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A MOISTURE MANAGEMENT STRATEGY FOR CLT USING SENSOR TECHNOLOGY TO CREATE A ROBUST NORWEGIAN SCHOOL

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ABSTRACT:

To monitor the use of cross-laminated timber (CLT) and how it is affected by moisture in the construction phase, Woodsense has incorporated sensor technology in the moisture management strategy and construction of the Sophie Radich school in Lillestrøm. The use of sensor technology supports several aims of the BREEAM-NOR manual, which seeks to increase the use of sustainable building materials and improve robustness to moisture damages. With a preventive approach in moisture management in the construction phase, it is possible to reduce resource waste, as damages can be found earlier in the process and before the building is put into use. After having used sensors on the Sophie Radich project, increased moisture levels were detected. The preventive approach made it possible to correct the cause of moisture increase, avoiding further damage to the construction while illustrating the advantages of sensor technology.

KEYWORDS: CLT, moisture management, sensor technology, sustainable building materials, BREEAM-NOR,

1 INTRODUCTION

More sustainable construction calls for solutions that reduce resource consumption and CO_2 emissions through an increased use of sustainable building materials such as timber. This is also emphasized in the new BREEAM-NOR manual V.60 [1] in issue MAT 01 – *sustainable material choices – LCA and climate gas calculation*s where points are given for using sustainable materials with low carbon emission. Although timber is a more climate friendly material than conventional structural materials such as concrete and steel, there are concerns with using it in construction due to challenges associated with moisture protection and management.

Some of the main barriers preventing the use of timber as a building material is the risk of moisture damage and as a result, a waste of resources. To document the moisture management of the Sophie Radich project - a Norwegian school constructed with cross laminated timber (CLT) - an intelligent sensor solution by Woodsense has been incorporated into the project. Through constant monitoring and automatic alarms, the sensors assist in carrying out an effective moisture content strategy with documentation of correct moisture management throughout the entire construction process.

The sensors are effectively used to, for example, document that there is no excessive moisture in the elements, and share said data between construction actors in the project. Additionally, the sensors contribute to the reduction of resource waste and a responsible use of building materials. This complies with the aim of issue MAT 05 *Robust and climate adapted buildings.* By preventively monitoring the growth of mold, the sensors also promote a healthy indoor climate to benefit the health and well-being of the building's users.

1.1 MOISTURE DAMAGES

Moisture is the leading cause of damage in construction, accounting for 71% of all damages from a study of 175 defect cases [2]. Of these damages, 69% occur within the first five years of a new construction project. In addition to causing damage, changes in wood moisture content can also impact the load bearing capacity and the tightening power of fastenings and screws, as studies show a reduction of WMC of 3-4% around threaded rods can lead to critical stresses leading to moisture induced cracks [3].

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The study between 2017-2020 shows that unventilated compact roofs and terraces (on concrete floors) are the most common building component exposed to damages mainly caused by precipitation. The study shows that around 80% of the defects on terraces are linked to penetration of precipitation, where leakages in the roof membrane and insufficient connections around terrace doors are recurring reasons for defects.
As climate changes cause more and more intense rainfall in short periods. Even with well designed building details and well done craftsmanship the risk of mistakes will always be applicable.
Measuring water content in building components before closing is well known. Disadvantage is that if small mistakes are done, the small mistakes can cause major damages. Sensor technology used during construction phase can discover the small mistakes before causing major damages.

1.2 MONITORING FOR CRUCIAL AREAS

Norwegian building regulations (Plan og bygningsloven and Byggteknisk forskrift) are familiar with timber constructions. Product and building components must be dry enough when installing and sealing that there is no risk of fungus, decomposition of organic materials or increased degassing.

Drying material takes time, especially components applied to one-sided drying, like sills in timber constructions. The moisture content must be measured in order to document that the required moisture content is met.

Pre-accepted moisture content to avoid fungal growth on timber is 20 weight percentage moisture. Building components with a low capacity for drying out the moisture content must be lower than 15 weight percentage moisture before closing the building component.

Risk strategies prepared according to MAT 05 *Robust and climate adapted buildings* should identify and propose risk reducing measures for parts of the building that are exposed for degradation as a result of the current and future climate. The risk strategy should also uncover risks of moisture damages caused by build in moisture during the construction phase.

The design phase should choose building materials and structural principles that are common. Roof constructions and access for maintenance are essential.
Norwegian Standard NS 3514:2020 *Moisture safe construction - Planning and execution* is meant to be a tool for the construction industry to prevent moisture-related incidents during the construction phase and create awareness about moisture-proof construction [4]. The standard shows guidelines and procedures related to moisture safe construction and reference to NS 3512 *Measurement of moisture in timber structures* [5].

1.3 DETAILS EXPOSED TO MOISTURE DAMAGES

Some construction principles can be risky to build. The figure below shows building details that above mentioned studies show that are exposed to moisture damages.

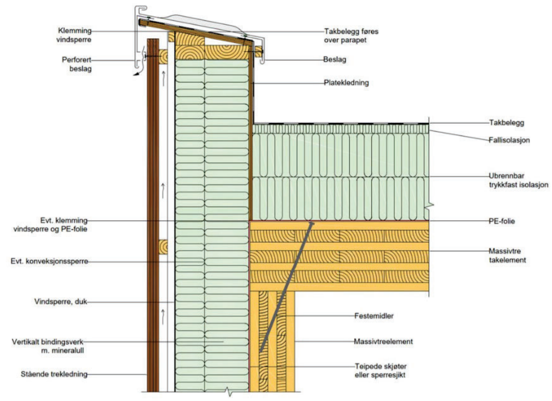

Figure 1: *Principal detail parapet at unventilated compact roof and CLT-Element [6]*

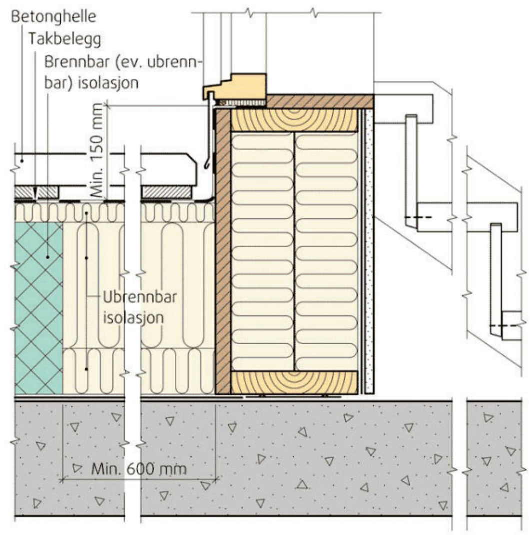

Figure 2: *[7] Terrace door to unventilated compact roof.*

Overlight windows are often placed during the roofing. The construction on the inside is open and affected by large amounts of building moisture from for example concrete work and straightening of floors.

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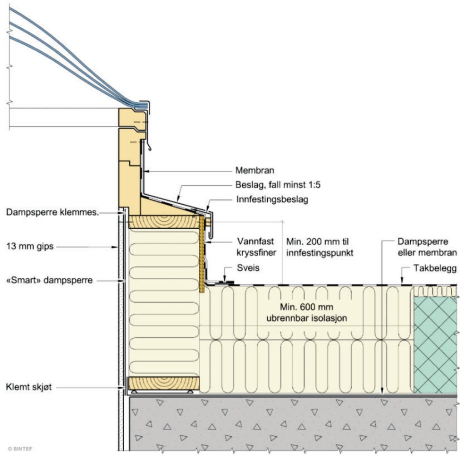

Figure 3*: [8] Overlight in unventilated compact roof.*

These are examples of building components that are well known details and common to build and still risky for moisture damages.

2. SOPHIE RADICH PROJECT AND MOISTURE MANAGEMENT STRATEGY

Sophie Radich ungdomsskole in Lillestrøm is a Secondary school with a total area of approximately 130000 m2 and space for 720 students. The project has been developed in collaboration with contractor Kruse Smith and Lillestrøm municipality. Arkitema is involved as architect and landscape architect. The building is a CLT construction and has a very high environmental ambition with a blue-green focus. The school has a distinctive footprint shaped like a four-leaf clover. With a strong focus on the surrounding nature, students will experience an interaction between the indoor and outdoor environment.

Timber has been chosen as part of the main construction for the entire building, primarily from an environmental point of view. However, the choice is also based on the theory that the use of wood has a positive impact on physical and mental health [9]. Findings from another study regarding the use of wood in buildings show a significant decrease of systolic and diastolic blood pressure [10]. This is, in addition to an aesthetic consideration, the reason for choosing visible wood in the building's interior.

2.1 THE MOISTURE MANAGEMENT STRATEGY

The Norwegian climate posed a challenge during the construction process, as rain, moisture, ice formation and snow can cause major problems.

Using a tent during construction was considered, but this would mean additional costs which is a disadvantage compared to traditional construction methods. It was therefore decided not to cover the building during the construction period. It was expected that repair of any damage would be less than the cost of a tent / superstructure. Unfortunately, the autumn of 2021 was particularly rainy and windy, and there was some concern related to moisture, especially on the roof. An agreement was therefore made with Woodsense, to uncover any leaks and moisture problems.

3. USE OF SENSOR TECHNOLOGY TO AVOID DAMAGES CAUSED BY MOISTURE

When working with timber in construction, one of the main issues is related to moisture damage. The sensor solution by Woodsense seeks to address that issue by measuring wood moisture, temperature and humidity, and comparing the data with local weather data. By analysing the collected data, it is possible to detect leaks and conditions that can lead to mould and rotting of the wood. Through constant monitoring, moisture damage can be prevented, thus reducing resource waste. The embodied CO2 emissions associated with a moderate defect in terms of disposing of materials and replacing with new materials amounts to 572.32 Total GWP [kg CO2eq] equivalent to 2% of the entire buildings embodied carbon emissions [3].

Figure 4*: Sensor that monitors wood moisture content, temperature and humidity from Woodsense.*

This strategy complies with the aim of issue MAT 05 *Robust and climate adapted buildings* which focuses on the reduction of the need to repair or replace damaged materials. It can also be part of the risk analysis which is needed to get the score in part 2 of MAT 05 – *Protect exposed parts of building against damage.*

Figure 5: *Blueprint from the 3rd floor. Sensor placement on this floor in wet rooms close to the concrete floor to detect leakages, on the balcony under a pavilion to ensure water doesn't get in and under a window to test window is tight during construction,*

Figure 6: *Sensor under window. © Kruse Smith*

The digital platform of the sensors has integrated the so-called mould curves, derived from mathematical models from research in the field. These are used, among other things, to visualise the environment of a given sensor and determine the risk of mould growth. By preventively monitoring the growth of mould, the sensors promote a healthy indoor climate to benefit the health and well-being of the building's users.

Sensors were placed on various locations in the main construction to monitor particularly exposed areas, detect critical moisture levels before damage could occur and document moisture management throughout the construction.

3.1 IMPORTANT DATA TO MEASURE CRITICAL FOR A HEALTHY BUILDING

According to *Sintef Byggforskserien 421.132 Fukt i bygninger. Teorigrunnlag.* To avoid moisture damage and other moisture-related problems during construction a critical moisture level is used as a limit to determine whether a material is dry enough to proceed in the construction process. Critical moisture level is usually given with the designation RH. Absolute moisture content is usually used for wood materials (Wood Moisture Content).
When RH in the surroundings is more than 80% and temperature above 0°C in some time, risk of mold growth can appear. Spruce and pine will have a WMC around 16-18%, when the RH in the surroundings are around 80%.
With well documented design phases and procedures to prevent moisture related damages there will always be some risks of moisture damages.
Due to tight schedules and time between planning and execution, drying of materials can be challenging.
Sintef byggforskserien 474.533 Uttørking og forebygging av byggfukt a sill as example for drying is made. For a sill 25 mm with natural one-sided drying from 28 to 18 weight percentage moisture in a building with 20°C and RH 60%. The drying time is estimated to be 21 days.

Developers have expressed their satisfaction when working with the sensors and digital platform, due to the ability to constantly monitor the moisture level. This leads to a higher sense of control with the moisture content of the construction materials.

4. CONTINUOUS ANALYSIS OF INCOMING DATA TO DETECT DAMAGES

4.1 WMC LEVELS IN DIFFERENT CONSTRUCTION PHASES

There are general thresholds of WMC values that are accepted in timber structures. These values vary based on whether the timber structures are exposed during construction or if they are enclosed and the building is in its maintenance period. Also, what measurements that are critical depends on the season and the local climate.

4.2 DURING CONSTRUCTION

The WMC can vary a lot during construction if the building is exposed to rain. Experts suggest that pools of water gets removed daily and that CLT shouldn't be above 20% for extended periods of time.
Many vendors of CLT put requirements for CLT to be enclosed at WMC levels below 12% to ensure no moisture is built in.

4.3 MAINTENANCE

In areas with high relative humidity, such as bathrooms and kitchens, the WMC of CLT elements should be kept below 20%. In other interior spaces with moderate humidity, such as living rooms and bedrooms, the WMC of CLT elements should be kept below 18%. In exterior wall and roof elements, the WMC should be kept below 16% to minimise the risk of decay due to exposure to the elements.

It is important to note that the WMC of timber can vary based on the ambient humidity and temperature conditions. In general, the WMC of timber will increase in humid environments and decrease in dry environments. This means that the WMC of timber may be higher in the summer months when relative humidity is typically higher, and lower in the winter months when relative humidity is typically lower.

Hence it is necessary to use an alarm system that takes into account all these parameters before it is possible to detect damages automatically without human supervision.

4.4 ANOMALY ALGORITHMS FOR DAMAGE DETECTION

Anomaly algorithms with multiple parameters have proven efficient to detect outliers in general data, but haven't been used before to detect damages in timber.

Anomaly algorithms work by forecasting a predicted value based on multiple parameters. On the Sophie Radich school Wood Moisture Content, Relative

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Humidity, Temperature and local weather data were taken into account.

Table 1: *Ongoing measurements every 4 hours*

Measurement	Location
Wood Moisture Content (WMC)	In 20mm depth
Relative Humidity (RH)	From sensor at timber surface
Temperature	From sensor at timber surface
Precipitation, snow, outdoor humidity & outdoor temperature	From local weather station integrated into platform

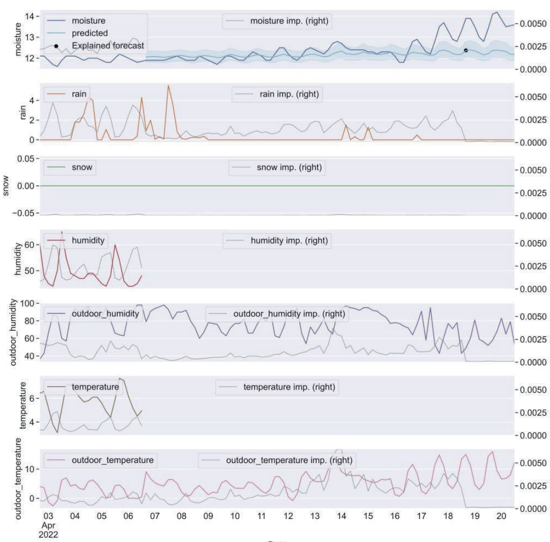

Figure 7: *Predicted value and the importance of supporting parameters in the prediction of that value.*

This result, when also taking into account the placement of the sensor, gives a strong indication when a sensor hits critical levels.

According to data from Woodsense, the WMC of CLT in roofs is the highest with a median value of 13.6 over an entire year, followed by slabs at 11.8 and external walls with 11.4.

4.5 TYPES OF ALARMS

In one of the selected areas, sensors were placed towards the edge of the roof, under rooflights, and on different facades to monitor the difference in north-, south-, east-, or west-facing facades. Additionally, a sensor was placed on a cornice to monitor the cover towards the edge. Here, the sensor found a mistake made by the roofer, as the covering had not been completed. This had resulted in water entering the construction and moisture levels rising to more than 30 %.

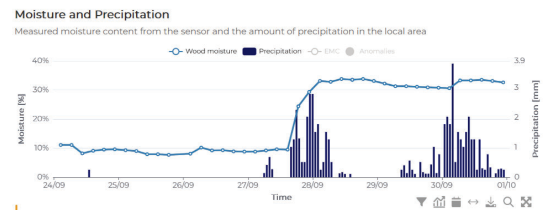

Figure 8*: Showing a rapid increase in WMC immediately after heavy precipitation.*

Had the sensor not detected the damage in the cornice, it could have led to a substantially more expensive repair, as the moisture could have been trapped in the construction for several months, potentially causing mould to establish. The same happened on a balcony where a temporary cover had been installed to protect the balcony from water damage. A sensor was installed beneath to monitor if the cover was efficient, but after just weeks of installation was the first water ingress found. This led to an immediate action to remove the water, dry the timber and improve the cover.

This exemplifies the advantages of sensor-based technology, as it is possible to capture situations such as these immediately.

Another sensor also detected a rise in wood moisture content, but a slower one over a 3 day period with ongoing rain. It is only normal to expect such an increase in WMC in the bottom of a facade element during construction when the building hasn't been enclosed, hence this did not trigger an alarm, but only led to a notification to the contractor.

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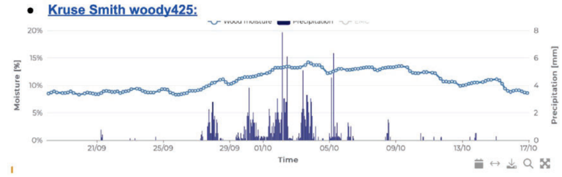

Figure 9**:** Showing the incremental moistening of a CLT slab due to continuous rain and increase in humidity, but not a leakage.

5. CONCLUSIONS

Using the sensor solution, several increases in moisture level were detected, which could have developed into more extensive moisture damage. The critical moisture levels found by the sensors exemplifies the advantages of sensor technology, as it is possible to immediately identify situations that can be damaging to the construction. Furthermore, developers and other participants of the project expressed their satisfaction with the product due to a higher sense of moisture control. Going forward, several sensors will remain on the roof to ensure that the green roof laid on top lasts as expected, and that the drains likewise work as intended.

Sensor technology can be used in most of the different building components. And the use of sensor technology should be more common in the future. To reduce the number of damages on terraces and similar components.

Further research can be done to investigate how different coating on the interior side of CLT, for example fire painting, affect the moisture storage in wood-based materials and the indoor climate. This can be done by using Woodsense sensor technology.

ACKNOWLEDGEMENT

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