DESIGNING FOR DURABILITY

Strategies for sustainable and durable timber facades

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ABSTRACT

This research explores strategies to enhance the durability of timber facades in exterior applications while maintaining sustainability. By focusing on European timber species, the study minimizes the ecological impact of transportation. The research examines three key areas: selecting naturally durable timber species, employing environmentally friendly treatments, and implementing effective design strategies. Robinia and Sweet Chestnut are identified as exceptionally durable species, while less durable woods like Pine can be improved through treatments such as acetylation and thermal modification. Effective design measures, including overhangs, proper ventilation, and precise detailing, are crucial in preventing moisture-related degradation. Insights were drawn from case studies, interviews, and literature reviews, providing architects and builders with practical guidance to design sustainable, long-lasting timber facades. This work highlights how combining material selection, treatment, and design can ensure the durability of timber facades in environmentally conscious construction.

Keywords: timber species, cladding, durability, timber facades, sustainability, design strategies

Content

Introduction

The building industry is increasingly focused on multi-storey developments to accommodate urban population growth and maximize space efficiency (González-Retamal et al., 2022). To create more housing or facilities within the existing urban landscape, the concept of "optopping" can be used. This approach involves adding additional floors to relatively low-rise, existing buildings, effectively increasing urban density without expanding the city's footprint. By building upward rather than outward, cities can make more efficient use of limited space and infrastructure, meeting growing demands for housing and services while preserving open land.

Problem statement

Contemporary multi-storey and optopping architecture are heavily reliant on synthetic materials such as steel and glass, which are favoured for their structural strength, minimal maintenance requirements, and compatibility with modern design aesthetics (John et al., 2009). Despite the widespread use of steel and glass in multi-storey buildings, their production is resource-intensive, significantly contributing to carbon emissions and energy consumption, which often contradicts sustainable building goals (John et al., 2009). This reliance on synthetic materials poses a challenge for the building industry, particularly in light of the urgent need for environmentally sustainable solutions.

Instead of relying on synthetic materials such as glass and steel, the building industry can utilize biobased materials that are more environmentally sustainable. Biobased materials, derived from renewable resources like plants and trees, offer numerous advantages over traditional synthetic options. Timber is a renewable, low-carbon material with a much smaller environmental footprint. Harvested sustainably, timber can act as a carbon sink, storing CO_2 over its lifetime, and it can be sourced responsibly without depleting resources (Fleming et al., 2014).

Despite these environmental benefits, timber remains underutilized in multi-storey construction, particularly in exterior applications. The main barrier to its adoption includes its natural susceptibility to decay, degradation, and general wear, which necessitate more intensive maintenance compared to steel and glass. Timbers's vulnerability to environmental factors raises concerns over its durability in exterior, multi-storey applications, where longevity, weather resistance, and structural integrity are critical. Nowadays, there is much more construction with timber, but this is often only evident in buildings that are relatively low, typically having 4 or 5 stories. It is often observed that beyond a certain height, timber is no longer used as a cladding. Fire safety regulations also play a significant role in this (Smith & Frangi, 2014).

The reluctance to incorporate timber in the exterior components of multi-storey buildings reflects a gap in the industry's ability to treat, engineer and design timber for prolonged exposure to harsh outdoor conditions. Advances in timber treatment and preservation technologies, such as modified timber, and specialized coatings, have shown promise in enhancing timber's durability, strength, and resistance to environmental stressors. However, these technologies are not yet widely adopted or optimized specifically for exterior use in multi-storey construction, leaving an opportunity to further explore, develop, and promote sustainable timber-based solutions for these demanding outdoor applications.

This research focuses specifically on the durability of timber used for exterior cladding. The lifespan of these timber facades depends on several factors that can affect the timber, such as moisture, mould and insects in the timber. This research focuses specifically on how timber facades are affected by moisture and what (design) choices can be made to counteract this.

While several studies have investigated the technical and natural properties of timber for exterior use, little research has been done on how moisture affects the durability of timber facades and what strategies can be used to work with this problem. The aim is to develop approaches that enhance timber's resilience and reduce maintenance needs, while maintaining its sustainability and aesthetic appeal for outdoor applications. Additionally, the study will focus exclusively on European timber species, to minimize the ecological footprint associated with transporting timber from distant regions such as Africa or America.

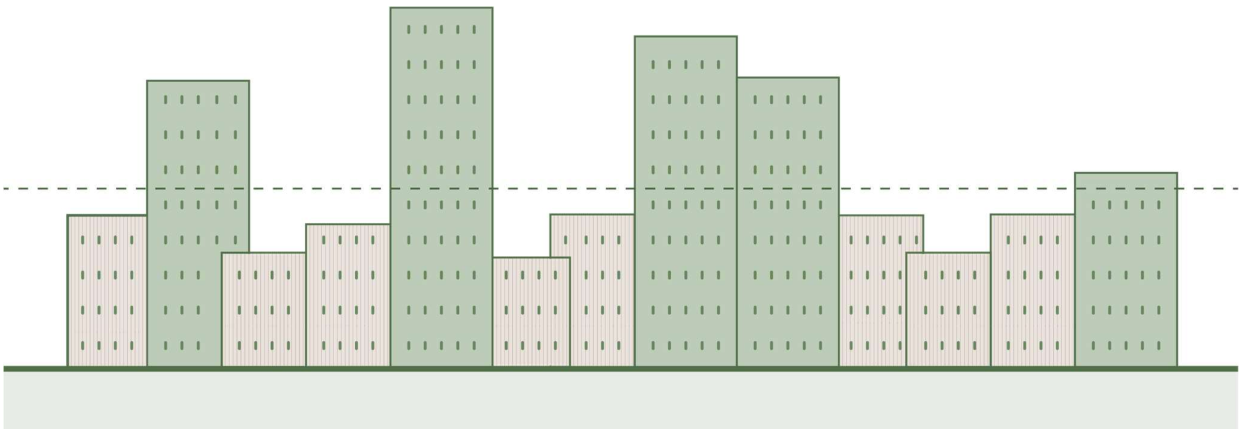

Figure 1 | Problem statement

Methodology

This paper answers the following research question:

How can specific design and technical factors extend the lifespan of timber in exterior applications while maintaining environmental sustainability?

To address the main question, it examines three sub-questions.

I. Which types of timber are naturally suited for outdoor durability with minimal treatment?

This question aims to identify timber species that have natural qualities making them suitable for outdoor use without extensive treatment. The inherent durability of untreated timber was examined, using established durability classes that range from 1 to 5. These classes provide a standardized way to assess how well different timber types withstand outdoor conditions, guiding the selection of species that require minimal intervention for extended durability. The scheme of the durability classes is shown in table 1. This scheme will be used to answer the first sub question.

Durability class	Designation	Timber life
1	Very durable	25+ years
2	Durable	15-25 years
3	Moderately durable	10-15 years
4	Slightly durable	5-10 years
5	Not durable	I-5 years

Table 1 | Information from Oldenburger et al. (2009)

In order to answer this question, a literature review was conducted to gain knowledge of the technical factors of untreated timber. Finally, interviews were conducted with several companies and the useful information obtained is discussed here.

II. What environmentally friendly treatments effectively enhance timber's resistance to outdoor elements?

This question explores alternative methods for improving the durability of timber without resorting to environmentally harmful chemical preservatives. First, literature research was reviewed, and a table was created using this knowledge. Then, literature research was used to investigate environmentally friendly methods of timber treatment. Finally, this sub-question also discusses the useful information that came out of the interviews.

III. Which design strategies can best protect exterior timber from environmental degradation?

The third question focuses on how design choices can protect timber from environmental damage. This involved a literature review of distinctive design strategies and types of timber façade cladding. Again, the interviews conducted were used and are discussed. Finally, several case studies are used, to see where the timber might have decayed on to draw conclusions of which design strategies work and which do not.

Results

The results are divided into the three distinct sub-questions, each of which will be addressed separately. The conclusions drawn from these sub-questions will ultimately provide answers to the main research question. Each sub-question is designed to explore specific aspects of the topic, contributing to a comprehensive understanding of how distinct factors can enhance the lifespan of timber in exterior applications while maintaining environmental sustainability.

I. Which types of timber are naturally suited for outdoor durability with minimal treatment?

This question is addressed by first reviewing the theoretical knowledge, followed by the creation of a table that compares distinct types of timber. Finally, the key findings from the interviews are discussed to provide further insights. The theoretical framework provides a solid foundation for understanding the natural durability of various timber species, while the comparative table offers a representation of their characteristics. The interview results complement this analysis, offering practical perspectives from industry professionals.

Theoretical framework

The natural durability of timber refers to the extent to which a timber species is naturally resistant to biological decay without any treatment. This property is determined by the cell structure, the presence of natural extractives, and the density of the timber (McCaig & Ridout, 2012).

The lifespan of untreated timber is not only determined by external influences. The way a tree grows and how the timber is processed also plays a significant role (McCaig & Ridout, 2012). The growth conditions of the tree such as: soil quality, climate, and growth rate, affect factors like the density and the number of extractives in the timber. Trees that grow slowly produce timber with a denser structure and higher natural durability (McCaig & Ridout, 2012).

The method by which timber is sawn plays a significant role in determining its performance and durability. Radially sawn timber, where the growth rings are perpendicular to the surface of the board, is more durable and stable than tangentially sawn timber, as shown in Figure 2. Radially sawn timber forms a cross sawn drawing, and tangential sawn timber forms a rift sawn drawing (figure 3). Radially sawn timber reduces the chance of warping and shrinking and makes the timber more resistant to moisture penetration. This makes radially sawn timber suitable for applications such as cladding, where prolonged exposure to weather conditions is inevitable (Englund et al., 2010). How the architect can manage this and design effectively with the shrinking of timber is further explained in chapter 3*.*

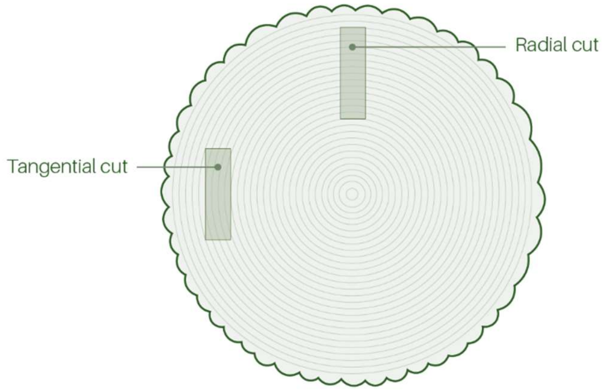

Figure 2 | Sawing method

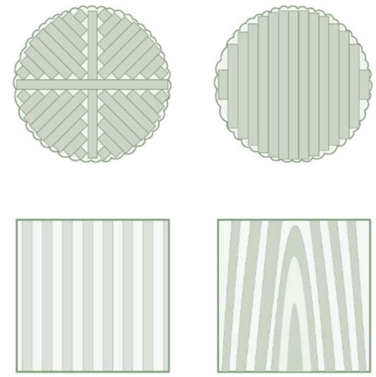

Figure 3 | Cross sawn (left) and rift sawn timber (right) | Information from Brookes and Meijs (2008)

Heartwood is generally more durable than sapwood of the same tree species (McCaig & Ridout, 2012). Sapwood is the outer, younger part of the tree trunk and is located between the bark and the heartwood, as seen in figure 5. Sapwood is typically less durable than heartwood. However, the sapwood is usually more impregnable because of the more open cel structure than heartwood. In the durability classification of timber, this always refers to the heartwood and not to the sapwood (Oldenburger et al., 2009). All moisture transport in a living tree occurs in the sapwood. Timber species with a high proportion of heartwood have natural protection against moisture and decay, which reduces biological degradation (McCaig & Ridout, 2012). Regardless of whether untreated or surface-treated timber is chosen for cladding, it is important to use timber species with a high proportion of heartwood (Bahrami et al., 2023).

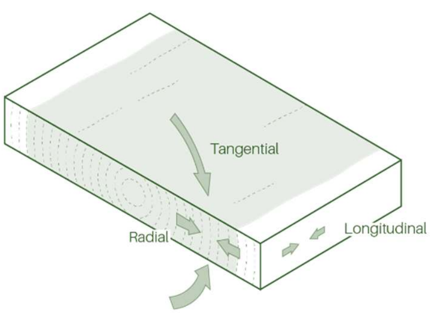

Figure 4 | Cutting detail | Information from McCaig and Ridout (2012)

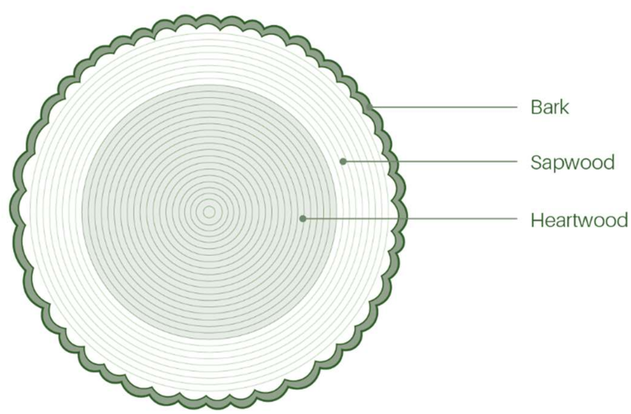

Figure 5 | Division of timber

Research by Bahrami et al. (2023) has shown that UV radiation only affects the surface of the timber. UV degradation does not reduce the durability of the timber but changes its architectural appearance, for example, causing the timber to grey. This process occurs more quickly in less durable timber species then in durable species.

Bahrami et al. (2023) state that untreated timber has proven to be durable over extended periods, even without a paint finish. This is because large variations in moisture content have less impact on the timber than when a paint layer traps moisture. Moisture can cause cracks and mold under the paint, leading to more maintenance.

Timber selection

Following the theoretical framework, the focus then shifts to specific timber species native to Europe. For the purposes of this study, twelve timber species have been selected to assess their suitability for use as cladding materials. The choice of these species is based on the following criteria:

- Timber species that are commonly used in practice for cladding due to their availability and application in the construction sector.
- Timber species that have high durability, which is essential for the long lifespan of the cladding.
- Timber species with a low durability class, but which are well-suited for impregnation and therefore can be used for durable cladding.

In table 2, the various timber species are presented. The analysis focuses on the natural durability of these species, considering factors such as their tendency to move, which influences the type of cladding that can be applied. Additionally, the proportion of sapwood in the timber has been evaluated. As previously mentioned, heartwood has a longer lifespan, meaning that species with a higher proportion of sapwood are likely to have a shorter lifespan.

Timber species	Movement	Width sapwood	Durability class
Birch	High	Unknown	5
Beech	High	Unknown	5
Douglas fir	Medium	70-80mm	3-4
Oak	Medium to high	25-50mm	2
Maple	Low	Only has sapwood	5
Spruce	Medium	Unknown	4
Larch	Medium to high	<20mm	3-4
Limewood	Low	Unknown	5
Robinia	High	13mm	1-2
Sweet chestnut	Medium	13mm	2
Yew	Low	Narrow	2
Pine	Medium	50-100mm	3-4

Table 2 | Untreated timber factors | Information from Fraanje (1999) and Wiselius (2010)

Upon reviewing the table, it is evident that Robinia demonstrates the highest natural durability. With a minimal proportion of sapwood, this species appears to be well-suited for use as cladding. However, it is prone to movement, which should be considered in the design process, as further explained in sub question 3. Birch, on the other hand, has a low durability class and tends to move significantly. Nevertheless, birch bark has a high resistance to decay (Fraanje, 1999), which means it could still be used for cladding purposes.

Interviews

As outlined in the methodology, interviews were conducted with various companies supplying timber cladding, which can also be found in the appendix.

The interview with Veteka and Eden BV revealed that Robinia and Sweet Chestnut possess good natural durability, as also demonstrated in table 2. However, both species are challenging to source in massive quantities, limiting their applicability in cladding. Furthermore, Robinia exhibits significant expansion and contraction when exposed to moisture, a characteristic reflected in the table. This issue can, however, be managed through specific design choices in the cladding, as discussed in sub-question 3. In the case of Sweet Chestnut, the challenge lies in the typically small size of the trees, meaning only small roundwood can be harvested. This presents a complication for cladding applications, as planks are required, as noted by Veteka.

II. What environmentally friendly treatments effectively enhance timber's resistance to outdoor elements?

This question addresses the treatments that can be used to make timber species that are inherently unsustainable more durable for use as cladding. First, the timber species that proved to be unsustainable from sub question 1 are listed and named whether they are impregnable. Then the various environmentally friendly methods of treating timber are named and, finally, an interview is briefly discussed.

Timber selection

Table 3 shows the selected timber species with the durability classes and impregnability of the heartwood and sapwood. 1 is the most impregnable and 4 the least impregnable.

Timber species	Durability class	Impregnability heartwood	Impregnability sapwood
Birch	5	1-2	1-2
Beech	5	1	1
Douglas fir	3-4	4	2-3
Oak	2	4	1
Maple	5	1	1
Spruce	4	3-4	3
Larch	3-4	4	2
Limewood	5	1	1
Robinia	1-2	4	1
Sweet chestnut	2	4	2
Yew	2	3	2
Pine	3-4	3-4	1

Table 3 | Impregnability | Information from Wiselius (2010)

As mentioned above, timber species with a higher durability class are more difficult to impregnate, which can also be seen in the table. It can also be seen that the sapwood is almost always easy to impregnate. This could provide opportunities to apply this to cladding.

Treatments

To extend the lifespan of timber, various strategies have been developed over the years. Traditional methods focused on keeping water out by applying external protective layers, such as coatings or stains, or impregnating timber with toxic preservatives (biocides). While these methods are often effective and cost-efficient, preservatives containing heavy metals such as CCA and creosote negatively impact the environmental profile of timber. These issues arise during use, such as leaching into the environment, and at the end of the material's lifecycle (Van der Lugt & Harsta, 2020).

In response to these challenges, there is a growing demand for environmentally friendly alternatives. In this chapter the following treatments are discussed:

- Acetylation
- Thermal modification
- Yakisugi

These treatments were chosen on the basis that they are the least harmful to humans and the environment (Van der Lugt & Harsta, 2020).

- **Acetylation**

Although acetylation is a chemical process, it is considered environmentally conscious due to the use of non-toxic chemicals. Acetylation involves treating timber with acetic anhydride, which alters the chemical structure of the timber. This results in significantly improved dimensional stability, resistance to fungal decay, and a reduction in shrinkage and swelling of up to 80% (Bongers & Titan Timber BV, n.d.).

Because acetylation requires the reaction to occur at the cell wall, the impregnation capability of the timber species is important. Species with good impregnation capabilities are potentially suitable, as outlined in table 3.

Research by Bollmus et al. (2015) on the acetylation of German timber species—including beech, alder, limewood, and maple—showed that all species were classified as durability class 1 after acetylation. The acetylated timber became highly stable under fluctuating moisture conditions (Bollmus et al., 2015). This research concluded that acetylation is indeed feasible for European timber species and has a significant impact, but factors such as supply reliability, and availability can limit its application. It can therefore be concluded that other woods with good impregnability can also be acetylated when looking at table 3.

- **Thermal modification**

Thermal modification is a process in which timber is heated to high temperatures in an oxygen-free environment to improve durability and reduce moisture absorption. This process is applied to timber species with low natural durability.

During thermal modification, some of the hemicellulose in the timber is lost, leading to less elastic cell walls, and making the timber more brittle. Additionally, the timber loses up to 50% of its bending strength, which makes thermally modified timber less suitable for structural applications (Van Der Lugt & Harsta, 2020). From an ecological perspective, thermal modification is energy intensive. However, as no unhealthy chemical additives are used, it is preferable to chemically impregnated timber (Unknown, 2021).

As shown in table 3, Robinia has a high durability class but is difficult to impregnate, making it also challenging to thermally modify. Additionally, Robinia is highly reactive to fluctuating moisture conditions. This combination of properties makes thermal modification and acetylation unsuitable for Robinia, and it is essential to account for these characteristics during design. For more information on incorporating Robinia in cladding, see sub-question 3.

- **Yakisugi**

  Yakisugi is a Japanese technique where cypress timber is charred on one side, creating a fire-resistant charcoal layer. Companies often claim that this method improves the durability of various timber species. However, research by Hasburgh et al. (2021) examined the durability of the yakisugi process on timber species other than cypress. In most cases, there was no significant improvement in resistance to decay compared to untreated timber. Only cypress showed a slight improvement in resistance to decay at low levels of charring.

  Therefore, it can be concluded that yakisugi should primarily be regarded as a method to enhance the aesthetic appeal of timber rather than its durability. This method is less effective compared to other timber protection techniques discussed above.

Interviews

During an interview with a representative from Accoya, several key points emerged. One drawback of acetylation is that defects already present in the timber, such as knots and cracks, remain visible. Timber species that grow quickly, are naturally less durable, and are easy to dry and impregnate have a higher success rate. Due to its rapid growth, Radiata Pine from New Zealand is commonly used by this company. This timber is often knot-free and fast-growing. However, the challenge of using locally sourced European timber lies in the availability and reliable supply of the required timber quality and dimensions.

III. Which design strategies can best protect exterior timber from environmental degradation?

This sub question addresses the ways in which a designer can design a sustainable facade that has a long lifespan. The diverse ways of cladding are also discussed. Interviews with experts are discussed and, finally, case studies are discussed where it can be clearly seen how the timber behaves in different situations.

Theoretical framework

The durability of timber facades can be significantly extended with careful detailing. It is important to avoid prolonged exposure of the timber to moisture. In particular, the end grain (figure 6) is vulnerable to water penetration, as the vessels responsible for moisture transport when the tree was alive are exposed (Brookes & Meijs, 2008).

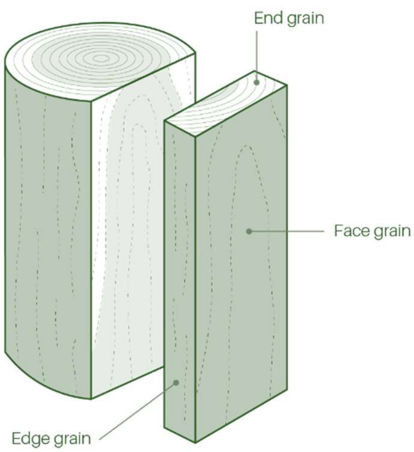

Figure 6 | Grains of timber

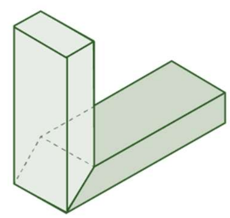

Figure 7 | Miter joint

Water can be retained in joints up to 7 mm wide through adhesion and capillary action. Therefore, it is important to design joints between non-durable timber elements with a minimum width of 10 mm. This includes 7 mm to prevent water absorption and 3 mm to account for possible swelling. Joints with a direct, closed connection pose a risk, especially miter joints (figure 7). This is due to the differences in expansion and shrinkage in the axial and tangential directions of the timber, which can lead to the joint opening and water infiltration (Brookes & Meijs, 2008).

Naturally, it is desirable not to allow timber to get wet, but this is sometimes unavoidable in exterior applications like facades. For timber species that are difficult to impregnate, such as Robinia, which is prone to movement, special attention must be paid to its behaviour when it gets wet. Figure 8 shows how the sawing method affects the deformation of the plank. Tangentially sawn planks will warp toward the core when they get wet.

The orientation of the planks has a significant impact on their performance under varying weather conditions. As mentioned earlier, tangentially sawn planks exhibit more swelling and shrinkage on the bark side, which can lead to warping and water penetration if the orientation is incorrect. Placing the planks with the heart side facing out minimizes these risks, while alternating the orientation increases the risk of openings and cracks (Englund et al., 2010), see figure 9.

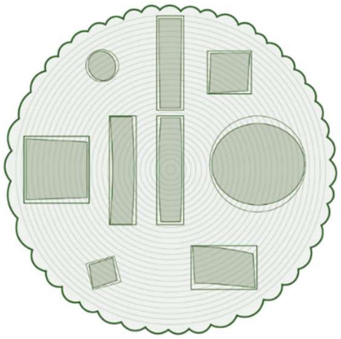

Figure 8 | Warping behaviour | Information from Brookes and Meijs (2008)

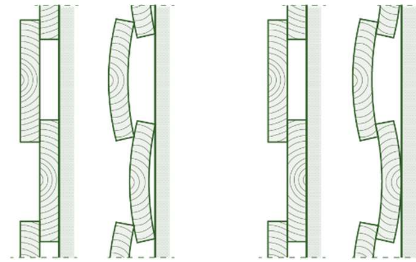

Figure 9 | Plank orientation| Information from Englund et al. (2010)

This approach assumes that the planks will have a higher moisture content during installation than they will have in the future, which may not always be the case. Additionally, differences in surface roughness can affect the uniform appearance of the facade. Discussions on whether the original top of the tree should face up or down are not scientifically substantiated and are rarely addressed in guidelines (Englund et al., 2010).

To ensure proper ventilation, the use of a cavity of 20-40 mm is essential. This cavity must allow vertical airflow (Brookes & Meijs, 2008). By placing the timber planks horizontally and the supporting battens vertically, vertical ventilation is facilitated, see figure 10. If reversed, with vertical planks and horizontal battens, vertical airflow is obstructed. Therefore, vertical counter battens are necessary, as shown in figure 11.

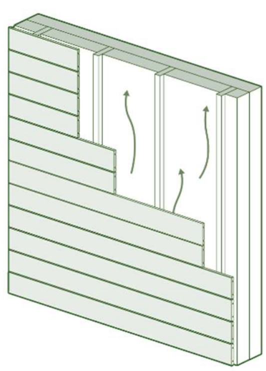

Figure 10 | Ventilation with horizontal cladding

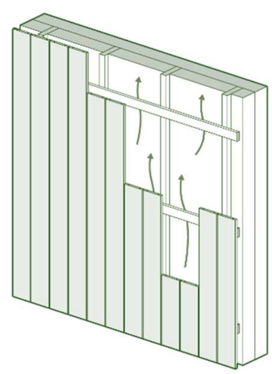

Figure 11 | Ventilation with vertical cladding

The advantage of horizontal planks is that less water can accumulate on the end grains than with vertical planks. On the other hand, vertical planks tend to grey more evenly. Greying is an aesthetic feature that the architect may or may not desire. It is important to note that the south-facing facade is exposed to more UV radiation, causing it to grey more quickly. Therefore, it might be beneficial to use a different type of timber for the south-facing facade if greying is undesirable, compared to other facades.

The study by Kaila and Heikkinen (2020) demonstrates that the orientation of the façade affects the durability of timber cladding. Each façade orientation presents unique challenges that impact the material's lifespan. The main findings of the study are summarized in table 4. Considering the specific risks associated with each orientation during the design phase can enhance the durability of timber façades.

Façade orientation	Key influences	Risks	Recommendations
West and South	- Highest exposure to sunlight and rain. - Faster degradation of coatings and discoloration of timber.	- Increased risk of timber rot due to the combination of sun and rain. - Requires optimal detailing.	- Use UV-resistant coatings. - Ensure proper detailing and water drainage.
North	- Least exposure to sunlight and rain. - Slower drying due to minimal thermal radiation.	- Higher risk of moisture issues due to slower drying. - Greater likelihood of moss or algae growth.	- Optimize ventilation. - Apply mold- and algae-resistant finishes.

Table 4 | Wind orientation of the cladding | Information from Kaila and Heikkinen (2020)

This research highlights the importance of considering facades as distinct elements rather than a unified whole. Designing for each facade orientation and addressing known issues specific to each side can significantly extend the durability of the timber.

Façade options

Cladding options that are extensively used in the Netherlands are compiled (Centrum Hout, 2024). To minimize moisture absorption, the following horizontal profiles are preferred: Overlapping, bevel siding, shiplap and Swedish rebate (figure 12). These are preferred because the end grain is always protected by the board above.

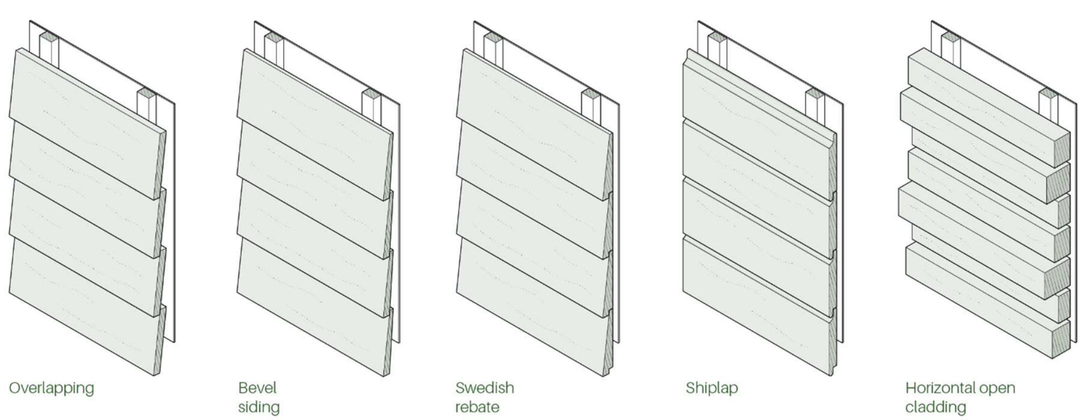

Figure 12 | Horizontal cladding options | Information from Brookes and Meijs (2008)

For vertical cladding, the following profiles are preferred: boards and battens, boards with overlap and channel siding (figure 13). These are preferred because the open sides of the board are always protected from moisture. As mentioned earlier, timber boards absorb moisture through the end grain. Therefore, it is advisable to install cladding beneath an overhang, as illustrated in figure 14.

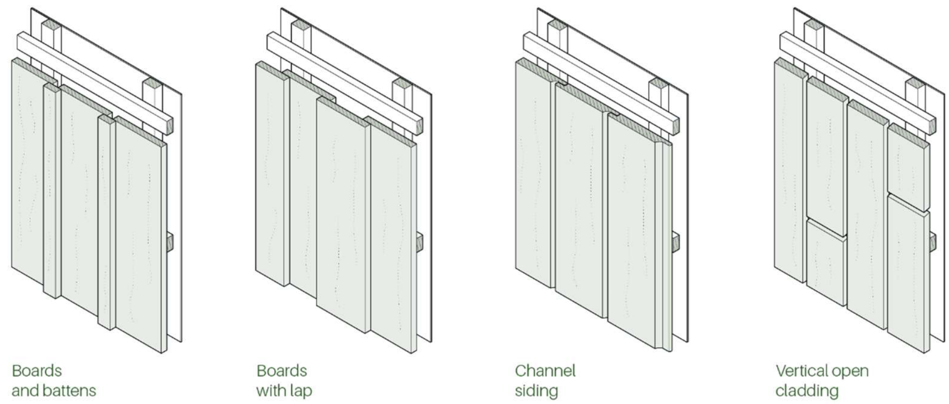

Figure 13 | Vertical cladding options | Information from Brookes and Meijs (2008)

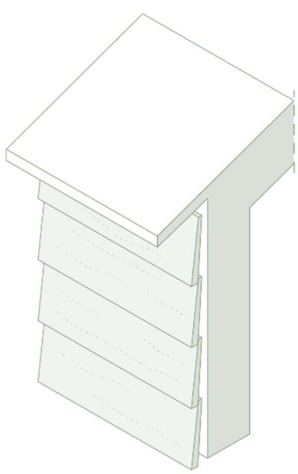

Figure 14 | Overhang to protect the timber

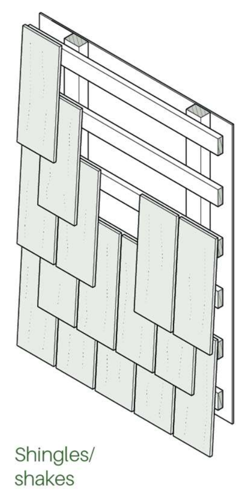

Figure 15 | Shingles and shakes | Information from Englund et al. (2010)

For timber species that are prone to movement, such as Robinia, it is advisable to choose cladding that allows for expansion, such as the use of shingles and shakes (figure 15). Shingles are sawn from a block, while shakes are split from a block. The surface of a shingle is smoother but shakes have the advantage that the vessels of the timber are not cut through, as the split follows the natural structure of the timber. This prevents water from entering the vessels (Brookes & Meijs, 2008).

Interviews

An interview with Veteka highlighted that it is always advisable to place the top of the plank under an overhang to prevent it from getting wet from above. For the bottom of the timber plank, it is recommended to saw it at an inward angle of 15 degrees, so that water droplets running down the plank will fall off rather than remain on the plank. It is also recommended to apply a sealer to both end grains.

In dry climates, where rain is infrequent, timber is often directly attached to the supporting structure without a cavity. In the Netherlands, however, this is not possible due to the wet climate, and the timber cladding must be given the opportunity to ventilate. Interviews with several companies, including Foreco, Accoya, Veteka, and Eden B.V., confirm that when a timber facade does not perform as expected, it is almost always due to inadequate ventilation, causing the timber to rot.

Case studies

Three buildings located in Germany were selected for analysis. All the buildings feature a timber facade. However, the specific type of timber used, or any treatments applied remain unknown. Nonetheless, these case studies provide insights into the design strategies employed and highlight the areas where the lifespan of the timber has been significantly reduced.

Case study 1




Figure 16 | Case study 1

This timber on case study 1 is protected by a gallery running alongside it, ensuring the timber remains dry. To make the gallery more enclosed, timber slats have been installed along its length. When exposed to weather, these slats are less likely to show visible effects compared to an entire facade exposed to the elements.

In the same building, it was observed that the timber cladding on the ground floor was not shielded by a gallery. One might expect that rainwater falling from above onto the facade would cause discoloration to appear from the top down. However, it was noted that discoloration occurred predominantly at the bottom of the facade, caused by splashing rainwater. This observation leads to the conclusion that timber cladding should not start directly at ground level but should instead begin higher up to prevent splashing groundwater from affecting the timber.

Case study 2

Figure 17 | Case study 2

In case study 2, shingles have been used, as discussed above. The shingles are placed in such a way that each floor has a slight overhang. This overhang is minimal, so from a certain level, the shingles are not protected from the weather. However, there is no visible difference in colour on the facade, as seen in case study 1. The facade has faded evenly due to the various small shingles. This could be a tactic to allow the facade to grey uniformly, rather than using vertical boards where greying would be clearly noticeable.

Case study 3

Figure 18 | Case study 3

In case study 3, horizontal facade sections have been used. The discoloration of the timber varies by floor. In the bottom two horizontal bands, the timber shows little to no discoloration. However, on the top three floors, the discoloration of the facade is clearly visible. This is likely due to vertical rainfall, with the three upper floors providing some protection to the lower floors, even though there is almost no overhang.

Conclusion

The durability of timber facades can be significantly enhanced through a thoughtful combination of material selection, environmentally friendly treatments, and effective design strategies. First, the choice of timber species plays a critical role. Among European species, Robinia and Sweet Chestnut stand out for their natural durability due to their high proportion of heartwood and resistance to decay. However, their application is limited by factors such as availability and dimensional constraints. Less durable species, like Birch or Pine, can still be used successfully if treated appropriately to mitigate their natural vulnerabilities.

In addition to material selection, treatments such as acetylation and thermal modification offer effective ways to increase the resistance of timber to environmental factors. Acetylation, which alters the chemical structure of timber, significantly improves its stability and resistance to fungal decay, particularly in species with good impregnability. Thermal modification achieves similar benefits by reducing moisture absorption, although it also decreases the structural strength of the timber, making it unsuitable for load-bearing applications. While Yakisugi, a Japanese charring technique, can enhance the aesthetic appeal of timber, its impact on durability is minimal compared to other treatments.

Finally, design strategies play a pivotal role in protecting timber facades from environmental degradation. Key measures include incorporating overhangs to shield the façade from direct rainfall, ensuring proper ventilation to prevent trapped moisture, and using precise detailing to avoid water ingress. Poor ventilation, in particular, is a common cause of degradation, emphasizing the importance of proper execution and installation. Together, these strategies ensure that timber facades can maintain their durability and aesthetic appeal, even under challenging outdoor conditions.

By integrating these approaches, architects and builders can create sustainable, long-lasting timber facades that balance environmental considerations with practicality and design.

To summarize the conclusion, an overview diagram has been created to illustrate the journey of the façade cladding from the tree to its final application. This allows for a quick understanding of the process, as shown in figure 19.

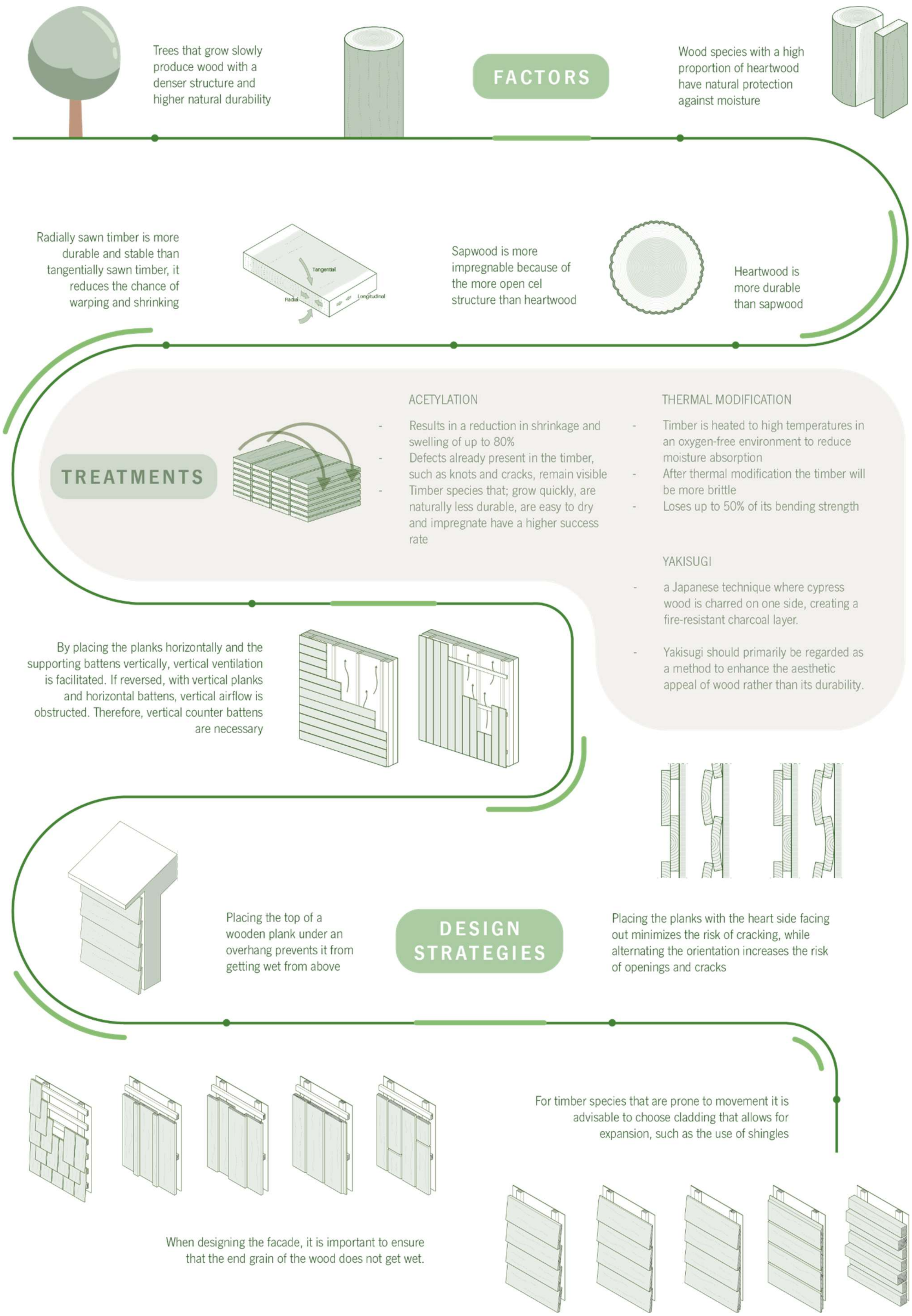

Figure 19 | Research diagram

Discussion

This study underscores the importance of selecting the right timber species and applying suitable treatments to extend the lifespan of exterior timber facades. While natural durability plays a significant role, design strategies are equally important in ensuring that timber can withstand the challenges posed by outdoor environments. However, there are limitations to the findings, as the research focused only on a selection of timber species and did not consider all possible treatments or environmental conditions in detail.

One area for further investigation could be a deeper exploration of the impact of fungal degradation and the fire class on timber facades, which has been an under-researched topic in this field. Additionally, while the study emphasizes environmentally friendly treatments, the economic feasibility and scalability of these treatments for large-scale construction projects could be explored further.

The findings also highlight the need for customized approaches depending on the geographical location and climate of the building site. Timber facades in regions with high rainfall or intense sunlight will require different strategies compared to those in drier, milder climates. More localized studies, including field tests and long-term monitoring of timber facades, would be beneficial in refining the strategies for maximizing timber durability per climate.

Finally, the research has practical implications for architects and builders in the design and selection of timber facades. By combining the right timber species with appropriate treatment methods and effective design strategies, it is possible to create sustainable, aesthetically pleasing, and durable timber facades that require minimal maintenance and offer long-lasting performance in the face of environmental challenges.

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Appendix

Timber species table

Timber species	Movement	Width sapwood	Durability class	Impregnability heartwood	Impregnability sapwood
Birch	High	Unknown	5	1-2	1-2
Beech	High	Unknown	5	1	1
Douglas fir	Medium	70-80mm	3-4	4	2-3
Oak	Medium to high	25-50mm	2	4	1
Maple	Low	Only has sapwood	5	1	1
Spruce	Medium	Unknown	4	3-4	3
Larch	Medium to high	<20mm	3-4	4	2
Limewood	Low	Unknown	5	1	1
Robinia	High	13mm	1-2	4	1
Sweet chestnut	Medium	13mm	2	4	2
Yew	Low	Narrow	2	3	2
Pine	Medium	50-100mm	3-4	3-4	1

Interviews

Four different companies were sent questionnaires by mail. Of these, two companies responded in writing, while the others preferred a telephone conversation. This telephone conversation was informal and in this, not exactly the same questions were asked, but was a conversation with information from the company. The useful information extracted from this conversation has been mentioned in the text.

Asked questions by mail:

- Does the company prefer locally produced timber, with a focus on timber from Europe? What do you see as the main benefits and challenges of this?
- What factors determine the choice of a specific timber species? (e.g., durability, aesthetics, cost)
- Does the company primarily work with treated or untreated timber species? What treatment methods do you apply to enhance durability (e.g., thermal modification, oiling)?
- What design strategies does the company implement to optimize the lifespan of timber facades? (e.g., use of overhangs, ventilation, detailing)
- How does the company design and protect timber facades to minimize exposure to extreme weather conditions, such as rain and UV radiation?
- What are your recommendations for maintaining timber facades to maximize their durability?
- Have you ever experienced a timber facade not performing as expected? What were the causes and lessons learned?

Answers Foreco:

- Does the company prefer locally produced timber, with a focus on timber from Europe? What do you see as the main benefits and challenges of this?

    For facade timber, Northern European Spruce and Pine (Finland, Sweden) as well as Radiata Pine from New Zealand are commonly used.
    Timber from Northern Europe is considered to be from a better growing region compared to Central Europe (e.g., Germany), making it of good quality for facades. Radiata Pine is free of defects and can be thoroughly impregnated with our NOBELWOOD. Additionally, all timber is PEFC or FSC certified.

- What factors determine the choice of a specific timber species? (e.g., durability, aesthetics, cost)

    We prefer the right quality and reliable sawmills, as this contributes to the aesthetics. Each type of timber has its own cost, offering something for everyone's needs.

- Does the company primarily work with treated or untreated timber species? What treatment methods do you apply to enhance durability (e.g., thermal modification, oiling)?

  We chemically impregnate our Northern European Spruce and Pine with Waxedwood to enhance durability, while we treat the Radiata Pine with BIOREZ (a byproduct of the sugar industry). All timber is DUBO certified. We do not use thermal modification, as many others already do this, and it can make the timber brittle (though there is nothing wrong with this approach).

- What design strategies does the company implement to optimize the lifespan of timber facades? (e.g., use of overhangs, ventilation, detailing)

  Proper detailing is certainly important to ensure the facade has the right lifespan

- How does the company design and protect timber facades to minimize exposure to extreme weather conditions, such as rain and UV radiation?

  We do not design ourselves, but we do offer advice. By enhancing durability, the timber is resistant to UV and other weather influences, which has no impact on its lifespan. If the timber is not treated, it will turn GREY (aging) in color.

- What are your recommendations for maintaining timber facades to maximize their durability?

  If one chooses a color, it should be reapplied for aesthetic purposes after approximately 4 years (this is not necessary for durability).

- Have you ever experienced a timber facade not performing as expected? What were the causes and lessons learned?

  In the 10 years I have been here, we have not had a facade that did not meet expectations based on our recommendations. However, we often encounter issues where the installation is NOT DONE PROPERLY, leading to problems. This includes a lack of ventilation, causing moisture to remain behind the facade, which then leads to the coating peeling off. Ventilation is truly the number one issue with facades.

Answers Accoya

- Does the company prefer locally produced timber, with a focus on timber from Europe? What do you see as the main benefits and challenges of this?

  At the moment, we primarily use Radiata Pine from New Zealand, mainly because this timber is available in defect-free (knot-free) qualities, along with its price, availability, and delivery reliability. Additionally, this timber species (in combination with the growing region) is highly suitable for the acetylation process. We are participating in various research initiatives to use local timber, but the challenge here lies in the availability (and delivery reliability) of the right timber quality and dimensions.

- What factors determine the choice of a specific timber species? (e.g., durability, aesthetics, cost)

  Accsys only performs the acetylation process and sells the "raw timber" to processors who then create a finished product. We assist our customers by providing information regarding costs (total cost of ownership), etc.

- Does the company primarily work with treated or untreated timber species? What treatment methods do you apply to enhance durability (e.g., thermal modification, oiling)?

  Accsys provides advice in this context. In principle, Accoya is already highly durable. However, for aesthetic reasons, coatings can be applied.

- What design strategies does the company implement to optimize the lifespan of timber facades? (e.g., use of overhangs, ventilation, detailing)

  Accsys provides advice on this matter.

- How does the company design and protect timber facades to minimize exposure to extreme weather conditions, such as rain and UV radiation?

  Accsys provides advice on this to our customers.

- What are your recommendations for maintaining timber facades to maximize their durability?

  Accsys provides advice on this to our customers.

- Have you ever experienced a timber facade not performing as expected? What were the causes and lessons learned?

  We are sometimes involved in issues, often due to detailing (insufficient ventilation), which can lead to unwanted discoloration.