

Master's Programme in Building Technology

Moisture control in mass timber construction projects

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Abstract

Building with engineered mass timber elements is becoming increasingly popular due to environmental and economic benefits of timber construction. Wood construction is typical for small residential buildings, but larger multistorey offices and residential buildings are rarely built by utilizing wood as the main load bearing material. Currently there is large potential on the market to increase the amount of wood used in the construction, but the lack of knowledge and experience still prevent the construction industry from utilizing wood on a larger scale.

The thesis consists of a literature review and a case study with project analyses, measurements and interviews. In the literature review wood's moisture behaviour, moisture measurement methods, moisture control practices and mass timber construction methods are investigated from different sources. The case study takes a closer look of the SRV Rakennus Oy's Wood City construction project, which is located at Jätkäsaari, Helsinki. This is achieved by monitoring the construction site, by interviewing personnel and by doing moisture measurements and other onsite observations. The main focus of this thesis are the moisture control practices of mass timber construction, and the main goal is to evaluate the best moisture control practices learned from the Wood City project.

Moisture control is an essential part of mass timber construction. Weak planning, lack of monitoring, inefficient methods and poor communication relating to moisture control can lead to potential problems. High moisture content changes in mass timber structures can cause critical deformations due to shrinking and swelling properties of wood. Exposure of wooden structures to significant and long-lasting moisture loads can also cause mould growth and structural damages due to rotting.

From this thesis it can be concluded that well planned and active moisture control is important in mass timber construction. Mass timber structures are by nature relatively resilient to short term moisture loads, but the moisture loads should always be minimized with expeditious and properly timed construction, appropriate weather protection and by taking care of air circulation and drying.

Keywords CLT, LVL, GLT, relative humidity, moisture control, weather protection, mass timber element, moisture content, mould, EMC

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Tiivistelmä

Massiivipuuelementtien avulla rakentamisesta on tulossa yhä suositumpaa puurakentamisen ympäristöystävällisyyden ja taloudellisten etujen ansiosta. Puurakentaminen on tyypillistä pienille asuinrakennuksille, mutta isompia kerrostaloja ja monikerroksisia toimistoja harvoin rakennetaan siten, että puu toimii pääasiallisena kantavana runkomateriaalina. Markkinoilla on tällä hetkellä paljon potentiaalia lisätä puun käyttöä rakentamisessa, mutta tiedon ja kokemuksen puute estää edelleen rakennusala ottamasta puuta käyttöön laajemmassa mittakaavassa.

Opinnäytetyö koostuu kirjallisuuskatsauksesta ja tutkimuksesta, joka sisältää projektianalyyskejä, mittauksia ja haastatteluja. Kirjallisuuskatsauksessa tutkitaan puun kosteuskäyttäytymistä, kosteuden mittaamenetelmiä, kosteudenhallintakäytäntöjä ja massiivipuurakentamista. Tutkimuksessa tarkastellaan SRV Rakennus Oy:n Wood City -rakennushanketta, joka sijaitsee Helsingin Jätkäsaarella. Tutkimus tehdään valvomalla työmaan toimintaa, haastatteleamalla henkilöstöä sekä tekemällä havaintoja ja kosteusmittauksia. Tämä opinnäytetyö keskittyy massiivipuurakentamisen kosteudenhallintaan ja päätavoitteena on selvittää, mitkä ovat parhaat Wood City -projektista opitut kosteudenhallintakäytännöt.

Kosteudenhallinta on oleellinen osa massiivipuurakentamista. Heikko suunnittelu, valvonnan puute ja huono viestintä kosteudenhallinnan osalta johtavat mahdollisiin ongelmiin. Jos puu altistuu pitkäaikaisille kosteusrasituksille, se voi alkaa lahota tai sen päälle saattaa muodostua homeita. Korkeat kosteuspitoisuuden muutokset puurakenteissa voivat myös aiheuttaa kriittisiä muodonmuutoksia puun kutistumis- ja turpoamiskyvyn vuoksi.

Tästä opinnäytetyöstä voidaan todeta, että hyvin suunniteltu ja aktiivinen kosteudenhallinta on kriittinen osa massiivipuurakentamista, varsinkin jos ei käytetä koko rakennusta peittävää sääsuojaa. Massiivipuurakenteet ovat melko kestäviä kosteutta vastaan, mutta silti massiivipuurakenteiden kosteuskuormitukset tulisi minimoida nopealla ja oikein ajoitetulla rakentamisella, tilapäisillä sääsuojauksilla ja tehokkaalla kuivattamisella ilman kierron avulla.

Avainsanat CLT, LVL, GLT, suhteellinen kosteus, kosteudenhallinta, sääsuoja, massiivipuuelementti, kosteuspitoisuus, home, tasapainokosteus

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Preface and acknowledgements

This topic was chosen due to the fact, that moisture control is an essential part of mass timber construction, and usage of timber as a construction material is expected to increase in the future as a result of the green transition.

I would like to thank SRV Rakennus Oy for letting me have this great opportunity to do my master's thesis together with them. In particular, I wish to thank SRV's Wood City office 2 organization for their cooperation and all the other people that took part of the thesis interviews.

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Last but certainly not least, I want to thank my parents and close family for continuous support during my studies.

Espoo 23 July 2023
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Symbols and abbreviations

Symbols

AH	Absolute humidity [g/m ³]
EMC	Equilibrium moisture content [%]
FSP	Fibre saturation point [%]
MC	Moisture content [%]
RH	Relative humidity [%]
SH	Saturation humidity [g/m ³]
T	Temperature [°C]

Abbreviations

AH	Absolute humidity
CLT	Cross laminated timber
EMC	Equilibrium moisture content
EWP	Engineered wood product
FSP	Fibre saturation point
GLT	Glued laminated timber
LVL	Laminated veneer lumber
MC	Moisture content
MIS	Moisture induced stresses
RH	Relative humidity
SH	Saturation humidity

1 Introduction

1.1 Background

People, companies, and governments have become aware of the current environmental issues and thus clients and regulations now require that buildings should be constructed with sustainable methods. This has especially increased the interest of using more sustainable materials such as wood in construction projects. Advancements in wood technology and construction engineering combined with increased awareness of environmental protection and sustainability have increased interest around multi-story mass timber construction. For example, the goal of the Finnish environmental ministry's "Wood construction" 8-year (2016-2023) program is to increase the use of wood in all areas of construction. The target is to double the use of wood in construction, improve internationally competitive know-how and industrial manufacturing in Finland (Ympäristöministeriö, 2023). Climate needs require the expansion of wood use and the development of wood-based construction systems and products. According to expert interviews, mass timber construction is developing and growing constantly, but it still covers only a small percentage of all construction.

Currently mass timber construction's main advantages are its sustainability and fast building speed. The fast construction speed is achieved with mass timber elements because those can be easily prefabricated to high level of detail in factory conditions, thus cutting down workloads and assembly times onsite (Koppelhuber et al., 2017). The sustainability of mass timber construction is achieved by the facts that wood is a renewable, more energy efficient and less carbon (CO₂) emitting material. In fact, wood acts as a carbon sink, meaning that it stores carbon rather than releases it into the atmosphere when it is been used as a building material (Valsta et al., 2017).

According to Green (2012) mass timber construction is also economically viable option when compared to concrete and steel because of its light weight, higher strength-to-weight ratio, high level of prefabrication, fast onsite installing speed, and superior lifecycle aspects such as easier recyclability and energy recovery. According to expert interviews, mass timber construction in general costs more than concrete and steel construction, but in some specific projects mass timber can in fact be cheaper than other materials.

Especially here in Finland, the wood reserves are abundant and thus the potential to build with wood on a larger scale is a great way to increase the usability of our forest resources. This would also be extremely beneficial for the Finnish economy to use national wood sources as building materials. In some

areas wood is a local resource which might grow faster than it is utilized. According to Luonnonvarainkeskus (2023), in Finland at year 2017 the total amount of tree that was cut down was 87,19 million m³ and tree growth was 103,23 million m³. At year 2021 the total amount of tree that was cut down was 91,64 million m³ and the expected growth was 103,5 million m³. This indicates that in Finland, usage of wood in construction would be sustainable as currently forests grow faster than those are cut down (Luonnonvarainkeskus, 2023).

Different organizations do recognize the potential of mass timber construction from the sustainability standpoint, but weaker cost competitiveness, lack of knowledge and experience still hinders the wider use of mass timber. Lack of experience leads to uncertainties with costs, design solutions and construction practices which consequently pushes people away from tackling construction projects where mass timber is used as load bearing material (Jones et al., 2016). Problem with mass timber construction is also that there are no standard solutions that can be repeated in every project the same way, thus everything is basically designed from zero and solutions are project specific. One important step to increase mass timber construction is the standardization of the structural solutions. According to expert interviews, the standardising will happen overtime, but it takes time.

Differing from other major construction materials like steel and concrete, wood requires more attention to details because of its characteristics. Wood is a hygroscopic material, which means that it will absorb and desorb moisture depending on the surrounding conditions. Because of this ability, wood also shrinks and swells, which in tight tolerance construction can be problematic. In addition, wood can rot and support mould growth, which can cause damage to the structures and indoor air quality problems. Thus, it is important to control the moisture conditions around the wooden structures in order to prevent these issues. Without proper moisture control actions during mass timber construction, the end building could be moisture damaged and not safe for healthy usage (Puuinfo, 2020B). According to Kalbe et al. (2022), recent surveys conducted in Sweden show that a significant factor deterring the selection of wood for constructing of multistorey residential buildings are the concerns around mould and moisture. Still, wood is in general relatively resilient to moisture if kept within certain limits (Wang, 2016).

Moisture damages are one of the most significant environmental factors harmful to human health. Excessive humidity causes biological and chemical decomposition of materials, the reaction products of which produce substances harmful to health. Especially mould, which will grow in indoor conditions when sufficient moisture and temperatures are available, is a key element of indoor air pollution (WHO, 2009).

Moisture control is a complete process that consists of moisture technically safe design solutions, moisture control during construction, controlled drying of structures, and proper use and maintenance of the building (Puuinfo, 2020A). According to Wang (2016), onsite moisture control is likely the most challenging from these steps due to several possible moisture exposure situations and due to cost and site constraints of a construction project.

1.2 Goal of the thesis

The main focus area of this thesis is to investigate mass timber construction's moisture control practices and the main goal of this thesis is to investigate SRV Rakennus Oy's Wood City construction project and to find out what are the best practices in mass timber construction's moisture control that have been learned from the entire Wood City project.

1.3 Research methods

Expert Interviews

With expert interviews the main goal was to gather additional information on the moisture control practices used in the already completed Wood City buildings and on best learned practices in mass timber construction's moisture control in general. Also, additional information on moisture measurements and mass timber construction in general was gathered during the expert interviews. Ten experts were interviewed during this thesis more specifically, but discussions were had with multiple additional experts about different topics surrounding mass timber construction and moisture control.

Document review

With document review the main goal was to gather additional information of the Wood City buildings and what moisture control practices were used while building them. Different documents were reviewed, but the main focus was on reviewing the moisture control plans and structural drawings of each building. On top of the project specific documents, also two master theses, that were made in 2017 about the moisture control and moisture measurement practices in the Wood City project's two residential buildings, are used as reference material for this master thesis. Sami Musakka's master thesis focused on the onsite moisture and temperature measurements and Olavi Penttilä's master thesis focused on the onsite moisture control practices.

Onsite observations and measurements

With the onsite observations the main goal was to monitor the progress of construction and moisture control practices done onsite and to effectively

document those. With the onsite measurements the main goal was to investigate what the moisture content levels of the different mass timber structures were during construction. Onsite observations were made from the Wood City's office 2 jobsite, which consisted of sensory monitoring of the worksite conditions, taking pictures, and interviewing workers and work management. Onsite observations were made during the regular workdays at least on average 2 times per week. Onsite measurements consisted of taking moisture content measurements from different mass timber structures and logging data of the onsite conditions.

1.4 Disposition

In the second chapter (Literature review) wood's properties, moisture related phenomena, mass timber construction related materials and structures, moisture control practices and moisture measuring methods are explained and defined. In the third chapter (Description of the case study) the Wood City project and all its individual buildings are introduced, and wood-concrete composite subfloors are handled. In the fourth chapter (Description of office 2 onsite measurements) onsite measurement plans and used measurements methods are defined and explained. In the fifth chapter (Wood City's moisture control) the moisture control practices, used in all the Wood City buildings are explained. In the sixth chapter (Findings from expert interviews and document review), moisture control related findings from expert interviews and document review are presented. In the seventh chapter (Findings from onsite observations), moisture control related findings from office 2 jobsite are presented. In the eighth chapter (Findings from onsite measurements) moisture measurement results from office 2 jobsite are presented and analysed. In the ninth and final chapter (Conclusion) the research question of the thesis is answered by listing all the best moisture control practices that have been learned during the whole Wood City project, and additionally further research topics are suggested.

2 Literature review

2.1 Moisture phenomena

Absolute-, saturation- and relative humidity

Absolute humidity (AH) denotes the mass of water vapor present in a specific volume of air. Absolute humidity fluctuates in response to alterations in air pressure. Notably, it exhibits considerable variations across the different times of the yearly seasons. The absolute vapor content in the air is much higher during summers than it is during winters. During summers AH can be 25 g/m³ and during the winters it can be 5 g/m³. The upper limit of absolute humidity is called saturation humidity (SH), which expresses what is the maximum amount of water vapor that can be in the air in a given temperature. Warm air can include more water vapor than cold air. If there is more vapor content in a given temperature than saturation humidity allows, then the vapor in the air condenses into water droplets. This especially happens when warm high vapor content air cools quickly near a cold surface, for example on a window. Relative humidity (RH) denotes the amount of water vapor present in the air relative to the maximum amount of water vapor the air can hold at a specific temperature. So, in essence, RH denotes what air's current water vapor content (AH) is divided by maximum water vapor content limit of air (SH) is in that given temperature. When RH is 100% then absolute humidity and saturation humidity are the same and water vapor condenses into water droplets. The warmer the air, the more I can hold water vapor, but this does not result into higher relative humidity. Seasonally during cold winter weather relative humidity is high but absolute humidity is low and during warm summer weather relative humidity is lower than during winter, but the absolute humidity is higher (Hens, 2012). Absolute humidity can be calculated with Equation 1 and relative humidity with Equation 2.

$$AH = 4,85 + 3,47 \cdot \left(\frac{T}{10}\right) + 0,945 \cdot \left(\frac{T}{10}\right)^2 + 0,158 \cdot \left(\frac{T}{10}\right)^3 + 0,0281 \cdot \left(\frac{T}{10}\right)^4 \quad (1)$$

$$RH = \left(\frac{AH}{SH}\right) \cdot 100 \quad (2)$$

Where AH is absolute humidity [g/m³], RH is relative humidity [%], T is temperature [°C] and SH is saturation humidity [g/m³].

Capillary suction

Capillary suction is a phenomenon where moisture is sucked inside a porous material like wood via pore pressure caused by water's surface tension and the pores of the material in contact with water. Capillary suction is greater when the pores of the material are smaller and weaker when the pores are

bigger. Capillary moisture balance is reached when water has risen to a height where the pore pressure and the earth's gravitational force directed to water are in balance (Hens, 2012).

Water vapor diffusion

Water vapor diffusion is a phenomenon where water vapor moves in air or in pores of material from higher concentration (higher pressure) to lower concentration (lower pressure) this way balancing out the pressure differences. Usually, diffusion happens from warm body of air to cold body of air because warm body of air holds more water vapor. This usually means that warm inside air tries to push through building's walls to get to the outside in order to balance out the pressure differences. This will cause moisture build up in the exterior wall layers if there is no vapor barrier in the external wall structure (Hens, 2012). The natural flow of water within trees follows the direction of wood's grains. As a result of this phenomenon, the diffusion coefficient of wood is approximately 2,5 times greater in the parallel direction to the grain compared to the perpendicular direction. Consequently, water absorption from wood surfaces cut perpendicular to the grain occurs at a much faster rate. Commonly, these kinds of locations are located at the end of wooden elements, which typically also house the element connection points. Water absorption and desorption of timber surfaces can also be affected with different coatings. By utilizing different coatings, it becomes feasible to either reduce the rate of moisture changes in wood or even completely prevent it (Puuinfo, 2020B).

2.2 Wood's properties

Wood's axes

Wood is a hygroscopic material which means that wood has the ability to absorb and desorb moisture according to the fluctuations in relative humidity and temperature of the surrounding conditions. As wood's moisture content changes, it shrinks or swells and changes its shape accordingly. Wood is also anisotropic material which means that the properties of wood are different in different directions of its grain (Puuinfo, 2020C). Wood has three different axial directions: radial, tangential, and longitudinal. These can be seen from Figure 1. Radial axis is also called perpendicular to grain direction and longitudinal axis is also called parallel to grain direction (AITC, 2012). Wood has a higher compressive strength parallel to grain than perpendicular to grain and wood shrinks and swells more perpendicular to grain than parallel to grain (Puuinfo, 2020C).

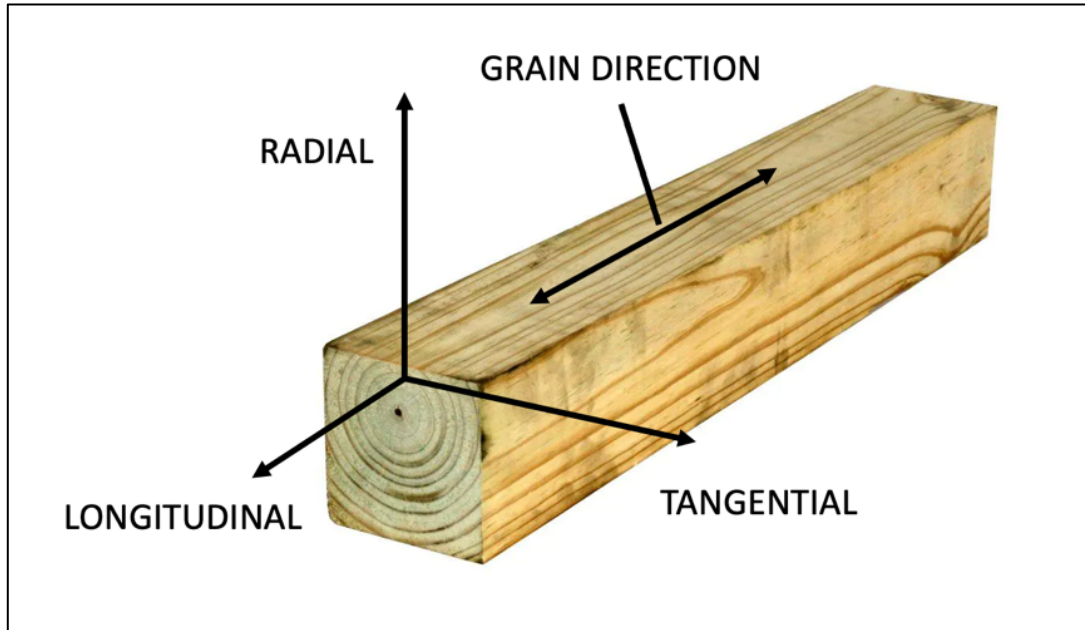


Figure 1: Wood's axial directions.

Wood's moisture content

Moisture content of wood is expressed as a percentage, which describes the ratio of the mass of moisture bound to the wood to the mass of completely dry wood. The amount of moisture is expressed as a percentage by weight (SFS-EN 13183-1, 2002). Wood's moisture content can be calculated with Equation 3.

$$MC = \frac{m1 - m0}{m0} \cdot 100 \quad (3)$$

Where MC is the moisture content of the investigated piece of wood [%], $m1$ is original mass of investigated piece of wood [kg] and $m0$ is absolute dry mass of the investigated piece of wood [kg].

Wood's moisture content is held in its cell walls as bound water and in its cell cavities as free water. When wood dries, the free water in the cell cavities leaves first. The moisture state of wood, where free water has left the cell cavities, but the cell walls contain the maximum amount of water, is called the fibre saturation point (FSP). At fibre saturation point the moisture content of the wood is around 30%. After the free water in the cell cavities is removed, the water bound to the cell walls begins to leave, as a result of which the wood begins to shrink. Shrinkage causes changes in the shape of the wood, which in turn causes internal stresses in the wood. Internal tensions cause cracks in wood and, for example twisting and buckling. When the moisture content of the wood is below 20%, it is usually safe from decay fungi, moulds, and other biological pests. The strength and stiffness properties of dry wood are also

superior to wet wood. The improvement in strength properties as the wood dries is based on the cell walls moving closer to each other and sticking to each other (Puuinfo, 2020B).

Wood's moisture content generally depends on the surrounding temperature and relative humidity conditions. Wood always tries to balance itself with surrounding conditions to reach its so-called equilibrium moisture content (EMC) by desorbing and absorbing moisture from surroundings accordingly with the changes of temperature and relative humidity. Equilibrium moisture content can be approximated for all wood species with Equation 4 (Mitchell, 2018).

$$EMC = \frac{1800}{W} \cdot \left(\frac{K \cdot h}{1 - K \cdot h} + \frac{(K1 \cdot K \cdot h) + (2 \cdot K1 \cdot K2 \cdot K^2 \cdot h^2)}{1 + (K1 \cdot K \cdot h) + (K1 \cdot K2 \cdot K^2 \cdot h^2)} \right) \quad (4)$$

Where EMC is equilibrium moisture content of wood [%], h is relative humidity in decimals, T is the ambient temperature [°C] and W , K , $K1$, and $K2$ are coefficients:

$$K = 0,791 + 0,000463 \cdot T - 0,000000844 \cdot T^2$$

$$K1 = 6,34 + 0,000775 \cdot T - 0,0000935 \cdot T^2$$

$$K2 = 1,09 + 0,0284 \cdot T - 0,0000904 \cdot T^2$$

$$W = 330 + 0,452 \cdot T - 0,00415 \cdot T^2$$

Wood reaches its EMC in different times according to its conditions. If wood is covered or sealed from air, it cannot absorb or desorb moisture effectively thus leading to longer times at finding the EMC. In addition, wood's own abilities and size affect how fast it finds the equilibrium moisture content. For example, some woods species reach EMC faster than others. But in general, the equalization process leading to EMC is relatively slow, for example, with mass timber elements, the levelling process may take several weeks. The speed of the levelling process can also be influenced by wood surface treatment that slows down the transfer of moisture (Puuinfo, 2020B). Figure 2 shows a chart from which wood's EMC can be determined when RH and temperature are known. For example, if temperature is 22 °C and RH is 42,5% then according to the chart the EMC of wood is about 8%.

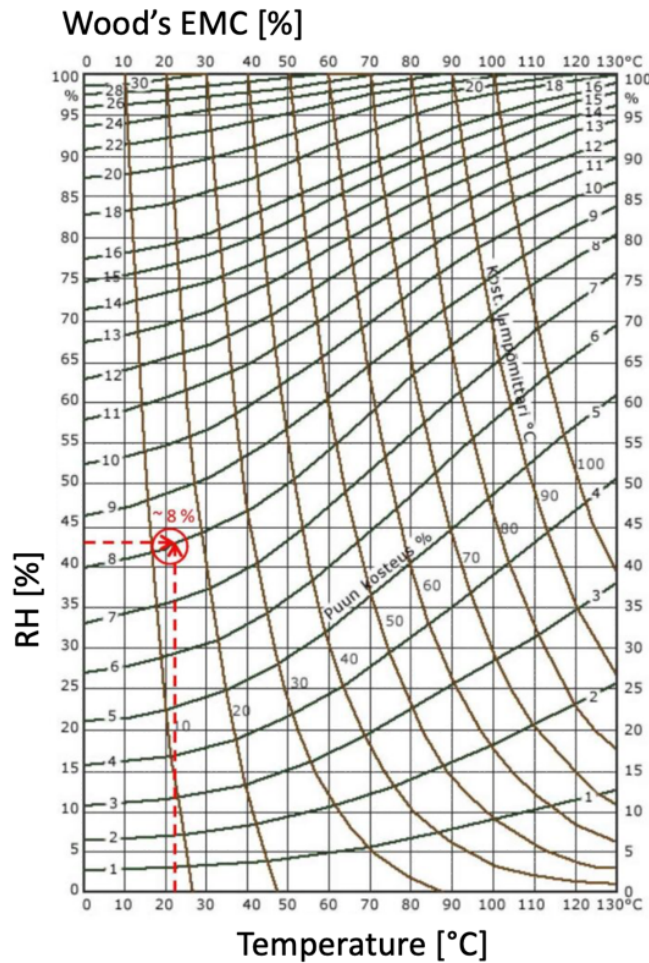


Figure 2: Wood's equilibrium moisture content chart (Puuinfo, 2020B).

Swelling and shrinking of wood

Wood shrinks and swells according to its moisture content which changes accordingly with surrounding temperature and humidity conditions. In addition, like all the other materials, wood also changes its dimension due to thermal expansion, but this is small compared to MC change induced swelling and shrinking. Drying wood under its FSP (MC \approx 30%) will decrease bound water from wood's cell walls which will result in shrinking of wood. Wood will only shrink if its moisture content drops below its fibre saturation point. Vice versa, wood can only swell to the point that its MC reaches its FSP. Most wood species shrink and swell parallel to grain about 0,02% and perpendicular to grain about 0,25% for every 1% change in wood's MC (Puuinfo, 2020B). Small dimensional changes in wood because of swelling and shrinking cause no problems, but excessive swelling and shrinking of wood after installation may cause structural problems, such as cracking of wood, possible wholes in structural envelope and issues in structural joints (AITC, 2012). Wood's size after it has shrunk or swollen can be calculated with Equation 5.

$$l_1 = l_0(1 + k(u_1 - u_0)) \quad (5)$$

Where l_1 is size of the wood after swelling or shrinking [m], l_0 is the size of the wood before swelling or shrinking [m], k is the shrinkage-swelling factor in decimals (k is about 0,0002 parallel to grain and 0,0025 perpendicular to grain), u_0 is the starting moisture content of wood in decimals where wood's size is l_0 and u_1 is new moisture content that induces the swelling or shrinking of wood in decimals (SFS-EN 14080, 2013).

Wood experiences internal stresses when it swells or shrinks due to moisture absorption or desorption from its surroundings. When moisture-induced stresses (MISs) surpass the maximum tensile strength perpendicular to the grain of the wood, they have the potential to result in cracks in the wood. Tensile strength of timber perpendicular to its grain is relatively low, thus cracks usually form in the longitudinal direction parallel to grain. Cracks that appear on mass timber elements due to moisture induced stresses can significantly reduce the load bearing capacity of timber (Mohebbi & Broushakian, 2022).

Mould growth

The presence of excessive moisture on commonly used wood species can promote the growth of microbes, including mould, fungi, and bacteria. These microorganisms then release spores, cells, and volatile organic compounds into the indoor air, posing health risks to humans. (WHO, 2009). Mould usually does not damage wood, but it shows as stains on top of wood, which decrease its aesthetic appearance (AITC, 2012). Mould growth possibility and speed are influenced accordingly by relative humidity and temperature of surrounding conditions, but also material's own sensitivity to support mould growth. Moulds and other microbes can grow when the relative humidity is constantly above 80% RH, and the temperature is +5-50 °C. Under favourable conditions (relative humidity above 90% and temperature around +20 °C) mould growth can occur within a few days or weeks. Microbes do not grow at temperatures below 0 °C. Organic building materials, such as wood are more susceptible to microbial growth than inorganic building materials (Tampere University, 2018). Incidents occurring during construction with mould growth are often associated with wetting caused by liquid water sources such as rainwater and work-related water usage (Wang, 2016). Figure 3 displays the general speed of mould growth on top of wood at different conditions.

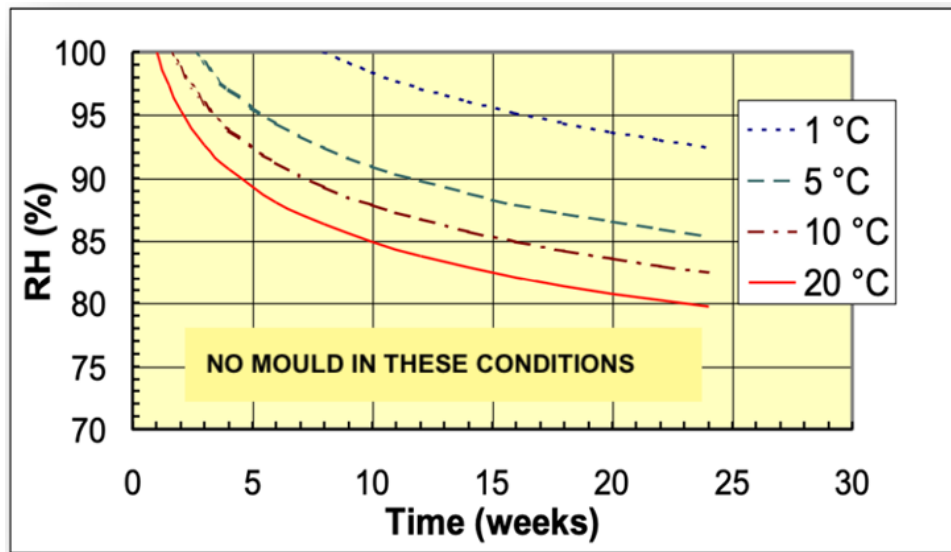


Figure 3: Mould growth speed on wood (Viitanen, 2019).

Wood decay

Wood's decay (rotting) is caused by a fungus. The fungus uses wood as its source of nutrients. The fungus can only survive on wood if it receives air, and the air temperature and moisture conditions are also favourable. Wood will not rot if its moisture content is maintained below 20% or temperatures are below 0°C or over 38°C. Decayed wood has a different volume and density leading to reduced strength and fire resistance (AITC, 2012). Figure 4 presents a wood's decay chart. For example, it can be noticed from Figure 4 that in order for wood to decay even in high humidity and temperature condition, 95% RH and 20°C, it takes as much as 4 months to happen.

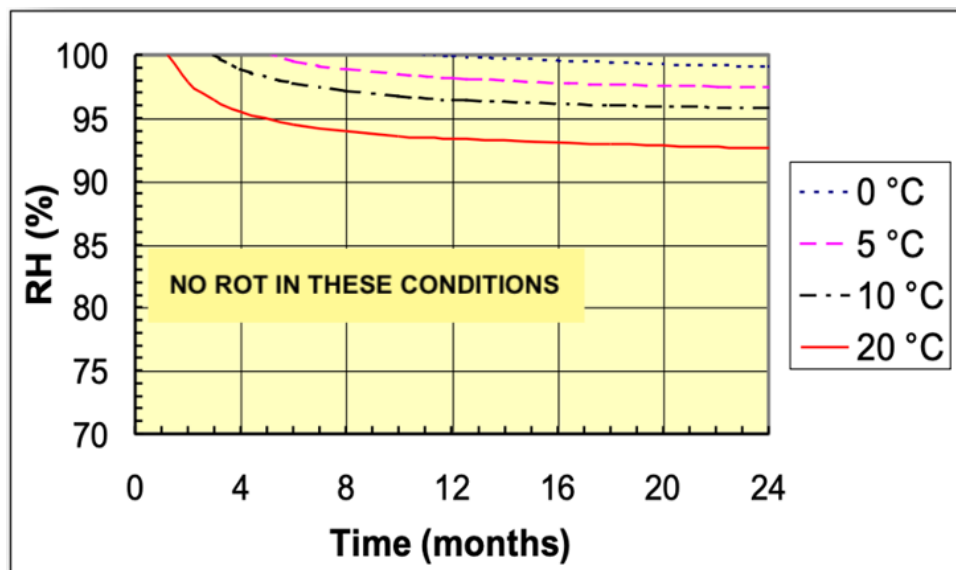


Figure 4: Decay initiation speed on wood (Viitanen, 2019).

2.3 Engineered wood products

Engineered wood products in general

Engineered wood products (EWPs) are all the wooden products that are enhanced by joining wood pieces together with different methods to form a final product. Engineered wood products have multiple advantages over plain wood products. EWPs are formed by using multiple pieces of wood and thus are more homogeneous. EWPs reduce the variability associated with solid sawn lumber, but still, they do not eliminate it entirely (Green & Taggart, 2017). According to Fink et al. (2018) also variability between EWP products is quite large. For example, CLT-products coming from different production series might have significant variability between them (Fink et al., 2018). EWPs also enable a higher level of finish in factory conditions, thus cutting down the time that it takes to finish the work onsite. For example, CLT facade elements can be ordered to have windows preinstalled to them in order to speed up the work onsite. EWPs are also highly durable, warp and twist less than sawn timber and have long service lives if properly protected from excess moisture. EWPs are also highly versatile and different types of elements for all kinds of needs can be made from them. In theory EWP dimensions are not limited by anything, but in practice transportation and factory capabilities limit the size of the elements that can be produced. In addition, EWPs are also cost-effective because of their ability to be quickly installed onsite and because they can be produced relatively easily in automated factories into high level of detail (Green & Taggart, 2017). Typical engineered wood products are made from spruce and those include glued laminated timber (GLT), cross laminated timber (CLT) and laminated veneer lumber (LVL). Figure 5 shows samples of all these engineered wood products.



Figure 5: GLT (left image), LVL (middle image) and CLT (right image).

Source: <https://puuinfo.fi/puutieto/insinoorituotteet/>

Glued laminated timber

Glued laminated timber (GLT) or glulam is an engineered wooden product. It is produced by gluing timber planks together in parallel pattern. Different types of elements can be made out of GLT, but it is mainly used for columns

and beams. In addition, GLT-elements can be produced with different types of shapes, sizes and lengths according to the needs (Green & Taggart, 2017). According to SFS-EN 14080 (2013) wood's moisture content should be around 8-13% when it leaves factory conditions.

Cross laminated timber

Cross laminated timber (CLT) is an engineered wood product. It is produced by gluing timber planks in layers and in crossing patterns. In addition, CLT also has odd number of glued timber layers, meaning the bottom and the top layers are always facing the same grain direction. Different type of elements can be made with CLT, but it is best suited for floor slabs and load bearing external or internal walls. Dimensional changes in CLT due to temperature and moisture changes are relatively small because of its crossed layering, thus cracks appear less in CLT than in GLT (Green & Taggart, 2017).

Laminated veneer lumber

Laminated veneer lumber (LVL) is an engineered wood product. It is produced by gluing multiple veneer layers together in parallel or in crossing patterns depending on the final intended use of the material. Different types of elements can be made with LVL, but it is best suited for floor slabs and external and internal load bearing walls (Green & Taggart, 2017).

GLT, CLT, LVL and moisture

According to Wang (2016) CLT and GLT are less vulnerable to moisture damages than LVL, because LVL has a higher water absorption and entrapment potential. Because LVL is more sensitive to wetting, it should be protected more from moisture during construction than CLT and GLT (Wang, 2016). According to expert interviews, if moisture penetrates deep inside mass timber structures, LVL-elements will dry out extremely slowly compared to CLT and GLT-elements. Because of this, CLT and GLT-elements are a safer option when it comes to mass timber construction's moisture control. According to Musakka (2017), from a LVL wetting and drying test it was found that a body of water can stay on top of LVL for 10 days without LVL's moisture content rising over 17%. Hydrophobic coatings should be used especially at LVL-element ends to prevent excessive wetting, because water penetrates easily inside LVL-elements when entering from the end grains parallel to the grain. Once the moisture has penetrated deep into the LVL-element, the drying of the excessive moisture is extremely slow (Musakka, 2017). If GLT, LVL and CLT only get wet on the surface, their drying times are quite fast, but if the moisture penetrates deeper and or they are covered or sealed with other materials, they all dry relatively slowly (Wang, 2016).

2.4 Structural systems

Mass timber construction

Mass timber construction utilizes large-sized engineered wood products in construction such as elements made from GLT, LVL or CLT. More specifically mass timber elements have to be lifted into place with lifting equipment, while timber elements can be lifted by using manpower (Mayo, 2015).

Load bearing walls system

In load bearing walls structural system, loads coming to the floor slabs are distributed to the load bearing walls that hold the floor slabs. The walls then distribute the loads to the foundation. The advantage of load bearing walls system is a faster building speed as the walls act as load bearing structures and room walls. Load bearing walls system is mainly used in residential buildings (Heikinheimo, 2012).

Column-beam system

In column-beam structural system, loads coming to the floor slabs are distributed to the beams that hold the floor slabs. The beams then distribute the loads to the columns that hold the beams and the floor slabs. Finally, the columns then distribute the loads to the foundation. The outer walls are usually completed with non-load bearing facade elements. The advantage of column-beam systems is that spaces are more flexible for post-construction because there are no fixed walls that cannot be moved. Column-beam system is mainly used in commercial buildings like offices (Heikinheimo, 2012).

Hybrid- and composite structural systems

In composite structural system, there are two or more different materials used in load bearing structures. For example, foundation, elevator shafts and stair shafts are made of concrete, beams are made of steel and columns and floor slabs are made of wood. In hybrid structural system, load bearing walls and column-beam system are combined together. A wooden office building with a hybrid structure can, for example, have a column-beam structure in the centre of the building and load bearing outer walls. The advantage of the system is its adaptability and small space costs of load bearing structures (Heikinheimo, 2012).

2.5 Moisture control in mass timber construction

Purpose of moisture control

The purpose of moisture control is to prevent the formation of moisture related damages during and after construction of a building. Moisture related damages can be prevented or decreased with properly planned moisture control practices, such as adequate onsite weather protection. How much effort is required in moisture control depends mainly on onsite weather conditions and the sensitivity of the materials used in the construction process. The

more the materials being used are vulnerable to moisture issues, the more moisture control practices need to be applied to ensure good built quality and prevention of moisture damages.

Factors affecting moisture control practices

Materials and structures

Different timber materials and mass timber structures absorb and trap water and dry out at different rates. Factors such as engineered wood product type, dimensions, method of manufacturing, wood species, presence of internal voids, surface treatment and exposure of end grains dictate how fast and how deep water will penetrate into mass timber structures during exposure to different water sources. For example, mass timber elements that are large in size naturally have a higher wetting potential, because larger surface area gathers more water and bigger scale results in slower drying once the water has penetrated deep inside the element. Drying and wetting potential of mass timber elements is also affected by their location and orientation. For example, horizontal structures, such as subfloors, are more likely to be exposed to rain and thus need more time to dry out after been exposed to water (Wang, 2016).

Wood's end grains and defects

Multiple factors increase the likelihood of moisture penetration deep into mass timber structures. End grains are the most absorptive part of mass timber elements thus moisture penetrates vertical elements from top and bottom and horizontal elements from side-ends more easily. Also, mass timber elements are usually connected from end grains and their connection points can also be trapping water, thus causing fast wetting of the mass timber elements and subsequently possible moisture damages. In addition, cracks, gaps, and various defections in wood increase the likelihood of moisture penetration deeper into the mass timber structures (Wang, 2016).

Limit values

Moisture control onsite has to follow limit values that have been set for the mass timber elements, in order to make sure that no moisture damages will occur during or after construction. General limit values for moisture content and relative humidity in mass timber construction according to expert interviews, Puuinfo (2020B), and Tampere university (2018) are 20% MC and 80% RH. In addition, the limit values can also be project specific.

Weather and location

Weather is a local phenomenon, and can change drastically between years, but overall weather tends to move close to the average values. Materials and structures onsite are exposed to significant moisture loads especially at

coastal areas that have rainy winter climates with high moisture loads. Weather conditions such as rainfall amounts, frequency of rain, humidity levels, temperature and wind speed affect the wetting and drying potential of mass timber structures. Typically, wood requires some time to absorb water and raise its moisture content. Therefore, the duration of wetting is more important than the overall quantity of water that falls on the wood's surface. (Wang, 2016). In addition, luck with weather conditions has a significant impact on how successful the moisture control can be during construction.

Seasonal timing

Seasonal timing of construction also affects the difficulty of onsite moisture control. For example, the moisture control practices needed onsite during spring are less significant than those needed in autumn. The added need for moisture control practices, such as weather protections, can also increase the building costs significantly. Because seasonal timing affects the difficulty and cost of moisture control, it is critical to schedule the construction phases considering the seasonal weather conditions, so that moisture sensitive work phases can be performed during good weather (Rakennustieto Oy, 2010).

Moisture control in design

Generally

Building moisture control starts with the design process of the building and its structures (Puuinfo, 2020A). The structural solutions should primarily be such that the entry of excessive moisture into the structures is prevented and if it enters the structures, there are exit routes and the possibility of efficient drying of the excess moisture (Helsingin rakennusvalvonta, 2016). The building, structures and building components must be moisture-technically functional during the planned service life, considering internal and external moisture stress. Excessive moisture content in the building or the accumulation of moisture in its parts cannot damage the building or cause health problems for its occupants. Designers must ensure that the building is designed in such a way that it meets the essential technical requirements for its moisture-technical functionality (Ympäristöministeriö, 2017). Design solutions have to also comply with building regulations and guidelines, the structures have to be designed to be damage- and mistake tolerant, risky structures have to be carefully considered using prior knowledge and experience, and design solutions have to be as simple as possible to prevent problems in the building process and design conflicts must be removed (Laamanen, 2015). In design, special attention has to be paid into moisture technical functionality of different structures and their connections, as well as to general material choices. In general, the solutions that have previously been found to be risk structures should be avoided and only use structural solutions that have been proven to work in terms of moisture technicality (Rakennustieto Oy, 2021A). For

example, end grain joints are moisture technically highly critical in mass timber construction as unprotected end grain surfaces absorb moisture quickly and joints usually have a poor air flow around them thus drying is slow. Because of this, joints of mass timber element should be designed to be sealed as well as possible in order to prevent moisture getting into them. Kable et al. (2022) study describes that there were instances where excess moisture did not dry out even after months, after getting into the mass timber element's joints, and drying out the moisture was only possible with the help of air dryers and heaters.

Shrinking and swelling design

Wood's transformations perpendicular to grain are much greater than parallel to grain. For this reason, problems may occur in mass timber structures with long spans perpendicular to grain, like in GLT-beams. Transformations in form of moisture content change induced shrinking and swelling and can cause problems especially in structural joints. Well-designed joints and connections that accommodate dimensional changes and especially proper moisture control design are essential to combat this problem (AITC, 2012).

Fault-tolerant design

Fault tolerance of structures refers to solutions where the smallest errors and deficiencies in the design, construction, maintenance, and use of building do not lead to harmful damages. The effects of climate change are predicted to bring wet autumn and winter periods and extreme weather phenomena. In a changing climate, the importance of the drying ability of structures is emphasized. This has been considered by guiding the construction more into fault-tolerant direction (Ympäristöministeriö, 2020). The best materials and structural solutions from perspective of moisture control are those that are durable, do not trap water and dry quickly. According to Wang (2016), as the last line of defence, structures should always be designed to dry out effectively if wetting occurs during construction or use.

Moisture control plan

In a moisture control plan, the construction plans of a building are checked, and structures, products and materials that are potentially critical, in terms of moisture control, are mapped. The primary goal is to find out whether there are structural solutions in the plans, that might involve moisture related problems on the construction site or where there might be risks of moisture damages later on (Helsingin rakennusvalvonta, 2016). Contract documents, duties and responsibilities of the different parties regarding to moisture control should also be agreed upon well in advance (Rakennustieto Oy, 2003). According to Helsingin rakennusvalvonta (2016), construction site's moisture control plan should include at least the following:

1. Mapping of moisture risks and risk structures
2. Drying time estimates for structures
3. Management of construction site conditions (weather protection)
4. Moisture control plan (methods, drying, storage and limit values)
5. Organization, monitoring, and control (responsibilities)
6. Orientation of parties involved in the construction process

Moisture control practices

Weather protection

The purpose of onsite weather protection is to protect structures from moisture loads, such as rainwater, minimizing moisture related construction risks and allowing construction to stay on schedule in difficult weather conditions. Good planning and appropriate protective actions are key to controlling difficult weather conditions (Rakennustieto Oy, 2013). The most critical factors that should be taken into account when determining appropriate onsite weather protection methods include onsite weather conditions, wetting potential of the materials, drying ability of the materials, sensitivity of the materials to moisture, cost of the weather protection and how the weather protection affects the onsite work, time schedules and drying practices (Wang, 2016). In addition, it is important to consider client's requirements, onsite logistics and storing of materials. For the onsite weather protection to work, all different factors need to be considered in good balance (Rakennustieto Oy, 2013). Usually, structures made of mass timber elements are not protected with weather protection shelters because speed of mass timber construction is relatively quick, thus moisture exposure of the structures can be kept to minimum. But fast onsite construction is not always enough to protect mass timber elements from excessive wetting. In Kalbe et al. (2022) study, it was observed from onsite measurements, that the wetting of CLT end grain edges occurred frequently. In addition, CLT reached high moisture content levels even after a single rainfall, which implies that, in some situations speedy construction process may not be sufficient enough to prevent wetting of mass timber structures (Kalbe et al., 2022). When weather protection shelter covering the entire building is not used, temporary weather protection methods should be applied in order to protect most moisture sensitive structures during construction. According to Wang (2016), the shell of a building often provides the most effective and economical weather protection which should be taken full advantage of during construction. In practice, highest floor or roof usually provides good protection for the floors and assemblies below, particularly when all gaps and joints are well sealed after installation to prevent water penetrating through to lower floors (Wang, 2016).

Water and snow removal

Any standing water and snow on top of mass timber elements should be removed immediately. If standing water is not removed and left long enough on top of a mass timber elements, it will eventually get absorbed through the face surface and deeper into the timber. Two days is enough time for moisture content to increase by several percent, if water is left standing on top of mass timber elements. Standing water can be removed by pushing it off with spatulas or it can also be vacuumed off (Wang, 2020). Temporary drainage systems can be necessary on larger building sites as those allow guiding water safely away from the upper floors of structure. Snow should always be removed from top of the unfinished building mechanically and not by using heat to prevent moisture damages that might be caused by the melting water. Water vacuums, spatulas, snow shovels and drying equipment should also always be readily available, so that during bad weather conditions excess water and snow can be removed from the mass timber structures immediately (Helsingin rakennusvalvonta, 2016).

Onsite delivery and storage

Wetting of the mass timber elements delivered onsite should be prevented by covering them in protective plastic wrappings before transportation. In addition, if possible, mass timber elements should also be delivered onsite just in time to minimize storage times. Best option would be for the mass timber elements to be attached to the building directly from the transport vehicle without any storage onsite. According to AITC (2012), mass timber elements when stored onsite should be kept off the ground and protected from sunlight, rain, snow and other sources of excess moisture. There should be protective wrapping around the mass timber elements when delivered from factory to the construction site which should not be removed before actual assembly. The wrapping on the other hand can prevent air flow around the mass timber elements, which might cause moisture build up inside the wrapping. To prevent this, small holes should be made on the underside of the wrapping to allow some level of airflow and drainage of possible excess moisture (AITC, 2012). If the mass timber elements are not wrapped in covering plastics, they should be protected with tarpaulins that are ventilated by lifting them off from the surface of the elements with blocks of wood to allow some air flow. In addition, the tarpaulins should be angled so that water runs off from top of them (Rakennustieto Oy, 2013). Mass timber elements should also never be covered with anything when wet, instead those should be left uncovered to guarantee good air flow conditions for drying.

Protective coatings

If it's likely that mass timber elements will be exposed onsite to wetting for a long period of time during construction, then protective measures such as self-adhesive breathable membranes, water repellent treatments like epoxy or moisture barrier coatings should be considered to protect the mass timber

elements from excessive moisture intake. Especially the end grains of mass timber elements should be protected with coatings because those are the most permeable area on a piece of timber. Without moisture barrier coatings the end grains of mass timber are going to absorb water extremely quickly which can lead to moisture issues. Moisture barrier coatings will slow down the absorption rate but it's not a complete barrier. If mass timber elements are in contact with ground, concrete or masonry, moisture can transfer from these to the timber and cause it to get damp. In these cases, the use of different wood protective coatings is especially recommended (Wang, 2016).

Water damage situations

In the event of water damage situation, the primary aim is to prevent further damages by limiting the damage area and by suppression the water source. The largest loose water should be removed immediately either with spatulas or with water vacuums. Construction site must be equipped with sufficient equipment to combat water damage situations. Everyone working on the construction site should be obligated to prevent water damages and to notify the main contractor of observed water damage situation. If necessary and if possible, structural parts damaged by water are immediately removed and drying is started. The need to demolish certain structures is assessed in the repair plan. Before demolishing structures, the moisture damaged areas are verified with moisture measurements (Rakennustieto Oy, 2021A).

Drying, heating and ventilation

The main goal of drying should be to remove excess moisture from the structures with proper heating and air ventilation. Mass timber structures dry out relatively quickly when completely open to air, but after those are coated with other materials or air flow around them in general has been decreased, their ability to dry out efficiently without drying equipment and onsite heating is removed (Helsingin rakennusvalvonta, 2016). Improper drying or too short drying times increase the risk of moisture damages inside buildings. Especially in tightly scheduled construction projects, covering wet structures too early with different materials usually leads to moisture related issues, as the wet structures cannot dry as efficiently when covered and the covering materials may also suffer from the excess moisture (Rakennustieto Oy, 2013). Proper drying of structures requires a low enough relative humidity, which can be achieved by increasing the temperature or by using specialist equipment like absorption dryers or dehumidifiers. In addition, ventilation of the moist inside air to outside is important for drying to work properly. Ventilation must still be done in a controlled manner, so that it does not affect the heating efficiency too much and thus cause additional costs (Wang, 2020). According to Penttilä (2017), drying conditions in the building should be maintained at <60% RH and >10 °C in order to allow wet structures to dry out effectively. Good drying conditions should always be maintained inside a

building, so that excess moisture in the inner parts of the thick mass timber elements has enough time to dry out (Penttilä, 2017).

Factors affecting success of moisture control

Monitoring of conditions onsite

During the construction weather forecast should be actively followed in order to react to the moisture control needs onsite as early as possible. In general, onsite moisture control situation should be monitored daily and weekly moisture control check tours onsite should be conducted with larger group of experts to verify that everything in moisture control is in order. Especially it is recommended to keep an eye on places where water is setting, moisture sensitive structures, holes and gaps in the structure, connection points and slow drying structures. Quick reacting to moisture damages, leakages and other short comings in moisture control is important to minimize possible damages to the mass timber structures. In addition, drying conditions inside a building should be monitored with condition measurements in order to know that mass timber structures are drying effectively. The drying and weather protection needs of the mass timber structures should also be monitored with moisture measurements (Rakennustieto Oy, 2021A).

Speed of construction

According to Musakka (2017), in addition to various weather protection solutions, fast building speed and fluent building generally also reduce moisture exposure of mass timber structures. With a faster building speed, the building's envelope can be sealed quicker, and the moisture exposure of the mass timber structures can be stopped earlier, and controlled drying of the structures can also be started faster (Musakka, 2017). According to Penttilä (2017), delays in the construction process usually increase the severity of moisture risks, because it exposes the mass timber frame to outside weather conditions for a longer period and thus increases the moisture loads coming on them. The delay in installations also causes schedule pressure and postpones the start of heating. This may shorten the time scheduled for drying of the mass timber structures, although the need for drying increases with longer exposure to poor weather conditions (Penttilä, 2017).

Reasons for problems

Problems related to moisture can result from multitude of different things, but common reasons that lead to these according expert interviews include:

- Design errors
- Poor material choices
- Lack of planning
- Poor quality of moisture control plans
- Too tight construction schedule

- Mistakes made in the construction work
- Lack of proper drying of the structures during construction
- Use of wet and moisture damaged materials
- Wood materials are in direct contact with wet materials like concrete
- Poor sealing of seams, connections, penetrations, and wet spaces
- Poor ventilation of the structure during and after construction
- Lacking surveillance and quality management of the construction
- Poor communication between involved parties
- Lack of motivation
- Poor communication
- Lack of cooperation
- Unclear responsibilities

2.6 Measuring of wood's moisture content

Onsite moisture measurements

With moisture measurements, the drying progress and needs of structures can be determined, and possible moisture damaged areas can be located so that those can be fixed. For example, moisture measurement result can be compared with planned limit values and that way decisions can be made to either increase or decrease heating and ventilation accordingly. Moisture measurements are usually done to different surfaces before those are coated with other materials to prevent moisture related issues such as mould growth. A moisture measurement plan for the construction site should also be made well in advance. The plan must describe the measuring methods, equipment and their details, measurement schedule, scope, and the locations of the necessary measurement points on floorplans. In addition, the moisture measurement plan should include measurement times, measurement depths, measured structural types, limit values and the qualification of the measurer. Measuring devices must be suitable for their task and calibrated. The measurer must have sufficient knowledge of the operating principles of the measuring device and the factors affecting it, the functionality of the structure to be measured, and the effect of the properties of the material being measured. The importance of measurement work should not be underestimated, because financially significant decisions can be made based on the measurement result (Timber Queensland, 2014).

Oven dry method

In oven dry moisture content testing, samples of wood are taken from the mass timber elements of the construction site. Those samples are weighed accurately and then dried. Drying should be done with equipment that can maintain about 105°C temperature and air must also be able to circulate. After drying, the samples are weighed again and then values of wet and dried are compared and moisture content of the sample is derived with the basic

moisture content equation. The cut samples should be as clear wood as possible without knots, bark or other deformations. The test sample width should be a minimum 20mm and weigh about 50g. In addition, the test samples should be sealed in plastic packs immediately after cutting to prevent moisture changes. In addition, when drilling the samples, it is important that the drill cannot create too much heat, in which case the water inside the samples will evaporate and the test results will be false. After drilling, the samples should be weighted, sealed in plastic backs, stored into a cool place and tested with the oven dry method within 24 hours. The best practice would be to perform the oven-dry test immediately after taking the samples if possible (SFS-EN 13183-1, 2002). Main advantage of the oven dry method is its accuracy, and the main weakness is that the process of getting results on the wood moisture content takes a plenty of time and effort, thus being expensive. In addition, this method requires taking samples which means that it is a destructive method, and thus cannot be used on structures that need to be preserved (Timber Queensland, 2014).

Electrical resistance method

The electrical resistance of wood decreases as the moisture content in wood increases. Electrical resistance meters (spike meter) measure the flow of electricity between two electrodes (spikes) where wood acts as an electrical resistor between the electrodes. The results are influenced by the temperature of the wood, necessitating the application of temperature correction, unless the meter already accounts for it. Furthermore, species correction is essential because two different wood species with identical moisture content might not have the same electrical resistance. Also, the orientation of the measuring spikes relative to the grain direction of the wood at the measured spot affects the results (Timber Queensland, 2014). When measuring, the spikes of the meter are hammered into wood at the desired measuring location, after which the meter gives the user the moisture content of the measured wood. Before the measurements, the meter should be calibrated accordingly (SFS-EN 13183-2, 2002). If measurements need to be made more accurately from different depths, then the measuring spikes need to also be partially insulated. Advantages of electrical resistance moisture meters are easy to use, and that result can be acquired quickly. Disadvantages on the other hand are that the spike meter damages the wooden structure that is being measured and the accuracy and reliability of the results are not the best (Timber Queensland, 2014). In addition, electrical resistance method is poor at measuring the moisture content of LVL, because LVL has multiple glue layers, thus only oven dry method gives accurate results (Finnish woodworking industries, 2019).

Drill hole measurement method

With drill hole measurement method, the relative humidity and temperature of mass timber elements can be measured and from there with the help of wood's EMC-chart or equation the moisture content of the wood can be derived. The idea is that moisture inside the drill hole will balance with the moisture content of the measured wood. According to Rakennustieto (2021B), when taking drill hole measurements, a hole is first drilled into the wood to the desired measuring depth. The minimum diameter of the hole is 16 mm. After drilling, the hole is cleaned from any dust and debris by vacuuming. A measuring tube is then tightly inserted into the hole, which extends to the bottom of the hole. The interface between the measuring tube and the material is sealed airtight and the end of the measuring tube is also sealed, for example with putty or silicone, after the measuring probe has been inserted into the measuring tube. The conditions inside the hole are allowed to settle after the measurement probe has been inserted and sealed. Before inserting the measuring head in the measuring tube and before making any measurement, care must be taken to correctly calibrate the measuring device (Rakennustieto Oy, 2021B).

According to Musakka (2017), sample pieces and drill hole measurements are more recommended methods for measuring LVL, because electrical resistance and capacitance methods, give unreliable results. However, the drill hole measurement method is not the most accurate way of measuring moisture content levels of mass timber structures because it is based on wood's EMC values which are reached by the wood quite slowly after changing conditions. In practice this means, that wood might get wet, but the results of drill hole measurement do not change because wood find its EMC quite slowly (Musakka, 2017).

Condition meters

The external and internal conditions for temperature, relative humidity, and absolute humidity of the air on the construction site can be measured with the condition meters. Condition meters are placed in a place protected from rain, wind, and direct sunlight. If the condition meters are placed on the wall of a building, care must be taken that the heat leaving the building or radiating from surfaces heated by the sun do not hinder the measurements. Condition meters should also be protected from dust, dirt, and possible hits as those can damage the meter and cause faults in the measurement results (Rakennustieto Oy, 2006).

3 Description of the case study

3.1 Wood City generally

Wood City is SRV Rakennus Oy's and Stora Enso Oy's multistorey mass timber construction project, which is located in Jätkäsaari, Helsinki, Finland. Stora Enso and SRV both worked in Wood City as project developers, but SRV mainly works as the general contractor and Stora Enso as main mass timber element supplier. The project has attracted plenty of interest around the world, thus it is being considered as a flagship of Finnish mass timber construction. The Wood City project consist of two 8 story residential buildings, one 8 story office building (office 1) and one 7 story office building (office 2) which is currently under construction and will be finished in summer 2024. In addition, there is a three-story parking hall build in the Wood City block, that is made out of concrete (SRV Rakennus Oy, 2023). Building sizes are presented in Table 1 and Wood City block is presented in Figure 6.



Figure 6: Wood City block concept art. The parking hall is located behind the office 1 building (SRV Rakennus Oy, 2023).

Table 1: Wood City block's building sizes.

Building	Size
Parking hall	5000 m2
Office 1	13850 m2
Office 2	8720 m2
Residential buildings (almost identical)	9580 m2 (overall), 4790 m2 (one building)

3.2 Residential buildings

The each of the residential buildings, shown in Figure 7, mainly consist of multiple apartments, basement, one stair shaft and one elevator shaft. Both buildings use LVL as the main load bearing material. The first floor and the basement floors in both buildings have been made of concrete and the floors from 2-8 are made of LVL-mass timber elements. Even the elevator shafts are made by using LVL. The main structural system of the buildings is load-bearing walls system.



Figure 7: Wood City residential buildings.

The structural system mainly uses load bearing LVL-walls and LVL-floor slabs, but the shorter external facades of the structures are also made from load bearing LVL-facade elements. Rest of the structure's facade are made by using non-load bearing wood-based facade elements. The Roof of the structure is also made from LVL-mass timber hollow core slab elements. GLT-columns were also used in the stair shaft area and near bathrooms to give the structure extra stability. The bathrooms in the structures are made by using bathroom space modules. Construction work on the two residential buildings started in 2015 and both were finished in 2019.

3.3 Office 1

The office 1, shown in Figure 8, mainly consist of different office spaces, basement, elevator shafts and stair shafts. The office 1 uses LVL as the main load bearing material. The foundations, basement, first floor, stair shafts and

elevator shafts are made of concrete. Floors 2-8 are made by mainly using LVL-mass timber elements. The main structural system of office 1 is column-beam system. The structural system mainly uses load bearing LVL-beams, columns, and floor slabs. All the external facades of structure are made from non-load-bearing wood-based facade elements. The Roof of the structure is also made of LVL-mass timber hollow core slab elements. The different concrete shafts are located in the middle of the structure, and those also work as load bearing and stiffening structures. Construction work on the office 1 started in 2018 and the building was finished in 2020.



Figure 8: Wood City Office 1.

3.4 Office 2

The office 2, shown in Figure 9, consist mainly of different office spaces, base-ment, elevator shafts and stair shafts. The office 2 uses CLT and GLT as its frame's main load wooden bearing materials. The structure's foundations, basement, the first and second floor, stair shafts and elevator shafts are made of concrete and floors 3-7 are made by mainly using mass timber- and steel elements. The main structural system of office 2 is column-beam system. The structural system mainly uses load bearing Delta beams, GLT-columns, and CLT-floor slabs. All external facades of the structures are made from non-load-bearing wood-based facade elements similar to office 1. The roof of the structure is also made of CLT-slabs and additional layers. The different concrete shafts are located in the middle of the structure, and those also work as load bearing and stiffening structures. Construction work on the office 2 building started in summer 2022 and it is expected to be completed in summer 2024.



Figure 9: Wood City office 2 at 19.6.2023.

3.5 Wood-concrete composite subfloor

General

Some parts of the mass timber floor elements of all the wood city buildings are covered with concrete. In office 2, all the CLT-intermediate floors are covered with 80mm layer of concrete in order to interlock the CLT-slabs together and to form one uniform floor structure. The office 2 CLT-concrete composite subfloor is presented in Figure 10. According Tannert et al. (2019), CLT-concrete composite subfloor is in many areas superior to only wood or only concrete subfloors. Compared to wood, it has a higher load-bearing capacity, higher fire resistance, superior sound insulation, is stiffer, and vibrates less. Compared to a concrete slab, it has a lower own weight, lower carbon dioxide emissions and a higher degree of prefabrication, which leads to shorter construction times onsite (Tannert et al., 2019). According to Lukacevic et al. (2021), one of the most relevant problems with CLT-concrete composite subfloors is the problem caused by concrete's moisture and the absorption of the moisture released from the casting into the CLT-slab. Too high moisture content can cause CLT's strength properties to deteriorate and mould to form between the CLT-concrete interface. However, the moisture levels are usually so low that at least the deterioration of the structural properties of CLT or the occurrence of rot is not likely. Also, the formation of mould is unlikely due to concrete's alkalinity, but it is possible and therefore it is a major problem that needs to be addressed (Lukavevic et al., 2021).

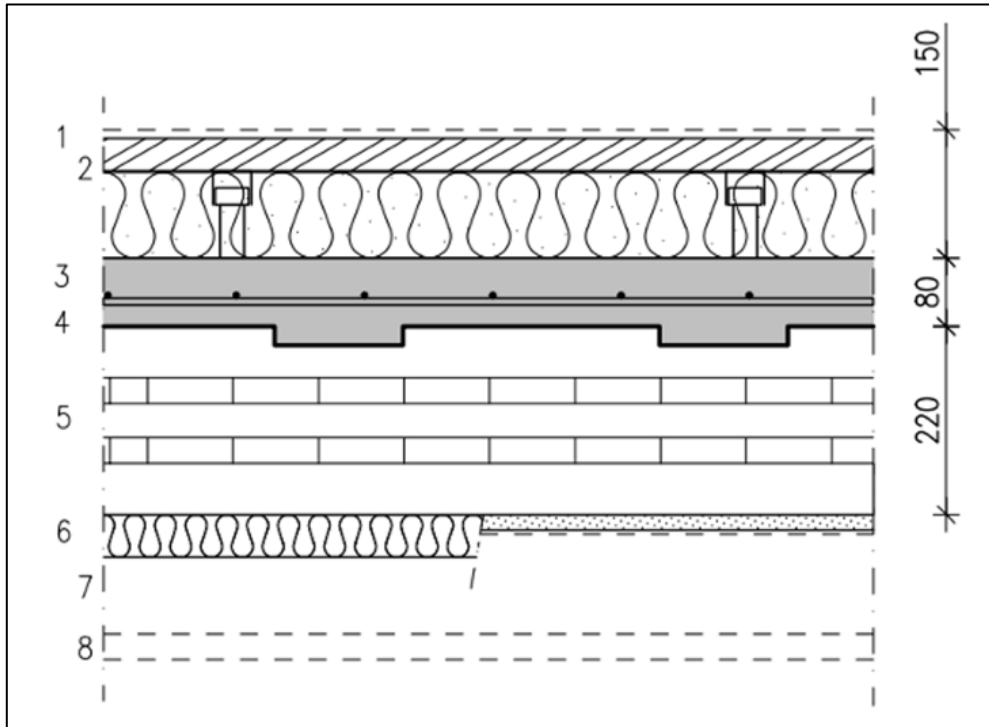


Figure 10: Office 2 CLT-concrete composite subfloor structural drawing. Layer 5 is CLT, layer 4 is a double moisture barrier coating and layer 3 is surface concrete casting.

Limit values

One of the biggest challenges at the office 2 jobsite from a moisture control perspective was that the CLT-floor slabs needed to be dry enough before the surface concrete casting could be done on top of them to ensure that there will not be any moisture issues after the casting has been made. If rainwater is allowed to puddle and stay on top of the CLT-slabs, the moisture content values of the CLT-slabs may rise too high, in which case the concrete surface casting cannot be made on the CLT-slabs until the slabs have been dried out sufficiently. The office 2 jobsite followed a limit value of 15% MC for the CLT-slabs. If the MC of the CLT-slabs was higher than 15% MC, the surface casting could not be done, because then according to expert interviews, there might be a risk of mould growth with the CLT-slabs. After the CLT-slabs are casted with concrete they get wetted by the concrete and the drying ability of the CLT is significantly reduced because it is covered with concrete. Because of this, the moisture content of the CLT-slabs needs to be low enough before the concrete cast, to ensure that no moisture problems, such as mould growth or possible even rotting of the wood occur after the casting has been made. Due to these factors, it was important to keep the CLT-slabs dry enough, so that the surface concrete castings could be made in planned schedule to prevent any project delays.

Moisture barrier coating

According to Ailio (2022), pouring concrete on top of CLT without a moisture barrier, creates a risk of mould growth at the interface between concrete and wood. If moisture barrier coatings are used between wood and concrete, the mould growth risk can be reduced significantly (Ailio, 2022). According to expert interviews, the edges and the top surface of CLT-slabs should be treated with a moisture barrier coating, because moisture barrier coating effectively prevents the transfer of moisture from wet concrete to the CLT-slab. But it cannot be concluded with absolute certainty, that there is no risk of mould growth in the interface between CLT and concrete when using moisture barrier coatings. According to Ailio's (2022) simulation tests, pouring concrete directly on top of CLT without a moisture barrier cannot be recommended, because in that case mould would probably form between CLT and concrete in such large quantities that it would have adverse effects on indoor air quality and thus to people's health. Growth of rotting fungi on the other hand requires longer and higher moisture levels than mould growth, so the deterioration of structural properties as a result of rotting is very unlikely even without the use of moisture barrier coatings. Without a moisture barrier, the moisture content of the CLT's surface exceeds 85% relative humidity, which corresponds to approximately 20% MC. Although the moisture content of the surface is relatively high, the average moisture content of the entire CLT remains below 15%. When moisture barrier coating with at least $S_d=1\text{m}$ value is used then the moisture levels already stay under 85% and the mould growth risk is significantly reduced (Ailio, 2022).

Cleanliness

According to expert interviews, surfaces of CLT-slabs should also be thoroughly cleaned from any debris and organic material like wood chips before the surface casting because those might get wet, and mould may start to grow on them after the surface concrete casting if not removed.

4 Description of onsite measurements

Main goal of the measurements

The main goal of the onsite measurements done at office 2 jobsite was to monitor the moisture content levels of the mass timber elements during the assembly of office 2's mass timber frame. Especially, the goal was to measure moisture content of CLT-floor slabs before and after surface concrete casting came on top of them. Measuring the CLT-slabs' moisture content was especially important for the office 2 jobsite, because it had a specific 15% MC limit which was followed in order to make sure that no mould problems will form after the casting was made on top of the CLT-slabs. In addition to the measurement of CLT-slabs, the onsite conditions for relative humidity and temperature were also measured and GLT-columns were measured for moisture content.

Measurements generally

Four different measuring devices were used to measure the moisture content of CLT-slabs and two different measuring devices were used to measure onsite conditions. Wiiste wood moisture meters, Vaisala HMP44 probes combined Grant dataloggers, Celsicom easy connect wood moisture sensor and Gann Hydrotest LG2 combined with a spike hammer electrode were used to measure the moisture content of CLT-slabs. In addition, Wiiste wood moisture meters and Vaisala HMP44 probes were set to measure the onsite conditions. GLT-columns were only measured with Gann's spike meter. With data gathered from all these devices, a holistic picture of the onsite temperature and relative humidity conditions and moisture content levels of mass timber structures was able to be obtained. All installed measuring device locations are presented in Figure 11 and the focus areas of spike meter measurements are presented in Figure 12. Spike meter measurement were made at different locations at the building, not only on those that are marked in Figure 12, but locations in Figure 12 were followed more consistently with more frequent measurements. Table 2 presents how many measuring devices were used to do all the measurements, at what floor the measurements were mainly taken from and what were the end and start dates of the measurements. Celsicom, Wiiste and spike meter measurements will be continued at office 2 jobsite in the future as well, but datalogger measurements needed to be stopped because the devices were borrowed.

Table 2: Measuring devices and tools generally.

Device	Amount	Floor measured	Start date	End date
Spike meter	1	3	20.3.2023	Continues
Celsicom	3	4	22.5.2023	Continues
Wiiste	2	3	20.3.2023	Continues
Dataloggers	3	3	23.3.2023	19.5.2023

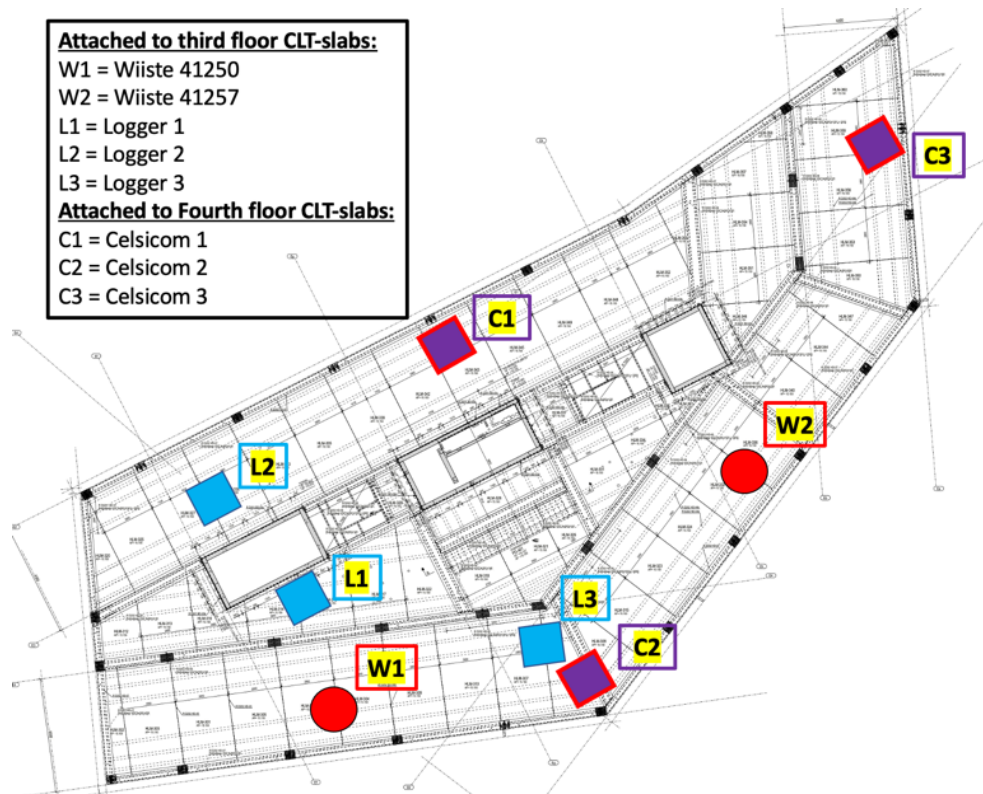


Figure 11: All measuring device locations.

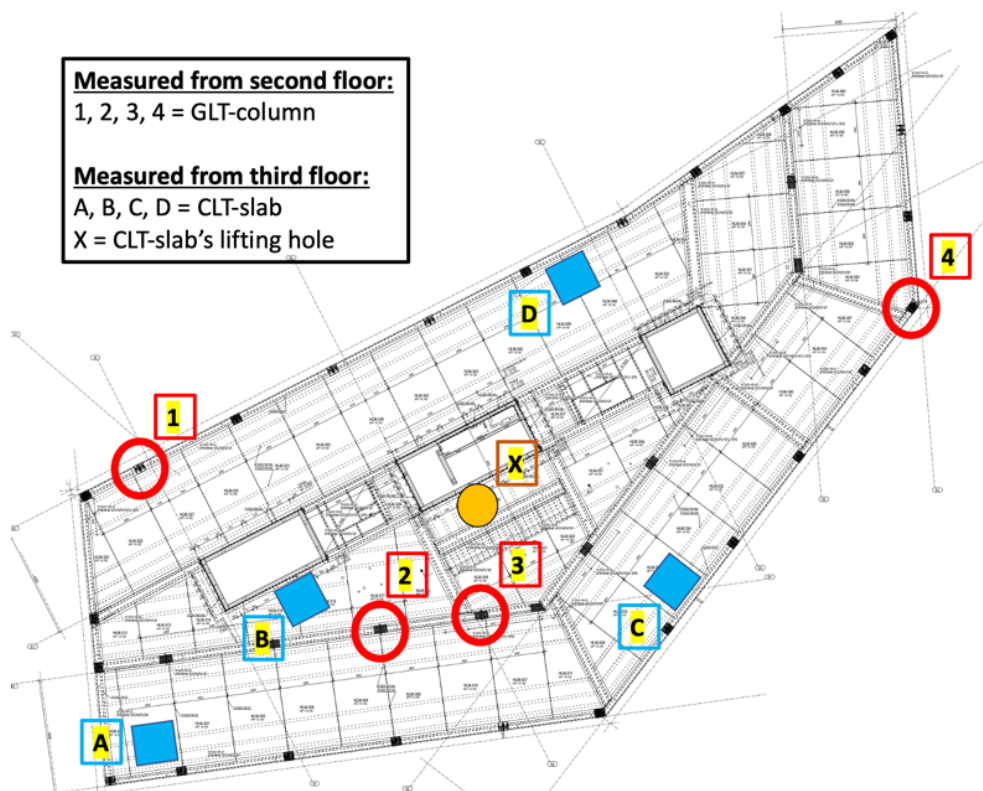


Figure 12: Spike meter measuring locations (focus areas).

Datalogger (drill hole) measurements

Vaisala HMP44 probes combined with Grant 1000 series dataloggers, shown in Figure 13, were used for measuring onsite relative humidity and temperature conditions and relative humidity and temperature of the CLT-slabs with the drill hole measuring method. With the relative humidity and temperature data gathered from inside the CLT-slabs, the moisture content of the CLT was able to be predicted with the wood's EMC equation (4). Idea is that wood as a hygroscopic material desorbs moisture into the sealed drilled hole so that the conditions inside it will be balanced with the moisture content of wood accordingly. Conditions inside the sealed drill hole can be then measured with the HMP44 probes and with the gotten RH and temperature values the EMC value of the CLT can be calculated. HMP44 probes' measuring specifications are presented in Appendix B.

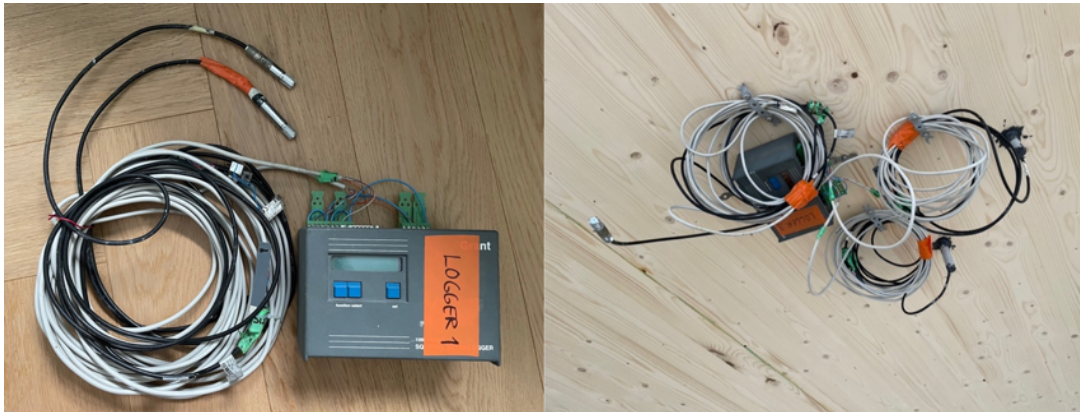


Figure 13: Two Vaisala HMP44 probes connected to Grant 1000 series data logger (left image). Datalogger and measuring installed onsite (right image).

Three Grant dataloggers were attached to the underside of office 2's third floor's CLT-slabs. There the loggers were safe from poor weather conditions and any construction work in general. In addition, the loggers could not be placed on top of the CLT-slabs because then they would get covered with concrete during the surface concrete casting. The dataloggers were attached to the underside of the CLT-slabs with perforated metal tape and screws. The HMP44 probes were inserted into the CLT-slabs by following RT-103333 concrete's drill hole measuring guide's instructions. First, 17cm deep holes were drilled into the CLT-slabs from their underside. Then plastic pipes were tightly inserted into the drilled holes. After that, the measuring probes were inserted into the plastics pipes to 17cm depth (5cm from the CLT-slab's surface) and lastly the outside ends of the pipes were sealed off with vapor diffusion resistant silicone. Figure 13 shows how the dataloggers and the measuring probes were installed into the CLT-slabs onsite.

In total, three dataloggers with 8 HMP44 probes were used to do the measurements. One logger had two HMP44 probes attached to it and two loggers had three. All the dataloggers had one probe measuring outside conditions and rest of the probes measuring the CLT-slabs. In total three probes measured outside conditions and five measured CLT-slab's EMC. The dataloggers were placed into three different locations onsite. Logger 1 was placed more middle of the structure, logger 3 at the sea-side edge of the structure and logger 2 at the inner yard-side edge of the structure. The datalogger onsite placement locations were presented in Figure 11. The drill hole measurements devices were installed, and the data logging started onsite at 23.3.2023 and stopped 19.5.2023. Thus, the dataloggers gathered data of the CLT-slabs and onsite conditions for 57 days. The drill hole measurement results were viewed only after the devices had been removed and the logging had been stopped.

Problem with the dataloggers was that all of them turned off at some point during the measuring period and stopped the data logging because they run out of batteries probably due to cold weather or because the Grant data loggers were quite old and thus there might be some issue with the devices. When the loggers were noticed to have turned off, they were given new batteries and the data logging continued. Also, some of the already logged data was lost because of this issue during the reset of device. Especially the data gathering of logger 1 suffered from stops due to running out of batteries in short time windows. Due to these reasons, logger 1 data is not analysed in this thesis. Data from logger 3 was most reliable of all the loggers because it only suffered one short stoppage during measuring period.

Wiiste measurements

Wiiste WM1-WAN IoT wood moisture meters, shown in Figure 14, were used to measure onsite temperature and relative humidity and moisture content of CLT-slabs with the electrical resistance method.



Figure 14: Wiiste wood moisture meter with electrode screws (left image). Wiiste meter installed onsite (right image).

Wiiste wood moisture meter uses 2 pairs of long insulated electrode screws which measure the electrical resistance between them to determine wood's moisture content at the depth of the screw tips. In addition, the screws hold the device itself in place against wood while taking measurements. Wiiste moisture meters sends all the measurement data automatically to a cloud data bank, which allows the user to view the results from anywhere. Wiiste wood moisture meter specifications are presented in Appendix B.

The Wiiste measuring devices were attached to the underside of office 2's third floor's CLT-slabs. There the Wiistes were safe from poor weather conditions and any construction work in general. The Wiistes were not able to be placed on top of the CLT-slabs because then they would get covered with concrete during the surface concrete casting. The Wiiste devices were attached to the underside of the CLT-slabs with two 220mm and two 190mm long insulated screws that also act as the devices measuring electrodes. The Wiiste device shortens the electrode screw penetration depth for about 22mm, thus the 220mm screw pair measures CLT from 22mm from its surface and the 190mm screw pair measures CLT from 52mm from its surface. Wiiste-CLT measuring setup is also illustrated in Figure 15.

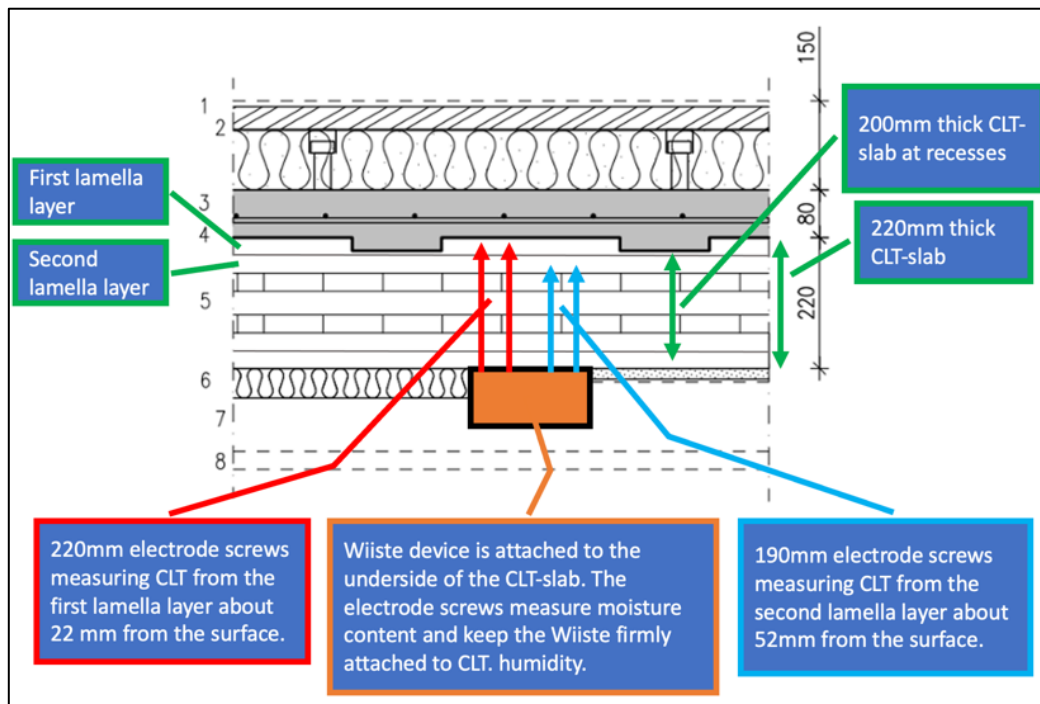


Figure 15: Wiiste-CLT measuring setup.

The longer screw pair measures the moisture content of CLT from its first lamella layer and the shorter second screw pair measures moisture content from second lamella layer. The CLT-slabs that are used in the Wood City

office 2 building are mostly 220mm thick and have lamella layers of 30L, 30L, 30C, 40L, 30C, 30L, 30L mm. The CLT-slabs also have 20mm recesses made in them because of the surface concrete casting and at those spots the CLT slabs are 200mm thick. The idea of hitting the first two lamella layers of the CLT-slab is to see how far the moisture will penetrate inside the CLT-slab before and after the surface concrete casting.

In total only two Wiiste wood moisture meters were used to do the measurements. Both Wiiste devices had 190mm and 220mm electrode screw pairs and both Wiistes were placed to the sea-side edge of the structure. Figure 14 displays how the Wiiste measurement devices were installed onsite and Wiiste onsite placement locations were presented in Figure 11.

Spike meter measurements

Gann hydrotest LG2 moisture meter with Gann M20 drive-in electrode, which can be seen in Figure 16, were used for measuring CLT-slabs' moisture content with the electrical resistance method.



Figure 16: Gann hydrotest LG2 and Gann M20 drive-in electrode.

Gann hydrotest LG2 uses short spikes that are hammered into wood to measure the electrical resistance between them to determine wood's moisture content. The spikes themselves penetrate about 2cm inside the wood when taking the measurements, but the spikes are not insulated. The device is small, lightweight, and fast to use, thus it was used for measurements all over the

building at different locations. Some of the measured locations were randomly selected, some were measured because those were of high interest and some of the measuring locations were prespecified and measured regularly. Gann hydrotest LG2's measuring specifications are presented in Appendix B.

Measurements should be made with spike meters perpendicular to wood's grain in order to measure multiple grains at the same time and that way to get more accurate results, but measurements parallel to grain are also viable. There was basically no difference between parallel and perpendicular to grain results when taking measurements with this specific spike meter. This was also confirmed by doing measurement parallel and perpendicular to grain to wood at Aalto University's climate room. These results can be found in Appendix C.

Spike meter measurements were mainly made from specific focus areas that are illustrated in Figure 17 and from locations that were displayed earlier in Figure 12.



Figure 17: Spike meter measurements from: 1. GLT-columns, 2. regular CLT-slabs, 3. CLT-slab deliveries and 4. CLT-slab lifting holes.

Measurements were taken with the spike meter on top of the CLT-slabs first when the CLT-slabs arrived onsite to determine that the elements were not

wetted during transportation. Secondly the wetting and drying progress of the CLT-slabs onsite were monitored with frequent spike meter measurements. Especially it was important to determine that the moisture content levels of the CLT-slabs were under the limit values before the surface concrete casting, so those can be casted on without any future moisture issues. Thirdly the spike meter was used to measure the moisture content of GLT-columns near filling concrete castings. In addition, it was noticed during the mass timber frame's construction process that the CLT-slab lifting hole also needed to be measured for moisture content as water easily puddled into those during poor weather if those were not plugged and taped over.

Areas marked in Figure 12 were focused on more specifically with more frequent measurements in order to follow how moisture content values develop over time in the GLT-columns and CLT-slabs in these spots. In addition to measurements made from the lifting hole at location X, multiple measurements were made evenly around third floor's lifting holes on 18.4.2023 before those were authorized to be plugged and taped over on 21.4.2023. Also, multiple measurements were made evenly around the third and fourth floor CLT-slabs before the surface concrete castings on 11.5.2023 (third floor) and 22.5 (fourth floor) in order to verify that the moisture contents were low enough, that the CLT-slabs could be casted on with concrete.

Celsicom measurements

Celsicom easy connect wood moisture sensors were used to measure moisture content of CLT-slabs after the building's fourth floor's surface concrete casting on 22.5.2023. Celsicom uses long insulated nails to measure the moisture content of the CLT between those nails with the electrical resistance measuring method. Onsite the measuring nails were inserted into the CLT from top and those were protected with plastic pipes, putty and silicone in order to protect the measuring nails from concrete and from the construction workers during the surface concrete casting. Like Wiiste, Celsicom moisture meters also send all the measurement data automatically to a cloud data bank, which allows the user to easily view the measuring results. The Celsicom measuring setup can be seen from Figure 18 and Celsicom easy connect measuring specifications are presented in Appendix B.

First, small holes were drilled for the plastic pipes (about 1cm) and the nail were inserted about 1,5cm deep inside into the measured CLT inside these plastic pipes. This way the electrode nails can measure CLT-slabs more reliable as those are protected during the surface concrete casting. The actual measuring devices were attached above the floor level to nearby GLT-columns and the nails were connected to the device with wires. This can be seen from Figure 18.

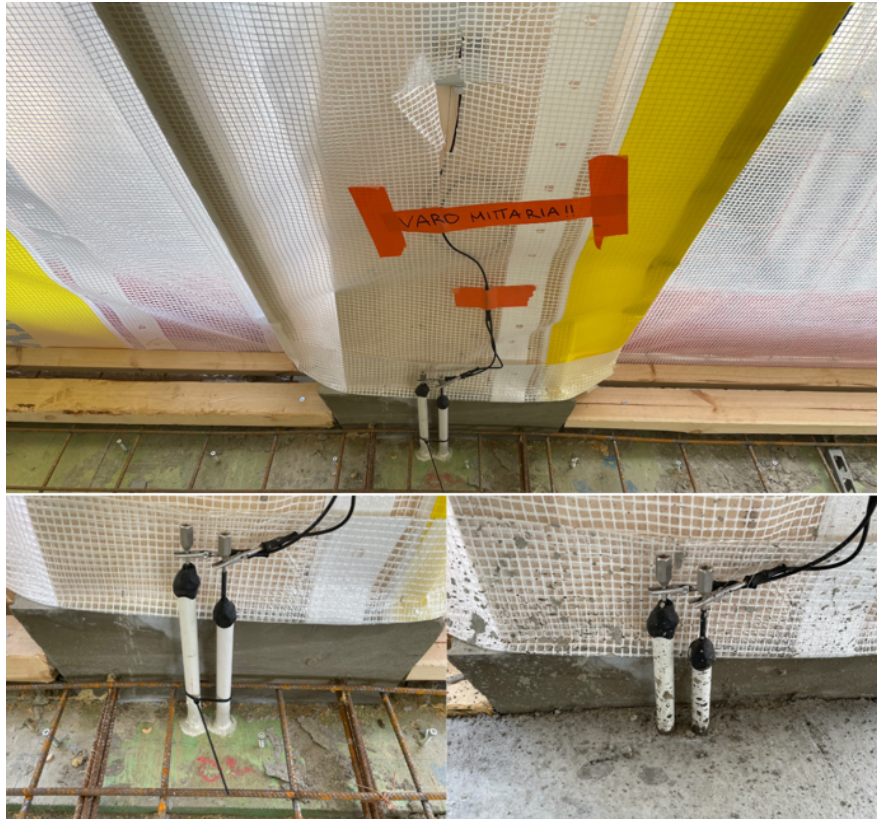


Figure 18: Celsicom measuring setup (top image). Celsicom measurement nails before and after casting (lower images).

In total three Celsicom measurement devices were used on the fourth floor to measure the CLT-slabs before and after the surface concrete casting at locations that were presented earlier in Figure 11. One of the Celsicom measuring devices was at the seaside edge of the building, one at the yard side and one near the office 1-office 2 connection point.

Conditions measurements

Onsite condition measurements were also made with Wiistes and dataloggers in order to monitor how effective the onsite conditions were at supporting the effective drying of the mass timber structures and would there be a risk of mould caused by the humidity of the onsite air. Generally, the onsite condition measurement would have been more important if those were taken when the envelope of the structure was sealed. As the envelope was still open during the measurements, it was impossible for the construction management to take an advantage of the condition measurements because the onsite conditions were basically impossible to be controlled yet.

From the onsite condition measurement obtained from all three dataloggers, only the results of datalogger number 3 are analysed as its results were the most consistent and reliable as it suffered least from sudden stoppages.

5 Wood City's moisture control

Factors affecting moisture control in Wood City

Facade and roof

Different materials have different abilities to resist moisture, some can withstand excessive wetting and some not even the smallest amount. Especially the insulation layers in structures are weak to wetting, thus in all the Wood City buildings the facade elements and the roof structures were found to be sensitive to moisture and thus those were protected from wetting more extensively.

Joints and connections

All the structural joints and connection locations were in general found to be locations that needed to be protected from moisture as those usually house the end grain parts of mass timber elements which absorb moisture more effectively than face surfaces. Thus, if water gets to these locations, it can mean fast and excessive wetting of these structures. In addition, it would be difficult and slow to dry the extra moisture out from these structures because airflow around joints, connection and corner locations is usually weaker than around other areas.

Wood touching concrete

In all the Wood City buildings there were places where concrete was in touch with mass timber elements. In these locations it was important to protect the wood from the moisture of the concrete in order to keep the wood dry.

Hollow mass timber elements

The office 1 and the residential buildings used partially hollow LVL-elements at their roof structures. As the hollow spots inside these elements are difficult to dry and inspect due to weaker airflow and more difficult access, it was important to protect these elements from excess moisture.

Weather

The Wood City block is located near a windy coastal area and therefore sloping rain was considered to be an important weather factor from moisture control's perspective. Because of this, during the construction weather conditions had to be monitored constantly and weather protection methods against sloping rain were also applied.

Location

Wood City's limited available area and the location near busy harbour traffic made the logistics and space usage difficult during construction. Space and

logistical limitations might also affect moisture control practises onsite. For example, office 2 would not have been able to use a whole building covering weather protection shelter during construction because there was no space onsite to build the supporting scaffolding for the shelter.

Moisture control practices used in Wood City

Construction sequencing

Different construction sequences have their positive and negative sides. In Wood City, all the buildings had different construction sequencing for the mass timber frames, which also affected to moisture control needs accordingly.

In the residential buildings the facades that were load bearing needed to be assembled with the rest of the load bearing frame, but the non-load bearing facade elements were attached to the building after the roof was completed, which can be seen from Figure 19. By attaching the facade elements last, the moisture loads to the facades were able to be minimized and the already completed roof of the structure also added extra protection for the facades.

In the office 1 the wooden frame was assembled in a way that the facade elements were attached to the building two floors behind the load bearing structures, which can be seen from Figure 20. This meant that exposure to moisture could be limited to two floors at a time, but this also meant that the floors already sealed with facade elements did not dry as effectively as the open floors due to decreased air flow. In addition, the intermediate floors needed to be tightly sealed in order to prevent water coming into the closed floors through upper intermediate floors.

In the office 2 the load bearing frame was built first. Then after the skeleton of the frame was completed all the facade elements are attached to the building and lastly the roof of the structures would be built. The frame of the structure could not be built in the same way as in office 1 because of the surface concrete castings and wind load limitations. All the floors of the structures were open during the construction of the building's load bearing frame, which allowed the wooden structures to dry efficiently during good weather because of efficient air flow, which can be seen from Figure 21.

Weather protection

All the Wood City buildings were built without the whole building covering weather protection shelter. Weather protection was mainly managed by using the highest floor of structures as a cover to the floors below it and the sides of the structures were sealed with ether veneer sheets like in the residential buildings project (Figure 19), directly with facade elements like in the

office 1 project (Figure 20) or kept open for maximum air flow like in office 2 (Figure 21). Additionally, smaller more specific weather protections were used at critical parts of the buildings. For example, in the residential buildings, LVL-boards were installed on to the sides of the structures in order to block sloping rain from entering into the building, this can be seen from Figure 19 and in Office 2 plastic coverings were placed on the open sides of the structure in order to protect CLT-slab from wetting caused by sloping rain before and after surface concrete casting, which can be seen from Figure 22. The tops of the weather protections were open in order to allow efficient air flow to dry out structures and to minimize wind loads.



Figure 19: Residential buildings sealed with LVL-sheets (Musakka, 2017).



Figure 20: Office 1's facade elements assembled with the rest of the frame.
Source: <https://puuinfo.fi/2021/09/16/wood-city-the-flagship-for-finnish-wood-construction/?lang=en>



Figure 21: Office 2 frame open during construction to allow good air flow.



Figure 22: Office 2 CLT-slabs protected from sloping rain before the surface concrete casting.

Joints and connections

More specific weather protection methods were also applied for protecting critical structures from moisture loads. Figure 23 shows some of the weather protection methods that were planned to be used in the residential buildings to protect the buildings' joints, connections points and end grains of load bearing walls with EPDM-rubbers strips and water blocks.

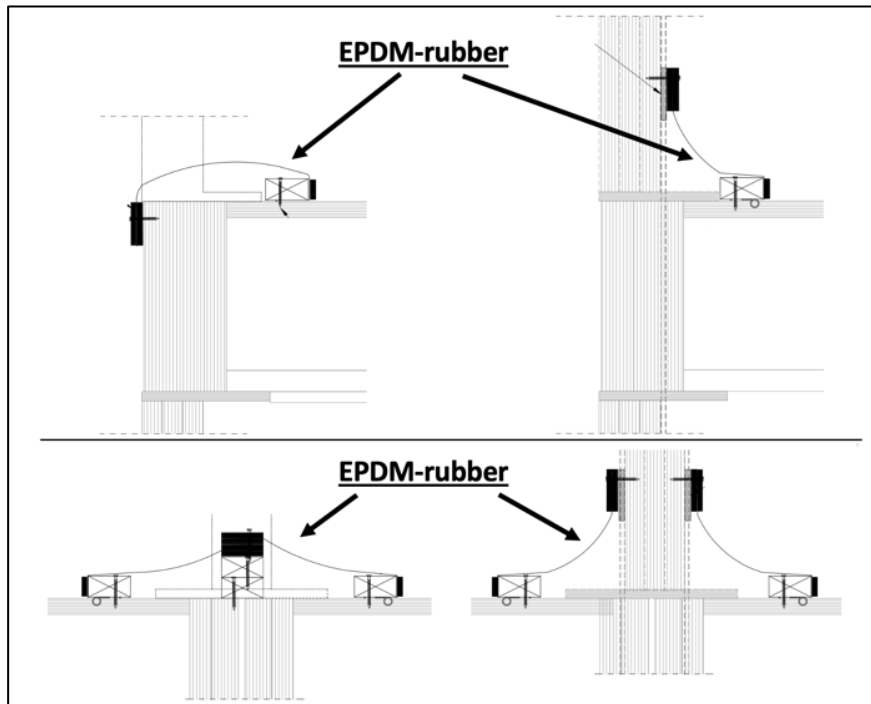


Figure 23: Moisture control work drawings for protecting connection points, end grains and structural joints with EPDM-rubber strips. Top image shows protections for load bearing outer walls and lower image for load bearing inner walls.

In office 1 water was prevented from entering into the mass timber element connection points before element installation were made. The connection points of the LVL-beams and columns were protected with veneer boxes that were sealed with tape. After the elements were installed the seams of the connection points were also taped to prevent water getting into the connections.

Facade elements

Facades elements housed moisture sensitive insulation layers, thus those needed to be protected well from wetting during the installation process. During the building process the facade elements were not installed to the structures during rainy weather in order to prevent moisture damages. After installations the facades were protected with different methods. In the residential buildings and in the office 1 the facade elements were protected with EPDM-rubber strips, which can be seen from Figures 24 and 25. In the office 2 the facade elements were planned to be protected with tarpaulins before rainy weather. In all the Wood City buildings the facade elements were pre-fabricated to such extent that after installation and sealing of seams, the facades were waterproof. This also required that the facade elements were covered from all sides with other elements in order to be waterproof.

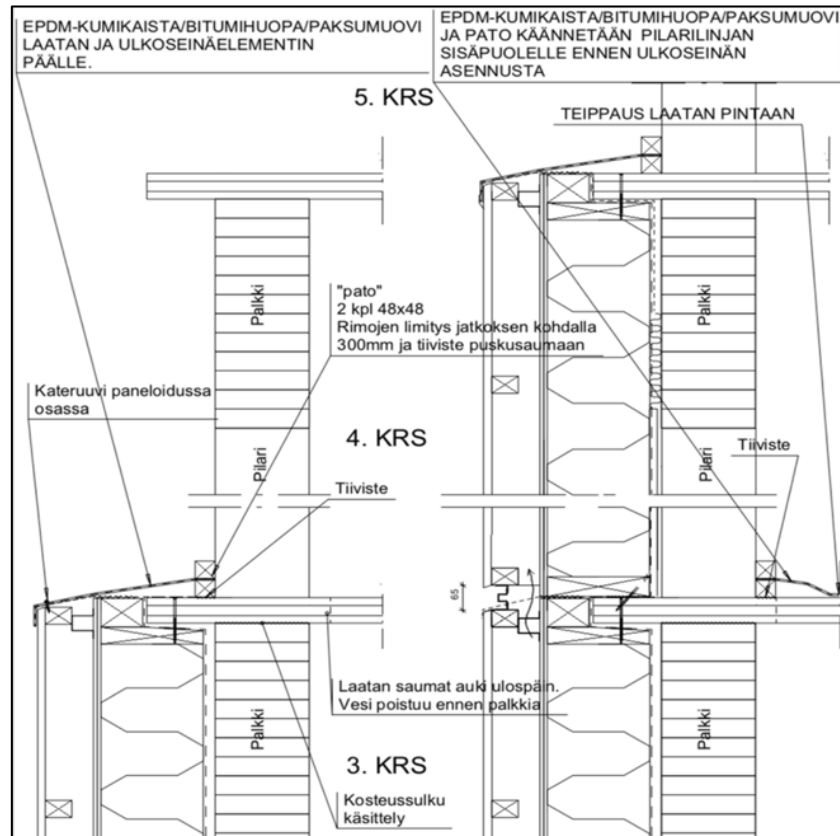


Figure 24: EPDM-rubber strip and water block protections for facade elements and for column connection points.



Figure 25: Facade elements protected from their ends and sides with EPDM-rubber strips (Penttilä, 2017).

Roof structures

With all the Wood City buildings the goal was to get envelope of the structure sealed as fast as possible in order to minimize the moisture load coming to the mass timber elements, thus it was also important to complete the roof

structure with quick pace as that allowed the building to stop water inflow from above to the lower floors. Whole building covering weather protection shelters were not used, but in office 1 a shelter was used to protect the building's roof features, like roof windows, and in office 2 a shelter will be used to cover the roof structures during onsite construction of the different roof layers. The residential buildings and office 1's roofs were built by using hollow heat insulated LVL-mass timber elements that were also pre-covered with bitumen membrane. Because of the high prefabrication, these buildings' roofs were able to be built and sealed fast. Only the seams between the elements needed to be sealed with extra bitumen membrane to make the roof waterproof, which was extremely fast to do onsite. Still, the office 1's and residential buildings' roofs were only assembled during good weather in order to protect the moisture sensitive insulation layers. Different from other buildings, the office 2's roof will be built mostly onsite. The base is made out of CLT-slabs, but the added layers will be made onsite. Because of this a weather protection shelter is a must to guarantee that the moisture sensitive roof structures do not get wet during the assembly and the schedule of the project is maintained even if the weather conditions are not ideal.

Temporary drainage pipes

Temporary drainage pipes were also used in all the Wood City buildings during construction in order to help with rainwater removal from the intermediate floors. With the water pipes it was possible to manage and efficiently remove water from the higher floors of the structures without causing moisture damages to the floors below. With the help of the temporary water pipes rainwater was easily pushed with spatulas or water-vacuumed and emptied into them, which helped significantly with the onsite water removal. The temporary water pipes were also connected to the municipalities rainwater system, which allowed the rainwater to be removed from the entire jobsite in an efficient manner. Figure 26 shows a drain connected to temporary water pipes in the office 2 jobsite.



Figure 26: Drain on top of the fifth floor (left image) and pipes guiding water of from the fifth floor (right image).

Moisture barrier coatings

Moisture barrier coating were also used to protect mass timber elements from moisture loads. In the residential buildings and office 1 all the LVL-element ends were treated with hydrophobic moisture barrier coatings at factory conditions in order to protect the moisture sensitive end grain parts of the mass timber LVL-elements from moisture loads onsite. Additionally, in residential buildings and office 1, parts of the LVL-walls that were in touch with concrete were covered with epoxy in order to protect the LVL from the concrete's moisture. In the office 1, stronger moisture barrier substances were used especially at the LVL-mass timber element connection points. In office 2, moisture barrier coatings were used at the edges of the CLT-slabs but also on top of the CLT-slabs to protect them from the surface concrete casting's moisture that comes on top of the CLT-slabs, this can be seen from Figure 27. In addition, in the office 2, the ends of GLT-columns were treated with epoxy in order to protect their moisture sensitive end grains especially during the filling concrete castings that come around the bottom part of the GLT-columns, this can be seen from Figure 27.



Figure 27: Office 2's CLT-slabs covered with moisture barrier coating at factory conditions (left image) and GLT-columns ends covered with epoxy (right image).

Taping of seams and moisture barrier membranes

In all the Wood City buildings the seams between intermediate floor slabs were taped and penetration were sealed in order to prevent water getting through these caps and dropping down into the already sealed floors. Figure 28 shows how the seams of the CLT-slabs were taped in the office 2.

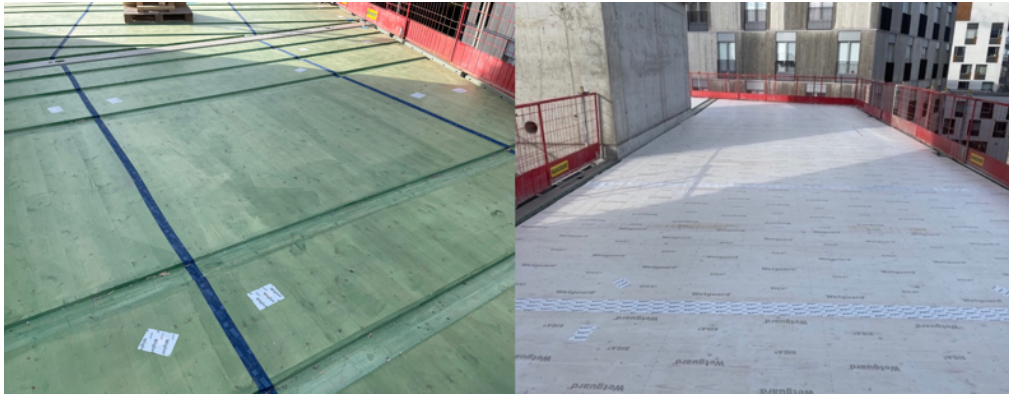


Figure 28: CLT-slabs' seams and Sihga lifting holes covered with tape (left image) and Fifth floor CLT-slabs covered with Siga Wetguard (right image).

In office 2, Siga Wetguard, a breathing plastic moisture protection membrane, was used as a water stop on top of the fifth floor's CLT-slabs. The purpose of Wetguard was to protect the fifth floor from excessive moisture loads and floors below from water, which without the membrane could drop down on them from above and cause moisture damages. Wetguard also protects the fifth floor CLT-slabs from excessive moisture during transportation, storage, installation and during the concrete surface casting. The idea of covering only the fifth floor with the Wetguard was that it would act as a moisture barrier within the floors of the structure, thereby more effectively block water from getting through the floors below the fifth floor. Figure 28 shows the fifth floor of the office 2 that was covered with the Siga Wetguard membrane.

Storage and delivery of materials

In all the Wood City buildings the mass timber elements were delivered onsite with just-in-time basis. The idea was that the mass timber element deliveries were made with such timing that the delivered elements could be installed to the structure immediately after arrival to the jobsite. This way it was possible to minimize the storage time and moisture loads of the mass timber elements onsite and to preserve onsite space for other actions. In addition, good basic storage methods were followed, such as covering onsite stored mass timber elements with tarpaulins or covering plastics and lifting those off the ground with wooden blocks, when storing of the mass timber elements onsite was sometimes still needed. Example of this from office 2 can be seen from Figure 29. In addition, all the mass timber elements were delivered onsite wrapped into covering plastics in order to protect those from excess moisture loads during transportation. Example of this from office 2 can be seen from Figure 29. Also, when the mass timber elements were received onsite, those were measured with spike meter in order to ensure that those did not get wet during transportation and arrived dry onsite.



Figure 29: GLT-columns been wrapped into covering plastics and lifted on top of wooden blocks when delivered and stored onsite (left image) and CLT-slabs wrapped into covering plastics when delivered onsite.

Drying, heating and ventilation

In all the Wood City buildings it was planned to use water circulation heating power by district heating after the building's envelope was sealed. Heating is especially important because it allows the jobsite to maintain adequate conditions inside buildings for effective drying of the structures after the building envelope is sealed. Heating must also be combined with proper air circulation, and this was planned to be done by using temporary air pumps (vacuum fans) or by opening windows or temporary protections to ensure that moist inside air can escape outside. In addition to basic heating and air circulation, also absorption driers and dehumidifiers were used when some structures needed be dried more effectively. Heating and drying needs in general were adjusted according to onsite moisture and condition measurement results. The target inside conditions were set to 50% RH and +10°C temperature. This way wood should release moisture effectively as a hygroscopic material and it should reach its EMC at 9-10% after some time.

Monitoring

Basic monitoring of the onsite moisture control practices and frequent moisture control tours were made in order to find out best possible ways to improve the moisture control practices used onsite. In office 1, the tours were attended by the developer's moisture control coordinator, the general contractor's job manager who was responsible for the mass timber frame, structural designer and a wood construction expert. During the tours, the current weather conditions, ongoing work phases, possible deviations, performed moisture measurements, follow-up measures, and also well-handled matters were reviewed. In office 2 frequent tours were made onsite with the moisture control coordinator in order to improve moisture control practices especially during the assembly of the mass timber frame. Weather forecasts and conditions were also closely monitored, and protective measures were prepared when bad weather was forecasted. Moisture and temperature conditions

were also monitored onsite especially during inside work phase were heating and drying of the structures was important. Heating and drying equipment usage was adjusted accordingly in order to maintain good conditions inside the buildings in order to allow different structures to dry out properly. In addition, moisture content measurements were taken actively in all the Wood City buildings from critical structures in order to confirm which mass timber structures needed extra drying. Especially it was important to monitor mass timber structures that were to be covered with other materials with moisture measurement, in order to verify that the covering process was safe from moisture control standpoint. For example, the mass timber structures that were covered with concrete were measured for moisture content levels prior to the casting.

In addition to other moisture control related monitoring and documentation, office 2 jobsite also followed Kuivaketju 10 instructed monitoring and documentation onsite. According to RALA (2023), with Kuivaketju 10 (Dry chain 10) 80% of the of the subsequent costs of moisture damages are avoided if Kuivaketju 10 risk list is followed accurately.

Water and snow removal

Water was vacuumed and snow was shovelled off from the intermediate floor of the structures in order to minimize moisture load coming to the mass timber subfloors. An essential part of moisture control during construction were so-called trowel patrols, which on rainy days constantly pushed and vacuumed water off from the subfloors of the buildings and made other moisture control procedures. This kept the moisture exposure of the mass timber elements to a minimum as water was not allowed to puddle on top of floor slabs for long periods of time.

Moisture measurements

Moisture measurements were made in order to monitor the moisture content values of mass timber elements and onsite conditions were monitored especially during the inside work phase in order to verify that the conditions inside the buildings were sufficient for effective drying of different structures. Moisture measurements also authorized some work steps during construction, for example moisture measurements were taken from mass timber elements before those were covered with other materials such as concrete. This was done to verify that the mass timber elements were dry enough to be coated in order there to be no problems with moisture in the coated timber or in the coating material after the coating had been made.

A lot of different measurements were taken during the construction of the Wood City buildings. In office 1 the measurements mostly focused on gathering data from inside temperature and humidity conditions with

dataloggers, when the building envelope was sealed, but also measurements from the LVL-mass timber elements were made with a spike meter to get some reference values, even though, it was known that measuring LVL with a spike meter is not optimal. In residential buildings inside relative humidity and temperature conditions were also measured extensively, but also a lot of sample pieces were taken from the LVL-structures which were then analysed with the oven dry method. In office 2 it was also planned that the inside relative humidity and temperature condition will be monitored. During the assembly of the mass timber frame, moisture measurements were done with different devices, but mostly with a spike meter. Measurements focused on monitoring the moisture content values of the CLT-slabs. Monitoring the CLT-slab moisture content values was important in the office 2 jobsite because of the tight limit value of 15% MC, which was set for the CLT-slabs before the surface concrete casting and other material coatings.

Worker orientation and information exchange

In all the Wood City buildings, the onsite orientation session highlighted to workers that moisture control was an important part of the building process and everyone working on the jobsite should also pay close attention to the onsite moisture control. Workers were motivated to report even smaller things that caught their attention about moisture control and even possible improvement possibilities were welcomed to be suggested. The workers were also instructed to take on preventive actions if they spotted any moisture damage situations happening onsite. In office 1, everybody that worked onsite went through a separate moisture control session in their onsite orientation to ensure that they understood the basics, onsite practices, and importance of moisture control. Everybody that were working on the jobsite were mandated to follow the moisture control instruction given to them. In addition, they were told to pay attention to the current moisture conditions and inform the person in charge of the moisture control or to the “moisture phone” if there were any problems or anything that could have been improved about moisture control. Everybody was also mandated to save the jobsite’s “moisture phone” number, so in the case of water damage situations everybody would be able to call the appropriate number to inform the site supervisors about the situation. The moisture phone was essentially a phone located in the middle of the coffee table at the onsite office and all the workers were given the number to this phone, which they then were instructed to call if they spotted anything moisture control related. In office 2, “moisture phone” WhatsApp group was used, for the same purpose as the “moisture phone” was used in office 1. Workers could join the WhatsApp group and report any moisture control related findings effectively with pictures and comments and get possible rewards from good findings.

6 Findings from expert interviews and document review

Moisture control

According to expert interviews, these methods listed below were used at Wood City office 1 building to reach the best possible results with moisture control:

- Careful advance planning and searching for the best solutions with different experts in the field.
- Involvement of subcontractors and keeping moisture control as a top topic in all meetings, especially in subcontractor meetings.
- Involvement of subcontractor's workers starting from the onsite orientation, which was the first point of contact for moisture control.
- Using a moisture control phone at the construction site, with which workers could report possible moisture damage and moisture control related finding from the jobsite.
- Workers were also motivated with rewards if they informed management about moisture control related issues.

Moisture control plan

Moisture control plan should, according to expert interviews, be thought out well in advance and all relevant stake holders involved in the project should be involved in planning of the moisture control practices in order to find out the best solutions and in order to form a holistic understanding about the moisture control between all parties. It would be recommended that mass timber construction projects would always apply real cooperation in making of the construction site specific moisture control plan. This way the moisture control plan can be optimized, weather protection methods can be planned, and responsibilities of different parties from moisture control perspective can be stated more clearly. Moisture control plan cannot be too excessive because that can lead to problems with schedules, implementation of the planned protections and with the actual construction of the mass timber frame.

Moisture risks

According to Wood City moisture control plans, the biggest moisture risks during construction of the mass timber frame of a building are:

- Water penetrates into the insulation layer of facade elements.
- Facade elements are poorly sealed and leak water.
- Water penetrates the intermediate floors and enters into floors that have already been sealed and thus dry out slower.
- Wooden surfaces get wet before those should be coated, for example CLT-slabs' surfaces get too wet before a surface concrete casting.

- Mass timber elements get exposed to moisture loads for multiple weeks in a row.

Monitoring

Weekly moisture control tours should, according to expert interviews, be made before the building has been sealed to ensure that all the weather protections are done correctly and there are no moisture damages in the structures. Also, additional measuring and weather protection needs of different structures can be determined during the tours. According to Wood City moisture control plans, the moisture control tours should be carried out on the construction site at least in cooperation with the main contractor and the developer's moisture technical supervisor. At office 1, weekly meetings, moisture control tours and reports of the moisture control were conducted, and with these the monitoring and communication of the onsite conditions was quite effective. At the very beginning of the construction, it was agreed that from the beginning of the frame phase until the point where the building is waterproof in terms of the shell, weekly moisture control tours will be carried out on the construction site. The tours were attended by the developer's moisture control coordinator, the general contractor's job manager who was responsible for the mass timber frame, structural designer, and a wood construction expert. During the tours, the current weather conditions, ongoing work phases, possible deviations, performed moisture measurements, follow-up measures, and also well-handled matters were reviewed.

According to Wood City moisture control plans, in order to monitor the inside conditions of a structure effectively, condition meters should be placed inside to each floor to measure relative humidity and temperature. With the data received from the condition meters, decisions can be made to either increase heating and drying equipment or decrease those accordingly in order to maintain appropriate conditions inside the building where effective drying of the mass timber structures should be supported. In addition, according to Wood City moisture control plans, the moisture-technical condition of the mass timber elements arriving onsite should be checked visually and with moisture measurements before starting the installation work. Possible wetting during transport and storage is documented and drying or repair measures should be started immediately, to avoid further damage if the elements are wet.

Resistance to moisture

Moisture sensitive materials should not, according to expert interviews, be used in the construction of a buildings frame if those cannot be sufficiently protected from moisture onsite. Especially if weather protection shelter is not used for the building, then materials need to be able to withstand some degree of wetting during construction without starting to mould or deteriorate.

Only materials that can withstand moisture should be used in the building process. Still, moisture exposure times of the structures should be minimized with fast building speed, good air flow and temporary weather protections.

Moisture penetration

Moisture does not penetrate easily deep inside CLT or any mass timber elements from their face grain side. According to expert interviews, usually, moisture penetrates only few millimetres inside CLT from its face grain side and in most cases the moisture penetration stops on the first lamella layer's glue inside CLT-mass timber elements. Even if there is a large body of water on top of CLT face surface for multiple days, the moisture will still only penetrate few millimetres inside the CLT. Water will penetrate eventually deeper inside CLT if a body of water remains on top of it for multiple weeks. On the other hand, moisture can easily penetrate deeper inside the CLT with fast speed from CLT's sides and ends where its end grains are located.

Surface concrete casting

CLT should be measured for moisture content before a surface concrete casting comes on top of it in order to verify that the CLT's moisture content is under the limit values before the concrete casting is made. According to expert interviews, with surface concrete casting the chance for mould and decay problems afterwards are quite small, but still possible, so it is worth avoiding them by using preventive measures like moisture barrier coatings and low limit values. Moisture barrier coatings effectively prevent the transfer of moisture from concrete to CLT-slab, thus those should be used to protect CLT-slabs from concrete's moisture.

Moisture measurements

According to expert interviews, there is currently no standard or guideline which to follow while taking moisture measurements from mass timber structures like there is for concrete structures. Without this type of guideline, it is difficult to determine how many moisture measurements should be made of mass timber structures, where the measurements should be taken and with which methods in order to achieve a good level of reliability with the measurements.

Spike meter measurements

Spike meter's spike orientation in contrast with woods grain direction does make a difference in the measurement results. According to expert interviews, with some devices the measurement should be taken parallel to grain, with some perpendicular to grain and with some devices it does not matter with what spike orientation the measurements are taken, but in those cases perpendicular to grain orientation should be preferred. Most of the times it is recommended to take the measurements perpendicular to grain because

that allows the spike meter to measure over multiple wood's grain and that way the results are more averaged over the measured piece of wood.

Drying

In order to make sure that all structures are dry before coating them, the structures should be given enough time to dry out properly and moisture measurements should also be made to confirm that the structures have dried enough. According to expert interviews, well-made moisture measurements should always be the ones that authorize coating of materials, especially if there is a risk for mould growth or material deterioration.

Sunlight and wind are, according to expert interviews, quite effective at drying out mass timber structures. To take a full advantage of this, the frame of the structure should be open during good weather in order to allow the sunlight and wind created air flow to dry out wet mass timber structures.

Onsite orientation

According to Wood City moisture control plans, everyone working on the construction site is familiarized and committed to follow the construction site's moisture control practices. Observing potential moisture damage situations, reporting them to the main contractor and taking actions on preventing further damages is the responsibility of every employee working on the construction site. In the onsite orientation, at least these things must be taken into account when talking about moisture control:

- Responsibilities and obligations of the employees during work
- Measures in case of water damage situation
- Storage and protection of building materials
- Weather protection of structures
- Project-specific moisture control practices

Additionally, according to expert interviews, the onsite orientation has to give workers simple methods on how to report moisture issues to work management. Simplest way to achieve this is by using the "moisture phone" method, where workers save a specific phone number to call when they spot any moisture issues.

Motivation

According to expert interviews presence of interest, good motivation and active collaboration are also extremely important in moisture control. If there is no interest and proper motivation to do moisture control practices correctly then those will ultimately fail in some area. Workers can also be motivated to be more involved in the moisture control process with different kinds of simple rewards like with lunch gift cards if they bring up good findings of onsite moisture control to the jobsite's management.

7 Findings from onsite observations

Lifting holes

All the GLT-columns and CLT-slabs had holes in them for lifting purposes, this can be seen in Figures 30 and 31. The holes in the CLT-slabs were made for Sihga pick lifting system, which can be seen in Figure 30. If rainwater would get inside these lifting holes, then the GLT-columns' and CLT-slabs' moisture content levels might rise to high levels in the middle parts. If moisture levels rise high in the middle of the mass timber elements, then drying of the excess moisture from the middle could be quite slow. In order to prevent this, the holes were plugged in both of the CLT-slabs and GLT-columns after installation in order to prevent moisture from getting into them, this can be seen in Figure 30 and 31. Additionally, the CLT-lifting holes were taped over to add extra protection for the wooden plugs, which can also be seen from Figure 30. The CLT-slabs were wet near lifting holes, which had not been plugged in time before poor weather conditions, because uncovered lifting holes easily gathered water into them. But, during good weather conditions the CLT-lifting holes dried out to acceptable moisture levels and those were able to be plugged and covered with tape.



Figure 30: Sihga pick lifting system next to a CLT-lifting hole created for it. Lifting hole filled with wooden plug (left lower image) and taped over (right lower image).



Figure 31: GLT-column lifting holes exposed (left image) and plugged shut (right image).

CLT-slab recesses and structural gaps

CLT-slabs had recesses made into them in order to add additional grip to the surface concrete casting that would come on top of the CLT-slabs. The CLT-slab recesses gather more water than flat CLT surfaces. Water puddled into the recesses and caused the CLT-slabs to get wetter in the recesses than they were at other plain CLT surfaces. The recesses made for the CLT-slabs can be seen from Figure 32. Also, there were gaps between the CLT-slabs, and the concrete shaft located in the middle of the structure, this can be seen from Figure 32. Water puddled into these gaps and water also came through these to lower floors during rainy days. This was noticed onsite, and the gaps were casted shut with concrete.

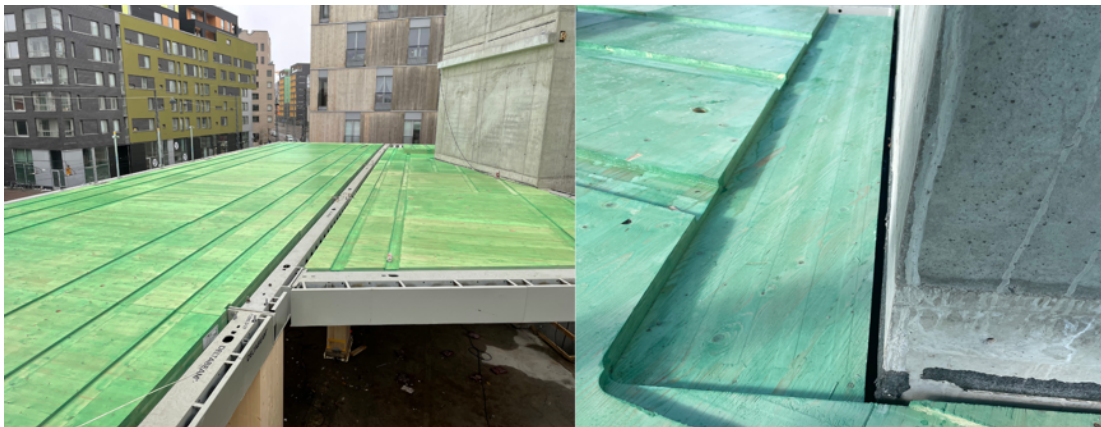


Figure 32: Recesses made in to the CLT-slabs (left image). Small gaps between concrete shafts and CLT-slabs (right image).

Structural openings

On top of gaps, the building had huge openings in the middle of the third, fifth and sixth intermediate floors because of the CLT-stairs that were

installed between the floors, this can be seen from Figure 33. The Huge openings in the middle of the structure were not able to be sealed since those had to be open for the CLT-stair installations. Because the openings were not sealed, water came easily through the openings during rainy days. In addition, CLT-stairs needed to be protected well from any scratches or moisture damages, thus those were protected with wooden frame and plastic sheets, which can be seen in Figure 33.



Figure 33: CLT-stairs covered with plastic sheets (left image) and opening made for the CLT-stairs at fifth floor (right image).

CLT-Delta beam and GLT-column filling concrete castings

The CLT-Delta beam filling concrete castings were made to each CLT-floor before the next floor's mass timber elements were allowed to be installed, this can be seen from Figure 34. The filling casting connected the CLT-slabs and the Delta beams together, this way giving the structure more integrity. The moisture content values of the CLT-slabs increased from the concrete castings. But as the filling concrete casting focused only on CLT-slab Delta-beam connections, most of the excess moisture coming from the concrete casting easily dried out from the exposed CLT-slab surfaces. However, some amount of moisture might have penetrated deeper into the CLT-slabs because the end grains of the CLT-slabs are in contact with the filling concrete casting. The GLT-column connection points were also covered with concrete during the assemble of the mass timber frame in order to give the GLT-columns connections more structural integrity. This can be seen from Figure 34. The moisture content values of the GLT-columns increased near the filling castings, but the columns dried out fairly well from the filling casting because the air flow around the columns was efficient during construction.



Figure 34: Filling concrete casting being done on top of the CLT-slabs (left image). GLT-column with filling concrete casting (right image).

CLT-concrete composite subfloor casting

CLT-slabs were covered with concrete during the assembly of the mass timber frame in order to give the building's CLT-floors more structural integrity by interlocking all the floor structures together with a concrete surface casting, this can be seen in Figure 35. The moisture content changes in the CLT-slabs after the surface concrete casting were monitored with Wiiste and drill hole measurements, and it was noticed that the moisture that comes from the concrete does penetrate deeper inside the CLT-slabs, but it takes weeks or even months to happen. Still, the moisture loads coming from the concrete casting mostly stay in the first CLT lamella layer.



Figure 35: Wet surface concrete casting on top of the CLT-slabs (left image) and cured concrete on top of the CLT-slabs (right image).

8 Findings from onsite measurements

Measurement results collectively

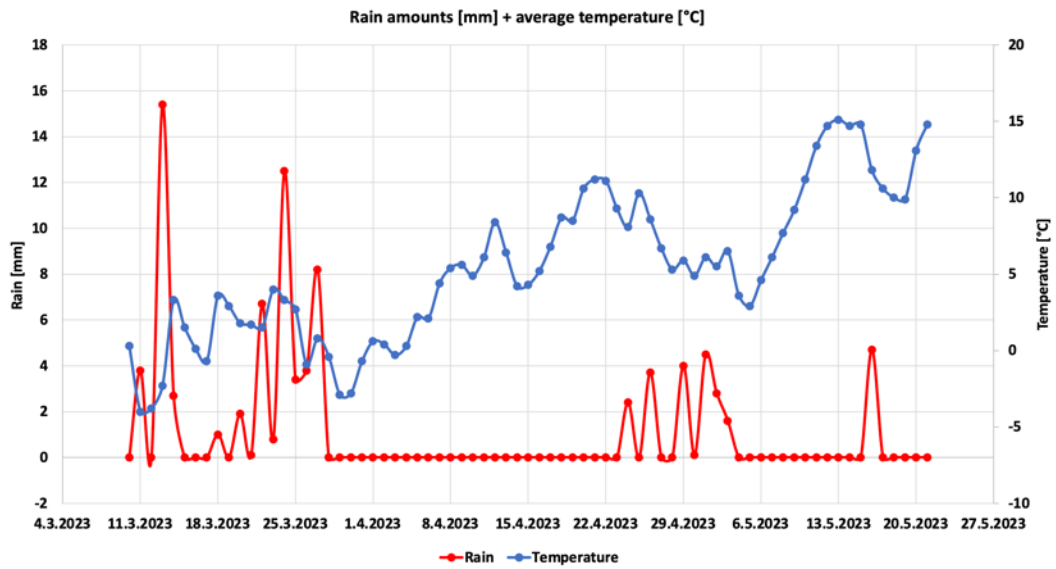


Figure 36: Average outside temperatures and daily rain amounts. Data gotten from Ilmatieteenlaitos.

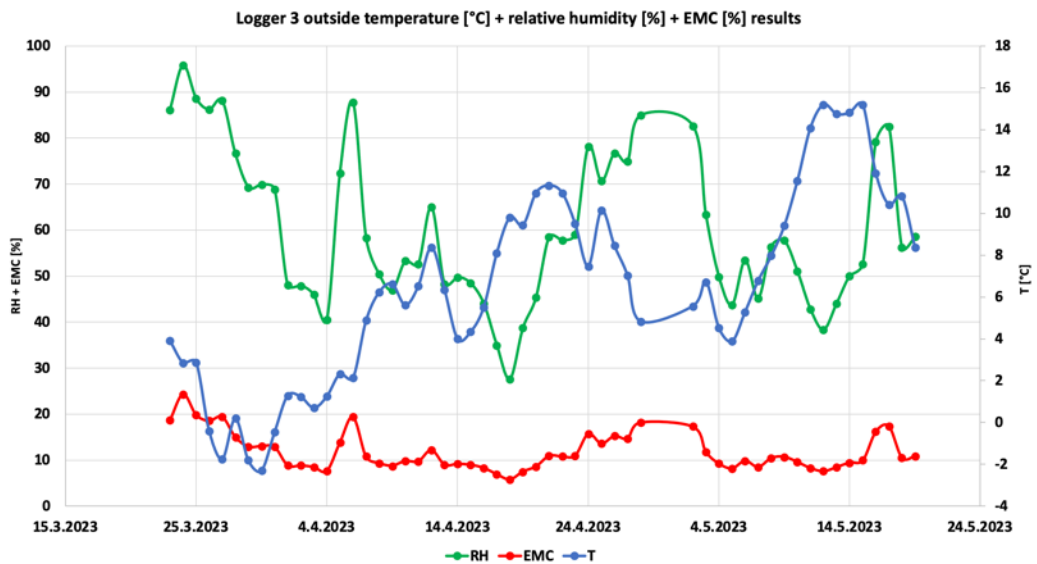


Figure 37: Outside RH, T and EMC measurement data from logger 3.

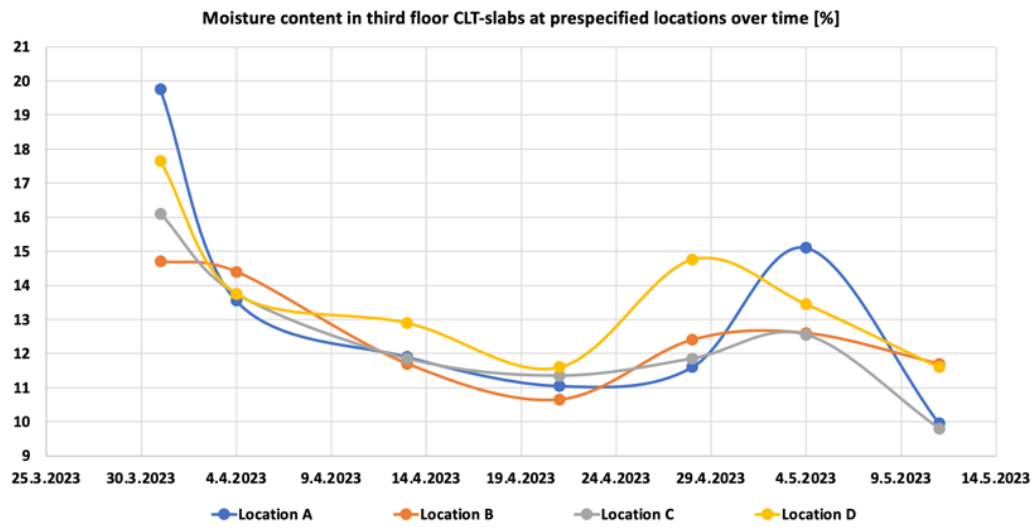


Figure 38: CLT's moisture content over time at prespecified locations at third floor.

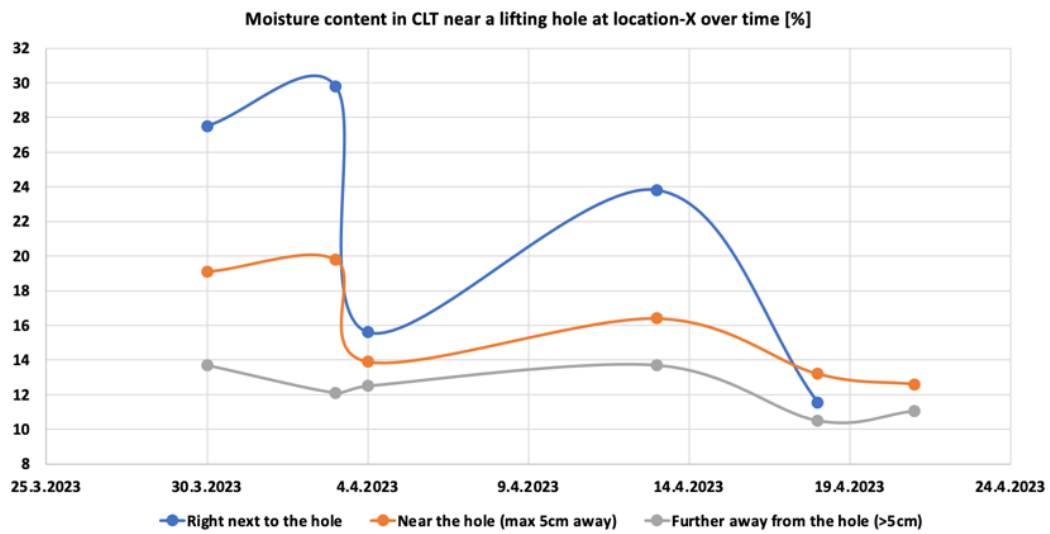


Figure 39: CLT-slab's moisture content near a lifting hole over time at location-X at third floor.

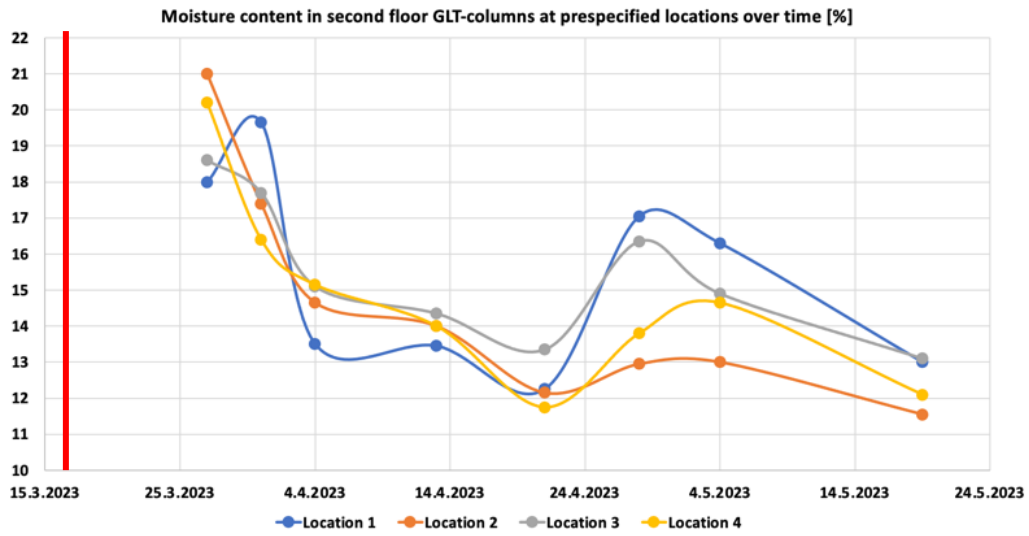


Figure 40: GLT- column moisture contents measured over time at prespecified locations. Red line marks the date of the filling concrete castings (16.3.2023).

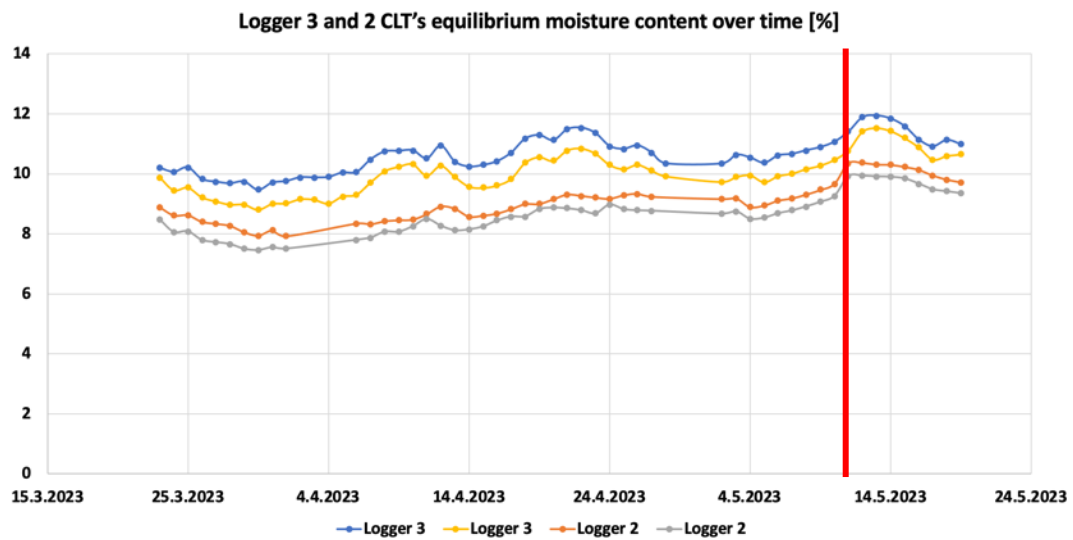


Figure 41: Logger 3 and 2 CLT-slab's EMC values. Red line marks the date of the surface concrete casting (11.5.2023).

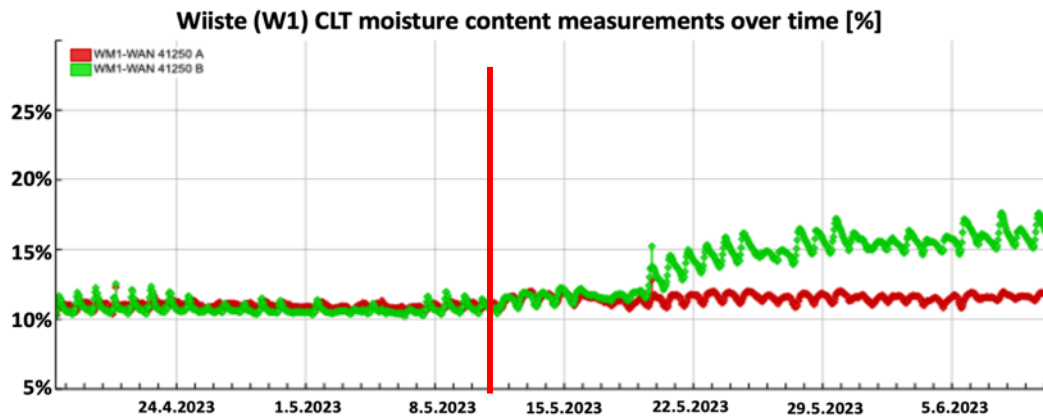


Figure 42: Wiiste 41250 CLT moisture content measurement results. Red line marks the date of the surface concrete casting (11.5.2023).

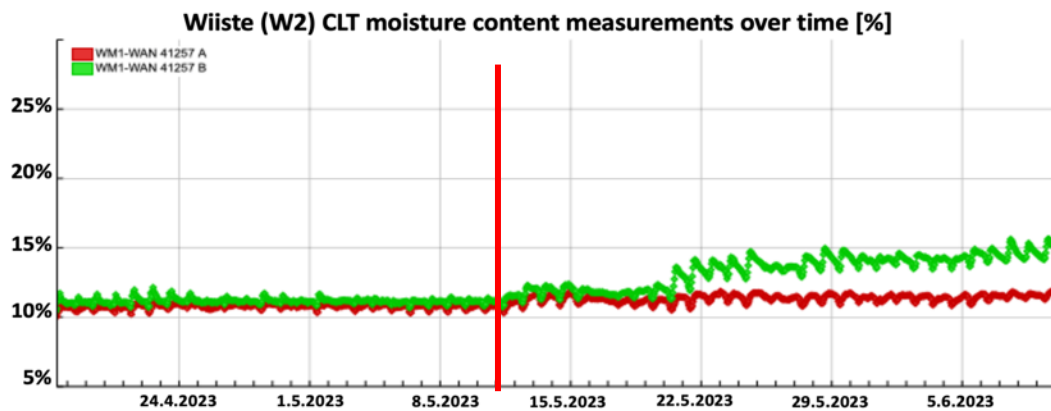


Figure 43: Wiiste 41257 CLT moisture content measurements. Red line marks the date of the third-floor surface concrete casting (11.5.2023).

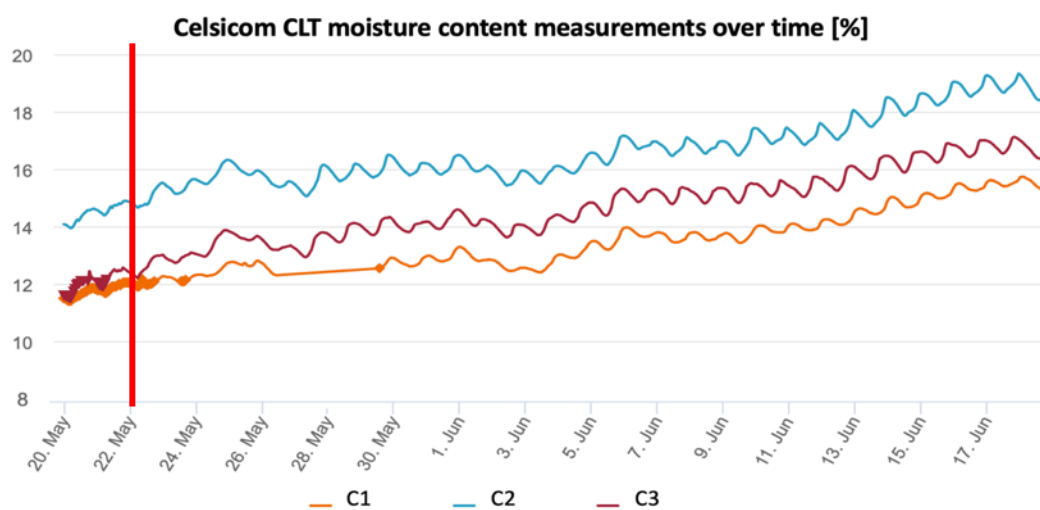


Figure 44: Celsicom results from 30.5.2023 at prespecified locations measuring CLT-slabs' moisture content. Red line marks the date of the fourth-floor surface concrete casting (22.5.2023).

Analysis of weather data

From Figure 36 it can be seen that temperature has naturally risen as winter progressed and from Figure 36 it can also be seen that the most significant rain periods occurred during late March and late April. The worst weather conditions that happened late March did not affect the structure that significantly because during that point only the first CLT-intermediate floor had been assembled. The mass timber elements that got wetted at that point easily dried back to normal levels during April when there was no rain for over 20 days. The poor weather conditions that happened during late April affected the mass timber structures more significantly because at that point the frame of the structure had reached five stories high and thus there were more mass timber elements onsite that got wetted than during late March. Still, the mass timber elements that were wetted easily dried back to normal levels in good weather conditions during May.

Analysis of condition measurements

From Figure 37 it can be seen that the relative humidity conditions onsite were most of the time quite low, on average 60% RH, which supported the efficient drying of the mass timber elements. Temperatures on the other hand were low during late March and early April, which did not help with the drying process, but after middle of April the temperatures started rising and that supported the efficient drying of the mass timber structures. The average temperature during the measuring period was around 6°C. Overall the conditions onsite supported quite effective drying of the mass timber structures as the average RH was 60% and average temperature was 6°C and effective drying of the structures requires conditions where RH is below 60% and temperature is above 10°C.

In order for there to be a risk of mould formation in the jobsite, the conditions should have been such that the relative humidity was at 80-100% and the temperature was over 5°C for multiple weeks in a row. From Figure 37 it can be seen that these types of conditions were reached few times, usually only during rainy weather, but the conditions never stayed in the same level for multiple weeks straight. Because of this, there was no risk of mould forming on the surfaces of mass timber structures due to relative humidity and temperature conditions.

From Figure 37 it can also be seen that the average outside EMC values moved around 11-12%. Some high peaks can be noticed from the graph that were caused by rainy weather periods onsite, but all in all the average outside EMC values move around 11-12% quite consistently during the measuring period. This indicates that mass timber structures onsite should have their moisture content also moving around 11-12% on average. After wetting

conditions, the mass timber structures should desorb additional moisture out in order to reach their EMC value that should move according to these results around 11-12%. It can be noticed especially from Wiiste moisture content measurements showcased in Figure 42 and 43 that the moisture content values of CLT-slab did indeed move on average around 10-11%.

Analysis of drill hole measurements

From the drill hole measurement results, presented in Figure 41 it can be noticed that the results between loggers 2 and 3 are a bit different, because some part of the structure got more wetted during the rainy days than other. The EMC results indicate that moisture content levels were slightly higher where the logger 3 was located than where logger 2 was located. Logger 2 measured CLT-slab's EMC moved around 8-10% without any major deviations from those values and logger 3 measured CLT-slab's EMC moved around 9-11% also without any major deviations. This indicates that the CLT-slabs have been dry throughout the building process deeper inside them. Water rained at late March straight to the CLT-slabs that had the loggers installed to them, but the EMC charts indicate that the CLT was dry at least from 5cm deep from the surface. This highlights that moisture does not really penetrate deep inside CLT if the wetting period is relatively short, less than a week, and if the moisture tries to penetrate the CLT-slab perpendicular to its grain. How much the moisture barrier coatings helped prevent moisture from penetrating deeper inside the CLT is hard to predict, but those should slow down the moisture transfer into CLT to some degree.

Analysis of Wiiste measurements

From Wiiste measuring results presented in Figures 42 and 43 it can be firstly noticed that there are basically no differences between the Wiiste 41250 and 41257 results. Both of the Wiistes measured that the CLT-slab moisture contents moved on average around 10-11% and from both of the result graphs it can be noticed that the moisture content levels start to gradually rise after a week has passed from the surface concrete casting. Same type of gradual increase in CLT-slab EMC values cannot be noticed from the drill hole measurements in Figure 41 as the measurements were stopped too early to see any increases in the moisture contents before that. The fact that CLT-slab moisture contents started increasing only after a week from the surface concrete casting highlights how slowly moisture penetrates deeper inside CLT. In addition, it can be noticed from Figures 42 and 43 that the moisture coming from the surface concrete casting penetrates only into the first CLT lamella layer and not into the second lamella layer. This might be because it is generally more difficult for the moisture content to penetrate deeper into CLT and also the glue layer between first and second lamella layer acts as a moisture barrier.

It can be noticed from Figure 36 weather data that the third floor's CLT-slabs were exposed to heavy rain and snow conditions in early March for almost seven days straight, but according to Wiiste measurement results in Figures 42 and 43 indicate that the moisture content levels in the measured CLT-slabs only changed a little bit (maximum 1% MC) in the first lamella layer of the CLT. The moisture contents in the second lamella layer according to the Wiiste meters basically stayed at normal levels and there were no noticeable changes in the moisture content values during this high intensity wetting period. These results, like also the drill hole measurement results, highlight the fact that the CLT-slabs that are treated with moisture barrier coating are quite resilient against wetting if the moisture tries to penetrate through the CLT-slabs perpendicular to its grains. Rainwater and snow can come on top of them for seven days straight without significant moisture content increase beneath the CLT's surface. Rather, the moisture mostly stays on top or penetrates only few millimetres deep inside to the CLT-slabs.

Analysis of Celsicom measurements

From Celsicom measuring results presented in Figures 44 it can be noticed that the fourth floor CLT-slab moisture contents are also gradually rising after the surface concrete casting like in third floor, according Wiiste measuring results. But the Celsicom results rise quicker with less delay and to higher moisture content levels than the Wiiste measuring results because the measurements are taken closer to the surface of the CLT-slabs. It can also be noticed from both the Wiiste and Celsicom results that neither have yet reached alarming moisture content levels (20% MC) after the surface concrete castings. Highest Wiiste values move around 16-17% MC and highest Celsicom moisture content levels at 19% MC. More than 2 months would be needed to see were the moisture content levels would eventually rise, but unfortunately this time schedule does not fit this thesis work. Fortunately, Wood City office 2 jobsite continues to collect data on CLT-slab moisture content levels for several months onward from now. Later on, it can be seen from the results how high the moisture content levels will eventually rise in the first and second lamella layer in the CLT-slabs after the surface concrete castings.

Analysis of the spike meter measurements

CLT-slab truck deliveries

Spike meter measurement results taken from the onsite delivered CLT-slabs showed that the sides and corners of some CLT-slabs had significantly higher moisture content levels than the more middle parts of the CLT-slabs. Moisture content in some instances at the corners was around 16% and in the middle 10-12%. The reason for this difference in moisture contents might be that there were holes in the plastic covering wrapping of the CLT-slabs and thus the edges and corners of the CLT-slabs got wet during transportation. But

there is no clear reason why the edges and corners of the CLT-slabs were in few instances much damper than the middle parts of the CLT-slabs when those were received onsite. It can also be possible that the CLT-slabs got wet at factory before being wrapped into covering plastics. Some of the CLT-elements were also visible wet after transportation, and also in some cases there was water on top of the elements when the plastics wrapping was removed. But majority of the CLT-slabs that were delivered to the jobsite were completely dry and the moisture content of the CLT-slabs was around 7–10% MC. There was no time during this thesis to measure and check all the CLT-elements individually that arrived onsite, but the subcontractor that installed all the elements noted that from all the CLT-deliveries there were only one or two that had visible water on top of the elements.

CLT-slabs

Spike meter measurement results from CLT-slabs, which are presented in Figure 38, it can be noticed that CLT-slabs had high moisture content levels after rainy and snowy conditions, but those dried back to EMC values that moved around 11-12% relatively quickly during good weather condition. From Figure 38 it can be noticed that it takes under one week for CLT-slabs to dry back to safe levels after wetting conditions. Drying back to EMC values after wetting conditions took approximately 1-2 weeks.

From the spike meter measurement results presented in Figure 38 it can be also noticed that the CLT-slabs' moisture content values had ups and downs over time due to rainy weather. In contrast to this, the Wiiste measuring result presented in Figure 42 and 43, had no fluctuations due to rainy weather, because moisture does not penetrate deep into the CLT-slabs if the wetting period is relatively short. These results again highlight the fact that the moisture mostly stays in the surface of CLT-slabs or penetrates only few millimetres into the CLT, thus the spike meter measuring results were high after rainy days and Wiiste measuring results stayed the same.

It was also noticed onsite from the spike meter measurements, that moisture content levels were usually higher at or near CLT-slabs' gaps, holes, and recesses where water was able to puddle more easily during rainy weather. From Figures 38 and 39 it can be noticed that the CLT around the lifting hole had significantly higher moisture content values than plain CLT.

In addition, the third floor and fourth floor CLT-slabs were measured more comprehensively before the surface concrete castings came on top of them on 11.5.2023 and 22.5.2023. The average moisture content values for the third floor CLT-slabs moved around 11,2% before the surface concrete casting and for the fourth floor CLT-slabs the moisture contents moved on average around 10%. According to the measurement results, the fourth and third

floor CLT-slabs were below the jobsite's surface concrete casting limit value (15% MC) and thus the surface concrete casting authorized to be made on top of them.

GLT-columns

From the GLT-column spike meter measuring results presented in Figure 40 it can be noticed that the GLT-columns had high moisture contents levels near the connection points after the filling concrete casting. The wetness near the GLT-columns' connection point overall was not an issue because the columns had sufficient time to dry out properly and because the air flow around the columns was effective which increased the effective drying speed of the GLT-column. In the end, it can be noticed from the Figure 40 measurement results that the GLT-columns were at the beginning wet, but those dried out to reasonable values during good weather conditions. That how much the filling concrete casting affected the moisture content levels of the GLT-columns is hard to estimate, but most likely the concrete's moisture did increase the measured GLT-column moisture content values to some degree.

From Figure 40 it can also be noticed that moisture contents in the GLT-columns fluctuated over time quite significantly, because of rainy days. The GLT moisture content levels can be compared with the rain amounts at Figure 36 and it can be noticed that because of rain the GLT columns usually got wetted quite a bit and drying back to EMC values, which were around 11-12%, took about 20 days. If the GLT-columns' drying speed is compared to CLT-slabs' drying speed, it can be noticed that CLT seems to generally dry out bit faster than GLT, about seven days faster. This might be because the CLT-slabs have more surface area to dry from, those are thinner than the GLT-columns, and the CLT-slabs also have the moisture barrier coating as extra protection which the GLT-columns do not have on their face surfaces for visual reasons.

CLT-slab lifting holes

From spike meter measurement results near CLT-slab lifting hole, which are presented in Figure 39, it can be noticed that the moisture content levels near the lifting hole were at the beginning extremely high around 23-28%. This was due to the fact, that the CLT-lifting holes on the third floor of the building that were not plugged got filled with water during rainy days and thus moisture content levels around them rose to high levels. Still, it can be noticed from Figure 39, that over time and with good weather conditions and with effective air flow, the lifting holes dried back to acceptable levels, after which those were plugged and taped over, so water could not enter the holes again after that. Before all the third-floor lifting holes were plugged and taped, the average moisture content values near the third floors lifting holes moved around 12,9%.

9 Conclusion

This master's thesis investigated mass timber construction, mass timber construction's moisture control and moisture measurements of wooden structures. The research goal of the thesis was to evaluate the best practices of mass timber construction's moisture control learned from SRV Rakennus Oy's Wood City project. The case study part of the thesis was conducted by reviewing documents, making interviews, onsite moisture measurements and other onsite observations.

From this thesis it can be concluded that well planned and active moisture control is an essential part of mass timber construction. Mass timber structures are relatively resilient to short term moisture loads. However, mass timber structures should always be protected from excess moisture during construction in order to prevent unwanted damages. Especially joints, connections and end grains of mass timber structures are critical components that require appropriate protection from excess moisture. In addition, if the materials utilised in the construction of the mass timber frame are sensitive to moisture loads, the building under construction should be fully protected. If full weather protection is not used during the construction, the materials utilised need to be sufficiently moisture resistant. Different kinds of gaps, recesses and holes in the mass timber structures should be avoided in design and in onsite construction if possible. If any exist, those need to be appropriately addressed to avoid water puddling up into them during bad weather.

Mass timber structures are relatively resilient to moisture if the moisture exposure is occurring from the face side perpendicular to grain and not parallel to grain. When the moisture exposure happens perpendicular to grain, the moisture penetrates only few millimetres into the mass timber structures even after one week's exposure to high moisture loads. For moisture to penetrate deeper into mass timber structures it requires that the exposure times are over one week, or the moisture loads can access the timber's end grains. This means that it is more important to focus on protecting end grain parts of mass timber elements onsite, than it is to protect the face sides. Mass timber structures also dry out relatively quickly, in some cases under one week, if the excess moisture is not deep inside the mass timber structures and if structures are allowed to be dried out by efficient airflow and low humidity conditions.

Moisture control practices followed on the construction site should be well thought out, practical and simple. If the planned moisture control actions are too difficult or time consuming to implement, then those might negatively impact the speed of construction and the entire moisture control process.

Importantly, wood usually needs time to absorb water to increase its moisture content, thus the period of exposure to moisture is more critical than the total amount of water falling on the surface of mass timber structures. Since the period of exposure is critical, it should be minimized by paying attention to the timing and speed of construction and prompt removal of excess moisture. By increasing the construction speed the envelope of the building can be sealed quicker and that way the moisture loads coming to the mass timber structures can also be minimized. In order to maintain fast building speed, all excessive moisture control practices that slow down and complicate the building process significantly should not be implemented.

In terms of moisture control in mass timber construction, the column-beam structural system is superior to the load-bearing walls system, because it is more open and thus air flow around the structures is more efficient during construction.

Most of the structural moisture-induced damages to the mass timber structures can be prevented by simply leaving the wet structures uncovered with other building materials until those have been sufficiently dried out. This, of course, could be problematic, if the construction site has to follow a strict schedule where the coating of mass timber structures with other materials is necessary to proceed. This was a critical phase also in relation to the CLT-slab surface concrete castings of Wood City office 2.

It cannot be concluded from this master thesis, if moisture barrier coatings are necessary between CLT-slabs and surface concrete casting, but according to expert interviews and earlier studies it is recommended to use those, in order to prevent possible mould issues after the casting process. Moisture barrier coatings in general protect mass timber structures from moisture loads and thus those are recommended to be used to protect moisture sensitive end grain parts of mass timber structures.

In addition to moisture control practices, it is essential to have active communication and good cooperation between different parties involved in the construction project. Parties involved should be motivated to conduct moisture control practices with good quality to ensure successful onsite moisture control. Especially close cooperation should be implemented when planning the construction site's specific moisture control plan. This way task designations and onsite moisture control methods can be agreed together and made clear for everyone. Onsite orientation is also, an important part of the moisture control process. As part of the orientation, workers should be instructed how moisture control practices are correctly implemented onsite and how to react if moisture damage situations occur.

As the last line of defence, building assemblies should always be designed to dry, in case exposure to moisture occurs during construction or use. This is mainly facilitated by allowing sufficient air flow to dry out wet structures. Overall, building design should be direct to be more fault-tolerant, where small errors and deficiencies in the design, construction, maintenance, and use of a building do not lead to harmful damages.

Wiiste and Celsicom moisture measurement results indicated that the moisture content levels in the CLT-slabs start to gradually rise after one week from the surface concrete casting, but it would take according to earlier studies at least two months to see how far the moisture content levels in the CLT would ultimately rise. Due to the thesis schedule the moisture measuring results were not able to be monitored for more than two months, and thus it cannot be concluded how the moisture content levels will ultimately develop inside the CLT-slabs. Still, Onsite measurements will be continued after the thesis at the Wood City office 2 jobsite and the final results will be available in the future.

During the course of this thesis, it was noticed that more research is needed in relation to the CLT-concrete subfloor structures. Some studies have simulated that the use of moisture barrier coatings is required between concrete and CLT in order to prevent rotting and mould growth, but no comprehensive case studies have been made on this topic yet. Further research could increase our knowledge of these topics: Are moisture barrier coatings needed between CLT and concrete; and What are CLT's moisture content limit values prior to the surface concrete casting. These research questions should be investigated with empiric laboratory or onsite case studies rather than computer simulations. In addition to research questions relating to CLT-concrete subfloor and moisture barrier coatings, further research should also be conducted on mass timber structures' drying times and moisture measurements. Similarly, to concrete structures, there should also be guidelines and standards on onsite moisture measurements techniques for mass timber structures and how to accurately estimate drying times.

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Appendix

- A.** Interviews and visits table
- B.** Measurement devices table
- C.** Additional measurement results
- D.** Residential buildings structural drawings
- E.** Office 1 structural drawings
- F.** Office 2 structural drawings

A. Interviews and visits table

Date	Place	Number of people interviewed	Companies involved
10.2.2023	SRV's Kumpula, biology high school jobsite visit	2	SRV Rakennus Oy
15.2.2023	Hybrid meeting (Teams and Ete-läranta 10, Palace-building)	3	SRV Rakennus Oy HTJ Oy
17.2.2023	Teams meeting	1	WoodExperts
2.3.2023	Teams meeting	1	Stora Enso Oy
8.3.2023	Aalto University	1	Aalto University
14.3.2023	Factory visit	1	Puurakentajat Group Oy
30.3.2023	Teams seminar on Wood's moisture measurements (Wiiste Oy)	0	Ramboll Oy Wiiste Oy
2.5.2023	Lengthy phone call	1	Vahanen Oy

B. Measurement devices table

Device	Range	Accuracy	Amount	Purpose
Vaisala HMP44 (measuring probes) + Grant 1000 series (data logger)	Relative humidity: 0-100% RH Temperature: -20 – +60°C	Relative humidity: 0-90% RH -> $\pm 2\%$ RH 90-100% RH -> $\pm 3\%$ RH Temperature: At 20°C -> $\pm 0.4^\circ\text{C}$	8 probes 3 loggers	Measure wood's moisture content (5 probes) Measure conditions (3 probes)
Gann hydrotest LG2 (electronic moisture meter) + Gann M20 (drive-in electrode)	Moisture content: 4-30% MC	No accuracy details given	1	Measure wood's moisture content
Wiiste WM1-WAN IoT (wood moisture meter) With 190mm and 220mm electrode screw pairs.	Moisture content: 6-30% MC Relative humidity: 10-100% RH Temperature: -40 – +85 °C	Moisture content: $\pm 1\%$ MC Relative humidity: $\pm 2.5\%$ RH Temperature: $\pm 0.5^\circ\text{C}$	2	Measure wood's moisture content + Measure onsite conditions
Celsicom Easy connect MM601 Wood moisture content sensor	Moisture content: 9,5-50% MC	No accuracy details given	3	Measure wood's moisture content

C. Additional measurement results

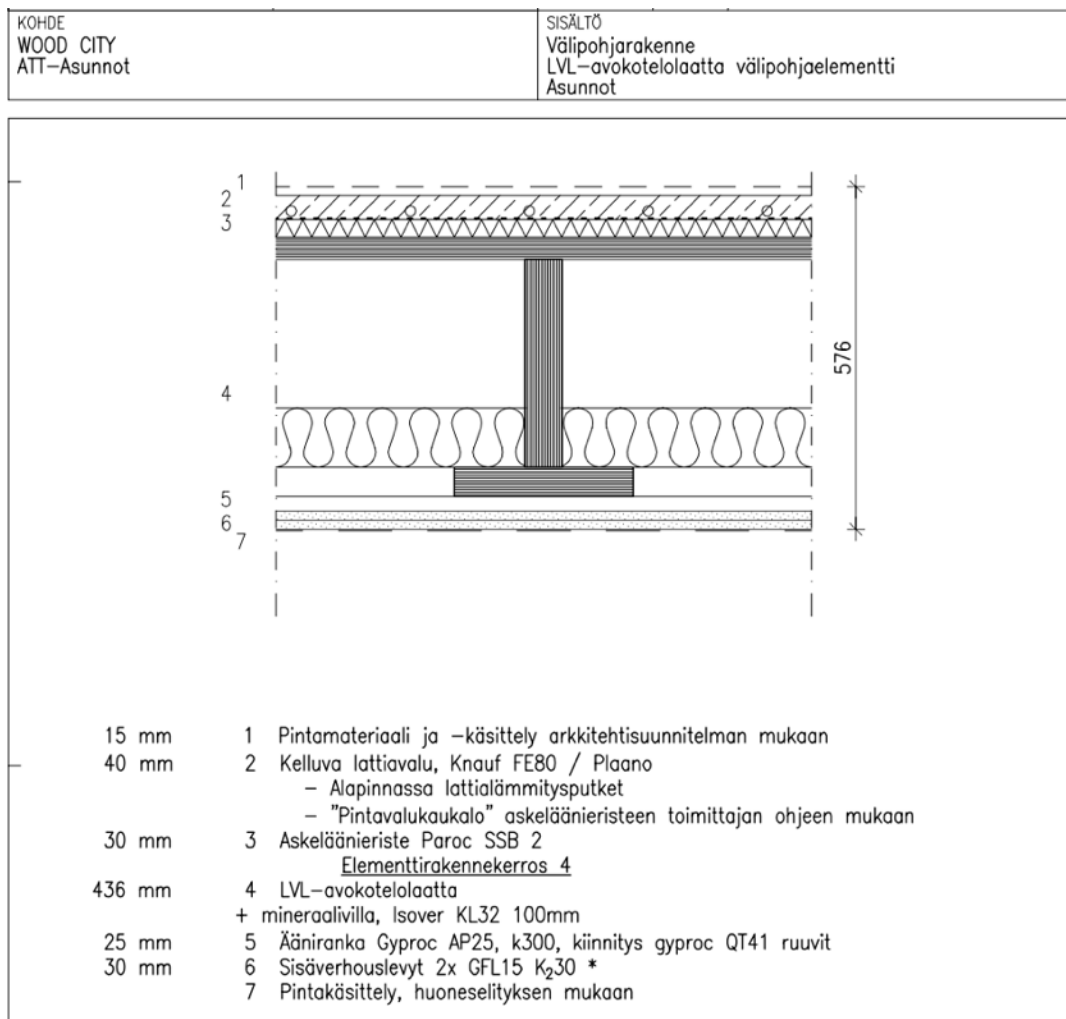
Parallel and perpendicular to grain test's measurement results:

Measurements on wood at Aalto University Climate room (20°C and 65% RH) (17.4.2023)		
Sample 1		
	Parallel to grain	Perpendicular to grain
1	11,5	11,5
2	11,7	11,6
3	11,6	11,5
4	11,6	11,7
5	11,5	11,6
6	11,7	11,7
7	11,8	11,1
Median	11,6	11,6
Average	11,6	11,5

Sample 2		
	Parallel to grain	Perpendicular to grain
1	12	11,5
2	12,1	11,6
3	11,7	11,9
4	11,8	11,5
5	12,1	11,5
6	11,8	11,6
7	11,5	11,8
Median	11,8	11,6
Average	11,9	11,6

D. Residential buildings structural drawings

LVL-floor slab



Load-bearing facade

KOHDE

WOOD CITY

ATT–Asunnot

SISÄLTÖ

KANTAVA ULKOSEINÄ

19 mm

1E

Ulkoseinäelementtirakennekerrokset 1–5

Accoya–pystypaneeli 19x195, pintakäsittely rakennusselityksen mukaan,

Palonsuojakäsittely B–s2, d0 ARK julkisivupiirustusten mukaan

k/k 184, kiinnitys valmistajan ohjeen mukaan

78 mm

2E

Tuuletusrako

+ vaakakoolaus 33x95 k<600

+ pystykoolaus 45x95 k<600

+ Palonsuojakäsittely B–s2, d0 ARK julkisivupiirustusten mukaan

Palon leviäminen ilmarakoon estetään palokatkoilla

+ kerroksittainen palokatko profiili + puu 45x95

+ ontelotiiviste FBH–36 + puu 45x95, asennetaan ilmanottoaukkoihin

9 mm

3E

Tuulensuoja K₂10 Glasroc H GHS 9 Storm

98 mm

4E

Runko 98x48 k600 + mineraalivilla

materiaali vähintään A2–s1, d0, λD=0,035 W/mK

5E

Tuulensuojakangas Windmax "Paavo"

Elementtirakennekerros 6

141 mm

6E

LVL

15 mm

7T

Palokipsilevy K₂30 Gyproc GFL15

10 mm

8T

Ilmaväli

66 mm

9T

Runko 66 mm + 50 mm Paroc extra ~30kg/m³

26 mm

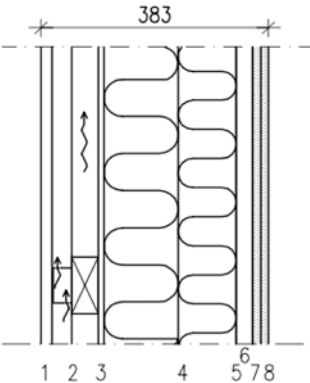
10T

2xKipsilevy GR13

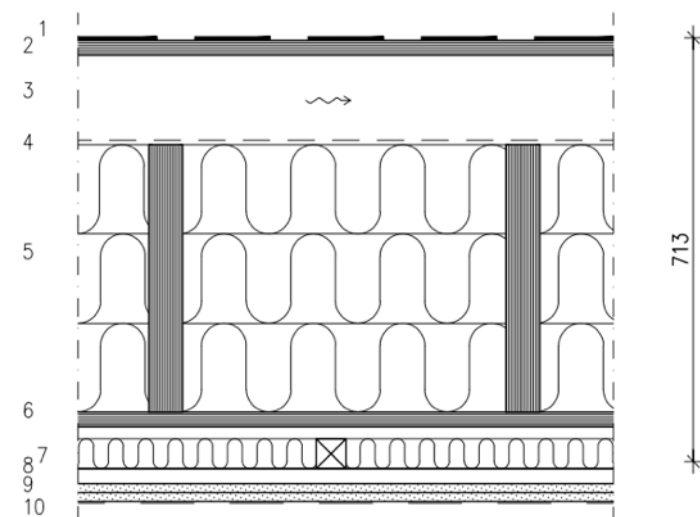
11T

Pintamateriaali ja –käsittely arkkitehtisuunnitelman mukaan

Non-load bearing facade

KOHDE WOOD CITY ATT-Asunnot		SISÄLTÖ EI-KANTAVA ULKOSEINÄ
		
		<u>Ulkoseinäelementtirakennekerrokset 1-5</u>
19 mm	1E	Accoya-pystypaneeli 19x195, pintakäsittely rakennusselityksen mukaan, Palonsuojakäsittely B-s2, d0 ARK julkisivupiirustusten mukaan k/k 184, kiinnitys valmistajan ohjeen mukaan
78 mm	2E	Tuuletusrako + vaakakoolaus 33x95 k<600 + pystykoolaus 45x95 k<600 + Palonsuojakäsittely B-s2, d0 ARK julkisivupiirustusten mukaan Palon leviäminen ilmarakoon estetään palokatkoilla + kerroksittainen palokatko profiili + puu 45x95 + ontelotiiviste FBH-36 + puu 45x95, asennetaan ilmanottoaukkoihin
9 mm	3E	Tuulensuoja K ₂ 10 Glasroc H GHS 9 Storm
223 mm	4E	Runko 223x48 k600 + mineraalivilla materiaali vähintään A2-s1, d0, λD=0,035 W/mK
	5E	Höyrynsulkukalvo
28 mm	6T	Pystykoolaus 28x95-k600 ja koolaus elementin reuna-alueilla
26 mm	7T	2xKipsilevy GR13
	8T	Pintamateriaali ja -käsittely arkkitehtisuunnitelman mukaan

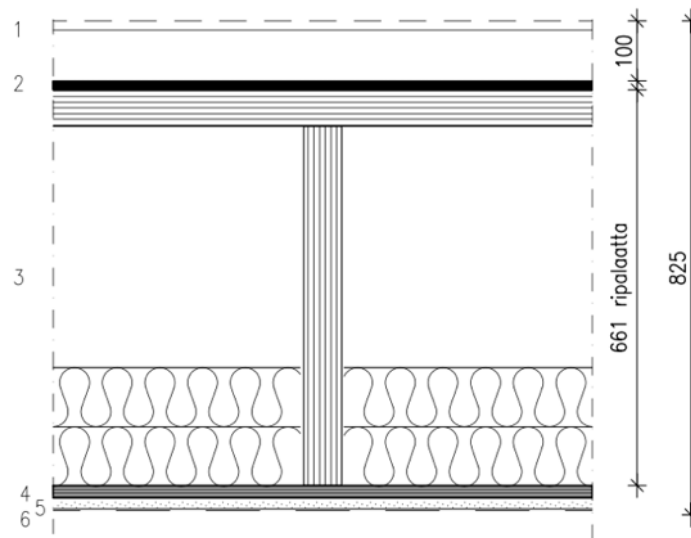
LVL-roof element

KOHDE WOOD CITY ATT–Asunnot	SISÄLTÖ Yläpohjarakenne Kattoelementti Asunnot		
<div style="display: flex; align-items: center; justify-content: space-between;"> <div style="display: flex; flex-direction: column; align-items: center;"> <div style="margin-bottom: 10px;">1</div> <div style="margin-bottom: 10px;">2</div> <div style="margin-bottom: 10px;">3</div> <div style="margin-bottom: 10px;">4</div> <div style="margin-bottom: 10px;">5</div> <div style="margin-bottom: 10px;">6</div> <div style="margin-bottom: 10px;">8</div> <div style="margin-bottom: 10px;">9</div> <div>10</div> </div>  <div style="margin-top: 20px;"> <p style="text-align: center;"><u>Elementtirakennekerrokset 1–7</u></p> <table border="0"> <tr> <td style="vertical-align: top; padding-right: 20px;"> 4 mm 25 mm 450 mm 25 mm 25 mm 30 mm </td><td style="vertical-align: top;"> 1E Vedeneriste VE80, kallistus jirissä $\geq 1:80$ 2E Ristiinviilotettu LVL (homeensuojakäsittely) 3E Poikittaisvasat C24 48x148 k600 + 148 mm tuuletusrako 4E Tuulensuojapaperi, Tyvek Pro 5E Yhteensuuntaan viilotettu LVL 57x450 + Kivivilla Paroc extra pro 3 x 150 mm materiaali vähintään A2–s1, d0, $\lambda_d=0,033$ W/mK 6E Ristiinviilotettu LVL 7T Alaslakurunko+50 mm mineraalivilla $\sim 30\text{kg/m}^3$ 8T Ääniranka Gyproc AP25, k300, kiinnitys gyproc QT41 ruuvit 9T Sisäverhouslevyt 2x GFL15 K₂30 10T Pintakäsittely, huoneselityksen mukaan </td></tr> </table> </div> </div>		4 mm 25 mm 450 mm 25 mm 25 mm 30 mm	1E Vedeneriste VE80, kallistus jirissä $\geq 1:80$ 2E Ristiinviilotettu LVL (homeensuojakäsittely) 3E Poikittaisvasat C24 48x148 k600 + 148 mm tuuletusrako 4E Tuulensuojapaperi, Tyvek Pro 5E Yhteensuuntaan viilotettu LVL 57x450 + Kivivilla Paroc extra pro 3 x 150 mm materiaali vähintään A2–s1, d0, $\lambda_d=0,033$ W/mK 6E Ristiinviilotettu LVL 7T Alaslakurunko+50 mm mineraalivilla $\sim 30\text{kg/m}^3$ 8T Ääniranka Gyproc AP25, k300, kiinnitys gyproc QT41 ruuvit 9T Sisäverhouslevyt 2x GFL15 K ₂ 30 10T Pintakäsittely, huoneselityksen mukaan
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E. Office 1 structural drawings

LVL-floor slab

KOHDE Wood City Toimistotalo Helsinki	SISÄLTÖ Ripalaatta-välipohja
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100 mm	1	Asennuslattia* (asennuslattian askeläänitason parannusluku ΔL_w vähintään 21 dB, ilmaääneneristävyyden ΔR_w vähintään 1 dB ja suurin sallittu massa 40 kg/m ²)
12 mm	2	Weber 120 Reno Saneeraus Plaano 12mm + lasikuituverkko
661 mm	3	Ripalaatta 61 LVL-X kansilevy 63x600 LVL-S ripa k570 + mineraalivilla 200 mm
21 mm	4	Vaneri 21 mm
18 mm	5	Gyproc GFL 18*
	6	Pintamateriaali, rakennusselityksen mukaan

Non-load bearing facade

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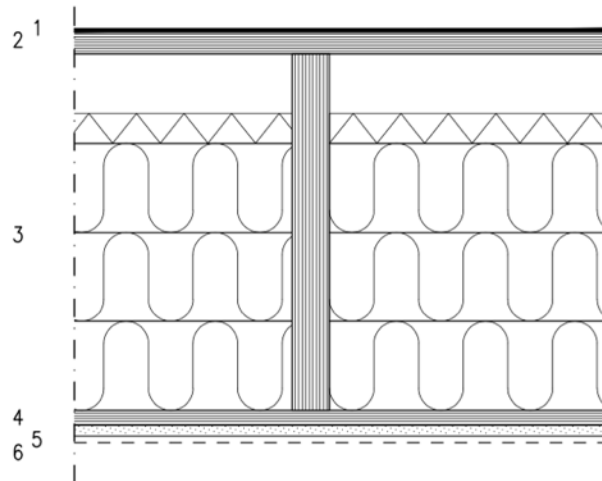
SISÄLTÖ
Puurakenteinen ei-kantava ulkoseinä
Accoya-julkisivupaneeli

19 mm	1	Accoya-julkisivupaneeli, rakennuslityksen mukaan
115 mm	2	Tuuletusrako, vaakakookaus 45x65 k600
9 mm	3	Tuulensuojalevytyt CEMBRIT WINDSTOPPER EXTREME suojaverhou K ₂ 30, A2-s1, d0
12 mm	4	Tuulensuojalevytyt CEMBRIT MULTIFORCE suojaverhou K ₂ 30, A2-s1, d0
245 mm	5	Pystykoolaus, 45x245 C24 k600 + lämmöneriste, mineraalivilla Isover KL35, $\lambda_d=0,035$ W/mK
0,2 mm	6	Höyrynsulku, polyeteenikalvo, saumat diffuusioteiivit
18 mm	7	Sisäverhoulevytys GFL18 työmaalla, suojaverhou K ₂ 30, A2-s1, d0
	8	Pintamateriaali- ja käsittely huoneselityksen mukaan

LVL-roof element

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SISÄLTÖ
Kotelolaatta-yläpohja
Toimisto yläpohja



37 mm	1E	Vedeneriste VE80, kallistus jirissä $\geq 1:80$
600..1000 mm	2E	Ristiinviilutettu LVL (homeensuojakäsittely)
	3E	Yhteensuuntaan viilutettu LVL 63x600 + 100 mm tuuletusväli + Tuulensuojapaperi Tyvek Soft + 500 mm Kivivilla Paroc extra pro, $\lambda_d=0.033$ W/mK materiaali vähintään A2-s1,d0
25 mm	4E	Ristiinviilutettu LVL
18 mm	5T	Palonsuojakipsilevy GFL18, Suojaverhousluokka Ks30
	6T	Pintamateriaali, rakennusselityksen mukaan

F. Office 2 structural drawings

CLT-concrete subfloor

KOHDE Wood City Toimistotalo II Helsinki	SISÄLTÖ CLT-välipohja CLT-betoni liittorakenne – Uritus Valun aikainen tuenta
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150 mm	1	Pintamateriaali ja -käsittely arkkitehtisuunnitelman mukaan
	2	Täriäeristetty asennus/korotuslattia(*) arkkitehdin ja akustiikkasuunnitelijan mukaan, massa $\leq 40 \text{ kg/m}^2$ (**)
80 mm	3	Liittobetonilaatta, keskeinen rauditus T8 k150/150
	4	CLT:n kaksinkertainen kosteussulkukäsittely
220 mm	5	CLT-levy+yläpinnan lovetus, Rothoblaas CTC, CS, d = 7 mm
18/50 mm	6	Palosuoja- ja akustinen villa, esim. Paroc FPS17t tai palokipsilevy GFL18, K ₂ 30 suojaverhous
	7	Delta-palkisto rakennesuunnitelmien mukaan
	8	Alakatto ja huoneakustiikkaverhoukset, ARK ja AKU mukaan

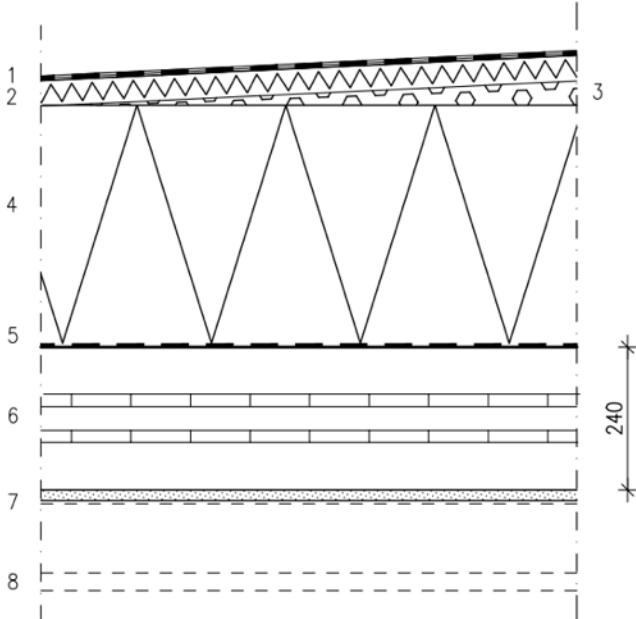
Non-load bearing facade

KOHDE
Wood City
Toimistotalo II
Helsinki

SISÄLTÖ
Puurakenteinen ei-kantava ulkoseinä
Accoya-julkisivupaneeli

19 mm	1	Accoya-julkisivupaneeli, rakennuslityksen mukaan
123 mm	2	Tuuletusrako, Pystykoolaus 48x123-k600 + Vaakakoolaus 48x98-k600 yläpinta viistetty
9 mm	3	Tuulensuojalevytytys, suojaverhousluokka K ₂ 10, A2-s1,d0. Vesihöyrynvastus $\mu \leq 10$ (EN 15283-1).
248 mm	4	Pystykoolaus, 48x248 C24 k600 + lämmöneriste, mineraalivilla $\lambda_d=0,035$ W/mK
0,2 mm	5	Höyrynsulku, MH2-luokka SFS EN 13984, saumat diffuusiotiiviit
18 mm	6	Sisäverhouslevytytys GFL18 työmaalla, suojaverhous K ₂ 30, A2-s1, d0
	7	Pintamateriaali- ja käsittely huoneselityksen mukaan

Roof structure

KOHDE Wood City Toimistotalo II Helsinki	SISÄLTÖ CLT-yläpohja vaihtoehto b vesikatolle
<div style="display: flex; align-items: center; justify-content: center;">  </div> <div style="display: flex; margin-top: 20px;"> <div style="flex: 1;"> <p>30 mm</p> <p>0...200 mm</p> <p>400 mm</p> <p>240 mm</p> <p>18 mm</p> </div> <div style="flex: 2;"> <ol style="list-style-type: none"> 1 Bitumikermivedeneristys VE80 (TL2+TL2) 2 Uritettu mineraalivilla, paloluokka A1 3 Vastakallistukset kevytsoralla 4 Lämmöneriste: mineraalivilla, $\lambda_d=0,036$ W/mK, paloluokka A1 5 Höyrysulku BH1 6 CLT240-L7s2-levy Delta-palkisto rakennesuunnitelmien mukaan 7 Suojaverhous palokipsilevyllä GFL18, K₂30 8 Alakatto ja huoneakustiikkaverhoukset, ARK ja AKU mukaan </div> </div>	