-based materials and their behaviour in façades. Future research could benefit from supplementary interviews with start-ups that help figure out the challenges in addition to complementary case studies that observe which issues are experienced. The recommendations are elaborated upon below.

The primary suggestion flowing from this research is for current actors in the field of bio-based building products to update the infographic's format to make it open-source and spread it, opening it up to those with experience and those gaining experience in the future. An organisation could be set up for the upkeep of the infographic and its spread amongst the appropriate parties. The infographic should be updated to ensure its actuality, and further improvements can be made. Two substantial suggested improvements, which follow after suggested further analysis on the design & development process, are the following. Clarification of the entry point(s possible) of this infographic, achieved by analysis of the process steps: what has the infographic user already done in the process of creating their product once they start using this guide (e.g. they have a material, they have a proof of concept, they have an application already, etc.)? This can help putting a focus on the guide and make it more accurate for these target groups. A second substantial improvement considers differentiation between development of the 'material' or 'resource', 'product' and 'façade'. This improvement aims at separating these different types of end-states to clarify for each which methods should be used. A clear example can be found in the test methods: different tests should be used for material development than for façade certification. A suggestion is to cut up the testing and design blocks each into three separate blocks with loops: the material development and testing phase, the product development and testing phase and the façade development and testing phase.

The second recommendation is for scientists and engineers to proceed with research into bio-based materials. Available information of bio-based (building) materials is scarce, which is one of the hurdles for using them in construction. It is vital to do more experiments, small and large scale, to figure out how all the available materials behave. Much of the information that is found and used in this thesis is based on guidelines for the more traditional building materials and thus might not (fully) apply to bio-based materials. As more research is done on these materials, it is critical that (mostly the design and testing) information is spread, either through updating this infographic or by ensuring the information is easily available. Furthermore, in this thesis, advice is gathered from players in the field (expert dialogues), but this is not backed up by data or confirmed by academic research. When more experience is gained, new pieces of advice should be formulated. Finally, the sector itself will also develop in the upcoming years, which requires a need for updated information. This information should be gathered by researchers and spread, either through the updated infographic or through other means. All this research and the developments should lead to updated NEN-standards, that should make it easier for bio-based product suppliers to comply to the market standard.

Final recommendations for the stimulation of the use of bio-based materials in the construction sector are the following. It could benefit from supplementary interviews with start-ups and case studies. Supplementary interviews with start-ups will help to further map experienced challenges. Resembling this thesis, the challenges could be analysed and a way to help overcome them could be fashioned. Complementary case studies would help observe which issues are experienced and can also show the different start-ups and their ways to deal with these issues. Other ways to aid the stimulation of bio-based materials lie in the development of (better) standards and certification, the offering of monetary support and availability of low-key testing and production facilities.

8. Reflection

The world is ever-changing. Engineers must be equipped to adapt to these changes and address the associated challenges, particularly those posed by climate change. While the transition towards bio-based materials presents a viable solution, the path to widespread adoption remains unclear. The conservative nature of the building sector further complicates efforts to innovate and integrate sustainable alternatives. The desired effect of the efforts made in this thesis is that engineers are further encouraged to adopt these sustainable materials.

This MSc-thesis adopted a distinct approach compared to conventional research projects, navigating an inherently uncertain process. Rather than starting off with a predefined end-product, the research embraced an open-ended methodology to achieve its objectives. An initially broad scope was essential to establishing the correct boundaries later in the study. In the opinion of the researcher, this initial ambiguity concerning the end-product contributed to the quality of this end-product. By progressively narrowing the scope to the most relevant topics and corresponding information, the research yielded an end-product highly applicable to the intended target group.

It was a process of taking many small steps in many directions—broadening the search area to explore what was potentially useful, then narrowing the focus again to distill the essence of it all. A wide range of topics was covered, of which the newest one for me was infographic design. I was very proud of my first design in Prezi, which made it hard at first to accept the constructive feedback. I was so satisfied with my work! Looking back now, I completely agree with the feedback. Comparing the first version to the final one…the improvement is great. I learned by talking to my supervisors, studying examples, and flipping through design books. And I improved. I'm fully aware there's still a lot to learn, in general, and when it comes to the design, I know that a professional designer could make it look ten times better. I guess that accounts for all aspects of my thesis: an expert would always be able to improve something. But I am the one who put *all* aspects together, and that is something, too. Experts are good at zooming in, whereas my strength is zooming out and seeing the whole picture. I'm proud of how far I've come, learning so much about so many new things, proud of what I've learned from everyone around me, and of how I went from knowing almost nothing about bio-based materials and their applications to almost feeling like I could succeed in the field with my own little straw-hot-pressed-sheet product...or something alike.

I now understand the complexity of introducing something that is different from the thing everyone is used to. In the end, I believe that the process of widening the scope and then narrowing it back down, guided by input from experienced professionals, is what led to a strong final product. I'm curious to see if starting entrepreneurs will actually use it, and I'm sure there's still plenty of feedback to be gathered for further improvements. But overall, the infographic includes what it needs to include and fulfils its purpose. So I can confidently say that the goal of this thesis was achieved: a guiding product was created to help bring a bio-based façade building product to market—addressing key challenges and supporting the overcoming of barriers.

References

Acoustical Surfaces. (2024, July 28). *Soundproofing vs Sound Absorbing – Explaining the Difference*. https://www.acousticalsurfaces.com/blog/soundproofing/soundproofing-vs-sound-absorbing/

Amziane, S., Merta, I., & Page, J. (2023). *Bio-Based Building Materials* (S. Amziane, I. Merta, & J. Page, Eds.; Vol. 45). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-33465-8

Boswell, C. K. (2013). *Exterior building enclosures : design process and composition for innovative facades*. John Wiley & Sons. http://site.ebrary.com/id/10718824

Bourbia, S., Kazeoui, H., & Belarbi, R. (2023). A review on recent research on bio-based building materials and their applications. In *Materials for Renewable and Sustainable Energy* (Vol. 12, Issue 2, pp. 117–139). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s40243-023-00234-7

Brischke, C., & Jones, D. (2017). *Performance of Bio-based Building Materials* (D. Jones & C. Brischke, Eds.). Elsevier. https://doi.org/10.1016/C2015-0-04364-7

Commission Delegated Regulation (EU) No 574/2014 (2014).

Dainty, A. R. J., Briscoe, G. H., & Millett, S. J. (2001). Subcontractor perspectives on supply chain alliances. *Construction Management and Economics*, *19*(8), 841–848. https://doi.org/10.1080/01446190110089727

Dam, J. van, & Oever, M. van den. (2019). Catalogus biobased bouwmaterialen 2019: Het groene en circulaire bouwen. In *Groene Grondstoffenreeks* (Vol. 22). https://doi.org/https://doi.org/10.18174/461687

Dams, B., Maskell, D., Shea, A., Allen, S., Cascione, V., & Walker, P. (2023). Upscaling bio-based construction: challenges and opportunities. *Building Research and Information*, *51*(7), 764–782. https://doi.org/10.1080/09613218.2023.2204414

Dijk, A. van. (2022, January 31). *Biobased in de NMD*. https://www.iagroep.com/biobased-in-de-nmd/

Dunlap, J. C., & Lowenthal, P. R. (2016). Getting graphic about infographics: design lessons learned from popular infographics. *Journal of Visual Literacy*, *35*(1), 42–59. https://doi.org/10.1080/1051144X.2016.1205832

Emmitt, S. (2006). Selection and Specification of Building Products: Implications for Design Managers. *Architectural Engineering and Design Management*, *2*(3), 176–186. https://doi.org/10.1080/17452007.2006.9684614

Harrison, L., Reinecke, K., & Chang, R. (2015). Infographic Aesthetics. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 1187–1190. https://doi.org/10.1145/2702123.2702545

Herzog, T., Krippner, R., & Lang, W. (2021). *Facade Construction Manual* (3rd ed.). Birkhäuser, DETAIL.

Houben, H., & Guillaud, H. (1994). *Earth Construction: a Comprehensive Guide*. Intermediate Technology Publications.

House, C., & House, S. (2020, December 6). *Inexpensive Homemade Materials Testing Jigs*. https://kidizenscience.com/2020/12/06/inexpensive-homemade-materials-testing-jigs/

Klein, T. (2013). *Integral Façade Construction Towards a new product architecture for curtain walls*. https://doi.org/https://doi.org/10.7480/abe.2013.3.611

Konijnenberg, F. (2024). *Bio-based Binders for Rammed Earth Construction: Experimental research exploring the use of historic binders for future material implementation*.

Konstantinou, T., Klein, T., Boess, S., Guerra Santin, O., & Silvester, S. (2015). *An integrated design process for a zero-energy refurbishment prototype for post-war residential buildings in the Netherlands*. https://www.researchgate.net/publication/291115677

Kültür, S., Türkeri, N., & Knaack, U. (2019). A holistic decision support tool for facade design. *Buildings*, *9*(8). https://doi.org/10.3390/buildings9080186

Linden, A. C. van der, Zeegers, A., & Kuijpers-van Gaalen, I. M. (2016). *Bouwfysica* (8th ed.). ThiemeMeulenhoff.

Logan, K. (2024, July 1). *Continuing Education: Bio-Based Materials*. https://www.architecturalrecord.com/articles/16974-continuing-education-bio-based-materials?utm_source=chatgpt.com

Markus, T. A. (1970). *Optimisation by Evaluation in the Appraisal of Buildings*.

Martin, Y. (2017). Fire safety of facades: basic principles, Belgian regulation and solutions for timber frame facades. In *Fire Safe Use of Bio-Based Building Products for Facades - Challenges and Limitations, Detailing and Testing* (pp. 5–7).

Moghtadernejad, S., Chouinard, Luc. E., & Mirza, M. S. (2018). Multi-criteria decision-making methods for preliminary design of sustainable facades. *Journal of Building Engineering*, *19*, 181–190. https://doi.org/10.1016/j.jobe.2018.05.006

Moisture Control Guidance for Building Design, Construction and Maintenance. (2013). https://www.epa.gov/indoor-air-quality-iaq/moisture-control-guidance-building-design-construction-and-maintenance-0

National Institute of Building Sciences. (2024). *Green Building Standards and Certification Systems*. https://www.wbdg.org/resources/green-building-standards-and-certification-systems#ar

Norton, J. (1997). *Building with Earth: A Handbook*. Practical Action Publishing.

Oever, M. J. A. van den. (2024, January). *Milieu-prestatie Biobased bouwmaterialen in de Nationale MilieuDatabase*. https://www.wur.nl/nl/onderzoek-resultaten/kennisonline-onderzoeksprojecten-lvvn/kennisonline/milieu-prestatie-biobased-bouwmaterialen-in-de-nationale-milieudatabase-1.htm

Patil, H. M., Sirsikar, S. S., & Gholap, N. N. (2017). Product Design and Development: Phases and Approach. *International Journal of Engineering Research & Technology*, *6*(7). www.ijert.org

Perruchoud, V. ;, Alderliesten, R. ;, & Mosleh, Y. (2024). *The Effects Of In-Situ Temperature And Relative Humidity On The Tensile Response Of Flax Vs. Glass Frp Composites* (Vol. 3).

Principles of Data Visualization - What We See in a Visual. (2016). www.fusioncharts.com

RIBuild - Guideline for selecting an internal insulation system. (n.d.).

Sandak, A., Sandak, J., Brzezicki, M., & Kutnar, A. (2019). *Bio-based Building Skin*. Springer Singapore. https://doi.org/https://doi.org/10.1007/978-981-13-3747-5

Scott, H., Fawkner, S., Oliver, C. W., & Murray, A. (2017). How to make an engaging infographic? *British Journal of Sports Medicine*, *51*(16), 1183–1184. https://doi.org/10.1136/bjsports-2016-097023

Soon, C. F., Yee, S. K., Nordin, A. N., Rahim, R. A., Ma, N. L., Hamed, I. S. L. A., Tee, K. S., Azmi, N. H., Sunar, N. M., & Heng, C. (2024). Advancements in Biodegradable Printed Circuit Boards: Review of Material Properties, Fabrication Methods, Applications and Challenges. *International Journal of Precision Engineering and Manufacturing*, *25*(9), 1925–1954. https://doi.org/10.1007/s12541-024-01027-2

Stones, C., & Gent, M. (2015). *The 7 G.R.A.P.H.I.C. Principles of Public Health Infographic Design*.

Trip, M. S., Vervuurt, W., Verstand, D., Liu, C., Dam, N. L., Verschoor, J. A., Selnes, T., Garcia Chavez, L. Y., Pellens, N., Niermans, K., Safitri, R., Poelman, M., Pulskens, J. A. M., Fonteijn, H. M. J., & Budding-Polo Ballinas, M. (2023). *Synergies & Trade-Offs of Wageningen Climate Solutions in Primary Production Systems: Case Study: Agriculture Carbon Sequestration in Agricultural Soils*. https://edepot.wur.nl/660790

Verslag interessebijeenkomst Biobased Bouwen. (2024).

Willemse, H., & Zee, M. van der. (2018). *Communicating the bio-based content of products in the EU and the US*. https://www.researchgate.net/publication/328538329

Yadav, M., & Agarwal, M. (2021). Biobased building materials for sustainable future: An overview. *Materials Today: Proceedings*, *43*, 2895–2902. https://doi.org/10.1016/j.matpr.2021.01.165

Appendix A. Interviews: Challenges of the Innovation

The complete notes from the interviews from the state of the art.

Interview 1

- Soort start-up, maar ook al 13 jaar bezig → traditionele bouw zorgt ervoor dat het lastig is.
- Begonnen met twee van ons die een strobaalbouwcursus hebben gevolgd: uitgegroeid tot uiteindelijk prefab systeem.
- Bedrijf in Litouwen (Ecococon: stroblokken) gevonden dat het al had gemaakt. Exclusieve partner in Nederland geworden. Vanaf toen promoten en in de markt brengen
- Begonnen met bescheiden projecten. Nederlandse aannemer is niet gewend om het droog te houden → doorontwikkeling tot gesloten gevel, komen waterdicht op de bouwplaats aan. → ook grotere bouwmarkten zijn nu beter te bedienen.
- Snelbouwsysteem! (1 woninglaag per dag)
- Hoge kwaliteit, biobased (CO_2 opname, 100kg per m2), dampopen gevel. Isolatiewaarde tot RC = 8,3 (weinig installaties nodig).
- Nu wordt het langzaam serieuzer genomen. Daar hebben wij veel in gedaan. Planbureau voor de leefomgeving: we gaan 2030 niet halen. → jawel! Van alle miljoen woningen, 150-200,000 van biobased.
- Opschalingstrategie (met Ecococon) → ook certificeren. Kijk [Technical documents | EcoCocon](#).
- Regelgeving is belemmerend voor bijv. dampopen en passief bouwen.
- Vraag 1: het duurt zo lang (13 jaar!!!) voordat we een keer geld gaan verdienen met een perfect product.
- DDW: stand → opschalen van bio-based materialen met stro en hout.
- Voorbeeldproject: Bestsellers Lelystad: distributiecentrum
- Vraag 2: bouwfysische aspecten zijn heel belangrijk! Bijv. extra brandweringplaat invloed op de vochtverdeling door het jaar.
    - Inblaasstro is echt een probleem met vochtigheid en rotten → dampdicht maken aan de binnenkant kan wel, maar is echt zonde van het binnenklimaat. Dampopen aan de buitenkant moet wel, anders kan het vocht niet weg en kan het rotten.
    - Vocht en brand zijn de afwijkende factoren!
        - Wij kunnen brandcertificaat van 2u afgeven! De stro is meerzijdig met forse kracht ingeperst: lucht is verdwenen, dus het dempt de brand: het schroeit dicht.
- Ons systeem is constructief voor 4-5 lagen. (hoger dan dat: brandoverslag)
- Vraag 3: beeld zegt het meeste → infographic met stroomschema, met verwijzingen naar hoofdstukken.

- Wij hebben met Ecocon een heel fijne partner: eerste gerobotiseerde productielijn (nu in Slowakije), voor hun stroblokken op de mm nauwkeurig. → deze zouden ook in Nederland geplaatst kunnen worden, om lokale stro te gebruiken. Dit is de doorkijk naar de toekomst, als opschalen nodig is.
- Er moet een stimuleringsbeleid zijn! → CO2 opslag waarderen.
- Graag document opsturen

Interview 2

- Grootste drempel: onbekendheid en dus angst → overheid heeft grote rol
- Geld tegenaan gooien en dan is het opgelost. Als je geen geld hebt is het wel een probleem.
- Is niet heel anders dan een gewoon bouwproduct maken.
- Tip: Niet stoppen, doorgaan!

Interview 3

- Wel onderzoek naar biobased en certificeren
- We passen het op dit moment nog niet toe
- Stein: kunststof composieten → RC Panels (zelfde soort constructie, sandwich met EPS, het is maar 2%), maar… hoe verduurzamen?
- Circulariteitsmeting mist in NL (10R) → hoe kunnen wij ons product zo circulair mogelijk maken?
    - Materiaalgebruik omlaag!
- Productie: uitfrezen van vierkant paneel → 50% verlies op paneel!
    - Hoe alleen materiaal gebruiken wat ook daadwerkelijk een functie krijgt.
    - → EPS neerleggen, glasvezel polyester platen neerleggen → deze kun je niet meer gebruiken → zelf lamineren, AOC heeft hars ontwikkeld die compatibel is met EPS, heeft wel thermische behandeling nodig. De sandwich wordt hierdoor anders! →
    - Subsidie en Europese subsidie
    - Hars is deels biobased (60-80%)
    - Problemen: testmethode is er niet om goed te keuren, productiemethode is zo verschillend dat het materiaal aan de kwaliteitsnorm nog niet kan voldoen, de normen zijn er niet. We zitten vast aan de business case.
- In de bouw zijn de winsten zo geminimaliseerd, dat je met nieuwe materialen nooit kan concurreren.
- Circular Reno: verzekering, wettelijke eisen, productie, testmethodes… https://circularreno.nweurope.eu
- Schaling is een ontzettend groot probleem: kan alleen met prefab
    - Je zit vast aan bepaalde halffabricaten
- Composiet industrie: hoe garandeer je bepaalde kwaliteit?

- Raw materials → halffabricaat → samengesteld product, allemaal andere certificeringsinstanties
- Europese wet- en regelgeving voldoet niet aan landelijke/lokale wet en regelgeving.
    - Voorbeeld: we willen fabriek in Duitsland, check wet- en regelgeving: die is er niet. Waar schalen we het dan onder?
    - Hoe gaan we pilotprojecten draaien met producten die nog niet gecertificeerd zijn?
- Building Balance! → die moet je spreken
    - Mark Kok: die kan je doorverwijzen
    - Ligt aan het gewas waar en hoe het kan (miscantus kan bijv. niet als rotatiegewas)
- Renoveren is belangrijk voor verminderen uitstoot: wonen is meeste uitstoot!
- '’De esthethiek moet bijdragen aan de uitstraling van de natuur” → wat zit er in een paneel → laten zien!
- Boek (uit podcast Duurzaam Hoe Dan): economische berekening aan de hand van wat wij kapotmaken.
- Business case: wat als bedrijven eigenaren blijven van hun producten? Dus lease/lenen en wij ruimen het weer op → voorinverstering is veel te groot. Veel te lange tijdsperiode.

1. In NL kunnen we makkelijk een product verkopen, de aannemer is verantwoordelijk. Wij geven een product met interne berekening. De juiste testen en het op de markt brengen (met certificaten). Vanaf 2025: WKB → wet kwaliteitsborging! Altijd gerelateerd aan BBL. Lastig want een nieuw product is vaag.
    a. Op moment dat je nieuw product wil gaan verkopen: idee tot daadwerkelijk opleveren is anderhalf jaar. Voor de sales is dit super moeilijk: producten verkopen kan nog niet.
    b. Certificeren van nieuw product (vervanger voor bitumen uit olifantengras: Miscancell) en wat is de kwaliteitsnorm? Natuurproduct!!!
    c. CERTIFICERING IS HET BELANGRIJKST! “Waar ga je je materiaal naar bewijzen?”
2. Welke informatie is er nodig om beter te snappen hoe je je bio-based building product ontwerpt en toepast in een façade? (e.g. manieren van productie, montage, technische aspecten, bouwfysische aspecten, verbindingen, duurzaamheidsaspecten zoals losmaakbaarheid).
    a. Welke materialen kun je toepassen? Wat is de capaciteit van je materiaal? Wat is de tolerantie van je materiaal? Wat kán je materiaal? (sandwich panelen: dwarskrachtcapaciteit nodig (momentcapaciteit heeft met laminaat te maken) → krachten doorvoeren naar de skin of de balken)
    b. Zo min mogelijk gewicht! → zeker voor renovatie (de muur moet het paneel kunnen dragen)

    c. Grootste uitdaging: de juiste toepassing vinden
    d. → helaas ga je echt nog niet goedkoper zijn dan conventioneel
3. Zou een gids die alle fases en stappen doorloopt, kunnen helpen bij het hele proces? Wat mist er?
    a. Afbakenen! Kijk wat er nodig is vanuit de gebruiker.

Interview 4

- De gebruikelijk gang van zaken in de bouw
- Je materiaal zit niet in de standaardlijst kostbaar en uitgebreid
- Eurocode normen: zitten gaten in toch echt zelf die tests doen
- Waar loop je als start-up tegenaan? Altijd kosten
    - Brandklasse test: gehele façade test 15-25000 eu
    - Simpele test voor materiaal: dure aansteker
- Aannemer's eerste vraag: Wat kost het? Is het duurder dan de traditionele materialen?
    - Of dat niet gek is? Nou ja, het is een kortetermijnvisie
    - Installatie van product kan wellicht goedkoper.
    - Bijv. trespa: kosten voor verwerking aan einde levensduur
    - Deze plaat kun je gewoon hergebruiken
- Om de kosten inzichtelijk te hebben, moet je op schaal produceren, maar dit kan alleen als je vraag hebt vanuit de markt.
    - Business model valideren: daarmee krijg je investeerders over de drempel
    - is er genoeg vraag vanuit de markt: met iedereen praten!

Botte en eerlijke opinie is nodig: productvalidatie
Daarna: waar moet het product aan voldoen? Wanneer is de klant bereid? Technische en financieel-economische eisen
We kopen het, als het: niet duurder en dezelfde garanties kunnen leveren

1. Het is belangrijk wat de functie is: zijn de functies die je nu hebt voldoende?
    a. Er kunnen ook meerdere lagen zijn die bijdragen aan één functie?
    b. Klant wil gebouw projectontwikkelaar / architect + lokale overheid (locatie) klant geeft wensen en eisen architect: lokale overheid eisen (bestemmingsplan) + BBL (technische eisen) + kosten (vanuit klant) + eigen visie
        i. Amsterdam heeft veel strengere eisen voor omgeving (omgevingswet, deze is per gemeente) positief voor biobased! de vraag is heel groot, maar de oplossingen zijn er nog niet (positieve impuls).
        ii. Triodos bank: veel hogere duurzaamheidseisen

c. HSB-element voorbeeld: HSB-constructie+isolatie+gipsplaat+binnenplaat+buitenplaat+gevelbekleding
    i. Binnen- en buitenplaat doen ook constructief mee
d. Zijn er meer dingen waar je tegenaan loopt?
    i. Afhankelijk van toepassing krijg je minimale eisen lijst aantonen van voldoen aan eisen: samples maken en deze testen opschalen productiemiddelen aanpassen opnieuw testen. Voordat het in gebruik wordt genomen, iets kunnen zeggen over continuïteit van kwaliteit. Certificering is van belang.
    ii. Productieproces systematisch inrichten: certificering voor productieproces
    iii. '’Je kunt niet nuttig certificeren op labschaal.”
    iv. Grondstoffen kwaliteit is ook belangrijk: elke batch opnieuw testen
    v. Grondstof kwaliteit + productieproces + machines dán certificering bij notified body (bijv. tuff of lloyds)
    vi. Tussendoor zelf testen: versimpelde testen zelf een idee krijgen van bijv. brandklasse door aanstekertest te doen.
e. Testen:
    i. 5x5 plaatje tussen twee stukken RVS. Koken 2u, drogen. Kijken hoeveel van de internal bond nog over is duurzaamheid
    ii. Buiten nat, nat, vriezer in, verwarmen 70 graden.
    iii. Schimmelbestendigheid
    iv. Welke testen? Normen (90eu per stuk)… welke normen? Dat is moeilijk normen over materialen (nieuw materiaal…?)
    v. Welke materialen worden er in de markt gebruikt? welke tests/certificaten hebben zij? je klanten stellen eisen
    vi. Volkern / HPL wordt gebruikt. Dit is een MDF-materiaal.. dus laten zien dat we aan dezelfde eisen voldoen. Heb je die eigenschappen allemaal wel nodig?
    vii. Dit hoeft niet materiaalspecifiek: geveleisen zijn noodzakelijk met toepassing.
f. Idee → gecertificeerd product is de hele uitdaging.
    i. Aan welke normen moeten we überhaupt voldoen?!
    ii. Voor constructies: EC-normen
    iii. Voor gevels: geen duidelijke norm zoveel verschillende mogelijkheden
g. Peuts: brandtests waren ook aan het struggelen: aan welke normen moeten biobased producten voldoen?
h. Inblaasstro: bioblow dit wordt al toegepast, dus er moet een norm voor het materiaal zijn (of moet in ieder geval aan een aantal eisen voldoen).

i. Vocht is een grote uitdaging.
j. Investeerders krijgen:
   i. Start-up 1 advies: Alles voor elkaar krijgen zonder intellectual property (IP) in gevaar te brengen. patent aanvragen
   ii. Wat is je aandelenverhouding? Zelf eigenaar of al aandelen weggegeven?
k. Go to markt strategie (laag (laaghangend naar hoogdrempeliger (hogere technische eisen en dus meer testen), investeringskosten): keuken/meubel façade draagconstructies

- Keukenkastjes: MDF-plaat / vezelplaat huidige kastjes: vezelplaat met HPL (afwerking). De afwerking is krasbestendig, hittebestendig, waterbestendig, etc.
    - Testen

2. Hierboven
3. Elke start-up met apart product heeft iets anders nodig.
   a. Façade: welke normen. Nieuw materiaal: hoe voldoe ik hier dan aan?
   b. Materialen: hoeveelheden zijn schijn. 80.000 ton tomatenstengels per jaar in westland. 80% vocht… is niet veel
   c. Aanvliegen vanuit bestaande materialen tippen aan de eisen die daar aan gesteld worden.

Tips voor vervolg:
- ABT: regelgeving expert
- Bluecity
- Bouwlab

Interview 5

- Uitgangspunt is belangrijk: boer met materiaal of ontwerper die met biobased wil?
- Testen en certificeren zijn twee verschillende dingen
    - o Je hoeft ook helemaal geen eisen te halen
    - o Certificeren = normeren/markeren à CE-markering = volgens de Europese regels
    - o Testen is gewoon zelf proberen of je de regel haalt.
- Krimppp = testfaciliteiten voor biobased materialen in de regio
- De markt vraagt om een datasheet == ze willen niet met je werken (of het nou bewust of onbewust is)
- Adoptie van innovatie à iedereen denkt dat ze heel goed bezig zijn, maar het is een normaalverdeling waarin niet iedereen bewust is van zijn plek.
    - o Certificering wordt gebruikt als goede reden…

- Terugvragen aan bouwbedrijf à wat moeten wij dan gecertificeerd hebben?
    - De juiste persoon (in Marc's geval: deuren, etc.) gingen zelf certificeren.
    - Gaat het om testen, normeren (aan de NEN-normen voldoen), of certificeren? à de markt gaat zelf hogere eisen stellen, en dat wordt de certificering
- Duurzaamheidstest, wat weet je van je product?
    - Één winter: best veel
    - Vijf jaar: het meeste
- Materiaalinnovatie: via interieur, waar het innovatief en esthetisch kan zijn, en minder risico's.

- Studie building technology à circulaire economie:
    - Waarom zou je iets recyclen als het niet economische waarde heeft?
    - Dus natuurlijke materialen ipv staal enzo
    - Maar niet hout
    - Schimmelstukjes samenpersen: bouwmateriaal
    - Eerste bedrijfje: fumologic à R&D
    - Daarna Fairm: meer fabrikant à marktontwikkeling (toepassing vinden bij het materiaal), materiaal is altijd onderdeel van een systeem, niet los te kopen. + productietechnologie (obv technologie uit de paddenstoelenindustrie, maar groter).
        - Meer geld nodig voor opschalen, maar dit duurde helaas te lang :(
        - De plek die we in de markt zien zouden met andere materialen makkelijker gevuld worden.
    - Building Balance adviseur: industrieactivatie

- Voorspelling: heel weinig van deze start-ups gaan het redden omdat . Wel genoeg subsidies
    - TRL: technology readiness level (1-9), 0-2 is lab testen, vanaf 5-6 ga je pilotten. In 5,6 komen veel start-ups vast te zitten. Marktpartners vinden is lastig en probleem oplossen is echt nodig.
    - Voornamelijk subsidies in kleine potjes, grote klap geld nodig om door de grote technology valley of death (= technologie is te hoog risico om de investeringen te accepteren, subsidies houden hier op en privaat investeerders zijn er nog niet, investering is te groot maar productverkoop nog niet in zicht) te komen.
    - Bijv. alternatief voor lijm, dit is overal nodig en heel duidelijk. Voor een bouwmateriaal is het vaak onduidelijk wat het gaat zijn, worden…
    - Bijv. Strotec kan zelf producten maken en een beetje pilotten omdat het een heel product is.
    - Of in de interieurmarkt beginnen en heel duidelijk pad naar de markt hebben.

- Partijen die al in de markt zitten hebben veel meer de mogelijkheid om te innoveren.
- Potenties om baanbrekende innovaties te maken is er niet echt in start-ups
    - Hemflex opgekocht door kingspan

1) Toepassing vinden en klanten krijgen zijn hetzelfde + productie à enorme verhouding tussen type klant en type productie
   a. Je moet een toepassing vinden waarvoor je kunt produceren op een schaal en voor een prijs dat het in jouw productiemethode kan. En daarvoor moet je ook snappen hoe jij het produceert. (dunne platen kosten net zoveel als dikke, maar leveren minder op, en uiteindelijk gingen we er verlies op draaien).
   b. Je weet dat alleen als je het doet.
   c. Plaatmateriaal initiatieven zijn er relatief veel: materiaal + pers = product! à je hebt bedrijven die een plaatermateriaalfabriek kunnen maken voor je. Heb je iets unieks toe te voegen voor die producent van die platen?
2) Er is heel weinig anders, behalve dat:
   a. mensen bang zijn voor de consequenties van vocht. Als je een gebouw maakt van materialen die niet vergaan als er vocht bij komt, letten op: Detaillering, Opbouw van pakket (dampopen)
   b. Brand à stroomdiagram: is het onder 15 meter? Ja? Mooi. Nee? Dan opletten, maar kan alsnog. De notie wat brandveilig is en inkadering, is ook nog maar de vraag. Makkelijke oplossing: magnesium oxide plaat, of dubbele gipsplaat ervoor.
   c. Als je met iets nieuws wil beginnen, maak het makkelijk!

- Europese norm voor plaatmateriaal (NEN EN13986:2004+A1:2015) bestaat, makkelijk te volgen:
    - BB geeft SHR opdracht: plaatmateriaal van hout à niet hout.
    - Materiaal aan de norm laten voldoen
- Voor alles is een norm! Ook al is het er eentje die je tijdelijk mag gebruiken. Er zal een alternatieve norm zijn (EOTA) of een geharmoniseerde norm (CE-norm).
- Onderzoeken!
    - Testinstellingen bellen
    - RVO (ook voor subsidies): CE-markering (VOOR VEEL!) of anders alternatieve norm.
    - SKH bellen
    - NEN EN310
- Plus fabrikanten verantwoordelijkheden in NEN-norm
- BRL: iets in de certificering

3) Het testen heeft ook fases, van heel laagwaardig, naar goedkope indicatieve test, naar heel hoogwaardig

a. geluid: van schreeuwen tot impedantiebuis (kleinschalig, paar honderd euro) en daarna op echt grootte meten (paar duizend euro)
b. brand: aansteker op de grote vlam (gele vlam) tot SBI-test (paar honderd euro), cone choloric test (10x10x10 materiaal: opbranden, hoeveel energie, hoe snel, wat voor gassen à extrapoleren tot brandklasse, paar 100eu), hoektest kost 5000piek.
c. Duurzaamheid: pleur het in een bak water, zet het eens buiten, etc.
d. Structural: driepuntsbuig- of duwtestje à die kennis schaalt wel!
e. Isolatie: weerstand tussen twee pinnen…beetje gek, 1D, terwijl die waardes niks zeggen (behalve vergelijken), doe gewoon legit isolatietest (duizend eu).

Interview 6

- Meer dan 10 jaar bezig met geëxpandeerde kurk
- Grote pakketten isolatie voor energie nul
- Kurk: co2 opslag, hergroeibaar, 100% biobased
- Ook inzameling en recycling van kurk, focus is kurk in de bouw, veel duurder helaas.
- Op plekken waar andere materialen niet de prestatie kunnen leveren.
- Kurk als gevelafwerking (in het zicht, want daar betalen mensen voor) + thermisch en akoestisch.
- +groendaksysteem (kurk kan ook drijven!) + bekasting eromheen

- Eerste referentie 2013: kurkpaneel buitengezet
    a. Geexpandeerde kurk wordt al langer toegepast als isolator, vóór de industriele isolaties
    b. Uit zicht geweest, behalve in monumentenbouw

1. Zelf zien hoe het wordt gemaakt en het hele proces is waardevol. Het liefst wilde ik een visueel resultaat, kurk als gevel. Hiermee kun je meer vertellen. In 2016 (binnen 2 jaar) had ik het eerste gevel op de innovation expo. Ecobouw Nederland gevormd → biobased demo woning. Gezocht naar samenwerking. Kurk op zichzelf gaat niet de verandering brengen in de bouw, het is een onderdeel.
    a. Launching customer nodig: particulieren die zelf de wens hebben.
    b. Brandklasseverbetering was nodig (EC1), test ook niet klaarliggen want dat gebeurt voor 5000eu bij een Peutz
        i. → verbetering door bedrijf in Portugal (extra product toevoegen, tweelaags toevoegen), dit product lever ik nu.
    c. TKI-project met biobased isolatie, met als doel toetreden tot de NMD: eigen LCA en eigen DPE en eigen MKI (funding vanuit houtsector en NMD)

    i. Ook hier dus weer de samenwerking: in het collectief zitten
d. Kurk duurzaamheid: het is een veranderlijke gevel, de kleur verandert. Als je de kurk afschuurt krijg je nog precies de laag die eronder zit. We hebben gewoon de ervaring nog niet met hoe lang het volhoudt.
e. Garanties kunnen geven aan de klant.
f. Ik had andere partijen nodig dus kurk als onderdeel van hun oplossing gingen aanbieden.
    i. Gewoon een goed product en telkens terug blijven komen: al is het maar dat ze de kurk toevoegen naast hun andere producten, voor klanten die het zoeken, of voor vergelijking met hun goedkopere materialen.
    ii. Het kan geen kwaad.

2. Eerst aangeslagen puur of zicht, controleren hoe je het nu eigenlijk echt gaat doen en je bent zelf verantwoordelijk voor de juiste referenties. Beschikbaarheid van het materiaal is van belang → het is niet zomaar te leveren, zeker niet in de opstartfase van een start-up. Het is een heel productieproces.
    a. Het is redelijk te voorspellen hoeveel we jaarlijks zullen hebben, we kunnen niet zomaar 2x zoveel kurk hebben.
    b. Nadenken over waar je het inzet en waar het het meest oplevert.
    c. We kunnen niet elke woning met kurk in de spouwmuur voorzien.
    d. Testfase: in eigen huis + via een architect die een boomhut voor kleinkinderen heeft gemaakt: kurk was product achter de waterkerende laag → gaten geboord → water gaan doorsijpelen → leerzaam! + Friesland & Amsterdam: blauwe of groene specht die maakt perfecte rondjes uit kurk als het 20mm dik is.
    e. Je moet testen! En ook meegeven in advies wat je eruit haalt voor je ontwerpen.

3. De markt is ook heel belangrijk: sparringspartners voorbeelden → Building Balance, Holland Houtland, Lectoraat Biobased Bouwen (Mnext) Avans, Agrodome, material district, bepaalde beursen, etc.
    a. Verderklikken naar wat jij interessant vindt.
    b. Open source! Kunnen blijven aanvullen: toevoegingen kunnen blijven doen.
    c. Kwalificering van biobased: percentage, wat is er biobased aan? Maar ook CO2 en LCA-berekeningen. → het gaat over de benaderingsmethode (TKI-project met Wageningen): andere methode van hoe je materialen beoordeelt → bijdrage voor het Parijs-akkoord om snel een substantiële bijdrage te kunnen leveren, dat kan alleen biobased! → CO2 is ook iets om op te gaan waarderen.

- Joost van der Waal

Interview 7

- TNO: lab waarin start-ups platen goed kunnen testen biobased à heel duur voor start-ups à Gerrit vragen.
- Collega Arnoud: veel met start-ups gewerkt, hoe kan normalisatie hen helpen? à innovatie funnel [NENnovation funnel - NEN Webtool]
    - Eerst ook innovatielab bij NEN
    - Ook NENnovationaward: start-ups die vroeg in het proces normalisatie / standaardisatie hadden toegepast.
- Onderzoek naar waar start-ups tegenaan lopen:
    - Testen zijn niet geschikt voor bio-based: bijv. dampdicht aanname
    - Brand: zoveel /dure (complexe) testen dat het niet mogelijk is (branddoorslag en overslag)
    - Financiën…..
- NEN-normen: het stellen van eisen begint bij Bouwbesluit
    - 30.000 normen! Grootste deel is Europees (Eurocodes), klein deel is nationaal (deze kunnen door NEN opgesteld worden).
    - De Europese NEN heet CEN à Technical Committees ontwerpen de eurocodes: NEN EN 1992 bijv. à Nationale Bijlage (NB) mag toegevoegd, en is afhankelijk van landparameters.
    - De meeste van de NEN-normen zijn marktstandaarden, een klein deel is wetgeving (als het om de bouw gaat, vind je dit terug in BBL).
    - Minder strenge afspraken bij NEN heten NTA's à deze worden gemaakt om sneller íets er te hebben liggen (het komen tot consensus bij een NEN-norm duurt heel lang), voornamelijk bij innovaties. NTA kan al vanaf 2 partijen, hoeft ook niet door NEN-normcommissie goedgekeurd te worden, maar NEN brengt het wel op de markt.
    - Normcommissies: zoeken op brand à welke normen horen hierbij.
    - Standaardisatie versus normalisatie: standaard = afspraken, normen zijn maar een deel hiervan (dat zijn dus echte eisen)
    - We gaan waarschijnlijk een NTA maken voor biobased bouwen voor building balance.
    - Hoe weet je welke NEN-norm verplicht is en welke niet? à in BBL is een annex waar de normen staan die verplicht zijn. "Als je iets wil bouwen moet je zorgen dat je daaraan voldoet".
    - Norm stelt x,y,z als eis. Certificaat: hoe moet ik aan x,y,z, voldoen?
    - Naast NEN zijn er andere partijen: bijv. COMO
    - NEN-normen en innovaties gaan niet zo goed samen, je kunt beter met NTA's werken. En dan kan het later altijd een NEN-norm van komen.

Interview 8

- Startblock: modulair opbouwen in de fabriek en neerzetten
- Bezig met

    - Traditionele isolatie → biobased, en kijkend naar vervangende plaatmaterialen
    - Biocomposieten
    - Hergebruik van hout
- Nieuw lab, maakfacaliteit: van prototype naar echt product en nulserie maken.
    - Persen voor plaatmaterialen
    - Hybride CLT (+persen met vacuum)
    - Prestaties van totale elementen te bepalen: hotbox (voor bepalen lambda-waarde)
    - Kleine monstertjes testen == gokken → kwaliteit kan heel erg verschillen
    - Duurzaamheid
- Testen en ook vooral maken van nulserie is uitdaging
- WUR is vier soorten stro aan het onderzoeken, BB is met inblaasstro bezig.
- Check BRL 1001
- Barchi.be → strobouw huis
- NL: dampdicht aan de binnenkant, dampopen aan de buitenkant, niet gewend om met volledig dampopen te bouwen.
- Ecococon: wufi berekeningen (kans op condensatie), Strotec is vertegenwoordiger van stro, worden gevels van gemaakt. https://www.linkedin.com/posts/joost-van-der-waal_de-fik-erin-de-uitkomst-zal-je-verbazen-activity-7247840636551254016-96JB?utm_source=share&utm_medium=member_desktop

Appendix B. Expert Dialogues

The complete notes from the expert dialogues.

Dialogue 1

- Groeifonds: toekomstbestendige leefomgeving
- Collega: normen die relevant zijn voor circulaire geveleconomie
- Ruimte bij NEN waar je in NEN-connect kunt neuzen: kun je gewoon afspraak voor maken
- Handleiding NEN Connect: hoe zoek je? Normcommissienummer bij de norm die je hebt gevonden → alle normen die hier van toepassing zijn
    - ICS-code → alle gerelateerde normen
    - Normen bevatten ook weer verwijzingen
- Eisen: BBL, de rest vd normen zijn afspraken
- Biobased: weinig normen, maar wel veel BRL's (europees: EAD's, vallen onder CPR) → procedure om EAD aan te vragen.
- Advies: eerst BBL verplichte normen, dan vrijwillige normen, dan BRL's (en EAD's).
    - Er is ook een biobased isolatie BRL
- BCRG: registreren van testen die gedaan zijn (stichting registratie van verklaringen)
- CPR-normen, EAD, BRL → link met overzicht
- Groeifonds: NTA opstellen voor plaatmaterialen en ook een persoonlijke (AI) scan maken → welke normen en eisen horen erbij?
- Groeifonds project: er wordt heel veel ontwikkeld en bedacht, maar de kennis wordt niet gedeeld, vooral de kennis die je nodig hebt om een innovatie verder te brengen.
    - Open source: resultaten delen van welke normen op jouw start-up van toepassing zijn → andere start-ups kunnen dan reageren.
    - Cases opslaan: materiaal x, dit hebben we uitgeplozen.

Dialogue 2

- BB kennisbank
- Biobased teststraat: certificering is heel ingewikkeld, ook per universiteit waar ondernemers gebruik van zouden kunnen maken.
- Afgestudeerde bouwkunde-student: Fieke Konijnenberg (onderzoek naar biobased binder in plaats van cement)
- Aanpak TGV met onderzoeken: vraag → Hoe ver is het bedrijf en wat willen ze onderzoeken?
    - Bijv. biobased vleermuizenmuur: onderzoek naar isolatiewaarde en uitblijven koudebrug.
    - Akoestische metingen…
    - TGV doet niet de metingen, maar dat doet de onderzoeker zelf. TGV is verbinding en het faciliteren van de testen.

- The Green Village: gevelproduct in de praktijk testen (voordat je een compléét gebouw gaat maken), de stap ná het testen in een lab
- The Green Village opschaalmodel: techniek, businessmodel, gebruiker, wet- en regelgeving.
    - Businessmodel en gebruiker worden nog weleens vergeten: hier ondersteunt TGV ook in.
    - Ook beginnen met contact met incubator (YES!Delft)

Dialogue 3

- Je mag ook zonder te testen iets op de markt brengen, zolang je maar laat zien dat je aan de norm voldoet.
- Je moet zelf bepalen wat voor eisen je aan je product stelt en hoe het in de markt past
    - Je hebt een product die een bepaalde functie moet vervullen: welke functie heeft jouw product?
- BBL moet je altijd aan voldoen (bouwvergunning), zijn altijd de minimale eisen.
- Product: certificaat nodig waarmee je aantoont dat je aan bepaalde eisen voldoet.
- Aannemer mag zelf andere producten kiezen om te gebruiken: "of gelijkwaardig" → aannemer kiest veiligheid en zekerheid, gecertificeerde producten.
- Normen en BBL zouden moeten volgen en niet moeten sturen, vindt Frank.
- UBAKUS als programma
- Collega die bestaande bouwwerk details kan delen
- Contacten: koplopers in brandtesten
- Collega's in brand en bio-based: linken aan onderzoeker die hier veel verstand van heeft
- Project: doen van brandtests op bio-based gevel (dampopen) à wanneer gaat dit feitelijk lopen? (met mycelium isolatie)
- Dampopen: van binnen naar buiten steeds grotere dampdiffusiecoëfficient.

Dialogue 4

- Simpele test is eigenlijk functionele test
- We doen meer dan alleen testen!
- Wageningen Food en research → onderzoek naar natuurlijke vezels, voornamelijk kijkend naar het materiaal en hoe pas je het toe in de industrie
- Krimppp heeft mij gevraagd om opstartende bedrijven te helpen
- Niet zozeer certificering
- Je mist een stuk: hoe maak je van je raw material je uiteindelijke materiaal?
    - oogstperiode, welk onderdeel van de plant, etc.
    - MDF-plaat: 12% lijm (18% voor badkamers)

- Bijv. akoestiek en brand heb je het grote product voor nodig, voor veel testen kun je gewoon je plaatmateriaal gebruiken.
- Afbakening uitleggen: non-structural
- Gewicht toevoegen
- Veel projecten gedaan: dus zeker wat toevoegingen

- Compressive and flexural strength test: staat goed → nen of iso voor testen van plaatmateriaal
    - Plywood: breekt ie op de lijm off op de plank (intternal bond): twee blokjes, bovenop elkaar plakken, kijken waar hij breekt.
- Impact test: bros?
- Hardness test voor oppervlakten: misschien niet toepasbaar…
- Spijkeren / schroeven: wel nuttig voor gebruik (moet je voorboren?)! Verven, lijmen, etc.
- Vocht: koud en warm water en afwisselen → hoeveel water opgenomen? En hoeveel dikker?
    - Druppel water: trekt deze in (plus camera) of niet? De tijd = echt waterdicht of…
- Brand: bunsen brander: 45 graden eronder, brandt het door uit zichzelf? En vlamt het aan? Is de lijm die je gebruikt brandbaar?
- Thermal: kleinn schaal is lastig… er zijn kleine machines die de geleiudbaarheid meten. Voor plaatmaterialen wel makkelijker dan voor losse materialen.
- Akoestische isolatie: drie luidsprekers met isolatie eromheen → bij verschillende frequenties (vergelijken met bestaande isolatiemateriaal)
- Durability: gewoon op het dak leggen, UV-testkast of temperatuur testen ook.
- Trekbank meten: ijzeren bolletje die je er doorheen drukt (**zoek ik op**)

- SHR: cerrtificeringsbedrijf voor hout.
- Grasisolatie valt af want '’dat is niet voor een boer’’, politiek gestuurd.

- Eigenschappen: dichtheid → je eigen verschillende producten vergelijken op basis van dichtheid, belangrijk!!!
- Je gedrag van je materiaal als het vriest: wat zijn de eigenschappen onder het vriespunt (brosheid, etc.)
- Gebruikshandleiding toevoegen bij productinformatie!
- Raw material: lijm toevoegen, op dit moment zijn ze nog niet zo goed. Process tijd is veel te lang (slecht!). Kan ook zijn dat je veel meer lijm nodig hebt (30-40%), duur en potentieel minder duurzaam onderdeel.
- Duurzaamheid: end-of-use, wat doe je als je het gebouw weer afbreekt? LCA-analyse! Herbruikbaar of hernieuwbaar? → go-to-market strategy heeft dit ook nodig. Het VERHAAL erbij, en waarom?
- Universiteit Wageningen (WUR WFBR): plaatmateriaal van biobased materialen. Zit veel kennis. Advies geven (compactboard, riet of stro? lijm?) en samen project doen.

Dialogue 5

1. Bouwfysica
   a. Inhoud
   b. Voorbeelddetails
   c. Simpele rekenmodellen of simulaties?
      i. ubakus.de voor al uw problemen!

- Moisture:
  - Dampdiffusieweerstand binnen hoger dan buiten = goed
  - Condensvorming excel
  - Ubakus.de
- Brand: collega
- Thermal: RC=4,7, faseverschuiving is onzin
  - Dichtheid hoger, geleidt goed, minder isolerend, iets ander thermisch gedrag.
  - Normale muur: niet zo lange faseverschuiving, je wil graag 12u voor constante temperatuur.
  - Thermische massa aan de binnenkant, isolatie aan de buitenkant (dan kan de muur opnemen en afstoten aan de binnenkant).
- Durability toevoegen bij Design! → BBL eis voor levensduur
- Biobased: broeien/rotten voorkomen → waterdichtheid is cruciaal!
- En UV! En bevriezen
- → waterdichtheid van HSB bijv. in Australië, hoezo gaat het daar goed? Ervaring?
- Opbouw is belangrijk → hoe gaat het in de opbouw en hoe past het in de façade?
- Testing
  - Martin Tenpierik voor akoestische testen: buis met absorptiewaarden
  - Waterabsorptie en waterdampdiffusie?
  - Testprotocollen voor hout
  - → Willem kan kijken voor testen
- Eisen voor de kwaliteit van bouwproducten https://www.rijksoverheid.nl/onderwerpen/bouwproducten#:~:text=De%20Rijksoverheid%20stelt%20eisen%20aan,en%20moeten%20ze%20brandveilig%20zijn. Europese Verordening bouwproducten.

Dialogue 6

- Wat test je? Materiaal of product of façade?
- Structural
  - gewoon breken! En vergelijken met eventuele bestaande producten op de markt.
  - Fysiek zelf voelen
  - Buigen versus breken.
- Moisture:
  - Toevoegen Plaatmateriaal norm dimensions en uitzetten en krimpen.

- Fire:
    - Cone calorimeter ISO 5660-1:2015
    - Brandgedrag en brandwerendheid zijn twee verschillende dingen
        - Allebei testen → houdt er een vlammetje (grote aansteker op gele vlam voor 1 minuut) bij: wat gebeurt er: brandt het heftig (SBI-test) voor brandgedrag (kijk naar aangetaste oppervlakte, of het blijft branden, etc.)
        - Brandwerendheid: hoeveel houdt het tegen?
    - Advies: voor brandwerendheid zelf dingen aanschaffen.
- Thermal:
    - DIY: Werkt voor water, maar in een gebouw heb je geen water, water geleidt veel beter → warmtelamp (thermosensor aan onderkant, lamp aan de bovenkant) → neemt ook thermische massa mee!
    - Hot wire is nutteloos, hot plate is meest nuttig.
    - Misschien is hier geen tussentestje nodig → isotest (300-900eu) is minder duur dan bijv. brandtest van 25,000eu.
    - Je hebt gewoon een isolatiestandaard (Marc zit maandag SKG voor tests, SKH, KIWA, Cauberg-Huygen)
- Acoustic:
    - Gewoon er heel hard tegenaan gaan schreeuwen
    - Of met speakers en dan vergelijken.
    - Of toch weer die vliegtuigmotoren…
- Durability
    - One document to rule them all is heel lastig
    - Wat is het doel van je test?!
    - IKEA: robot die 10,000 keer op een stoel ging zitten → durability test.

Dialogue 7

- Afgestudeerd als architect
- Strobouw: 300 bouwprojecten
- Alleen maar biobased → stro en hennep (kalkhennep)
    - Duuur
    - 95% van de uitdaging lossen we hier mee op
- Alles eerst zelf uitgetest en dan pas toegepast
- Zelf testen:
    - Eerste woning in strobalen was schoonzus
    - Daarna zelf woning
    - Huis grootouders: eerste keer stro in plat dak
    - Kalkhennep als eerste van partner → toegepast in hun vochtige kelder
- Volledig dampopen (behalve tussen fundering)
- Luchtdichting is met leem (?), buitenkant draskalk
- Samen met hogeschool gemonitord in de winter → droog!!!
- Publicaties: worden me opgestuurd

- Woonder → internationaal advies!
- Kalkhennep stopt de brand, het is ook thermisch isolerend en het houdt warmte vast. Neutraliseert straling.
- Te veel vraag.
- Studie met tips en adviezen: wordt opgestuurd
- Opsturen als het klaar is! Dan kunnen we nog feedback geven.
- Fantastisch.