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Review

The Potential of Uncoated Norway Spruce as a Façade Material—A Review

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Abstract: This article reviews the potential of uncoated Norway spruce as a façade material. Aspects such as natural durability, permeability properties, impact of density, and product dimensions are discussed. The review concludes that a careful design of the product is needed due to the intrinsic properties of the spruce species. Natural photodegradation will occur but has been proven not to impact spruce to a greater degree than other species. The optimal choice for a Norway spruce panel would be made of heartwood without juvenile tissues, with a vertical growth ring orientation. The selection of density is, however, unclear since low density reduces crack formation but could facilitate favourable levels of moisture for fungal colonisation. Additionally, the width of the growth ring has an unpredictable effect on the formation of cracks when the effect of early and latewood interaction cooperates with the effect of density.

Keywords: ageing; density; durability; façade; Norway spruce; permeability; uncoated wood

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1. Introduction

Uncoated wood is gaining popularity as a façade material. However, some form of surface treatment is traditionally carried out to increase the durability and moisture performance [1] as well as protect the surface from weathering and erosion [2], all of which contribute to an improved service life. The design of the cladding system also affects the service life [3–5]. However, the influence of the construction itself is not covered in this review. Many different treatments and modifications can be used, such as thermal modification, acetylation or furfurylation [6]. A major treatment commonly used to protect wood is the less environmentally friendly impregnation with a copper-based solution. Nevertheless, all the above treatments are related to an increased usage of chemicals and/or energy. Natural durable wood, carefully selected due to its properties, could be a sustainable approach towards facades with a lower environmental impact.

There are wood species that are naturally more durable, such as English oak (*Quercus robur*). However, in Scandinavia, the dominant species are Norway spruce and Scots pine, whereof the amount of spruce is increasing. Today, the majority of untreated wood panels are from species grown outside Scandinavia, such as Siberian larch (*Larix sibirica*) and Western redcedar (*Thuja plicata* (D.Don)). The production of these far-away species comes with a higher environmental impact when used in Scandinavia due to the longer material transport. The aim of this paper is, therefore, to investigate the desirable material properties of locally produced Norway spruce (*Picea abies* (L.) H.Karst) to optimize its usage as an uncoated façade material.

Historically, uncoated wood has been widely used in timber houses where solid logs served as both the load bearing structure and as the façade. The logs of old timber houses were often made of available species in the surrounding areas. The dominant species in Sweden were already at that time Scots pine and Norway spruce. Instructions from that time say that the logs selected for timber houses should be mature in order to achieve the highest durability [7]. The term mature was, however, not well defined, but rather a description of old trees with seized growth. The instructions did not mention heartwood ratio, but it was most likely one of the reasons why mature trees were selected.

It is apparent that there has been a long tradition of using uncoated spruce wood for outdoor applications in Sweden. In the Black Forest region and Northern Switzerland, the use of Norway spruce for construction started increasing around 1400, and during 1750–1850, it made up around half of overall construction timber [8]. Norway spruce was also the dominant building material in the Austrian Alps for several centuries, and log houses are still the typical construction type in rural parts of Austria [9]. The remaining old standing timber houses indicate that there is also a good chance to achieve a long service life as well. However, there are some differences in wood used for timber houses compared to facade panels. For example, the geometry of the wood piece is different (logs vs. panel) and may affect the moisture profile in the wood. Even if wood is a renewable material, it is of great importance to increase the life span of the material to create a longer buffer for the carbon dioxide to be released back into the atmosphere. The geographic location of exposure is an important parameter regarding the decay susceptibility. One way to assess the risk of decay at different locations is by calculating the Scheffer Climate Index [10], in which arid and cold climates receive much lower indices. The distribution of Norway spruce is mainly limited to regions where relatively low indices are found [11,12]. With regular maintenance every 3–5 years, untreated cladding can be expected to last at least 50 years with limited loss of function, whereas a lack of regular maintenance leads to more rapid deterioration [13]. Norway spruce is a drought-sensitive species [14,15], and as a result has declined in population size due to climate change [16], to which southern latitudes are more vulnerable. The decrease in population size makes it important to actively select properties to improve the durability, as the material itself might be harder to find in the future.

If the potential for Norway spruce to be used as a façade material is good, several countries where the species grows naturally could have the opportunity to produce cheap claddings with minimal environmental impact.

2. Durability of Spruce Relative to Other Wood Species

In the European standard EN 350:2016 [17], different species are listed according to their resistance against fungal decay in a field test with specimens exposed to ground contact. The species are placed in different durability classes ranging from 1 to 5, where 3 = moderately durable, 4 = slightly durable, and 5 = not durable. Norway spruce is rated 4. Surprisingly, Siberian larch (*Larix sibirica*) is not far from spruce with a rating of 3–4. Western redcedar (*Thuja plicata* (D. Don)) from the United Kingdom is rated 3. Scots pine heartwood (*Pinus sylvestris*) is rated 3–4.

Another study aimed to test the durability of different wood species against decay fungi [18]. This study classified the decay after 5 years of ground contact from 0 to 4, where 0 meant no attack and 4 meant failure. Norway spruce received a rating of 4; however, the heartwood-to-sapwood ratio was not defined. Scots pine heartwood received a rating of 3.1, and Scots pine sapwood received a rating of 4.

Norway spruce was tested in above-ground exposure [19] using the double-layer test according to Rapp and Augusta [20]. The decay was rated after 8 years of exposure in Norway on a scale between 0 and 4. Norway spruce received a mean rating of 3, while Scots pine heartwood and Western redcedar both received ratings of 1 or less. The rating for Scots pine sapwood was 3.5. Similar results were found in [21], using a modified version of the double-layer test. However, the moisture trap is considered severe in double layer-testing [22]. In above-ground testing with less severe moisture trapping, such as the Johansson method [23], Norway spruce and Scots pine heartwood were given similar ratings after 5 years of exposure.

The difference in performance between Norway spruce and Scots pine heartwood during severe moisture trapping and limited moisture trapping is also highlighted in a study by Brischke et al. [24]. The decay rating in a north-oriented façade of spruce was

1.0 after 6.4 years of testing, while the rating for double-layer tests was 2.8. For Scots pine heartwood, these values were 0.0 and 0.6, respectively. For specimens in a south-oriented façade, both Norway spruce and Scots pine heartwood received ratings of 0.0 at the end of the tests.

In an effort to develop a new prediction approach of the service life, both the wetting ability and the durability of several wood species was tested by Meyer-Veltrup et al. [25]. Norway spruce heartwood was used as a reference and performed reasonably well compared to other more durable species. For instance, the water uptake in Norway spruce was lower than both pine heartwood and sapwood during 24 h of submersion. The capillary water uptake was similar between Norway spruce and Scots pine heartwood, while pine sapwood had a much greater uptake. Scots pine heartwood did, however, outperform Norway spruce in mass loss after incubation with different rot fungi, whereas Norway spruce performed on a similar level to Scots pine sapwood. Siberian larch performed better (with regard to durability) than Norway spruce in all aspects except for capillary uptake. These similar mass losses between the sapwood of Scots pine and Norway spruce were also seen in a study by Keržič and Humar [26], where control samples of Norway spruce and Scots pine sapwood both lost 42.6% of their mass after exposure to brown rot, while Scots pine heartwood only lost 6.0% of its original mass. The durability ratings indicate spruce to be almost as good as other popular species to be used outdoors. It is possible, however, that the better moisture performance of some species [27] is overwritten when in ground contact. Hence, the durability classes stated in EN 350 relate primarily to the natural durability rather than the moisture performance of the species [28].

3. The Durability of Spruce Heartwood

The distinction between heartwood and sapwood in spruce is rarely made [29]. This could possibly be due to the difficulties to visually separate heartwood from sapwood in dry conditions. The sapwood border in spruce can be seen in freshly felled trees where the sapwood region has a darker colour due to a higher water concentration. However, several studies have shown that the properties between sapwood and heartwood in spruce differ, indicating that it could prove beneficial to separate the two. Spruce heartwood is shown to have higher durability and less microbial discoloration than spruce sapwood [30,31]. Sandberg [32] showed a clear difference in end grain capillary water transport between sapwood and heartwood. This was attributed to a higher degree of pit aspiration in heartwood than in sapwood. When comparing the resistance to brown and soft rot in heartwood and sapwood of spruce, the heartwood performs slightly better as the mass losses are smaller for heartwood after exposure to the rot fungi [33]. In natural exposure, the heartwood of spruce has been shown to have a significantly smaller decay rate than sapwood, especially when not in direct contact with the ground [21].

The heartwood–sapwood border can be found using either visual methods, such as staining or translucence measurement, or by assessing the difference in moisture content in fresh trees [34]. Since no fast and safe way to assess the border exists, production could be limited to achieve a high heartwood content by cutting centre boards close to the pith with limited length and width, and then placing the surface cut closest to the pith facing the outside.

In juvenile trees, the whole stem is made of sapwood. During maturation, the inner layers of wood cells transform from sapwood to heartwood. Even though heartwood formation is a well-known phenomenon, the actual mechanism is not yet fully understood. The transformation has been proposed as a regulating function of the tree sap flow, induced by drought stress and initiated by genetic expression [35–37].

Heartwood has the reputation of being more durable than sapwood due to the lower water-absorbing properties, and for some species, the higher ratio of protective resins and extractives [38].

There are several possible causes behind the higher durability of heartwood. Conifers are mainly made of two cell types: tracheid and parenchyma cells. The tracheid dies shortly after formation, but the parenchyma cells live longer and serve as nutrient storage and as fluid transport in radial direction. During heartwood formation, the parenchyma cell ceases its activity and dies. For Norway spruce, this starts happening around the age of 20–30 years [32]. The tree begins the withdrawal of nutrients such as starch, and the stored nutrients in the parenchyma cells convert to resins [39].

Fungal colonisation of the wood needs the presence of water and nutrients [40]. Norway spruce heartwood has a lower amount of sugar than sapwood [41]. The lower amount is suggested as a reason behind the lower amount of colonisation of discolouring fungi [42]. Both Norway spruce heartwood and sapwood are susceptible to rot fungi. Rather than absorbing nutrients, the fungi attack the cell wall components in the wood [43]. The active selection of heartwood for outdoors could, therefore, contribute to a panel with less discolouring microbial growth on the surface.

4. The Importance of Water Content in Wood

Water content is an important aspect regarding the service life in wood. A low moisture content (MC), with a low presence of water in the wood, reduces the risk of degradation by microorganisms. The fibre saturation point (FSP) is often used in the context of wood durability. The term FSP was first defined by Tiemann in 1906 and refers to the point where the cell walls are fully saturated and all water added after this point will be present in the lumen as free water [44]. However, recent studies have shown that, contrary to earlier belief, capillary water can be present before the cell walls are fully saturated [45].

The presence of free water is highly relevant when discussing wood durability since free water enables a favourable environment for the colonisation of various microorganisms. With high moisture content, the risk of fungal degradation will be dramatically increased. Studies have shown that moisture contents as low as 16.3% is enough to create fungus induced mass losses greater than 2% [46]. This suggests that the FSP is not sufficient for indicating whether decay will occur or not. When below the FSP, physical properties such as strength and swelling/shrinkage of the wood change rapidly. The variation in swelling and shrinkage may lead to crack formation and enhanced pathways for water to reach into the wood. Sorption-induced cracking is, therefore, an effect of differences in moisture content within the wood which give different swellings. These differences in dimensions cause stresses in the wood, which lead to cracking if they exceed the strength of the wood. The FSP of spruce is about 25% MC [47]. Uncoated spruce panels that had been exposed outdoors in Southern Sweden without any protection had an annual fluctuation between 10 and 70% in MC [48]. In this study, the panels had an inclination of 45°. The highest levels of MC appear during the colder months between September–October. Untreated spruce generally has greater moisture fluctuations than treated wood, and also has higher sorption due to capillary water uptake, which is almost zero for coated spruce [49]. Geving et al. [50] found annual fluctuations between 9.8 and 27.0% MC in one of the untreated claddings, while the annual fluctuations for one of the treated panels were between 13.4 and 22.7% MC in the same orientation. The panels were installed vertically with no inclination.

The same study concluded an approximately twice as great mould growth potential for untreated panels compared to panels with an oil-based paint treatment. The mould growth potential was calculated based on growth rate, relative humidity (RH) and temperature. As moisture performance generally decreases over time, differences between older panels and newer ones are expected. The time when MC is above FSP is unfavourable for the wood durability. Viitanen and Bjurman [51] have shown a halting of mould growth at periods with an ambient RH below 80%, while the growth continued above 97% RH (approximately 25–26% equilibrium moisture content at 20 °C, around the FSP for spruce).

5. Ageing of Spruce

Ageing in wood is a term to describe the process in which irreversible effects affect the properties and structure of the wood. These effects initiate after the felling of the tree and continue during the entire life cycle of the finished product. Ageing can lead to both desirable and undesirable effects from a durability point of view. It generally leads to an increase in moisture sorption [52].

Panels placed outdoors are exposed to natural weathering such as UV exposure and rain. Weathering from UV exposure, which is also known as photodegradation, is the most important factor of wood degradation [53]. During aging, the wood goes from yellow to brown and then finally to silver. The silver colour that appears in aged wood can be attributed to the delignification of the wood [54]. Facades will turn visibly grey within a year of natural exposure [55]. Lignin is the component which is most susceptible to photodegradation in wood [56]. However, the photodegradation is only acting on the surface of the wood as UV light is only able to penetrate a maximum of 75 μm in depth [57]. This is the reason why visibly aged wood can be made to appear much newer just by planing the outermost surface.

Oxidation is also a natural phenomenon related to aging in the wood. Similar to the intensified oxidation process induced by heat treatment, the natural oxidation creates a darker colour on the surface of the wood. Studies have shown that after 921 years at ambient temperature, the same colour appears on wood as that after 6.7 h heat treatment at 180 °C [58].

In a study performed by Žlahtič-Zupanc et al. [59], the contact angle of weathered untreated Norway spruce (heartwood/sapwood ratio not specified) was tested together with other species such as Scots pine heartwood and sapwood. Contact angle measurements are often conducted to investigate the hydrophobicity of a surface [60]. A high contact angle is generally related to greater hydrophobicity. In this study, the specimens were weathered for a total of 27 months and the contact angles were measured in intervals of 9 months. Initially, the contact angles of Norway spruce and pine sapwood were very similar. After 27 months, however, the contact angle of spruce was almost double that of pine heartwood, indicating a possibility of greater moisture performance in aged Norway spruce compared to Scots pine heartwood. Scots pine sapwood had a lower contact angle than Norway spruce throughout. Although better moisture performance can be observed on the surface of heartwood, it is unclear whether this gives favourable moisture conditions regarding biological degradation or not.

6. The Permeability of Spruce

The survey about old timber houses in Sweden by Sjömar [7] described narrow growth ring width as a very important parameter for durable Norway spruce wood, a but less important one for Scots pine. The phenomena of pit aspiration might be the cause of why narrow growth ring width is so important when selecting durable wood. With the closure of the pits (i.e., aspiration), the permeability between the cells decreases drastically.

For conifers, pit aspiration is part of the process in heartwood formation and during seasoning. For the green wood of *Pinus radiata*, between 80 and 100% of the bordered pits in heartwood are aspirated as compared to the sapwood region, where the equivalent number is an average of approx. 40% [61]. The rate of pit aspiration in *Pinus nigra* sapwood increases rapidly during seasoning, starting from around 10% of pit closure and increasing to 65% when drying from green to below the FSP [62]. The specific level of pit aspiration in Norway spruce heartwood is less known. However, the drying process of wood strongly induces the rate of aspiration. Even at a moderate drying temperature (20 °C), the permeability of eastern hemlock sapwood was reduced by more than 98% from 2.74 μm^2 to 0.0395 μm^2 [63].

The main pathway of fluid and gas transport between two water-conducting tracheids is through the bordered pits in Norway spruce. Liese and Bauch [64] explained the generally lower permeability of spruce compared to pine in terms of the smaller pits in ray parenchyma cells and the smaller half-bordered pits between the tracheids. However, the moisture dynamics in the inner parts of Norway spruce are similar to the heartwood of Scots pine [65]. The inner part of the stem was proposed to be dominantly made of spruce heartwood. Blom and Bergström [66] confirmed that the moisture dynamics of Norway spruce are like that of pine heartwood, although with a slightly higher moisture content.

Spruce heartwood, in comparison to pine, has a lower amount of water-repellent resin extractives [67] but has, on the other hand, a higher ratio of bordered pits that becomes aspirated and closes the openings between the cells. Hill et al. [68] argue that pit aspiration makes spruces (*Picea* spp.) perform well for claddings, even though the decay in the ground is rapid. Pine sapwood exhibits high permeability due to the presence of disrupted window pits that remain open upon drying. During heartwood formation in pine, the window pits close due to the deposition of extractives [69]. Studies have shown that drying causes the resin within Norway spruce boards to flow to the surface of the centre yield [70]; this could also have a positive effect on the moisture performance due to the hydrophobic qualities in the resin.

As previously mentioned, the properties of sapwood and heartwood in spruce can be widely different. One of the properties that differs the most is the permeability. Cracks appear due to stresses and strains caused by swelling and shrinkage in wood. The absorption of moisture can lead to changes in dimensional stability and cracking [71]. As cracks are formed due to moisture gradients across the board, this results in an uneven shrinkage [72]; having different permeabilities across the board can lead to cracks that would not appear on a more homogeneous board. Hence, permeability is an important parameter to study regarding the degradation of wood.

7. The Effect of Density

The density of spruce is affected by the ratio of latewood relative to earlywood. High density correlates to a higher ratio of latewood. Generally, an increase in earlywood ratio is expected for wider ring widths, but in regions with very short summers, the latewood development is restricted [73]. An example of this can be found in spruce wood grown in the northern part of Sweden which has lower density and narrower growth rings than wood from the south [74]. The growth ring width affects the internal strains in the wood during drying and swelling. Forces appear in the border of early and latewood according to an earlywood–latewood interaction theory described by Kifetew et al. [75], where the local density variation within early and latewood layers may influence the surface deformation. There are, however, no studies at present on the relationship between growth ring width and the cracking of spruce wood with the same density. A study on chestnut showed a lower tendency of cracking with a wider ring width [76] but a similar behaviour of conifers needs to be studied further.

High-density spruce increases its MC at a slower pace as compared to low-density spruce [77,78]. The phenomena can be attributed to restrained transport pathways for water due to the smaller pit openings and the smaller cavities. The thicker cell walls also increase the ratio of water transport through diffusion, which is a slower alternative of water distribution than capillary transport. Hence, high density leads to a slower moisture increase in wood and most likely contributes to a lower risk of fungal colonisation.

However, it is also known that high-density wood is more prone to crack formation. The phenomenon is due to the swelling capacity of the material. Wood with a higher ratio of cell walls (i.e., high density) has a higher water uptake capacity and, hence, swells more. Cracks lead logically to increased pathways for water transport deep into the wood structure and, hence, increased water uptake. The impact of cracks vs. density on the water uptake capacity in spruce is, however, not clearly known and needs further research.

Density has been found to have a positive correlation with the erosion of wood during weathering [79].

Density is generally correlated to greater strength and stiffness properties. For example, it has a positive correlation with the modulus of elasticity (stiffness of the wood) [80]. However, it has been shown that there is no significant correlation between tensile strength parallel to the grain and density [81].

The density has a positive effect on the modulus of elasticity but a negative effect regarding dimensional distortion during wetting. For façade panels, cracking only appears due to moisture-induced stresses caused by uneven swelling and shrinking, and not by an external load. Since an increase in density leads to both positive and negative effects regarding cracking, this needs to be studied further to understand which of these factors affects the cracking the most.

Regarding the natural durability in relation to the density in Norway spruce, a study by Alfredsen et al. [82] showed a good correlation between mass loss caused by brown rot fungus and the specimen density; a high correlation was also found for soft rot. No correlation could be found between density and mass loss caused by a white rot fungus.

8. The Processing of Wood

The way the wood is processed is of great importance to the final material. The biological nature causes unique structures in different samples which can vary greatly. Understanding how different parameters affect the wood will lead to better use of the available resources.

The selection and dimension of the wood to be used as panels are essential for the dimensional stability of the product. Juvenile spruce that is present at the inner part of the stem has a higher shrinkage and swelling than mature wood due to the shorter fibre length [83]. The tissue in juvenile wood is also weaker and may crack more easily [72]. Hence, the unevenness in moisture movement for the two types of wood contributes to a higher increase in warping and bending when these two types of wood coexist in a panel.

An increase in temperature for ranges between 0 and 100 °C has a negative effect on the strength of wood [84]. The stress levels in wood decrease as the temperature increases. However, since the tensile strength in wood decreases as the temperature increases, higher temperatures do not necessarily lead to more cracking.

Some of the moisture movement such as warping and bending in a wood panel can be prevented by an increase in dimensions. The larger dimensions serve as a buffer in moisture movement where the less swelled wood (normally in the core) restrains the wood with larger moisture movement.

To select wood free from sapwood, the wood close to the pith should be used. Due to the annual ring formation in these pieces, the dimensional changes will appear as cupping. Cupping is one of the factors leading to cracking in wood. Cupping appears when wood swells and creates tensile stresses at the convex surface and compressive stresses at the concave surface. To achieve better dimensional stability against cupping, a greater thickness of panels can be used [85]. In this study, it was shown that panels of 28 mm thick Norway spruce had a cupping curvature of 70% less than pine sapwood of 21 mm thickness. The authors, therefore, recommend using at least a thickness of 28 mm to achieve sufficient dimensional stability against cupping.

Commonly, uncoated facades have rough surfaces, usually achieved by cutting the samples with a band saw or circle saw. One reason for this could be the considered benefits of a rough surface when painting the panels, as the fibres anchored to the wood could act as reinforcements for the paint layer [86]. This alleged benefit is, however, for obvious reasons, not applicable for uncoated panels. Rough surfaces show a lesser amount of cellulose on the surface than planed surfaces after natural degradation, and perform poorly when compared to a planed surface [87]. Jämsä et al. [88] found no differences in samples with planed or sawn surfaces when comparing the crack formation and microbial growth on uncoated panels of spruce after five years of natural weathering. It is possible that the better performance is overwritten after longer exposure. This should be studied further to fully understand how the surface roughness affects the durability over longer periods.

Wood is a hygroscopic material that continuously adjusts its MC to the surrounding relative humidity [89]. The more wood substance (i.e., thicker panels), the slower the whole panel will reach the equilibrium moisture content (EMC) [90]. The buffering effect in MC by the wood will give a moisture gradient in the wood, where the outer part of the wood will have a higher fluctuation in MC than the core part of the wood [91].

The growth ring thickness seems to affect decay mostly in in-ground exposure. The tests carried out by Meyer-Veltrup, Brischke, Alfredsen, Humar, Flæte, Isaksson, Brelid, Westin, and Jermer [25] showed approximately double the decay rate in Norway spruce with 6 mm thick annual rings compared 1 mm annual rings for samples exposed in ground according to EN 252. Above-ground horizontal double-layer tests instead led to an approximately 1.4 times (average between two test sites, Bergen and Ås, Norway) greater decay rate in samples with 6 mm thickness than those with 1 mm thickness. In another study by Brischke et al. [92], the mean decay rating according to EN 252 was determined. Norway spruce with 6 mm annual rings for one test site had a mean decay rating of 2.4 and the mean decay rating for 1 mm annual rings was 0.9, while at another test site, ratings of 2.1 (6 mm thickness) and 1.9 (1 mm thickness) were determined. Thinner annual rings, i.e., slow-grown, does seem to have a positive effect regarding the decay resistance of wood.

Additionally, the growth ring orientation of the panel influences the effects on the internal strains in the wood that are caused by swelling and shrinkage. The orientation with less crack formation is with the rings perpendicular to the sawn surface (i.e., vertical growth rings) [93].

9. Conclusions

The potential of using uncoated spruce as a façade panel is good. This conclusion lies in several factors but one of them is in the success from the past in using uncoated spruce for timber houses. However, a careful design of the product is needed regarding the inherent durability of the spruce species. The optimal choice for a façade panel would be made of heartwood without juvenile tissues. Preferably, the growth ring orientation in the panel should be vertical. The choice of density is, however, unclear. Low-density wood gives less cracks but has a faster variation in MC. The greater variation in MC might, however, be beneficial for fungal colonisation, but due to a quicker drying time, this could also limit the time for the fungal colonization to settle. The choice of high-density spruce may give a slower variation in MC, but the higher amount of cell mass contributes to increased crack formation. It is also relatively unclear how much the density affects the strength properties of wood related to cracking.

To ensure that at least one of the sides of the panel contains only heartwood, the wood should be cut close to the pith. However, this makes it more difficult to achieve strictly vertical annual rings. The importance of these parameters should be weighed to conclude what should be prioritized. The width of the growth ring has an unpredictable effect on the crack formation when the early and latewood interaction effect cooperates with the density effect. Many studies conducted on Norway spruce fail to mention whether the samples studied are produced from heartwood or sapwood, indicating a need to present results proving a difference in moisture performance and durability between the two. Greater thickness leads to better dimensional stability in the panels. However, the difference between panels of different thicknesses needs to be studied further to confirm that stability leads to less cracking. The natural aging in wood gives properties that differ from when the panel was produced. To create a panel that can last for a long time, it is important to study how the weathered wood acts and if the same properties are also prioritized for weathered wood.

There is a good chance to achieve durable uncoated façade panels made of spruce. However, it is suggested that further research should be made to understand the interaction between wood density and growth ring width. The objective will be to find an optimal ratio for less crack formation and fungal colonisation.

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