Understanding and Addressing On-Site Moisture Protection Challenges in Timber Construction: A Comprehensive Review of German Practices

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Abstract

Wood is increasingly recognized as a sustainable building material due to its renewable nature and ability to sequester carbon dioxide (CO2) from the atmosphere. As a result, timber construction is gaining popularity, offering environmental benefits and contributing to the reduction of greenhouse gas emissions in the construction sector. However, due to its biodegradability, moisture protection poses a significant challenge in timber construction, particularly during the assembly process, where inadequate protection measures can lead to long-term damage and compromise structural integrity. This study examines the processes that affect moisture protection in timber construction on the basis of site visits to 21 construction projects over the period of three years. During the visits, photographic documentation was created and a self-developed register was used to record the processes of assembly-related moisture protection in timber construction. The analysis focuses on wall and ceiling assemblies, documenting the implementation of moisture control strategies and identifying common sources of error. The study highlights the necessity of comprehensive design and implementation of moisture control measures to fully realize the benefits of timber construction. Furthermore, the study highlights the need for a comprehensive understanding of the processes of moisture ingress and drying in various types of timber construction. In addition, appropriate quality management and easily implementable practices are needed to address this critical point in the assembly process. The systematic investigation presented in this study aims to contribute to the understanding of moisture protection in wood construction and to identify areas for improvement in current practices.

Keywords: *Assembly Processes, Timber Construction, Component Protection Concept, Structural Protection Concept, Rainwater Penetration*

1. Introduction

Wood is a sustainable resource that offers numerous ecological advantages. As a renewable material, wood grows by itself and is steadily regenerated [1]. Furthermore, wood absorbs Carbon dioxide (CO2) from the atmosphere during its growth and stores it long-term. 600 kg of wood can absorb approximately 1.5 tons of CO2 through photosynthesis [2]. Using timber in construction significantly contributes to the reduction of greenhouse gases, as the Carbon bound in the biomass is only released upon combustion or decay.

The construction sector accounts for 30 to 40% of global resource consumption and approximately 30% of CO2 emissions, making it a significant contributor to climate change [3-5]. In contrast, timber construction is steadily growing and extends beyond the construction of single-family homes [6]. Increasingly, multi-story buildings, daycare centers, nursing homes, and even entire neighbourhoods are being planned and constructed using timber. This shift is driven by material advances and sustainability considerations [4,6,7], as exemplified by initiatives in cities like Munich, where an entire housing estate has been planned and built in timber. The rising prevalence of these construction projects highlights the importance of wood as a building material in modern architecture and urban planning.

When used as kiln-dried lumber in timber construction, its properties can effectively counteract climate change in this sector by reducing the use of fossil resources. In Germany, almost 30% of the country is covered by forest [8], providing the material needed to construct the houses of the future. The use of wood in construction not only reduces the ecological footprint, but also promotes sustainable building practices. In the case of serial retrofitting as currently practiced in Germany, it can even accelerate the process of upgrading existing buildings that do not have modern low energy ratings and would otherwise be demolished to make way for new construction. By renovating with prefabricated, serially produced timber elements, existing buildings can be preserved and the waste of existing structures can be avoided.

Wood in timber construction offers many advantages as a building material, but there are challenges that certainly need to be addressed. The biggest challenge is the hygroscopicity of wood: moisture is absorbed by wood both in the form of vapor and liquid. This absorption below the so-called saturation point leads to volume changes caused by swelling. The absorbed moisture can result in considerable deformation and expansion pressures, particularly in kiln-dried construction timber with a moisture content of less than 20 percent by mass [1]. Wood can be degraded as a result of biotic damage [9]. In timber construction, this usually presents itself through the decomposition of wood by various wood-destroying fungi following moisture accumulation. To prevent early moisture accumulation in timber, especially during construction, it must be protected from liquid water. This is of paramount importance because, as the assembly progresses, the components are not yet in their final arrangement and under the usage conditions for which they were designed and laid out. At this stage, there is no drainage, no roof, and even the materials (such as gypsum boards, fiber boards, insulation materials, and many engineered wood products) are often not designed to withstand exposure to liquid water. Moisture must therefore be prevented from ingress during assembly, because once moisture has penetrated, it can generally no longer dry quickly [10].

However, the implementation of moisture control during assembly is often insufficient, frequently resulting in damage as highlighted by the VHV Bauschadenbericht Hochbau (Construction Defects Report on Building Construction by the VHV Insurance group). The VHV reports that nearly one-third of all damage claims in German construction are attributed to water-related issues [11]. Furthermore, the report indicates a lack of comprehensive planning specific to the needs of timber construction in Germany.

There are different approaches in timber construction to protect components from weather influences. Mainly two systems can be defined: the component-specific method (Component Protection Concept) where the components are individually protected from moisture using fully adhesive membranes or large-format films and adhesive tapes. In this method, each component must be connected to the others in a second step to prevent moisture from penetrating into cavities. The second system can be considered a construction-specific protection system (Structural Protection Concept). In this system, the construction site is protected from the weather with a temporary roof or tent. Ideally, a crane is located inside the tent system so that unloading of components can also take place using this crane. However, there are also tent elements where the roof can be opened to allow components to be lifted in.

However, if the prefabricated elements are not adequately protected against moisture during construction by any means, this can lead to long-term damage and compromise structural integrity. Therefore, it is crucial to implement suitable moisture protection measures to ensure the longevity and quality of these structures. Proper planning and execution of moisture protection measures are crucial to fully leverage the advantages of timber construction and to realize the ecological and economic potentials of this sustainable building material. There is currently a lack of quality management and easily implementable practices for all those involved. There are only a few scientific studies that focus on this topic. This results in a concrete research goal. This study aims to make a contribution by systematically investigating moisture protection during the assembly process in timber construction. The aim of the study is to determine the processes occurring in timber construction that impact moisture protection

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2. Methodology

Over the past three years, 21 different construction sites were visited for this investigation. A register was used to document the construction sites, the structures, and the materials used. This documentation was supplemented by extensive photographic records. The analysis focuses on the wall and ceiling constructions in use, as well as the corresponding moisture mitigation strategies complementing the assembly. All influential steps and materials were categorized according to their use, with an emphasis on location and purpose. weaknesses were identified, In a subsequent analysis step.

The photo documentation provided visual support for the data collected during the visits, while the protocols enabled a structured recording and analysis of moisture mitigation practices. This analysis aims to highlight common sources of errors and offer solutions. It's important to note that the results presented here represent an interim status of the ongoing investigation. The sites were, with one exception, projects larger than single-family homes. Visits were carried out if at least one of the following criteria was met:

1) The construction schedule could not be adjusted according to the weather, necessitating the expectation of rain due to a tight timeline.
2) The project involved long and complicated assembly processes or construction-related assembly breaks, as in hybrid structures.
3) The project included more than two residential units and/or more than two stories.
4) Special moisture protection efforts were required, particularly for sensitive constructions such as glue-free massive timber elements.

Planning the site visit was essential to ensure that it coincided with the critical phases of timber element assembly. Detailed preparation aimed to observe the construction processes in their most informative stages, with a particular focus on critical assembly stages and construction details.

The inspection was conducted systematically, moving from the bottom to the top of the structure to ensure comprehensive coverage. A structured protocol was followed during the inspection to ensure consistency and accuracy in data collection. In addition, any unresolved details or specific questions were clarified through direct inquiries to the site manager or architect. This approach ensured that the data collected was reliable and comprehensive, and thereby provided a solid foundation for the analysis.

3. Findings

In the following section, a special focus is placed on moisture protection during the assembly of wall and ceiling elements. This specifically pertains to the critical interfaces between the positioning of components with the crane and their connection to adjacent parts of the structure. Effective moisture protection at these junctions is considered paramount to prevent long-term damage and ensure the structural integrity of timber constructions. By examining these interfaces, common challenges are identified and strategies for improved moisture management during the assembly process are proposed. This analysis aims to contribute to a deeper understanding of how timber structures can be safeguarded against moisture-related issues, thereby enhancing their durability and performance.

3.1 Ceiling construction and wall structures in regard to their moisture protection systems

This analysis focuses on the distribution and frequency of various ceiling types and the prevalence of moisture protection strategies to elucidate their implications and correlations. Table 1 provides data on different ceiling types in combination with the moisture protection measures implemented. Table 2 provides an insight into wall construction and moisture control measures in the projects visited. It complements this by illustrating the wall systems observed and their protective components. In cases where projects or parts thereof were deemed irrelevant due to their construction or materials used, the corresponding field was filled out in gray. For instance, site number 19 did not involve a ceiling construction as it was a single-story extension. Therefore, the corresponding field is marked in gray. The outliers are nevertheless included in the analysis as they pertain to the total number of projects visited, and other areas of these projects may still be relevant and analyzable. The table lists 21 construction sites as numbers. The upper part of the table discusses the various ceiling constructions:

Tab. 1 Ceiling construction and moisture protection implemented

	Number of construction site																						
Ceiling type/ Protection	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Σ:	%
Solid wood ceilings	x	x	x		x	x		x				x		x	x	x	x	x				12	57.1
Hybrid ceilings							x											x				2	9.5
Wooden beam structures																				x		1	4.8
No timber (concrete)													x								x	2	9.5
Protective measures taken																							
Fully bonded membranes	x	x	x		x				x			x		x		x	x					9	42.9
Other foils or membranes				x							x				x	x		x				5	23.8
Conections sealed to walls	x		x		x							x						x				5	23.8
Perimeter protected																						0	0
Drainage applied	x			x	x													x	x			5	23.8

- Solid wood ceilings refers to a ceiling construction made of solid wood components. This could be Cross Laminated Timber (CLT) or board stack elements, elsewise known as: Brettstapel (solid wood panels manufactured from timber connected by hardwood dowels [1]). However, also, some hollow box elements would be counted here.
- Hybrid ceilings are ceiling constructions that combine wood with other materials to create a composite material. In this case, all hybrid constructions are wood-concrete composite constructions.
- Wooden beam structures are so-called timber beam ceilings, which are characterized by mostly parallel beams that can be prefabricated as panel elements with insulation or traditionally created on-site through cladding.
- Under No timber are all constructions that were mounted or crafted on-site, which did not include any wood components. These include, for example, reinforced concrete elements.
- The next section, or lower part of the table, shows the moisture protection strategies and materials applied to the floors;
- Membrane fully bonded refers to a fully adhesive construction-time seal that protects the components from moisture ingress as a diffusion-open membrane. These foils remain in the building until it is demolished.
- Other foils or membranes includes all non-adhesive foils. These can be simple PE sheets or facade membranes that are also diffusion-open.
- The last two rows cover the application of the foils:
- The category Connections sealed to walls consider whether the sheets or membranes were connected to the adjacent walls so that accumulating rainwater is not led into supports or into the wall elements.
- Perimeter protected describes the exposed cut edges of the elements, mostly in CLT or other massive wood components. Here, the end grain is exposed, which can quickly absorb a lot of liquid water. This absorbed moisture dries out much more slowly than it is absorbed. It is particularly difficult to remove the quantities of water absorbed by capillary processes from the elements.
- Drainage applied focuses on whether the ceiling elements were drained in any form or not. This can be done, for example, by pipe connections in the still unused installation shafts.

The most commonly used ceiling type across these projects is the solid timber ceiling, implemented in 12 of 21 projects, accounting for 57.1%. Solid timber ceilings are mostly fabricated from CLT, and in 2 cases, from brettstapel elements. These elements are typically screwed together during assembly and can be pre-fitted with fully bonded membranes from the factory. The preference for these constructions is likely due to their structural benefits, aesthetic appeal, and the rapid construction progress they facilitate. Additionally, they can be ordered and delivered ‘just in time’.

CLT components are limited in the extent to which they swell when exposed to moisture. This is due to their structure of orthogonally glued boards. However, drying these components has been found to be problematic, so preventing them from getting wet is necessary. Board stack elements, on the other hand, can deform significantly because it consists of individual boards simply strung together. This allows these elements to deform freely in the transverse direction, which makes it essential to prevent water from accumulating on these components. Expansion pressures can lead to distortions or necessary rework at the construction site.

Of the 12 projects that utilized solid wood ceilings, eight employed fully bonded membranes to safeguard against environmental factors, representing a total of 66.7%. This emphasizes the perceived importance of protecting these structures from moisture. It is noteworthy that in none of these projects were the edges (end-grain) around the perimeter of the structure screened or sealed. This absence may suggest practical challenges or a perceived low necessity in protecting the perimeter specifically, with other measures deemed sufficient. By adding the rows of the table where membranes and foils of any kind are used, counting construction sites that use both only once, it is found that 13 construction sites have protected the ceiling construction with some form of foil. Comparing this with the construction sites that use wood in the ceiling constructions (21-2, as 2 sites did not use timber), the ratio is 13 out of 19 (68.4%). However, only in five of these cases (38.5%) were the wall elements mounted on top sealed to the ceilings with adhesive tapes or foil strips to prevent the intrusion of trapped moisture into the wall elements or the supports below. This suggests a reliance on factory-applied ceiling sealing as sufficient rain protection, neglecting the need for adjacent component protection.

Hybrid constructions combine different materials to expand their properties. However, it must be noted that the careful development of these systems in a laboratory setting is quite different from on-site conditions, where weather, time pressure, and human factors influence the outcome and quality of the product. Hybrid floor structures have been facilitated in around 9.5% of all projects, where timber and concrete were combined to form a new composite material. Ideally, this method leverages the strengths of both materials, with timber bearing tensile forces and concrete handling compression. However, challenges may arise when concrete is poured in situ, as the water content in the fresh concrete can moisten the timber. The situation is exacerbated if the concrete mix is not properly managed or if the timber has already absorbed moisture over time

Only one project could be visited where wooden beam structures were used in a traditional way. This might be due to its limited popularity. In this case, the project's reliance on favorable weather conditions for construction reflects a common misconception in timber construction that prefabricated elements can be installed in good weather, with completion before any rain arrives. This approach poses significant risks, especially as project sizes increase and advances in materials allow fewer craftsmen to assemble larger structures.

And lastly in 9.5% of cases, construction featured timber walls without incorporating timber in the ceilings (No timber). Here, the floors were solely made of reinforced concrete. Timber components are restricted to the building's outer perimeter, while interior areas employ reinforced concrete or brickwork. In such scenarios, protecting elements from damage or moisture due to varying tolerances and external trades, as well as extended waiting periods until the timber assembly can proceed, presents hurdles. This highlights the necessity for careful planning, particularly in connection detailing.

In the following, the different rows will be briefly explained. Just as in table 1 above, the table lists the 21 construction sites as numbers. Here, the upper part of the table covers the different wall types.

Tab. 2. Wall structures and moisture protection implemented

	Number of onstruction site																						
Wall type/ Protection	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Σ:	%
Timber frame	x			x			x			x	x	x	x	x		x	x	x	x	x	x	14	66.7
Massive timber elements		x	x					x							x							4	19.0
Frame and massive timber					x	x							x									3	14.3
Protective measures taken																							
Top protection	x			x	x						x		x		x	x		x	x		x	10	47.6
Bottom protection	x				x						x	x	x					x	x			7	33.3
Lateral protection	x										x				x						x	4	19.0

- Timber frame refers to a system consisting of horizontal beams and vertical studs within a wall. The upper horizontal end of the frame is called the top rail, and the lower end is the bottom plate. The cavities between the studs are either filled with insulation material at the factory or insulated later on. The elements are clad on both sides in their finished state but can be delivered to the construction site as semi-finished products. In this case, the frames are only clad on the inside with a stiffening panel, and the rest is added during the construction process. These components can already have the finished facade on the exterior and the installation level for electrical installations and, if necessary, the first plaster layer. It is crucial to prevent moisture from entering these elements; if the insulation gets wet, the component must be opened. Such premature renovation costs not only time and money, it also leads to material waste and quality loss. Additionally, the materials on the exterior are often susceptible to moisture and cannot be easily dried.
- Massive timber elements are typically CLT or brettstapel elements. These are analogous to the ceilings and have the same advantages and challenges as their horizontal counterparts. It is particularly important to ensure that the underside of these components does not become wet. While vertical components allow water to run off, they can continuously absorb water if they are resting in a puddle on the ceiling, saturating the element base.
- Frame and massive timber refers to a combination of these two construction practices. The massive component is used on the interior, and the facade is usually added as a prefabricated element. This allows for heavy facade constructions to be fixed to the wall component. Additionally, large layers of insulation can be easily applied.

Regarding the lower part of the table, the applied protection mechanisms are listed. Here, the focus is not on the materials but on the areas of application. Table 2 distinguishes three areas in need of protection:

- Top protection for the upper wall edge, preventing water from saturating the wood, or running into cavities.
- Bottom protection, as the protection of components in conjunction with the ceiling elements on which they stand, or as a factory-applied membrane to protect the lower edge from moisture.
- Lateral protection for the vulnerable sides.

As for wall structures, the most common type found is the timber frame, which is utilized in 14 of 21 projects, accounting for 66.7%. Timber frames are highly favored. CLT and similar materials for walls are employed in only 4 projects, representing 19.0% of the construction sites. These are valued for their structural strength, stability, and sustainability, making it an increasingly popular choice in modern construction. A combination of frame structures and massive timber is used in 14.3% of the projects.

Fig. 1. Carefully protected element before ceiling is assembled in hybrid construction

The wall in Fig. 1 is carefully secured from all sides to protect the structure over the course of time until the ceiling is finished. The wall is constructed as a timber-framed structure with a finished façade on the exterior and gypsum fiberboard on the interior. To protect the materials and elements from moisture ingress, the components were safeguarded at the factory against moisture penetration from both the top and the bottom. This was achieved by covering the top and bottom with a fully adhesive membrane to protect against moisture intrusion. Once the elements were erected, they were shielded from driving rain on the interior side using large-format films. This protective measure ensured the quality of the building components could be maintained over extended periods.

This is one of only two examples where the protection of elements has been tailored into a holistic concept to tackle the particular challenges that arose from the construction. Roughly half of the sites (47.6%) protected the top of prefabricated elements. This measure involves various applications such as sealing material joints with water-repellent tape, covering the top with tarpaulins, or utilizing fully bonding membranes. Shielding the components from above acts as a barrier against water ingress.

This protection is especially critical for timber-framed structures, where the insulation must be kept dry. Furthermore, only 33.3% of the sites protected the underside of elements against moisture. This solely focuses on protecting the lower parts of the wall structures from moisture accumulation through direct contact with water. Even fewer companies (19.0%) utilized lateral protection, all of which protected the sides with sheeting attached to the element to direct rainwater away from the surface. This measure, though less common, is crucial, especially in scenarios where walls are particularly vulnerable. In the case of timber frame construction, a way to protect the outer sides of prefabricated wall units is to trim the bottom layers, which for instance consist of Oriented Strand Board (OSB), gypsum board, or gypsum fiberboard, by approximately ten to twenty millimeters at the bottom. This trimming prevents the board from being immediately exposed to liquid water when the structure is subjected to rain and water collects on the floor. However, it is still necessary to ensure that the OSB board itself is not continually exposed to rainfall. This can be achieved by covering it with tarps and sheets (Fig. 1).

Figure 2. Wall section transferred by crane without pre-installed protection

Figure 3. Blind holes pose a risk for the moistening of CLT elements

3.2 Favorable and damage-prone installation procedures

When the components are delivered to the construction site, they are ideally protected to prevent them from getting wet during shipping. However, transferring the elements from the transportation vehicle to the eventual installation location poses a challenging interface where the components are often unprotected. This challenge is particularly pronounced in urban environments, where crane scheduling for larger construction projects is tightly managed due to limited space and strict timelines. As a result, the components must be lifted out of protective coverings or tarpaulin trucks, regardless of weather conditions. In the lifting process depicted in Fig. 2, protection measures are typically minimal. However, there is one exception wherein a site covering tent with an integrated crane track is utilized, offering enhanced safety and efficiency. However, as no construction sites with such tents were observed in Germany, it can be assumed that these play a minor role in the construction process.

Solid timber components usually come directly from the factory to the construction site. The manufacturer provides the service of equipping the elements with weathering membranes as well as milling the holes for the crane loops.

There are a number of different ways to lift the elements up. Depending on how the hooks are secured, covering the connections should be considered (ideally, everything has already been prepared beforehand, so that protection doesn't need to be evaluated on site; e.g. Fig. 3). Pockets (blind holes), for the crane loops should be protected by covers, if possible.

Otherwise, screwing on mounts for crane hooks is an alternative to be considered that can prevent moisture ingress because the element does not need to have large holes through which water can accumulate. After the element has been lowered, Fastened and the hooks removed, the remaining holes should be covered with tape or otherwise protected. Otherwise, when water accumulates on the deck elements, a substantial amount can quickly infiltrate the otherwise protected component. The white discoloration in the Photograph is caused by the underlying moisture in the wood, indicating the extent to which water has penetrated via capillary action (around 35 cm in each direction with the grain). These situations pose an increased risk for undetected future damage. Such damage could potentially be mitigated or even prevented through extended drying times with proper ventilation and protection from additional moisture, or through preventive measures.

Once the elements are positioned, they need to be connected to the accompanying parts of the structure. In timber construction, larger structures cannot be erected in just a few days. It is common to use the ceiling as a whole to form a temporary roof. Before the ceiling is assembled, wall elements form a "bathtub" configuration that must be protected against moisture from above and below. To ensure protection, the joints between the panels need to be taped to prevent water from seeping through the gaps in case of rain. This is especially critical in timber frame structures, where water can accumulate inside the insulation. However, even solid timber structures should not be exposed to the weather. According to DIN 68800 Part 2, the moisture content of the wood must not be adversely affected during the construction process [12]. This means that any moisture that enters the structure must have time to evaporate. Unfortunately, construction schedules often do not allow for sufficient drying periods. Additionally, the undersides still need to be secured against moisture through their connection to the ceiling, just as the top must be protected from moisture ingress. This is particularly crucial when the ceiling elements are installed, and drainage occurs through gaps and open edges. In such cases, the supports can quickly receive a significant amount of liquid water, which, if not adequately protected, can accumulate or infiltrate the structure through joints. This area is difficult to monitor and later hard to dry out.

3.3 Protection of ceilings and adjacent walls

Fig. 4 illustrates an example of elements stacked before installation, and once assembled, shielded from potential rain by being covered with PE foil. The foil is tailored to the floor's shape and extends about 10 cm up the walls, with drainage through future installation shafts for collected water. However, it's crucial to safeguard the thin foil from punctures by dirt, tools, or screws. The foil's surface application allows for reusability or recyclability; however, it also permits moisture penetration through perforations, contrasting with fully bonded membranes that prevent water spread underneath.

Fig. 5 shows a construction site where the elements were protected before installation. During the laying process, they were promptly covered using foil strips. This method is simpler and faster because the membrane is pre-installed. It also requires less careful handling and attention from the workers than solely using tarpaulins. However, although diffusion-open, membranes hinder the subsequent drying of any moisture that has penetrated.

Fig. 4. Ceiling elements and upper wall sections covered with foil

Fig. 5. Ceiling protected by fully bonded translucent membrane

Especially in the adjacent areas, the membranes facilitate the rapid runoff of water, which can lead to a significant amount of water reaching the joints in a short period of time. For this reason, it is necessary to consider the potential implementation of a drainage system for larger surfaces.

3.4 Problems concerning insufficient process related protection

Fig. 6 shows a site where the ceilings have been protected from ingress with membranes, but the joints between the studs and the other walls have not been sealed. Initially, the necessary safeguards for the connections were not implemented, and subsequently, the studs and walls could accumulate water through the unsealed bottom end-grain. It was neither prevented that water could penetrate all floors (due to the large open structure) nor was there a plan for how to remove the water from the decks or where it should be drained.

Fig. 6. Water accumulation on undrained floor

Fig. 7. CLT element after extensive exposure to water

Situations like this could be found in 50% (six sites without sealing to walls in 12 cases of solid wood ceilings) of all cases where walls had not been sealed to the horizontal parts of the structure. One possible solution to prevent water on horizontal structures is to use existing shafts to drain the floors. By dictating the path the water takes through the unfinished structure, there is less risk of water running over exposed edges and causing unnoticed dampness in the construction. In Fig. 7, a wall panel CLT is shown where no sufficient protection measures were implemented. While the component is protected against moisture at the bottom through bituminous sealing as a connection to the reinforced concrete floor slab, two different moisture pathways can be identified:

1. Capillary Action: The dark line at the bottom of the component indicates that it must have stood in water before the sealing

was applied. Wood substances were washed out, leaving these marks behind.

2. Exposure to Rain: The surface layer, which leaves the factory as a smooth plane, has taken on a wavy structure due to water absorption. The individual lamellae have expanded, causing this undulating appearance.

Before the interior construction can proceed, it must be ensured that the moisture within the component is monitored and can be released. If this does not happen, it is likely that moisture related damage will occur.

4. Conclusion

Timber construction offers significant ecological advantages, but requires careful moisture management in order to prevent long-term damage. In order to fully utilize the benefits of timber as a sustainable building material, precise planning, combined with effective moisture protection measures is crucial.

It has been demonstrated that moisture protection in timber construction exhibits significant variability across different construction sites. On one hand, the organization and implementation of protective measures, as well as the level of protection afforded to components, vary considerably. It has been shown that in German timber construction, only a few companies utilize a comprehensive protection system for assembly. This poses significant risks for the durability of the structures. There is a risk of dampness in the structures going unnoticed, requiring renovation after only a few years or even immediately after completion. The economic damage is significant, but even greater is the potential damage of people losing trust in timber as a sustainable and durable material.

Pre-installed protection is a favourable way to reduce the risk of moisture intrusion on-site, where time pressure and misconceptions can hinder the effective implementation of systems. Furthermore, the use of a holistic approach that predicts the path of rainwater away from the structure is recommended. This can be achieved by using fully bonded membranes, sealing adjacent elements, and draining the structure to prevent water from running over unsealed edges and other surfaces. The implementation of systematic quality management practices is essential to ensure consistent moisture protection across all construction stages. However, due to a variety of timber construction systems and possible protection measures, this will be challenging. Continued research and development in this area will help to resolve unresolved challenges and improve construction practices.

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References

1. M. H. Ramage, H. Burridge, M. Busse-Wicher, G. Fereday, T. Reynolds, D. U. Shah, G. Wu, L. Yu, P. Fleming, D. Densley-Tingley, J. Allwood, P. Dupree, P. F. Linden, and O. Scherman, “The wood from the trees: The use of timber in construction “, Renewable and Sustainable Energy Reviews 68, 333 (2017).
2. F. Arriaga, X. Wang, G. Íñiguez-González, D. F. Llana, M. Esteban, and P. Niemz, “Mechanical Properties of Wood: A Review “ Forests 14, 1202 (2023).
3. A. Invidiata, M. Lavagna, and E. Ghisi, “Selecting design strategies using multi-criteria decision making to improve the sustainability of buildings“, Building and Environment 139, 58 (2018).
4. L. Tupenaite, L. Kanapeckiene, J. Naimaviciene, A. Kaklauskas, and T. Gecys, “Timber Construction as a Solution to Climate Change: A Systematic Literature Review“, Buildings 13, 976 (2023).
5. N. Ahn, A. Dodoo, M. Riggio, L. Muszynski, L. Schimleck, and M. Puettmann, “Circular economy in mass timber construction: State-of-the-art, gaps and pressing research needs“, Journal of Building Engineering 53, 104562 (2022).
6. M. González-Retamal, E. Forcael, G. Saelzer-Fuica, and M. Vargas-Mosqueda, “From Trees to Skyscrapers: Holistic Review of the Advances and Limitations of Multi-Storey Timber Buildings“, Buildings 12, 1263 (2022).
7. H. Svatoš-Ražnjević and L. Orozco and A. Menges, “Advanced Timber Construction Industry: A Review of 350 Multi-Storey Timber Projects from 2000–2021“, Buildings 2022, 404 (12).
8. R. Bocksch, “Wo Deutschlands Wälder wachsen [Digitales Bild]“, Statista GmbH (2023), https://de.statista.com/infografik/13293/waldflaeche-in-den-bundeslaendern/ (accessed 24.05.2024).
9. K. Kalbe, T. Kalamees, V. Kukk, A. Ruus, and A. Annuk, “Wetting circumstances expected moisture content and drying performance of CLT end-grain edges based on field measurements and laboratory analysis“, Building and Environment, 221, 109245 (2022).
10. J. Y. Wang, R. Stirling, P. I. Morris, A. Taylor, J. Lloyd, G. Kirker, S. Lebow, M. Mankowski, H. M. Barnes, and J. J. Morrell, “Durability of mass timber structures: A review of the biological risks“, WFS 50, 110 (2018).
11. H. Böhmer, T. Brinkmann-Wicke, S. Sell, J. Simon, and C. Tebben, VHV-Bauschadenbericht. Hochbau 2021/22 : Qualität und Kommunikation (Fraunhofer IRB Verlag, Stuttgart, 2022).
12. R. Glauner, D. Grosser, and E. Melcher, Holzschutz; Praxiskommentar zu DIN 68800 Teile 1 bis 4. Praxiskommentar zu DIN 68800 Teile 1 bis 4, 3., vollständig überarbeitete Auflage (Beuth Verlag, [S.l.], 2022).