BIOBASED ARCHITECTURE

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Abstract

The current challenge is how the urgent need to build and renovate houses can be combined with achieving sustainability goals. This research explores the potential of incorporating biobased façade materials in the transformation of post-war neighborhoods. Employing a product development methodology, the main task, designing a biobased façade, is broken down into sub-problems, focusing on the individual façade elements. Using a façade from the post-war neighborhood Boerhaave in Haarlem as a case study, elements like cladding, window frames, balconies, and horizontal bands are extracted, and biobased alternatives for each are examined. Criteria for sustainability, industrial construction, and architectural expression are established, and various alternatives are assessed based on these criteria. This process results in a concise overview of each element, allowing for a comparative analysis of different alternatives according to defined criteria. In a design process, this can be used to maximize the utilization of the chosen materials' properties. Additionally, it creates freedom for designers to give the façade a certain identity, while knowing the adverse and positive attributes of the materials

Keywords: *biobased materials, product develop methodology, architectural expression, industrial building, post-war neighborhoods.*

I. Introduction

By 2050, the Netherlands is confronted with the challenge of constructing 2 million new dwellings and making sustainable enhancements for 7 million existing residences (Ministerie van Economische Zaken en Klimaat, 2022) (Van Der Laan, 2020). While concurrently we are faced with the need to reduce CO2 emissions. Current construction practices are responsible for a substantial 40% of global CO2 emissions, with 11% attributed to material use, this presents difficulties in aligning with the reduction objectives (Cityfoster et al., 2022), (Studio Marco Vermeulen, 2020). The urgent nature of this challenge necessitates a reevaluation of established construction techniques and materials.

Historically, construction in the Netherlands utilized locally sourced materials, evolving into the use brick and wood. However, twentieth-century industrialization led to a surge in the use of fossil fuels for the production of concrete, steel, plastics, and synthetic insulation, accompanied by a decline in natural materials and associated knowledge (Blom et al., 2004) (Studio Marco Vermeulen, 2020). But recently, obtaining knowledge about these materials and their applications has become relevant once again (College van Rijksadviseurs, 2023).

Biobased materials, derived directly from biological renewable sources such as plants, trees, animals, fungi, and microorganisms, store CO2 from the air into the product. They, therefore, offer a promising way for climate-neutral construction (Van Dam & Van Den Oever, 2019). In particular, the use of wood as a construction material is increasingly popular, whereby new architecture with lighter façade materials must also be considered (Studio Marco Vermeulen, 2020). Despite advancements in recent years regarding the use of biobased materials, usage is not yet widely implemented in the construction industry, partly due to unfamiliarity among contractors and the inclusion of risks in pricing (Circulair Zuid Holland, 2021) (EIB, 2017). However, enhanced understanding and heightened use of biobased materials will result in cost reductions (Studio Marco Vermeulen, 2020). Additionally, current environmental performance for building calculations (MPG) does not account for the significant

advantage of biobased materials, the retention of stored CO2, keeping the alternative materials equally relevant (Houtkrant, 2022) (NPO [Wat houdt ons tegen], 2023).
A significant portion of the 7 million dwellings slated for sustainable improvements by 2050 were constructed in the post-war period, with about one-third being built between 1945 and 1965 (CBS, 2023) (Ministerie van Economische Zaken en Klimaat, 2022). The hurried construction practices of that time, prompted by post-war housing shortages, resulted in technical deficiencies such as low thermal and sound insulation, high energy consumption, and significant wood rot issues (Garritzmann Architects & hp architects, 2015) (Hulsman, 2023) (Ministerie van onderwijs, cultuur en wetenschap, 2021) Furthermore, these neighborhoods have lost their appeal due to the austere appearance and a lack of architectural expression, rendering them unsuitable for modern energy and living standards (Hulsman, 2023). The Boerhaave neighborhood is one example of a dilapidated post-war neighborhood located in Haarlem.

Meeting climate objectives necessitates the transformation of post-war neighborhoods. Sustainable material choices must harmonize with architectural expression to restore vitality. A structured product development methodology, dividing challenges into sub-problems for examination and comparison of alternatives based on measurable criteria, offers an effective approach (Mac-Lean, 2018) (Van Veen, 2016). This methodology empowers designers to make informed decisions. The central question of this research focuses on developing an industrial biobased façade element for the post-war Boerhaave neighborhood in Haarlem.

How can an industrial biobased façade element for the Boerhaave neighborhood be developed with product development methodology in which the properties of the materials are used optimally and at the same time the designer has the freedom to give the façade a certain identity?

This question is addressed through the following sub-questions:

- *Which façade compositions are found in the Boerhaave neighborhood, and what architectural elements do they consist of?*
- *What criteria ensure that the façade system is industrial, sustainable, and allows architectural expression, and how can these be made measurable?*
- *Which industrial biobased alternatives are available for the different façade elements?*
- *How are the various alternatives of biobased materials quantified according to the predetermined criteria?*

The central hypothesis of this study conjects that utilizing schemes for evaluating various alternatives based on criteria can help the decision-making of material or system choices. These choices collectively contribute to the development of a biobased, industrial façade element that permits architectural expression.

II. METHODOLOGY

Within the framework of a design process, conventional methods such as brainstorming can often prove to be overwhelming for certain multidisciplinary decisions (Van Veen, 2016). Analytical approaches from the product design industry are, occasionally applicable in the design sector (Mac-Lean, 2018).In this study the product development methodology focuses on breaking down a main problem, designing a biobased façade system, into sub-problems, representing the various elements within the façade system. Various alternatives are identified and analyzed for each element based on pre-determined criteria. For each element, a solution meeting the specified criteria is sought, These solutions are then integrated into an overall solution (Mac-Lean, 2018) (Van Veen, 2016). The entire method is visually presented in Figure 1, this paper focuses only on the first segment of the method, with each research question providing input for different steps throughout the process. The remaining part of the methodology will unfold during a design process, incorporating project-specific requirements. The first research question is on identifying the various architectural elements constituting the façades in the existing Boerhaave neighborhood. These elements form the base for exploring various biobased alternatives available. The second research question involves formulating criteria to evaluate the sustainability, industrialization, and architectural expression of the elements, along with making these criteria measurable. The third research question looks into the available alternatives for the chosen elements. In the fourth research question, each alternative is assessed based on the defined criteria. The tables curated per element serve as the end products of this research, subsequently, these can be utilized during a design process to make material choices.

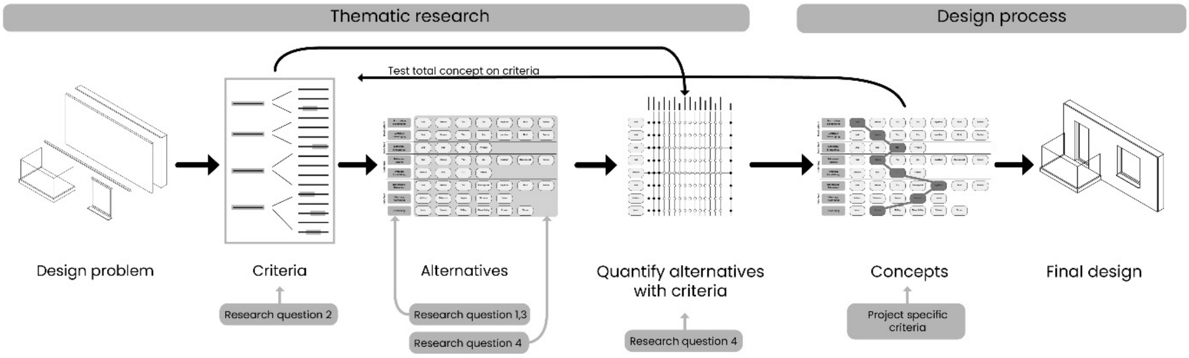

Figure 1. Product develop methodology

III. RESULTS

1. Façade compositions and elements Boerhaave neighborhood

The Boerhaave neighborhood, like many post-war residential areas, primarily consists of back-to-back row housing in combination with stacked flats. Influenced by standardization and rationalization in the architecture of that time, these buildings often exhibit a modest and monotonous aesthetic (Blom et al., 2004) (Mens, 2019). The neighborhood displays various façade compositions, categorized into three typologies: gallery flats (Appendix B.1), walk-up appartements (Appendix B.2), and row houses (Appendix B.3). One of the walk-up apartment blocks is selected, visible in Appendix C and used as a reference for extracting elements. The selection of this block was based on its unappealing exterior and low technical quality (*Gemeente Haarlem*, 2023). Characteristics of walk-up and gallery flats in the area include horizontal accents through galleries or balconies along the façade, or in the case of the reference building visible in Figure 2 and 3, decorative bands enclosing a horizontal strip of bricks at each floor level. Between these horizontal divisions, there is a repetitive rhythm of window frames, loggias, and brickwork. Loggia's are the most used type of outdoor space in the neighborhood, and their stacking reinforces the repetitive rhythm. Apart from these loggia's, the façades have minimal depth, the PVC window frames are aligned with the outer façade layer. The original frames were wooden, providing more refinement to the façade, but were replaced by PVC due to issues with wood rot (Mens, 2019). Furthermore, the houses are elevated from ground level, where storage areas are place, aligning with the philosophy of separating functions (Havinga et al., 2020). However, this results in an anonymous base on the street. Many buildings lack clear distinctions between front and back, they don't have a private and a public side, and they are standing as separate blocks in a public area, leading to a lack of intimacy (Blom et al., 2004). In the reference project, the only difference between the two sides is the entrance portals, featuring prominent entrances with a pink outline extending along the stairwell. Key elements in this façade composition include the cladding, loggia's, horizontal bands, and window frames. Section 3. will explore various biobased alternatives for these elements, while other pertinent elements are outlined in Appendix C.

Figure 2. Front façade reference building

Figure 3. Back façade reference building

2. Criteria

In the following chapter, various criteria are summarized, from which sub-criteria can be formulated, ultimately visible in Figure 4.

2.1. Sustainability

Various criteria can be established concerning the sustainability of a product or system, determined by different factors throughout its lifecycle. An all-encompassing and effective method of comparison could have been the use of Life Cycle Assessment (LCAs); which calculates the overall environmental impact of a product throughout its lifecycle. However, these calculations are intricate and require uniform execution on a national level to ensure comparability (*Stichting Nationale Milieudatabase*, 2023). Due to the unavailability of LCAs for every material, the sustainability of a material is determined by alternative criteria. This encompasses sustainable sourcing, production, lifespan, maintenance, and end-of-life activity (Van Dam & Van Den Oever, 2019). For systems composed of multiple materials, like balcony structures and horizontal bands, various criteria are established to assess how effectively the different materials are collaborating. The criteria encompass the proportion of bio-based materials, the amount of material employed in a system, and the protective measures implemented for materials susceptible to adverse weather conditions. For wood, standardized classifications and quality marks exist. The wood used must have FSC or PEFC certifications, indicating sustainable harvesting practices (Argodome, 2022). For wood used in outdoor applications, it must exhibit a minimum durability class of 1 or 2. This implies, that despite various weather conditions, wood classified as durability class 1 is expected to have a lifespan ranging from 25 to 50 years, while wood with class 2 endures 15 to 25 years (Houtwijzer, 2018) (Probos, 2009).

2.2. Industrial construction

The goal of industrial construction is to enhance efficiency, shorten construction time, and potentially reduce costs. Relevant criteria include scalability, minimal manual labor, efficient transportation, and production time (Mac-Lean, 2018) (Van Veen, 2016). The construction method significantly influences many industrial criteria. Therefore a pre-determined decision has been made for the core of the façade system. A timber frame straw wall system by *Ecococon* (2023), utilized by Strotec to produce a complete façade element with integrated interior layers, cladding, and window frames. This selection aligns closely with specified requirements, being fully biobased and suitable for industrialized prefab production. The system comprises compressed straw and wood, only applied at essential locations. Straw, a byproduct of grain production, is conditioned and compressed, resulting in a material with high insulation value, thermal mass, and fire resistance. The product is vapor-permeable and holds a cradle-to-cradle certification (*Strotec*, 2023). There are two criteria for the alternatives on industrially, the first being, compatibility with the Ecococon system. This implies that balcony constructions must either be stand-alone constructions or incorporate a structural steel or wooden element in the façade, and cladding must be lightweight and attached in a way that allows ventilation (*Strotec*, 2023). The other criterion is efficiency, for the cladding and window frames this means efficient production, and systems need to have an efficient assembly of various elements.

2.3. Architectural expression

The architectural expression of elements is evaluated on visual characteristics such as color, shape, texture, and refinement (Mac-Lean, 2018). However, also on the material's age over time, most architects prefer materials that have a controllable aging process (Verspeek & Van Der Burgh, 2019). For systems, like the balcony construction and the horizontal bands, measurements and flexibility in design are important criteria. The measurability of some of these criteria requires project-specific demands, referencing the preferences in the post-war Boerhaave neighborhood. Post-war neighborhoods often exhibit repetition, austerity, and a lack of identity (Abrahamse & Rutte, 2020). Yet, neighborhood identity is now crucial for residents (Spoormans et al., 2023). To impart more identity to façades, criteria can be established for façade elements, such as color and breaking repetitive rhythms with, diverse window sizes and staggered balconies in varying widths. Deeper balconies and recessed window frames not only disrupt the rhythm but also provide increased privacy in residences. From a heritage perspective, the absence of attributes at the façade level in these neighborhoods is emphasized. This is caused due to the replacement of refined wooden frames with plastic in the 1980s, and the addition of texture-less stucco façades, added with an insulation layer as a retrofit. Attributes in these neighborhoods include brick cladding, and horizontal accents (Havinga et al., 2020). In the reference building, appendix C, the horizontal accents consist of a drip edge that extends into string courses over the whole façade. Desirable criteria to measure the architectural expression of materials include color, texture, refinement, and the aging of materials. For systems, depth and design freedom emerge as significant criteria.

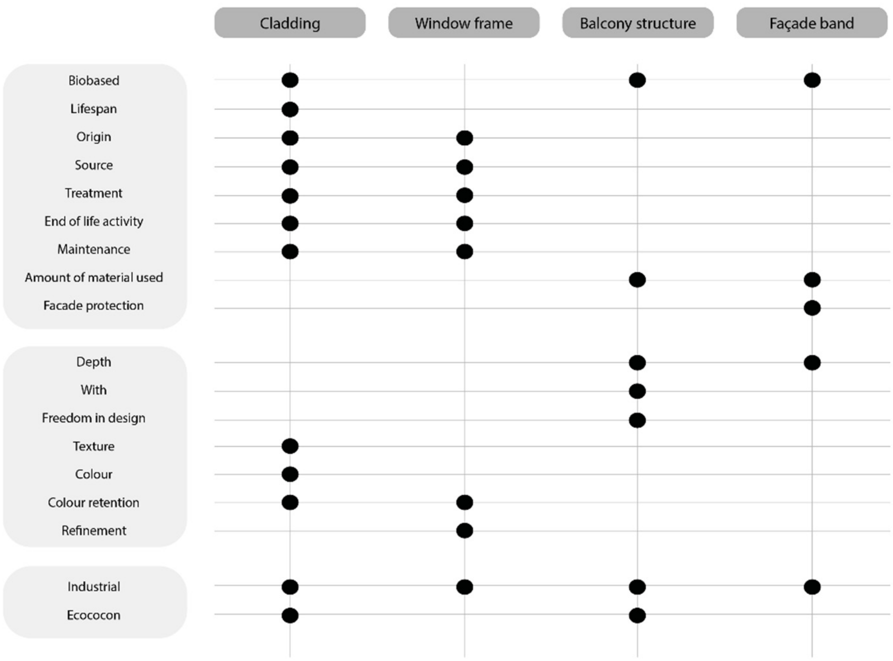

Figure 4. Sub-criteria per element (Appendix D)

3. Alternatives

For a selection of the elements, identified in section 1, biobased alternatives have been investigated. Selection criteria for the elements were based on their contribution to the architectural expression of the building, the availability of various products or references as alternatives, and the accessibility to sufficient information. Recent innovative insights and production methods have expanded the range of products and possibilities for building with natural materials (*Biobasedbouwen*, 2023) (*Materials - The Exploded View*, 2022) (Studio Marco Vermeulen, 2020). However, some of these alternatives are still in the experimental phase, resulting in limited available data for comparison.

3.1 Cladding

Several biobased façade materials alternatives are available (Appendix E.1), often requiring protection against weathering, mold, and pests (Studio Marco Vermeulen, 2020) (Van Dam & Van Den Oever, 2019). The most used material is wood, which can mainly be distinguished by hardwood and softwood. Hardwood species are highly resistant to weather conditions due to their hardness, have a natural high durability and can be used untreated. However, these hardwoods often come from tropical regions, necessitating significant transportation distances to Europe (Houtwijzer, 2018). Softwood species, which do not have a naturally high durability class, can be processed like boiling, baking, burning (carbonization), or acidification. These thermal modifications change the chemical structure of the wood, which results in the wood obtaining a higher durability class and ensures that the wood is more resistant to shrinkage and expansion. However, this process involves the use of energy, and the wood may no longer be entirely compostable (Studio Marco Vermeulen, 2020) (Van Dam & Van Den Oever, 2019). The impregnation of both the wood types, enhances its resistance to weather conditions and UV radiation, thereby preventing wood from aging. This process often involves the use of chemical substances; however, nowadays, there are also more natural alternatives available, such as biobased wax, shellac, dry oils, varnish, and plant-based paint (Van Dam & Van Den Oever, 2019). Besides wood, other biobased materials applicable as cladding, include expanded cork, created through thermal treatment of ground cork bark and mycelium-based panels formed by growing fungi and agricultural residues. This can be seen in the Growing Pavilion project but is further not yet widely applied (*The Growing Pavilion,* 2022) (Van Dam & Van Den Oever, 2019). More recent developments are biocomposites, where natural fiber fillers, such as hemp and flax are combined with bio-resin, offering lightweight panels, where different compositions create different properties. The mix of materials is poured into a mold, allowing for significant design freedom, resulting in 2D and 2.5D elements. Biocomposites are often resilient to various weather conditions and, depending on the resin used, can be recyclable (Van Dam & Van Den Oever, 2019). Various projects, like a biocomposite tiny house and the BRIC pavilion, showcase the versatility of this material (*Bouwwereld*, 2019) (*BRIC*, 2023).

3.2 Window frames

For window frames, the only applied biobased material is wood. However, similar to the façade material, diverse variations of wood are available, visible in Appendix E.2. Options for frame wood include hardwood or softwood, similar to those mentioned for façade cladding in 3.1. Softwood can be modified through finger jointing or lamination, which removes imperfections from the wood and increases stability, to create high-quality frame wood (Jellema, 2011). In addition, some of the naturally softer wood types undergo thermal modification, enhancing their resistance to various weather conditions (Appendix E.2). Despite the long-standing use of wooden window frames, with continuous improvements in techniques enhancing the longevity and quality of frames, manufactures are experimenting with frames from alternative materials, with applications such as hemp frames, biocomposites, and bio-attributed PVC. Due to the infancy state of these materials they are not yet considered comparable (*Bouwwereld*, 2019) (*Houtwereld & Eisma Bouwmedia BV*, 2023), (*Kommerling*, 2023).

3.3 Balcony constructions

Balconies or loggia's play a crucial role in the aesthetics of buildings and are essential for meeting outdoor space requirements for residences. Commonly used balcony constructions mainly consist of concrete, but there are also some biobased alternatives, of primary wood, which can be used for the structure (INBO, 2021). In Appendix E.3, various references with alternatives for balcony systems were explored, minimizing the use of no-natural materials. In some of these references, steel is used, it has good properties as a construction material and can ensure an efficient construction, without the need for excessive material consumption (*Detail*, 2023) (Zuschnitt, 2022). In the references, different materials are used for the floors of the balconies, these however can be replaced by a more sustainable variant, consisting of a solid CLT floor or a more cost-effective alternative involves using wooden or steel edge beams with an intervening wooden beam layer (INBO, 2021). Recently, experiments have been conducted with the use of biocomposite as a structural material such as in the BRIC pavilion exposition in the Dutch Design Week 2023 (*BRIC*, 2023). With biocomposite becoming more compelling, it is conceivable that balcony constructions in the future could also be composed of biocomposite elements (Studio Marco Vermeulen, 2020) (Van Dam & Van Den Oever, 2019).

3.4 Horizontal bands

In the references project façade, the prominent horizontal white bands play a vital role in its visual identity. These bands not only serve a decorative function, emphasizing horizontal lines but also function as a drip edge to prevent dirty water from running down the façade. The bands in the façade referenced are made of concrete, while other suitable materials for this application include natural stone, concrete, brick, or, more recently, composite materials (Jellema, 2005). In contrast to a brick façade where a solid band can be added, addressing a façade composed of sheet material requires a different approach. Examining reference projects, various detailing methods have been explored, incorporating a drip edge that transitions into a horizontal accent in a sheet material façade (Appendix E.4).

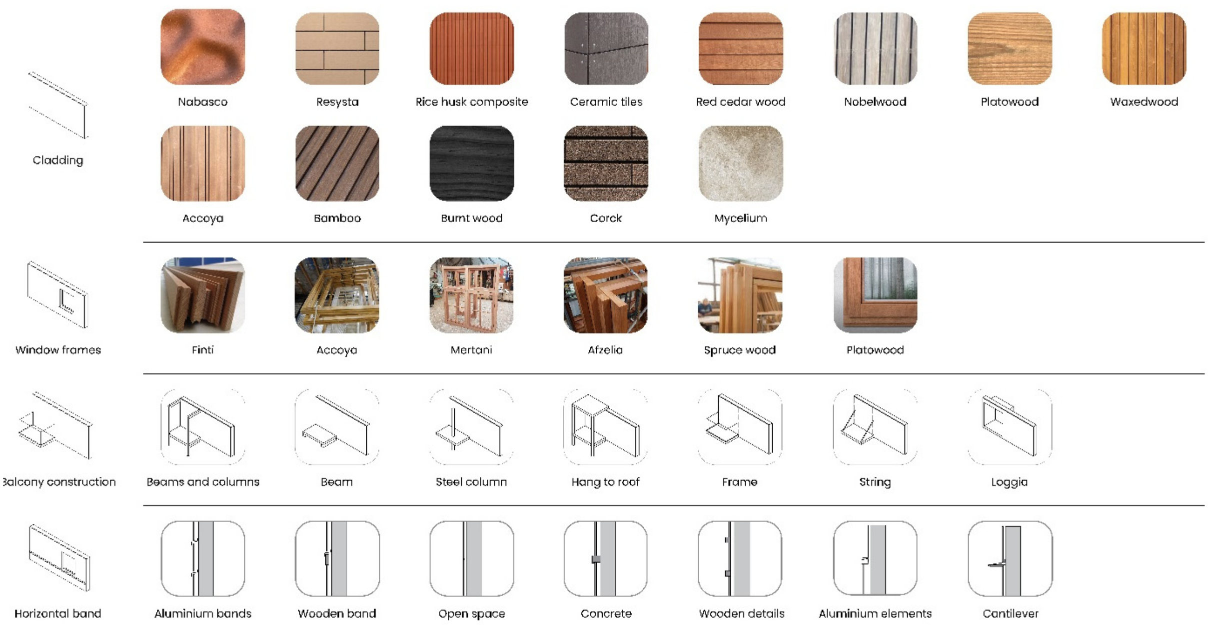

Figure 5. Overview of the alternatives per element (Appendix F)

4. Quantification of the criteria

The various alternatives discussed in Section 3. are evaluated against the criteria outlined in Section 2. Different criteria apply to each element, in the subsequent paragraph, an overview is provided in Appendix F.

4.1 Cladding

Alternative façade materials shown in Appendix G.1 encompass various wood and bio-composite types. Sustainability considerations revolve around the wood origin, where tropical hardwoods entail significant transportation distances, and softwoods require processing for outdoor use, which costs more energy. However, some of the more processed materials are fully circular. Currently, most wood is predominantly incinerated for energy after its lifespan, leading to the release of stored CO2. Another less-utilized post-lifespan application involves processing wood into chipboard; however, contemporary exploration focuses on alternative wood recycling techniques (Gemax, 2020). Other influencing factors are lifespan and maintenance. All materials consist of sheet material, produced industrially, except for mycelium, which must grow into its shape. Additionally, crucial criteria for architectural expression include texture, color, and form. Color retention becomes relevant if the designer intends to preserve the original color, otherwise, the façade needs to be painted, every few years, while biocomposites maintain their color and form.

4.2 Window frames

Appendix G.2 displays various alternatives for window frames. Sustainability choices involve considerations in wood origin and whether untreated wood is preferred, but also the end-of-life cycle, lifespan, and maintenance can weigh in the decision. In terms of industrialization and architectural expression, the choices can be negligible, due to the minimal distinction among window frames. All frames are industrially produced, exhibit refinement, and are available in different configurations, any potential differences in the color of most of the woods can be addressed through painting.

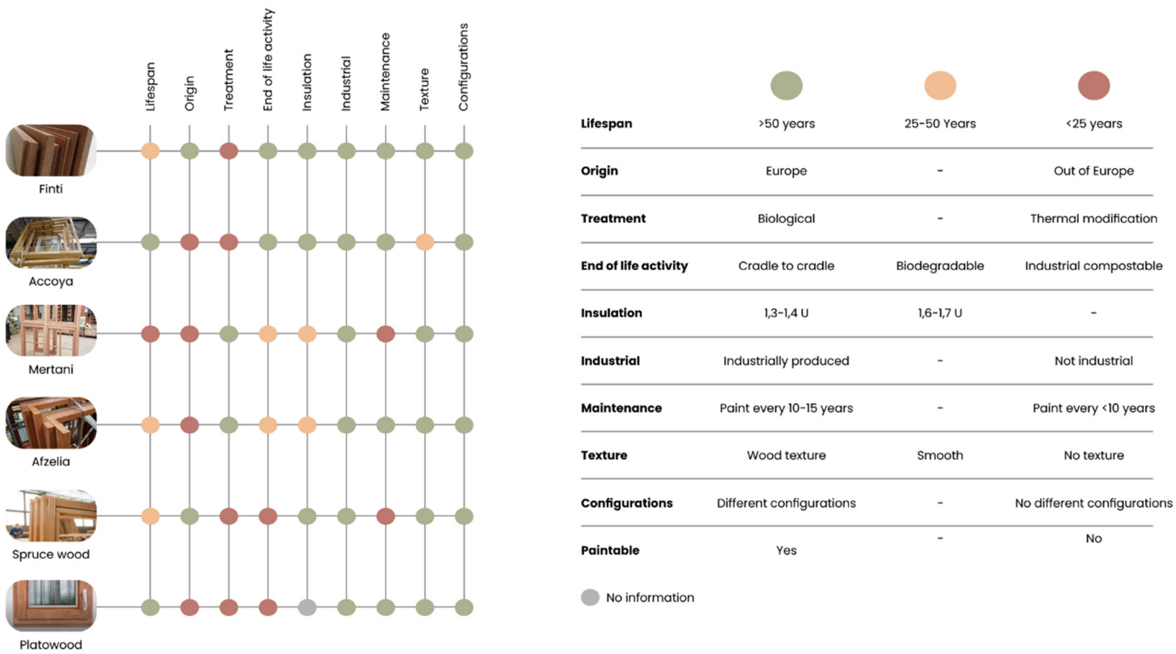

Figure 6. Example quantification window frames (Appendix G.2)

4.3 Balcony constructions

The various alternative balcony constructions are assessed against the criteria visible in Appendix G.3. Full wooden constructions require a relatively large amount of material when they protrude outside the building. Wood constructions need multiple columns and beams, or when cantilevering a ticker construction, to achieve a certain stiffness, which results in suboptimal use of material. In cases, where multiple balconies are above and adjacent to each other, employing various beams and columns proves to be an effective method. Introducing steel allows for a reduction in material usage; however, this is not a natural material and limitations exist in the widths and depths of outdoor spaces. This is due to the need for steel attachments at intervals. Constructions comprising multiple elements require more assembly time compared to those that can be hung on the façade in their entirety at once. Notably, the more freedom a structure has in the dimensions of outdoor spaces, the less freedom there is in positioning these spaces. This limitation is especially evident when separating structures like beams and columns, as they also need to transmit forces to the ground level. In these constructions, material efficiency is only achieved when all balconies are directly aligned beneath each other, restricting flexibility in balcony positions

4.4 Horizontal bands

The alternatives visible in Appendix G.4, show numerous examples that illustrate an effective collaboration between aluminum and wood, maximizing the utilization of both materials. The further an element protrudes, the bigger portion of the façade is shielded against weather influences. Drip edges occasionally collaborate with other materials to introduce a horizontal accent in the façade. At times, the drip edge may be located elsewhere in the façade, but this is inconspicuous due to its thin aluminum construction. In some details, wooden façade elements remain unprotected, necessitating a higher durability class, which isn’t optimal material use. The decisive criteria likely revolve around the architectural expression of the band, determining the desired thickness or depth of the accent in the façade, while criteria related to industrial and sustainability may be negligible.

IV. CONCLUSION

This paper demonstrates how utilizing a product development methodology can facilitate material choices based on a comparison of criteria. The methodology, structured by a series of sub-questions clarifies the properties of different elements in the façade. These elements, based on the key façade elements derived from various compositions in the Boerhaave neighborhood, include cladding, window frames, balcony structures, and façade bands. For each of these elements, various biobased available alternatives have been examined. Sub-criteria pertaining to sustainability, industrial construction and architectural expression have been defined and made measurable. Subsequently the various alternatives for each architectural element have been quantifies against the defined criteria, resulting in a clear framework. This framework can be used during the design process, allowing for a comparison of alternatives against different criteria, while simultaneously revealing the implications of certain choices and the relationships between the different criteria. Designers may employ the framework to make optimal use of the material or system properties. Furthermore, the framework can aid designers understand the benefits and drawbacks of specific choices when aiming to create a certain identity for the façade, enabling them to make informed decisions and avoid potential pitfalls. Appendix H illustrates how the framework can be used during the design process and expanded with a more specific focus as the design process progresses. This example shows how different design choices are based on the knowledge about the materials provided by the framework. Material choices are determined based on the best material properties, and through the optimization of system principles, the full potential of all materials is realized, ensuring an optimal utilization of resources and enhancing the overall performance of the design.

V. Discussion

Criteria have been drawn up and quantified for the various elements for this research. One of the main criteria is architectural expression, which is intricately linked to the entire façade composition and is challenging to assess at the element level. The sub-criteria outline aesthetic properties of materials and dimensions, emphasizing that these contribute to architectural expression only when integrated into a holistic composition. Furthermore, important factors such as price and availability were not extensively examined in this study; ongoing developments and production processes are anticipated to reduce prices with increased adoption of biobased materials (Studio Marco Vermeulen, 2020). The consideration of CO2 sequestration was omitted due to a lack of comprehensive data for each material but remains with the cost and availability, an intriguing criterion for future investigations. In addition, the accuracy of material property information relied on manufacturer data, with some materials indicating for example durability without quantification. This sometimes made it difficult to compare the different materials side by side. Finally, the materials and systems have not been discussed in much depth. More specific criteria could have been employed for comparison, but as this thesis primarily centers on the methodology, attention has been directed towards broader criteria a present. Despite these challenges, a clear framework has been developed to guide material choices and comparisons for future research.

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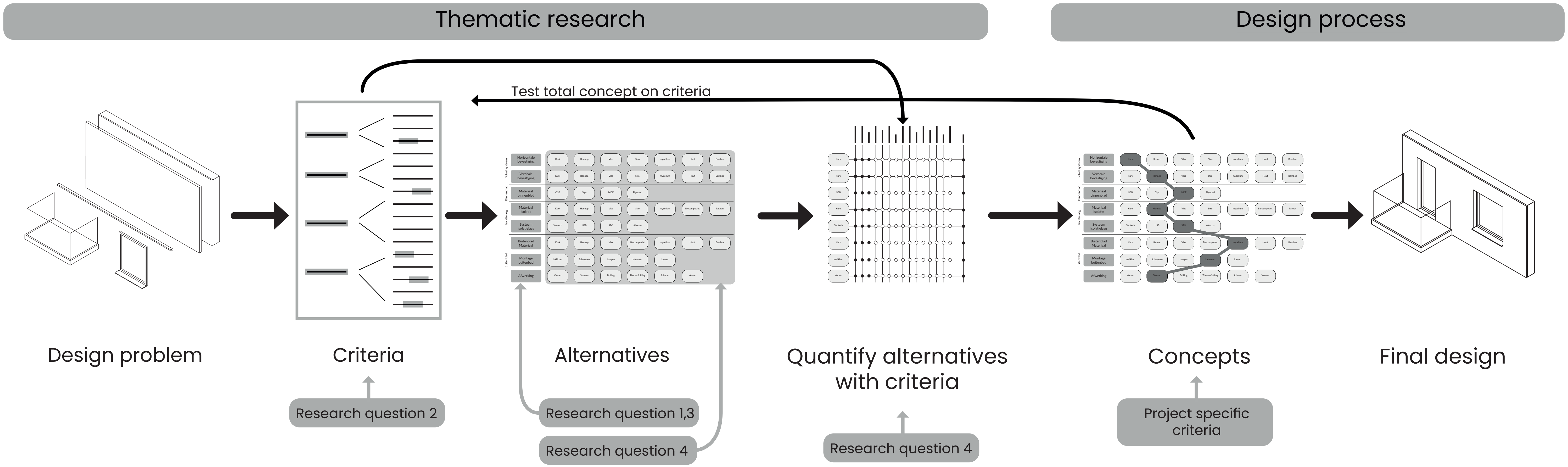
Appendix A | **Methodology**



Appendix B.1 | **Flats**

Front **Plinth** **End wall** **Entrance** **Balcony** **Detail**

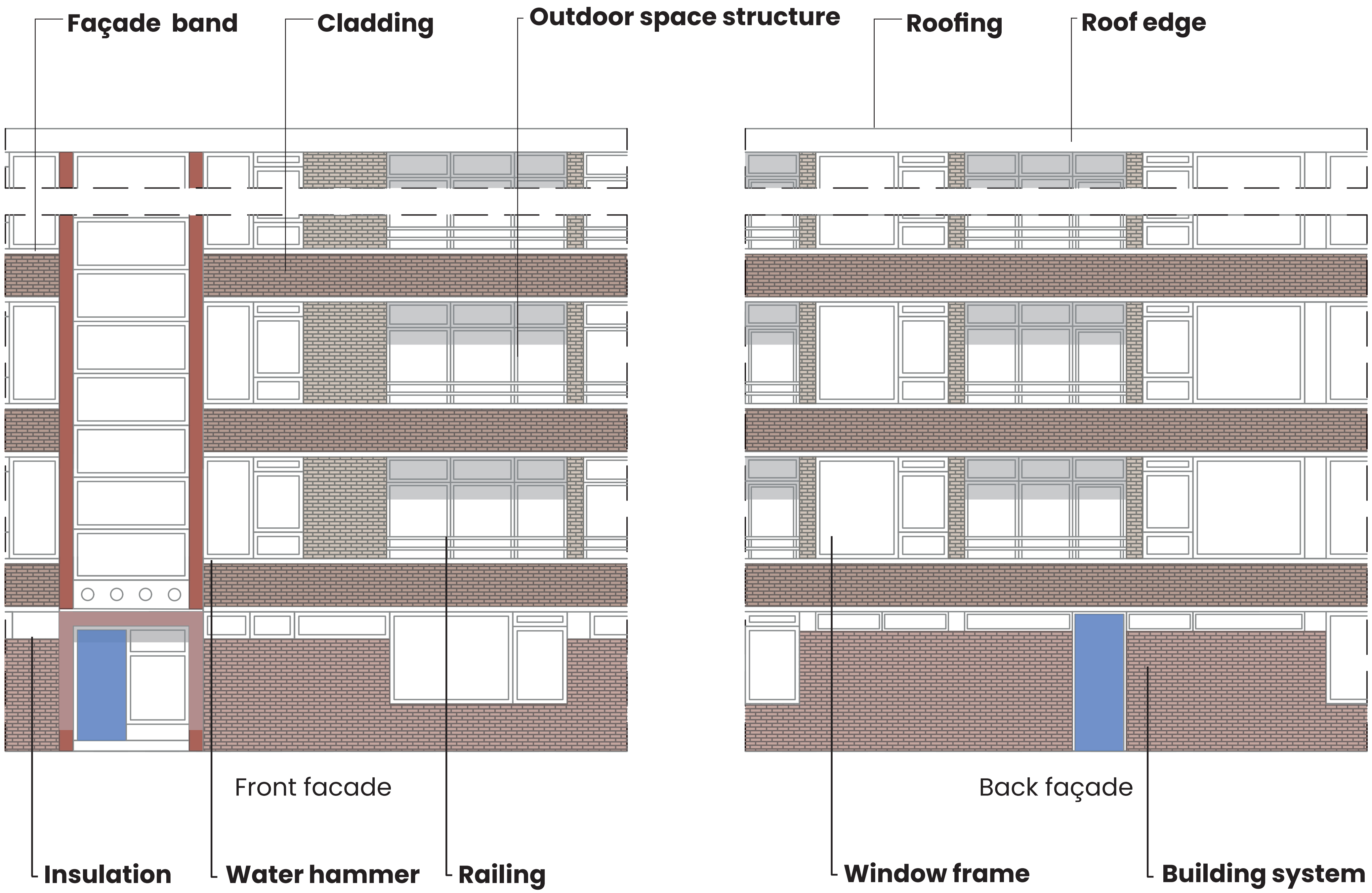
Appendix B.2 | **Walk up apartments**

Front	Plinth	End wall	Entrance	Balcony	Detail

Appendix B.3 | **Row houses**

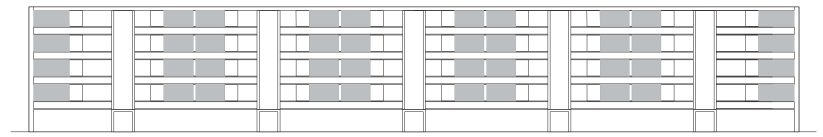
Front	Back	Front	Back	Front	Back
					
					
					
					

Appendix C | **Architectural elements**

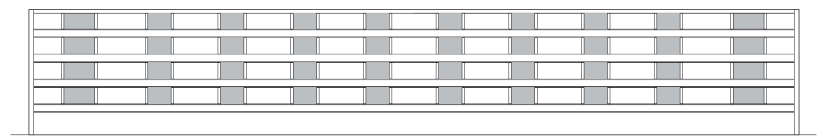


Front facade

Back façade



Front façade composition



Back façade composition

Context

Professor Krausstraat
Boerhaaveneighborhood, Haarlem
Building year: 1961

Appendix D | **Criteria**

Sustainability

- Biobased (%)
- Minimal waste
- Demountable
- CO2 storage (CO2 eq/m3)
- Necessary material
- Production processes
- End of life activity
- Lifespan (years)
- Material use
- Low weight (kg per m3)
- Dry assembly
- Origin
- Source
- Optimal material use

Architectural expression

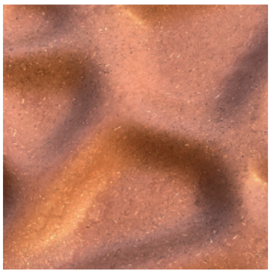
- Adaptability
- Made specific
- Finishing
- Scale
- Depth
- Connections
- Amount of elements
- Element variation

Industrial

- Risk of errors
- Process time
- Assembly time
- Minimal human labour
- Scalable
- Efficient transportation

Criteria	Cladding	Window frame	Balcony structure	Façade band
Biobased	●		●	●
Lifespan	●			
Origin	●	●		
Source	●	●		
Treatment	●	●		
End of life activity	●	●		
Maintenance	●	●		
Amount of material used			●	●
Facade protection				●
Depth			●	●
With			●	
Freedom in design			●	
Texture	●			
Colour	●			
Colour retention	●	●		
Refinement		●		
Industrial	●	●	●	●
Ecococon	●		●	

Appendix E.1 | **Cladding**



Biocomposite Nabasco

Company:	NPSP
Description:	Biobased circular composite, sheet material made from residual material, it can be easily processed with various techniques, such as engraving, milling, laser and water cutting.
Materials:	Natural fibres 33% reed and 33% lime as a filler from residual flows and a largely biobased resin 33%. The reed fibres come from nature reserves and cellulose fibres from toilet paper recovered from sewage sludge from water treatment plants.
Source/origin:	Waste
Biobased:	66%
Treatment:	Calcite (softening lime), reed or cellulose fibres and the resin are mixed to form a so-called Bulk Molding Compound or BMC. The BMC is hot pressed (at 140°C) into plates or molded parts that can optionally be finished with a high-quality environmentally friendly PVC-free film for UV protection.
Lifespan:	>50 years
End of life activity:	Cradle to cradle, 100% recyclable
Maintenance:	Little maintenance
Form:	Tiles 2D, 3D
Colour:	Multiple colours possible
Colour retention:	Good
Texture:	Little texture, easily processed with engraving

Sources:
https://www.npsp.nl/nl/nabasco-materiaal/1
https://www.biobasedbouwen.nl/producten/gevelbekleding-biocomposiet-nabasco-8010/#tab-id-1

Biocomposite

Company:	Resysta
Description:	Reysta is wood-free but does have the appearance of wood, it is resistant to water and it is possible to drill, sand or saw the material.
Materials:	60% rice husk with PVC plastic
Source/origin:	Waste
Biobased:	60%
Treatment:	Combines plastics with rice husk fibres, plastics are not biobased but do ensure that the product is easy to process and recyclable.
Lifespan:	>50 years
End of life activity:	100% recyclable
Maintenance:	Little maintenance, paint layer that must be maintained every 15 years
Form:	Tiles, planks
Colour:	20 colours
Colour retention:	Good, colour stays for 6 years
Texture:	Smooth, easily processed with engraving

Sources:
https://cirqlarconstruct.com/gevelbekleding/
https://www.biobasedbouwen.nl/producten/biobased-plaatmateriaal-resysta/

Appendix E.1 | **Cladding**

Rice husk composite

Company:	Riwood
Description:	Riwood is a type of bleached and purified wood, eco friendly option.
Materials:	15% rice husk 26% Calcite (calcium carbonate) 52% post production recycling PVC (grind) 7% process additives, among others. UV protectors & colour pigments
Durability class	1
Source/origin:	Waste
Biobased:	15%
Treatment:	Combines plastics with rice husk fibres
Lifespan:	>50 years
End of life activity:	100% recyclable
Maintenance:	Little maintenance 6 years
Form:	Planks
Colour:	4 colours
Colour retention:	Good, colour stays for 6 years
Texture:	Smooth

Sources:
https://www.fiberplastbiobased.nl/riwood/#

Ceramic tiles

Company:	Kerloc
Description:	Product made from residual waste fibres and natural minerals, a biobased sheet material, provided with a coating to meet fire resistance.
Materials:	Residual waste fibres and natural minerals
Source/origin:	Waste
Biobased:	100-90%
Treatment:	The product is made from residual material from land, garden and forest and consists of natural materials. It is formed at a low temperature by means of an exothermic reaction, energy consumption during production is low.
Lifespan:	>50 years
End of life activity:	100% recyclable
Maintenance:	Little maintenance
Form:	Tiles, planks
Colour:	Different colour options
Colour retention:	Good, colour stays for 20 years
Texture:	Grainy, natural looking

Sources:
https://www.biobasedbouwen.nl/producten/keramische-gevelbekleding-kerloc/#tab-id-1
https://martensgroep.eu/nl/producten/gevelbekleding

Appendix E.1 | **Cladding**

Red cedar wood

Company:	Gras wood wide
Description:	Western Red Cedar (WRC) is a sustainable softwood species from Canada. It has a natural resistance to rot and mold and has a natural appearance.
Durability class:	2
Source/origin:	Thuja plicata - Canada FSC
Biobased:	100%
Treatment:	No treatment needed sometimes dried
Lifespan:	25 to 50 years
End of life activity:	Biodegradable, downcycable
Maintenance:	Maintenance 3-5 years
Form:	Planks
Colour:	Natural different colours
Shape retention:	Yes, very shape retention
Colour retention:	No, aging natural otherwise a coating
Texture:	Wood texture

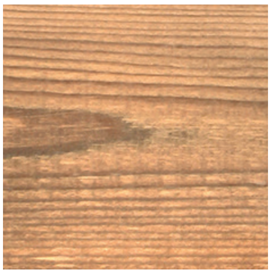
Sources:
https://www.graswoodwide.com/western-red-cedar/
https://www.houtinfo.nl/node/122

Nobelwood

Company:	Nobelwood
Description:	NobelWood is a unique type of wood that is made by impregnating fast-growing coniferous wood with a plant-based biopolymer. This process improves the quality and technical properties of the wood, making it a high-quality sustainable alternative to tropical hardwood. Residual waste fibres and natural minerals. The wood is free from shrinkage, swelling or deformation.
Durability class:	1
Source/origin:	Radiata Pine, Calafornia - FSC
Biobased:	100%
Treatment:	Wood is modified with biopolymers derived from the waste biomass of cane stalks. 100% organic.
Lifespan:	>50 years
End of life activity:	Biodegradable, because the treatment is biological
Maintenance:	Little maintenance
Form:	Planks
Colour:	Warm brown, will grey evenly without paint
Colour retention:	Aging, coatings can prevent this
Texture:	Smooth wood

Sources:
https://www.biobasedbouwen.nl/producten/nobelwood/

Appendix E.1 | **Cladding**



Platowood

Company:	Platowood
Description:	Spruce is made from spruce wood that has been preserved by a hydro-thermal modification process. This process enhances the properties present in the wood without chemical additives
Wood type:	Spurce tree - North of Europe FSC
Durability class:	1-2
Treatment:	The production process includes the hydro-thermal modification process, in which spruce wood is preserved without chemical additives. If wanted add a fire-retardant coating.
Lifespan:	50 years
End of life activity:	Biodegradable, downcycable
Maintenance:	To prevent ageing, add coatings, otherwise little maintenance needed. 3-5 years.
Form:	Planks
Colour:	Brown
Colour retention:	Aging
Texture:	Wood texture

Sources:
https://www.fiberplastbiobased.nl/riwood/#

Siberian larch

Company:	Waxedwood
Description:	WaxedWood is a preserved wood species with water-repellent properties.
Wood type:	Siberian larch - Russia - FSC
Durability class:	-
Treatment:	The impregnation of wood improves durability and gives the wood a water-repellent effect. The wood is impregnated under high pressure, after which a wax emulsion is added to the wood pores.
Lifespan:	25 years
End of life activity:	Industrial compostable
Maintenance:	Every 4 years to remain the colour
Form:	Planks
Colour:	Green brown to warm bronze
Colour retention:	Aging
Texture:	Wooden texture

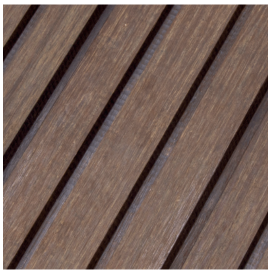
Sources:
https://www.biobasedbouwen.nl/producten/gevelbekleding-waxedwood-foreco/#tab-id-2
https://www.foreco.nl/nl/producten/waxedwood
https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_94363/

Appendix E.1 | **Cladding**

Accoya

Company:	Accoya
Description:	Accoya wood is acetylated monterey pine. It is very stable and durable. 100% rot resistant. The wood is softwood modified to the core.
Wood type:	radiata pine, New Zealand - FSC
Durability class:	1
Treatment:	Acetylation is a non-toxic, chemical process in which the wood is preserved with acetic anhydride. This gives the wood characteristics similar to those of (tropical) hardwood's.
Biobased:	95%
Lifespan:	60 years
End of life activity:	Cradle to cradle
Maintenance:	Little maintenance is required for this product. It is resistant to all extreme weather conditions and UV rays, and remains free of shrinkage, swelling or deformation throughout its life.
Form:	Planks
Colour:	Light pine
Colour retention:	Good
Texture:	Smooth

Sources:
https://www.biobasedbouwen.nl/producten/accoya-hout/
https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_91398/
https://www.accoya.com/nl/duurzaamheid/
https://milieudatabase.nl/nl/viewer/milieuverklaring/nmd_94363/



Bamboo

Company:	Mosa
Description:	The product is made by heat treating bamboo, a process that increases its durability. This results in a product that is fireproof, extremely hard with a natural appearance. While bamboo is heavier than wood, it is also the fastest growing grass species. The product in CO2 natural, the stored CO2 compensates for the long travel to Europe.
Wood type:	Bamboo, Asia FSC
Durability class:	1
Treatment:	The bamboo is thermally treated at 200 degrees and pressed, it comes from sustainably managed forests.
Lifespan:	25 Years
End of life activity:	Biodegradable, downcycable
Maintenance:	Almost no maintenance
Form:	Planks
Colour:	Depends on the painting normal brown/grey
Colour retention:	Aging
Texture:	Smooth

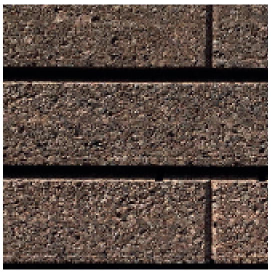
Sources:
https://www.moso-bamboo.com/nl/product/moso-bamboo-varibo/
https://www.biobasedbouwen.nl/producten/gevelbekleding-moso-outdoor-bamboo-x-treme/

Appendix E.1 | **Cladding**

Nakatado

Company:	Zwart hout
Description:	The wood is treated, giving it a high durability class, and burning gives it a black colour. Nakatado can withstand various weather conditions and does not shed.
Wood type:	Pinus Radaiata, new Zealand - FSC
Durability class:	1
Treatment:	The wood is thermally modified, charred, then brushed and post-treated, revealing the grain structure
Lifespan:	30 Years
End of life activity:	Biodegradable, downcycable
Maintenance:	3-5 years
Form:	Planks
Colour:	Black
Colour retention:	-
Texture:	Wood texture

Sources:
https://www.zwarthout.com/nl/product/17/nakatado



Corck

Company:	Isokurk
Description:	Isocork is a type of wood known for its excellent durability and ability to absorb a large amount of water. It is a popular choice for cladding because it has a natural, warm appearance and is highly resistant to the elements.
Materials:	Isocork is a type of wood extracted from the tree Kurrajong (Acacia pycnantha). The wood is soft and flexible. Extraction is 95% from parts of the tree that need to be pruned in any case.
Durability class:	2
Source/origin:	Waste, Portugal and Spain
Biobased:	100%
Treatment:	The expanded cork insulation boards (ISOKURK) are made by heating cork granulate, which causes the cork grains to expand, with the 'Suberine resin' already present in the cork serving as a binder; thus 100% cork.
Lifespan:	-
End of life activity:	Biodegradable, downcycable
Maintenance:	-
Form:	Panels
Colour:	Brown after aging grey
Colour retention:	Aging
Texture:	Rough

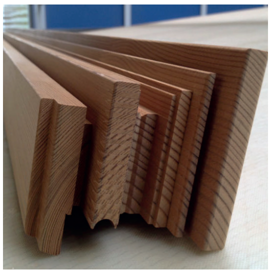
Sources:
https://www.biobasedbouwen.nl/producten/gevelafwerking-iso-kurk/

Mycelium

Company:	Grown
Description:	Grown makes building materials with mycelium and agricultural residual flows.
Materials:	MycoComposite is based on agricultural residual flows and mycelium. Mycelium is the root system of the mushroom and binds the fibres together within 7 days.
Source/origin:	Waste
Biobased:	100%
Treatment:	Mycelium is naturally hydrophobic, meaning it repels water. As the material also consists of hemp fibres, it is recommended to apply a bio-based waterproof coating.
Lifespan:	-
End of life activity:	Biodegradable, downcycable
Maintenance:	-
Form:	Panels
Colour:	White/yellow
Colour retention:	-
Texture:	Fibrous

Sources:
https://www.grown.bio/building/?v=796834e7a283
https://theexplodedview.com/the-exploded-view-beyond-building/materials/

Appendix E.2 | **Window frames**



Finti

Wood type: Pine wood
Description: Finti is, down to the core of the wood, defect-free, thermally modified pine from Finland. 80% of the energy required for thermal modification is generated from residual materials.
Origin: Finland
Durability class: 2
Lifespan: 15 to 25 years
Treatment: Thermal modification, finger joint and glued
End of life: 100% recyclable
Insulation (U): 1,4
Maintenance: Paint every 15 years
Configurations: Different configurations possible
Texture: Wood texture

Sources:
https://www.biobasedbouwen.nl/producten/hout-voor-buitentoepassing-finti/
https://www.finti.com/

Accoya

Wood type: Coniferous wood, pinus radiata
Description: Accoya is made from fast-growing coniferous wood from sustainably managed forests. The trees, pinus radiata, are harvested after approximately 30 years. The wood is then modified to the core through an acetylation process.
Origin: Asia
Durability class: 1
Lifespan: 75 Years
Treatment: Acetylation is a non-toxic, chemical process in which the wood is preserved with acetic anhydride. This gives the wood characteristics that resemble those of (tropical) hardwood.
End of life: 100% recyclable
Insulation (U): 1,4
Maintenance: Paint every 12 years
Configurations: Different configurations possible
Texture: Smooth texture

Sources:
https://www.toeleveringonline.nl/kennisbank/advies-houten-kozijnen/wat-is-het-verschil-tussen-de-verschillende-merken-hout/
https://www.accoya.com/nl/producten/houten-kozijnen/
https://www.webo.nl/houtsoorten-kozijnen/accoya-hout/accoya-kozijnen/

Meranti

Wood type: -
Description: Meranti is not actually a specific type of wood, but a collective name for various types of hardwood. The wood comes from deciduous trees from Southeast Asia and is comparable to sapeli mahogany. It is very durable and not very susceptible to damage.
Origin: Asia
Durability class: 2
Lifespan: 15 to 25 years
Treatment: No treatment needed, can be coated
End of life: Biodegradable, downcyclable
Insulation (U): 1,6
Maintenance: Paint every 6 years
Configurations: Different configurations possible
Texture: Wood texture
Colour: Red colours, a lot to choose from

Sources:
https://www.webo.nl/houtsoorten-kozijnen/meranti/

Appendix E.2 | **Window frames**

Afzelia

Wood type:	Hardwood species
Description:	The afzelia species are known for their excellent properties, the wood is almost inactive and naturally has a high durability class
Origin:	West Afrika
Durability class:	1
Lifespan:	25 years
Treatment:	No treatment needed, can be coated
End of life:	Biodegradable, downcycable
Insulation (U):	1,7
Maintenance:	Every 15 years
Configurations:	Different configurations possible
Texture:	Wood texture
Colour	Orange-brown, yellow-brown or red-brown

Sources:
https://www.webo.nl/houten-kozijnen/houtsoorten/afzelia/
https://www.af.nl/werkstukken/deuren/

Spruce wood

Wood type:	Coniferous wood
Description:	Spruce wood comes from Norway spruce. However, thanks to processing options such as thermal modification or patented flexible epoxy compounds, it is assigned durability class 1 or 2. This makes it on par with hardwood species and is therefore very suitable for indoor and outdoor window frames.
Origin:	Sweden and Finland
Durability class:	1 or 2
Lifespan:	15 to 25 years
Treatment:	Thermal modification or patented flexible epoxy compounds
End of life:	Biodegradable, downcycable
Insulation (U):	1.3
Maintenance:	Paint every 6 years
Configurations:	Different configurations possible
Texture:	Wood texture

Sources:
https://architectenweb.nl/producten/product.aspx?id=27692
https://www.hout100procent.nl/vurenhout-kozijnen-voordelen-en-nadelen/

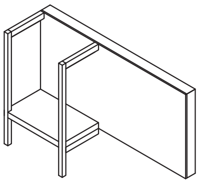
Platowood

Wood type:	Hardwood species
Description:	Fraké is a fast-growing hardwood species, which in itself has very limited durability. Platonizing accentuates the subtle flame-like drawing that is characteristic of the wood.
Origin:	West Africa
Durability class:	1 or 2
Lifespan:	50 years
Treatment:	Platonization - wood refinement via hydro-thermal modification - the wood is many times more dimensionally stable and requires less maintenance.
End of life:	Biodegradable, downcycable
Insulation (U):	-
Maintenance:	Paint every 15 years
Configurations:	Different configurations possible
Texture:	Wood texture

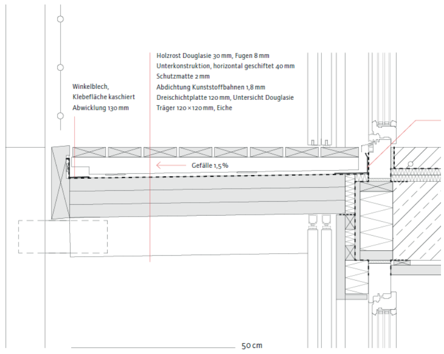
Sources:
https://architectenweb.nl/producten/product.aspx?id=27692
https://www.platowood.nl/producten/toepassingen/kozijnen-deuren/

Appendix E.3 | **Balcony structures**

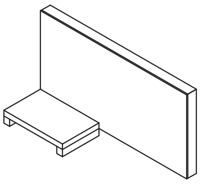
Beam and column construction



Source: zuschnitt 86- pdf balkonconstructies https://www.archdaily.com/930107/hagmannareal-housing-development

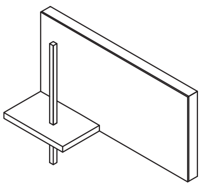


Beams

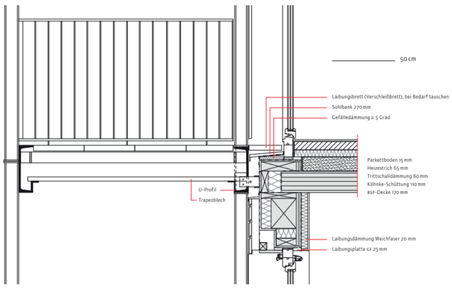


Source: https://mei-arch.eu/en/projects/sawa/

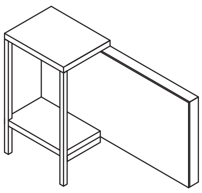
Steel columns



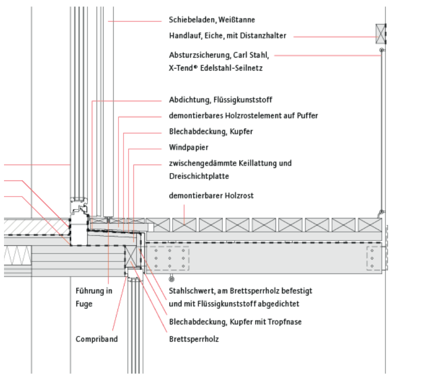
Source: zuschnitt 86- pdf balkonconstructies https://www.archdaily.com/930107/hagmannareal-housing-development



Hang to the roof

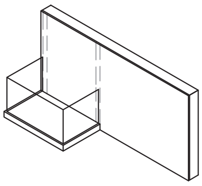


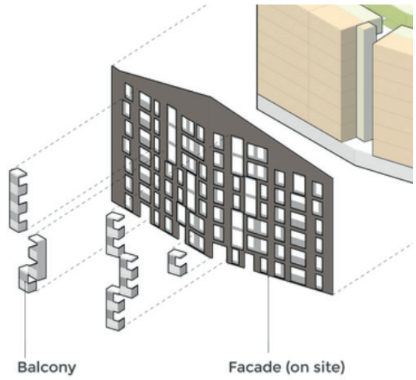
Source: zuschnitt 86- pdf balkonconstructies https://www.archdaily.com/930107/hagmannareal-housing-development



Appendix E.3 | **Balcony structures**

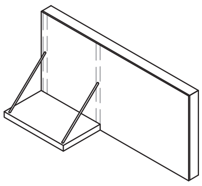
Frame

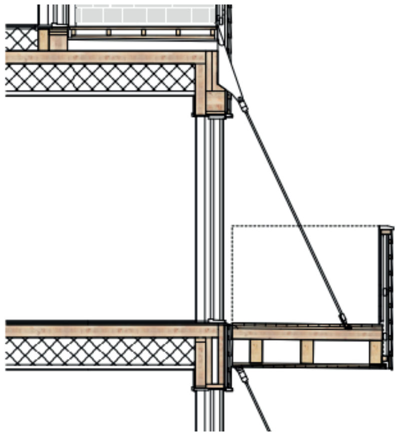




Source: https://www.archdaily.com/614915/puukuokka-housing-block-puukuokka-housing-block-oopeaa-photo?next_project=no

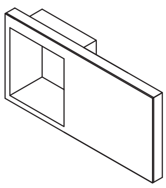
Strings

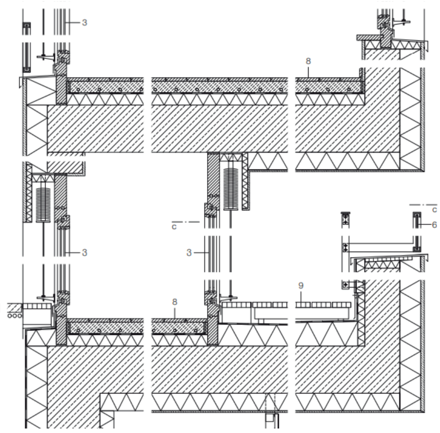




Source: zuschnitt 86- pdf https://www.archdaily.com/933091/kajstaden-tall-timber-building-cf-moller-architects?ad_medium=galler

Loggia's

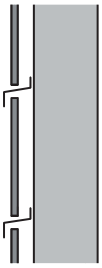


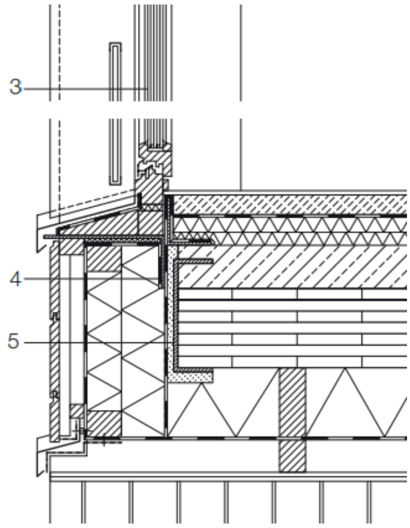


Source: https://inspiration-detail-de.tudelft.idm.oclc.org/housing-block-in-weimar-106114.html

Appendix E.4 | **Facade bands**

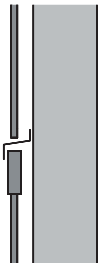
Aluminium band

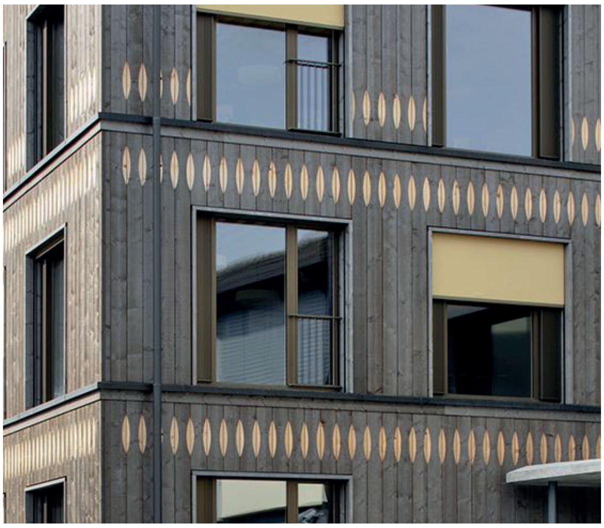


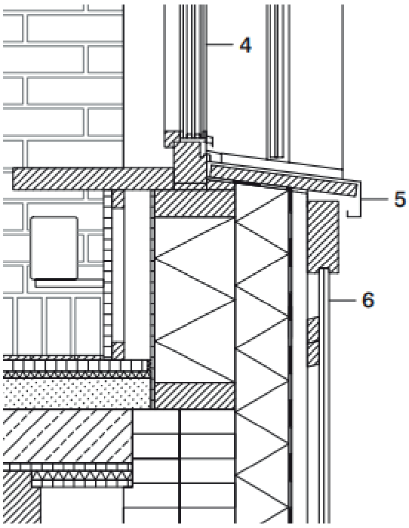


Source: https://inspiration-detail-de.tudelft.idm.oclc.org/iba-apartment-building-in-hamburg-108985.html

Wooden band

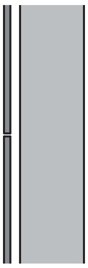


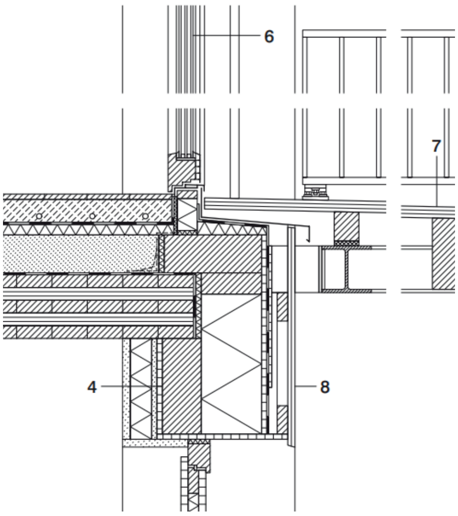




Source: https://inspiration-detail-de.tudelft.idm.oclc.org/riaz-primary-school-near-fribourg-115784.html

Open space

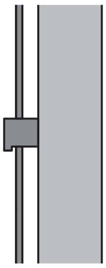




Source: https://inspiration-detail-de.tudelft.idm.oclc.org/Download/document-download/id/6538c1271849c

Appendix E.4 | **Facade bands**

Concrete



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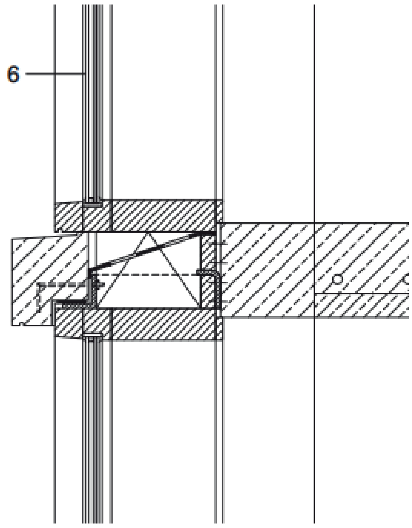
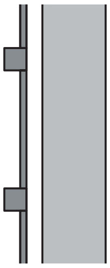
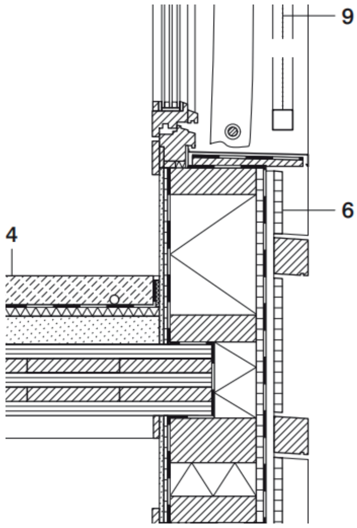


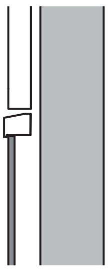
Wooden details



Source: https://inspiration-detail-de.tudelft.idm.oclc.org/living-simply-in-puchheim-115286.htmlfribourg-115784.html



Aluminium elements



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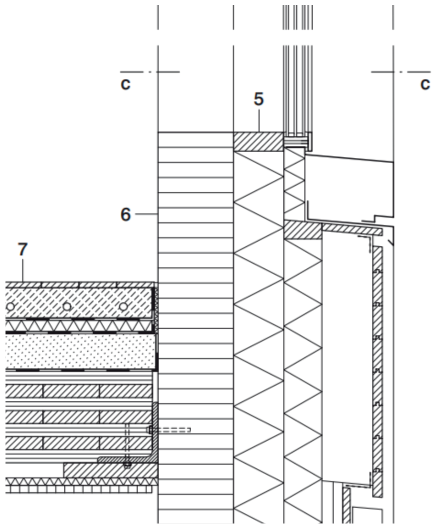
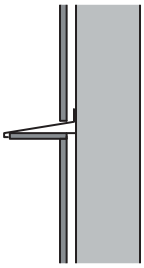
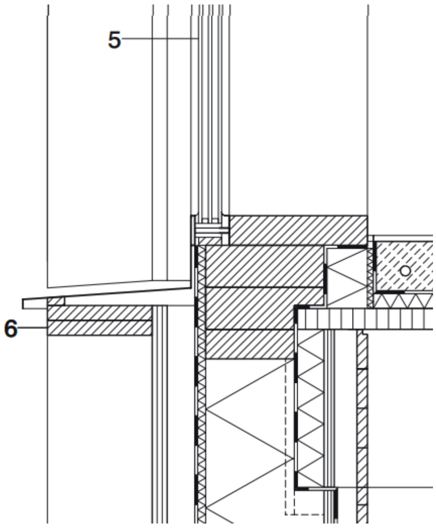


Appendix E.4 | **Facade bands**

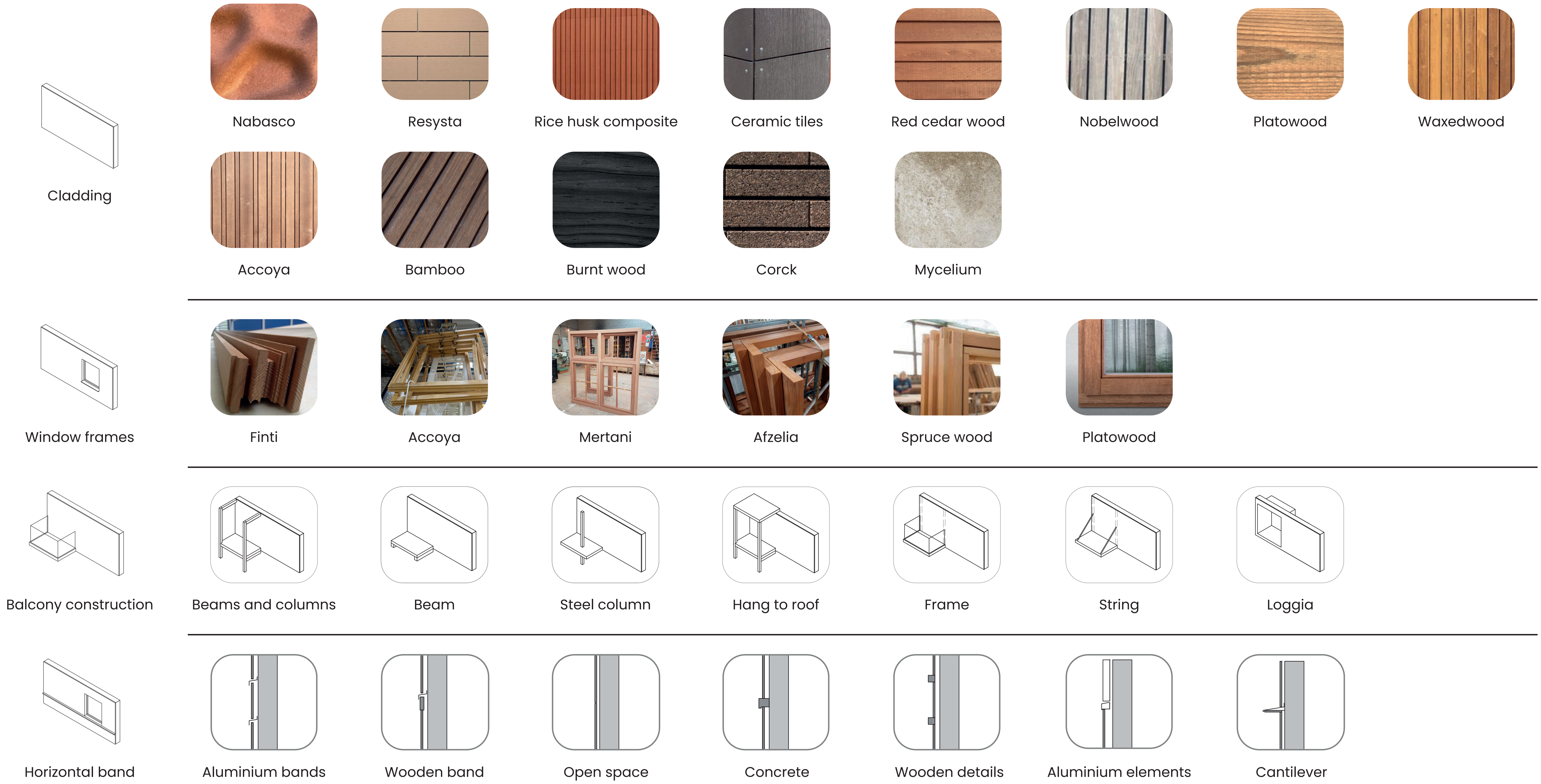
Wooden details



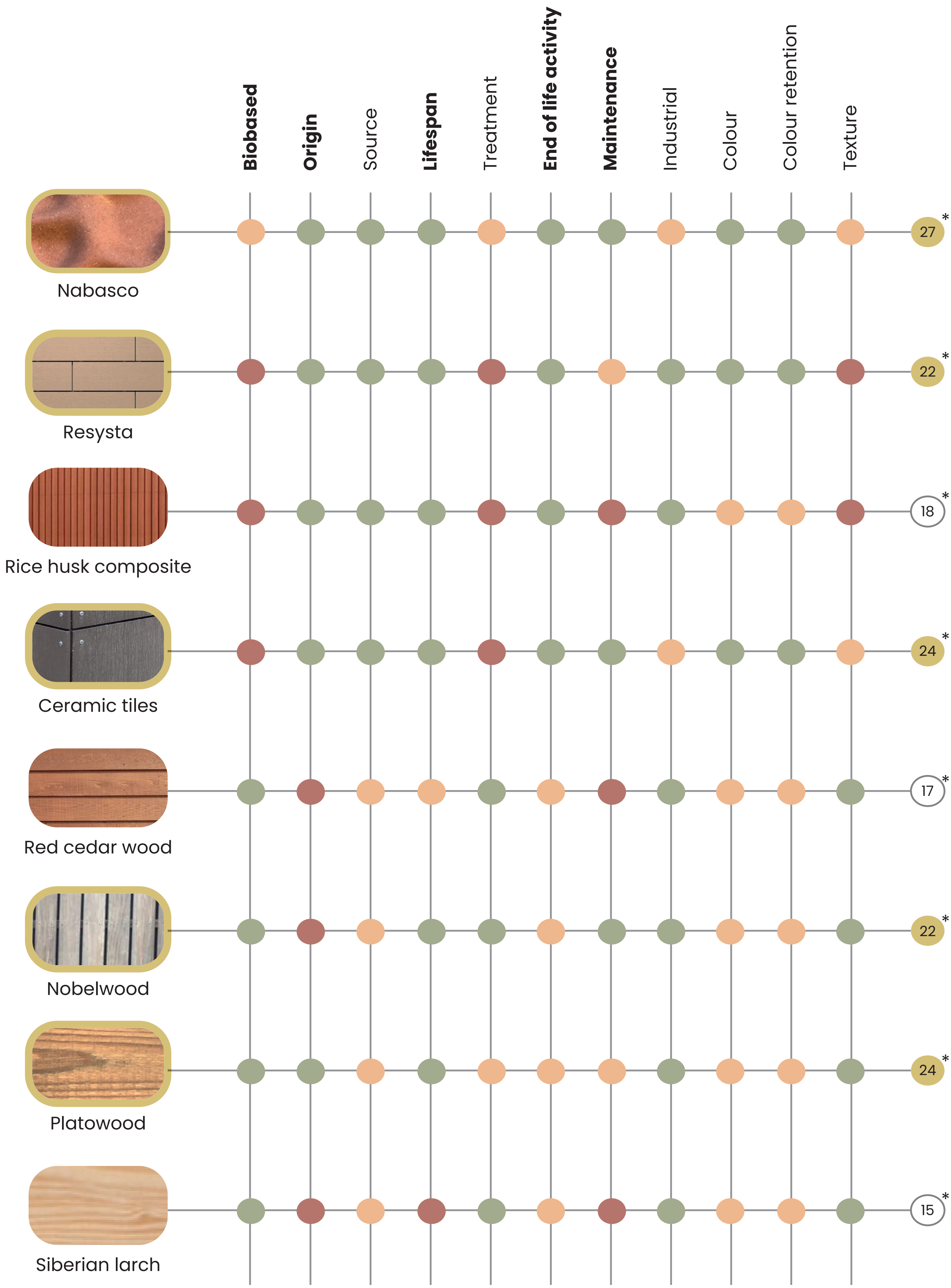


Source: https://inspiration-detail-de.tudelft.idm.oclc.org/Download/document-download/id/60e826f74b403

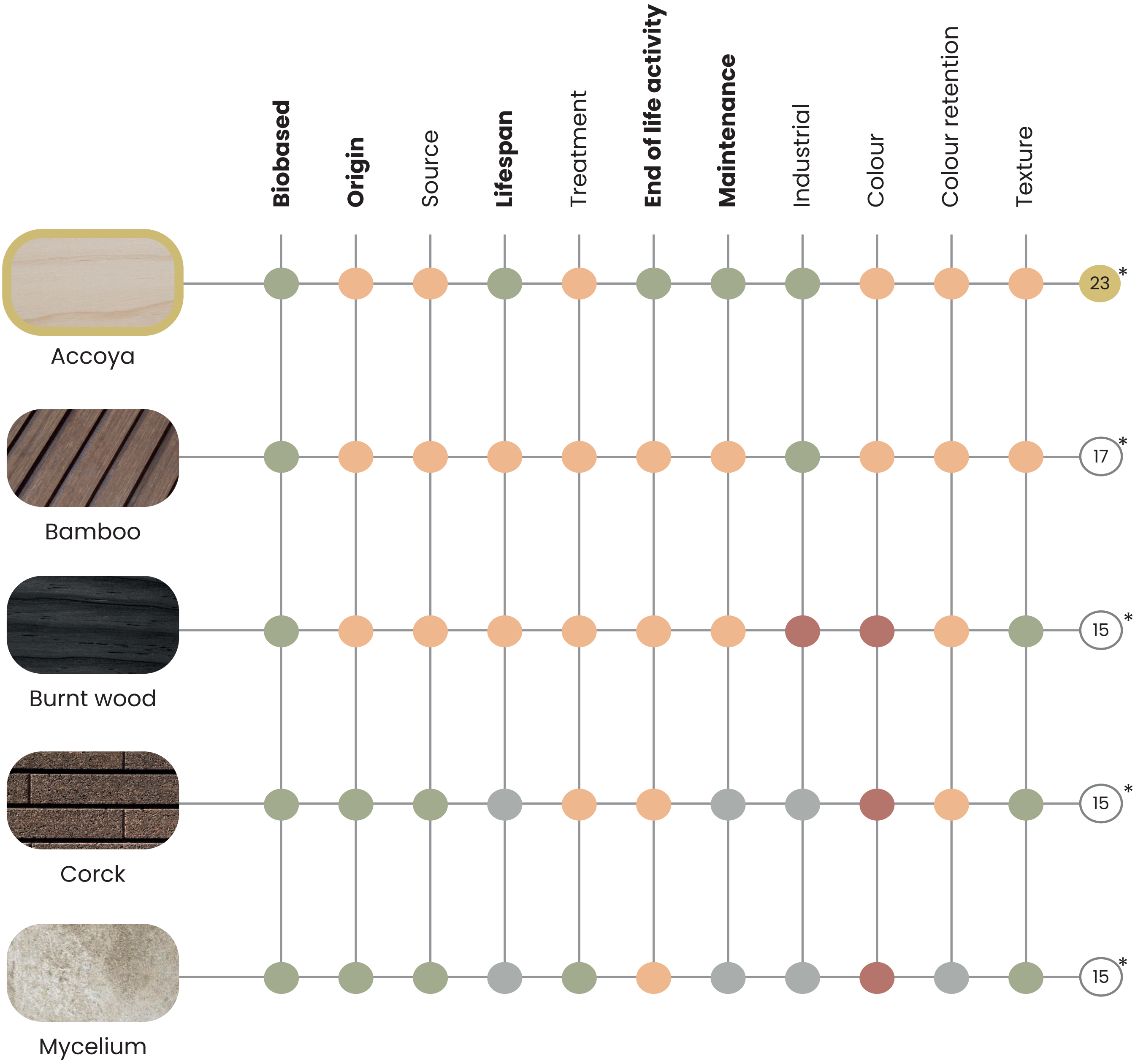
Appendix F | **Alternatives**



Appendix G.1 | **Cladding**



Appendix G.1 | **Cladding**



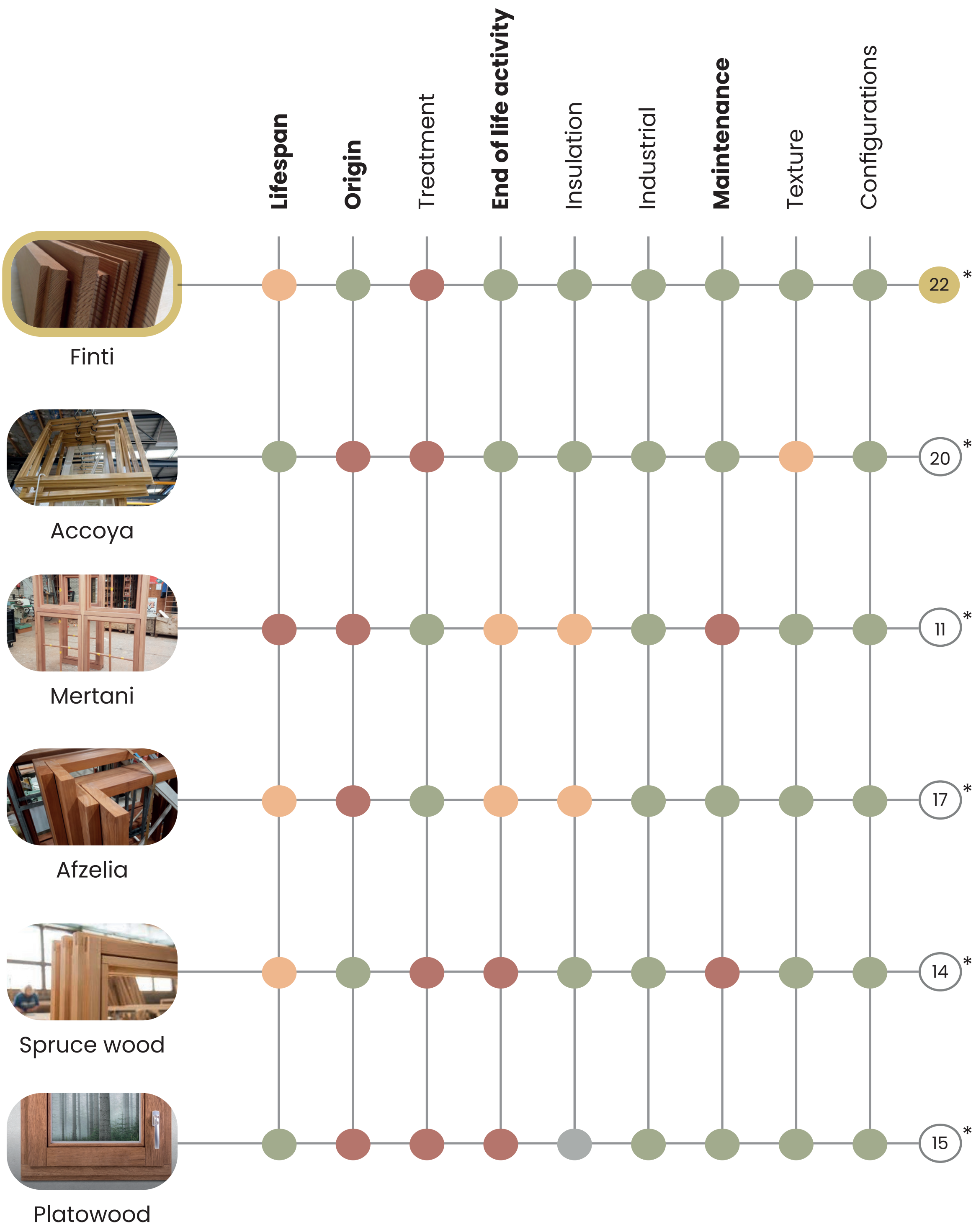
* The final column presents the quantification of the alternative incorporating project-specific criteria, which are further elucidated in Appendix H.

Appendix G.1 | **Cladding**

Biobased	100 - 90%	-	90 - 51%
Origin	Europe	-	Out of Europe
Source	Waste	Virgin	-
Lifespan	>50 years	25-50 years	<25 years
Treatment	Biological	Thermal modification	Adding PVC
End of life activity	Cradle to cradle	Biodegradable	Industrial compostable
Maintenance	Little maintenance	15-5 years	<5 years
Industrial	Industrially produced	New material	Not industrial
Colour	Different colours	Painting for colours	No colour options
Colour retention	Good	Aging, maintainable	Aging
Texture	Texture	Smooth	No texture

No information

Appendix G.2 | **Window frames**



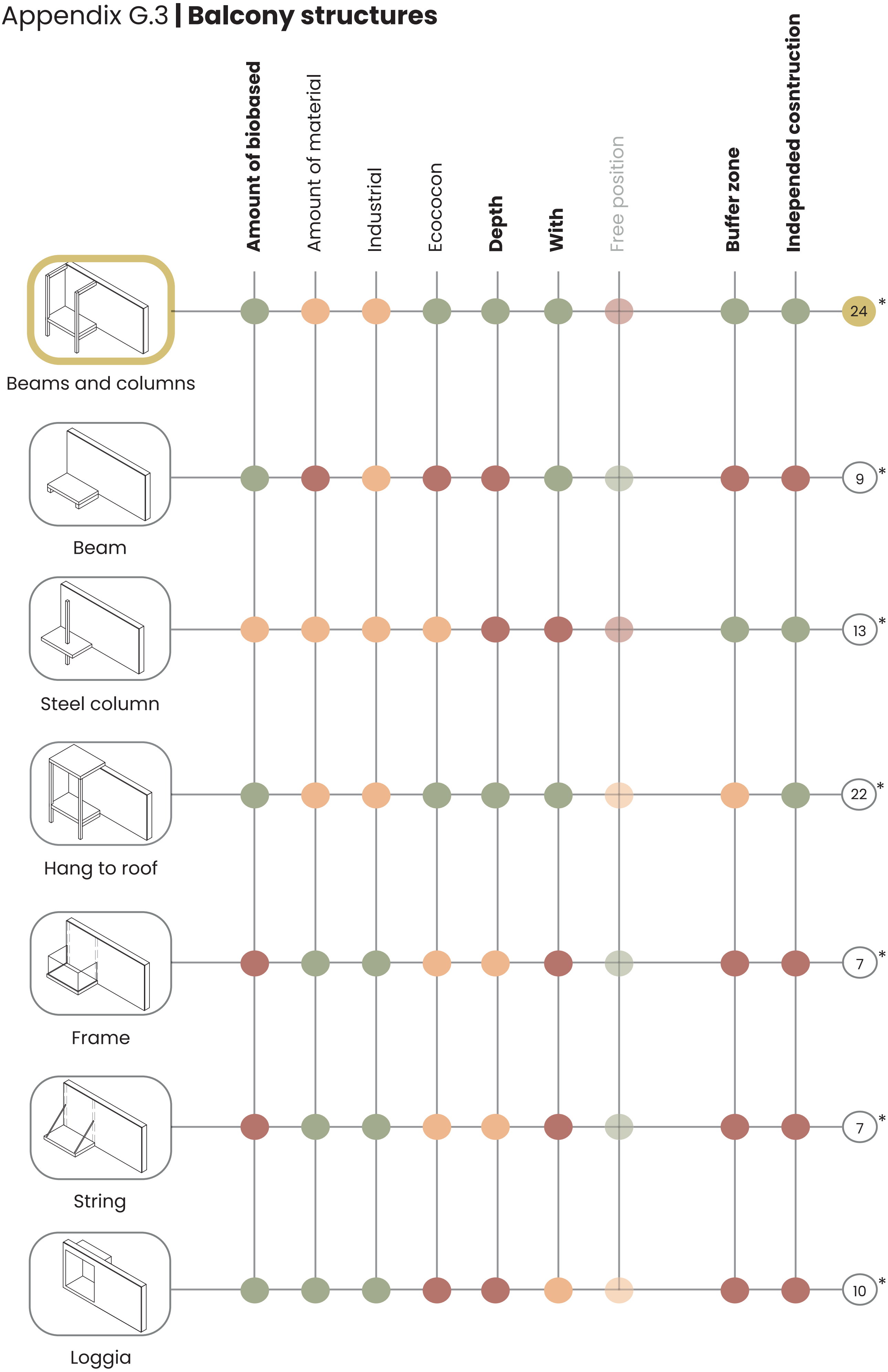
* The final column presents the quantification of the alternative incorporating project-specific criteria, which are further elucidated in Appendix H.

Appendix G.2 | **Window frames**

	(green)	(orange)	(red)
Lifespan	>50 years	25-50 Years	<25 years
Origin	Europe	-	Out of Europe
Treatment	Biological	-	Thermal modification
End of life activity	Cradle to cradle	Biodegradable	Industrial compostable
Insulation	1,3-1,4 U	1,6-1,7 U	-
Industrial	Industrially produced	-	Not industrial
Maintenance	Paint every 10-15 years	-	Paint every <10 years
Texture	Wood texture	Smooth	No texture
Configurations	Different configurations	-	No different configurations
Paintable	Yes	-	No

No information

Appendix G.3 | **Balcony structures**



* The final column presents the quantification of the alternative incorporating project-specific criteria, which are further elucidated in Appendix H.

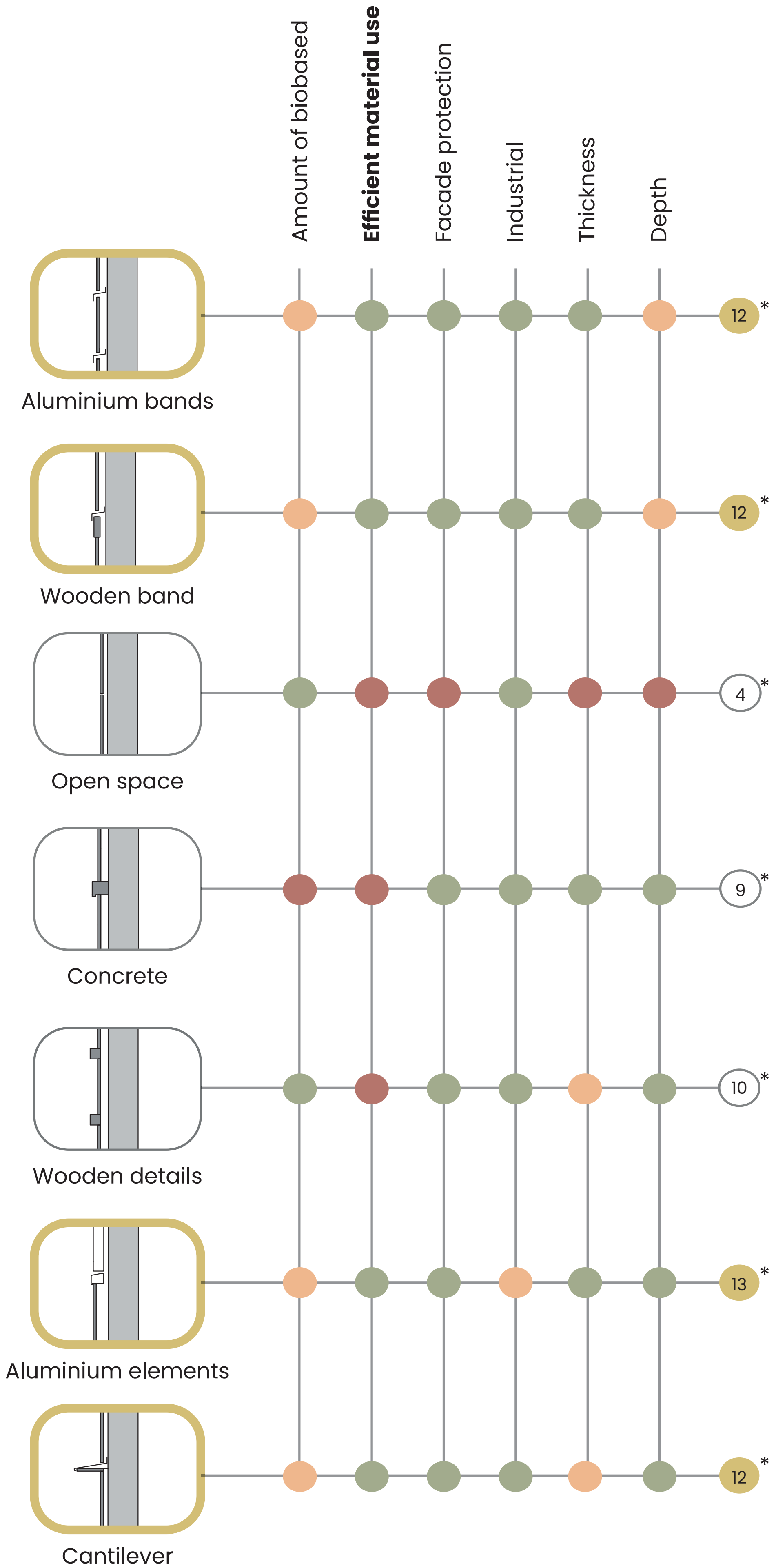
Appendix G.3 | **Balcony structures**

Amount of biobased	All biobased	Biobased not efficient	Not all biobased
Amount of material	Efficient	Medium	Inefficient
Industrial	Fully prefab	1D or 2D elements	Not industrial
Ecococon	Suitable	Elements in walls	Attachment to the floors
Depth	No limitations	1,5 - 2 m	< 1,5 m
Width	Unlimited	-	Limited
Free position	Free	More efficient above neighbours	Structure to the Ground

No information

* Measurments form references

Appendix G.4 | **Horizontal bands**



* The final column presents the quantification of the alternative incorporating project-specific criteria, which are further elucidated in Appendix H.

Appendix G.4 | **Horizontal bands**

	All biobased	Efficient use non biobased	Not all biobased
Amount of biobased	All biobased	Efficient use non biobased	Not all biobased
Efficient material use	Wooden detail protected	-	Detail unprotected
Façade protection	Good	Little	Non
Industrial	Part of façade element	Put together on site	Not industrial
Thickness	Chosen depth	Medium thickness	No thickness
Depth	Chosen depth	Medium depth	Little depth

No information

Appendix H | **Design process**

Design principles
The general quantification of the various alternatives can be observed in Appendix G on the left side, indicated by color codes whose quantification is explained on the subsequent page. This tables were utilized in the design process for making material choices.

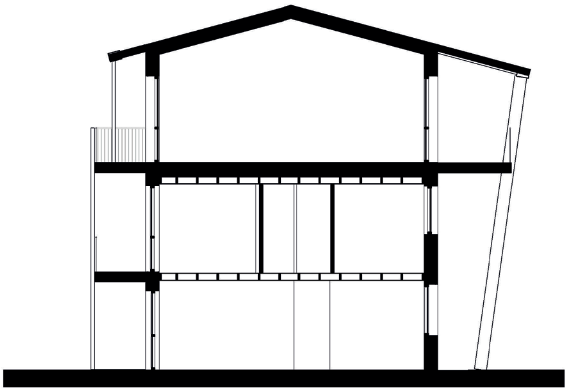
The design task was evaluated throughout the design process; initially, the research focused on the transformation of a walk-up flat, alongside the addition of entirely new residences. However, the project subsequently shifted towards a design that topped up existing row houses. Because it is desirable to retain the existing foundation, a lightweight construction is desirable, because the design task was not yet clearly defined during the research, this was not included. During the research phase, it was deemed relevant to include the amount of CO_2 sequestered in various materials as a criterion to maximize carbon capture. However, as the weight of wood is directly related to CO_2 storage – the more CO_2 stored, the heavier the wood is (Centrum Hout, n.d.), given the project's mandate for lightweight construction, carbon sequestration no longer serves as a decisive criterion.

The table below shows which of the criteria examined are extra relevant for the design project. A number of criteria have also been added that have become relevant during the course of the project.

	Cladding	Window frame	Balcony structure	Façade band
Biobased	● (gold)		● (gold)	● (black)
Lifespan	● (gold)	● (gold)		
Origin	● (gold)	● (gold)		
Source	● (black)	● (black)		
Treatment	● (black)	● (black)		
End of life activity	● (gold)	● (gold)		
Maintenance	● (gold)	● (gold)		
Amount of material used			● (black)	● (gold)
Facade protection				● (black)
Depth			● (gold)	● (black)
Width			● (gold)	
Freedom in design			● (black)	
Texture	● (black)			
Colour	● (black)			
Colour retention	● (black)	● (black)		
Refinement		● (black)		
Industrial	● (black)	● (black)	● (black)	● (black)
Ecococon	● (black)		● (black)	
Weight	● (gold)			
Independent construction			● (gold)	
Buffer zone			● (gold)	

Appendix H | **Design process**

From the investigation into biobased facade materials, it emerged that the lifespan of almost all biobased materials is shortened if the material is exposed to a lot of weather conditions such as rain and UV radiation. However, with proper maintenance and strategic detailing, the material's lifespan can be extended (Houtwijzer, 2024). Consequently, the decision was made to position the entire facade under an overhang, thereby enhancing its resilience against UV radiation and rain, reducing the need for frequent maintenance. This was a design decision based on the gained information of the research.



Overhang to protect the facades

Quantification of the design principles
In Appendix G, the various alternatives have been quantified against the project-specific criteria for each element, in the last column. A point system has been used, wherein criteria deemed important for the design objectives are given doubbeld weight. These criteria are highlighted in bold in the top row. Green criteria receive 2 points, orange 1, and red or grey 0; if the criteria are weighted doubly, green receives 4 points and orange 2. Ultimately, the points for each alternative are added together, with the result listed in the last column. For some elements, multiple alternatives score highly, prompting further investigation. The systems, are more difficult to directly incorporate into the design; nevertheless, the principles are highly applicable and can be effectively combined in some cases.

Facade material
The key criteria for the facade include the use of biobased material, origin, lifespan, end-of-life activity, and material maintenance. As several materials score above 22, further research will be conducted into these materials.

One of the key criteria from the design is the use of lightweight materials. Given the weight of each material, Nabasco or Ceramic tiles would not be considered due to their significantly heavier weight compared to the other options. For the remaining wood types the CO_2 storage and emmission during the production process will be examaind togheter with the different color options.

Nabasco	Ceramic tiles	Resysta	Nobelwood	Platowood	Accoya

1710 kg/m3	1850 kg/m3	1460 kg/m3	455 kg/m3	497 kg/m3	510 kg/m3

Appendix H | **Design process**

Accoya wood undergoes acetylation with acetic anhydride. The OH groups in the cell walls are replaced with acetyl groups, "locking" the cell walls, preventing moisture absorption, and making the wood impervious to fungal decay. Accoya primarily uses Pinus radiata from FSC-certified plantations in New Zealand, which is ideal for acetylation due to its low resin content and open wood structure, making it easy to impregnate (Accoya, 2023). Accoya wood won't be used in the project due to its origin in New Zealand, as transporting results in significant CO2 emissions.

Nobelwood uses a process based on biopolymers, where the wood is impregnated with bio-resins under high pressure. This bio-resin is made from a by-product of sugar production that also contains CO2. The wood is then heated, allowing the biopolymers to bond with the wood cell walls. This treatment grants the wood excellent workability, durability, and resistance to fungal decay. After modification, 750 kg of CO2 is stored in Nobelwood (Houtproducten, z.d.). Although the production of the wood takes place in Europe, the tree from which the wood is made, the Radiata Pine, grows in California and therefore has to travel a long distance to get to Europe, which causes additional emissions

Platowood uses a process called "platonization," which is a hydro-thermal modification involving only steam and increased pressure. The wood is then heated at a relatively low temperature under dry conditions. This process creates stable, durable wood without chemical additives. Platowood has a positive CO2 balance because about 60% more CO2 is stored in the wood than is emitted during production(Platowood, z.d.).

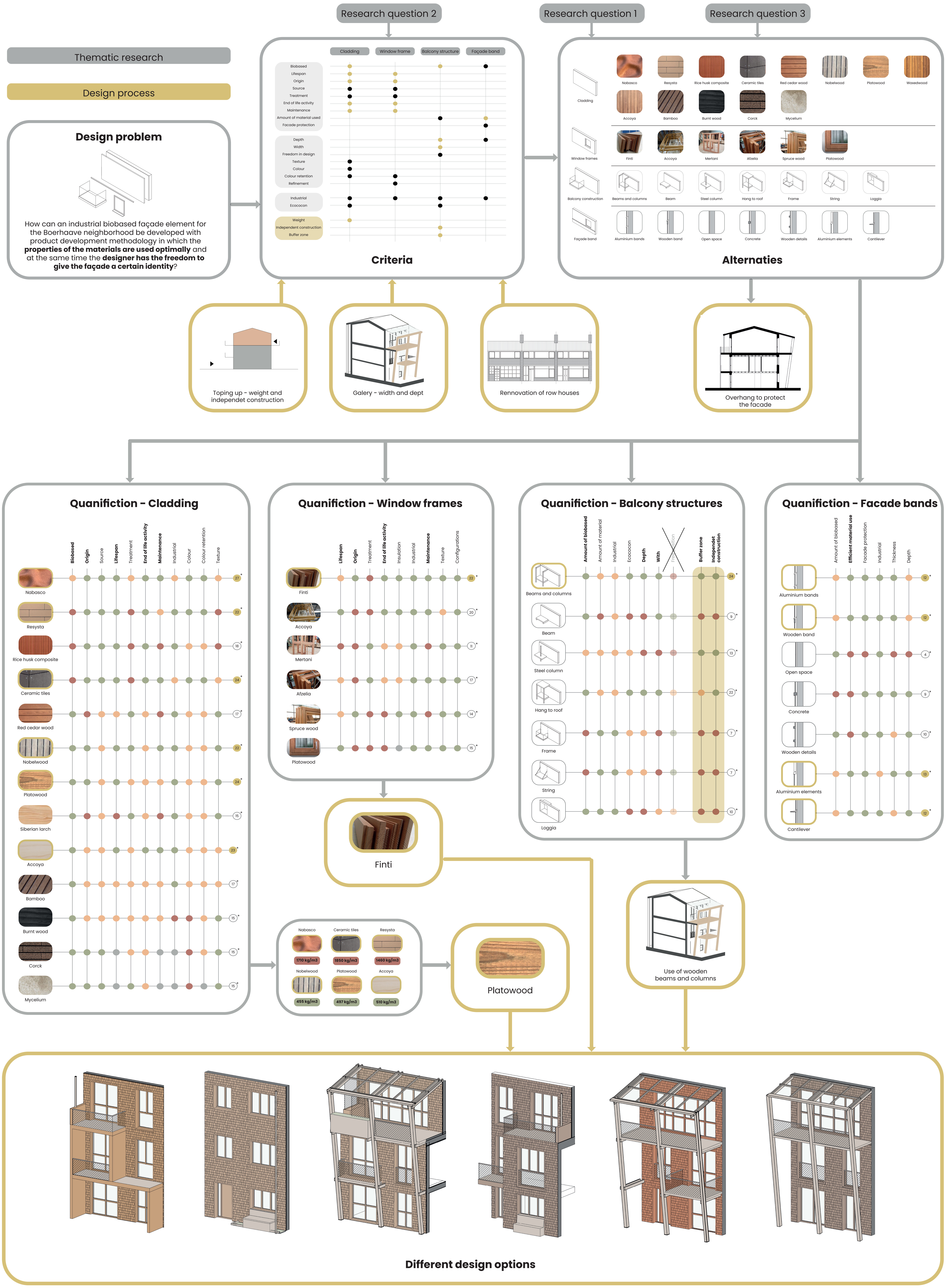
In conclusion, the facace will be made of Platowood, this wood has good properties and grows in Europe

Window frames
Many of the available wood types suitable for window frames are from hardwood. As it is desirable to use locally sourced materials as much as possible in the project, the origin of the wood is crucial, in addition to end-of-life activity, lifespan, and maintenance. The window with the highest score is the Finti window, made from European wood and fully recyclable. Due to these excellent properties, this wood has been chosen for the window frames.

Balcony constructions
Initially, it was deemed important in the initial research for the construction to provide freedom on the ground floor. However, during the design process, it was discovered that the continuous structure to the ground floor could also serve as a buffer between the privet space in the house and the public space, which is actually considered a positive element. Therefore, a contrasting criterion, the buffer zone, has been added, and the free position criterion is not included in the calculation. Additionally, the design features a gallery access on the second floor, with adjoining outdoor spaces, requiring both maximum width and depth. Another criterion added is that the construction should be standalone and put minimal pressure on the existing structure of the residences. Ultimately, the Beams and Columns construction emerged as the highest-scoring and was applied in the design. However, in the design, it was decided to place this column structure diagonally, allowing for maximum daylight in the lower residences.

Facade bands
The horizontal facade bands, which also serve as drip edges, were a key element of the walk-up apartments but are less prevalent in the row houses. Additionally, the facade is placed under an overhang, reducing the need for the drip edge to protect the facade cladding. The element itself does not directly translate into the new design.

The full integration of the research into the design is shown on the next page


Research question 2
Research question 1
Research question 3
Thematic research
Design process
Design problem
How can an industrial biobased façade element for the Boerhaave neighborhood be developed with product development methodology in which the properties of the materials are used optimally and at the same time the designer has the freedom to give the façade a certain identity?
Cladding
Window frame
Balcony structure
Façade band
Biobased
Lifespan
Origin
Source
Treatment
End of life activity
Maintenance
Amount of material used
Facade protection
Depth
Width
Freedom in design
Texture
Colour
Colour retention
Refinement
Industrial
Ecococon
Weight
Independent construction
Buffer zone
Criteria
Cladding
Window frames
Balcony construction
Façade band
Nabasco
Resysta
Rice husk composite
Ceramic tiles
Red cedar wood
Nobelwood
Platowood
Waxedwood
Accoya
Bamboo
Burnt wood
Corck
Mycelium
Finti
Accoya
Mertani
Afzelia
Spruce wood
Platowood
Beams and columns
Beam
Steel column
Hang to roof
Frame
String
Loggia
Aluminium bands
Wooden band
Open space
Concrete
Wooden details
Aluminium elements
Cantilever
Alternatives
Toping up - weight and independet construction
Galery - width and dept
Rennovation of row houses
Overhang to protect the facade
Quanifiction - Cladding
Biobased
Origin
Source
Lifespan
Treatment
End of life activity
Maintenance
Industrial
Colour
Colour retention
Texture
Nabasco
Resysta
Rice husk composite
Ceramic tiles
Red cedar wood
Nobelwood
Platowood
Siberian larch
Accoya
Bamboo
Burnt wood
Corck
Mycelium
Quanifiction - Window frames
Lifespan
Origin
Treatment
End of life activity
Insulation
Industrial
Maintenance
Texture
Configurations
Finti
Accoya
Mertani
Afzelia
Spruce wood
Platowood
Quanifiction - Balcony structures
Amount of biobased
Amount of material
Industrial
Ecococon
Depth
With
Freedom
Buffer zone
Independet construction
Beams and columns
Beam
Steel column
Hang to roof
Frame
String
Loggia
Quanifiction - Facade bands
Amount of biobased
Efficient material use
Facade protection
Industrial
Thickness
Depth
Aluminium bands
Wooden band
Open space
Concrete
Wooden details
Aluminium elements
Cantilever
Finti
Nabasco
Ceramic tiles
Resysta
1710 kg/m3
1850 kg/m3
1460 kg/m3
Nobelwood
Platowood
Accoya
455 kg/m3
497 kg/m3
510 kg/m3
Platowood
Use of wooden beams and columns
Different design options