



REINCARNATE

Application of Non-Destructive Testing Methods for the Assessment and Prediction of Wooden Roof Truss Serviceability

Innovation + Demo Case

Technical Deep-Dive Report



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Reincarnate project

The average lifespan of a building is 39 years — in Europe, it is only 25-30 years — and the main reason for demolition is obsolescence. This is why there is a large amount of construction and demolition waste (CDW) — representing approximately 25-30% of all waste in Europe —, in addition to that generated in current construction works.

The recycling rate for CDW is relatively high (above 75%). This activity generated \$126.89 billion in 2019 — Europe contributed the largest share, almost two-fifths of the total global market — and is projected to reach \$149.19 billion by 2027. Unfortunately, many of the most valuable materials in CDW cannot be meaningfully separated and end up in landfills.

This helps to get an idea of the efficiency potential for climate neutrality that exists in construction.

Reincarnate aims at advancing circular economy practices within the European construction industry and enabling to significantly maximise the life cycle of buildings, construction products and materials, reduce CDW by 80%, increase the reusability of buildings, construction products and materials and, as a result, lower the sector's emissions by 70%.

As a result of these actions, Reincarnate will significantly advance circular economy practices within the European construction industry.

First, it will create a Circular Potential Information Management (CP-IM) platform and a set of innovations to use it. These solutions will draw upon emerging digital technologies, such as digital twin representation, artificial intelligence, and robotic automation.

3 empirically proven social science insights will allow fostering widespread adoption of reused high-quality construction products and materials, and business eco-system development frameworks to combine actors within sustainable value chains.

All innovations will be demonstrated on eleven selected real-world projects and value chains. Furthermore, business process guidelines and an e-learning platform will be developed to drive the dissemination and exploitation of the Reincarnate results.

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1. Executive summary

This report presents the application of non-destructive testing (NDT) methods for the condition assessment and serviceability evaluation of timber roof structures. The work focuses on identifying degradation mechanisms, particularly moisture-related damage, and assessing their impact on structural performance through in-situ measurements. Two real-world case studies, located in Werdau and Berlin-Pankow, are analysed using a combination of manual inspection techniques and continuous sensor-based monitoring to capture environmental conditions and material behaviour over time.



Figure 1. Roof Truss examined in a backyard in Pankow, Berlin

The results demonstrate that continuous monitoring enables the observation and interpretation of moisture-related degradation processes and supports a more informed assessment of structural condition compared to conventional visual inspection methods. The integration of inspection data with time-dependent environmental measurements provides a more comprehensive understanding of structural behaviour under real operating conditions.

The main objective of this work is to establish a data-driven basis for evaluating the current condition of timber elements and to support their future integration into predictive lifecycle assessment frameworks. The approach contributes to improved maintenance strategies, supports life extension of building

components, and aligns with the development of digital tools for circular construction within the REINCARNATE project.

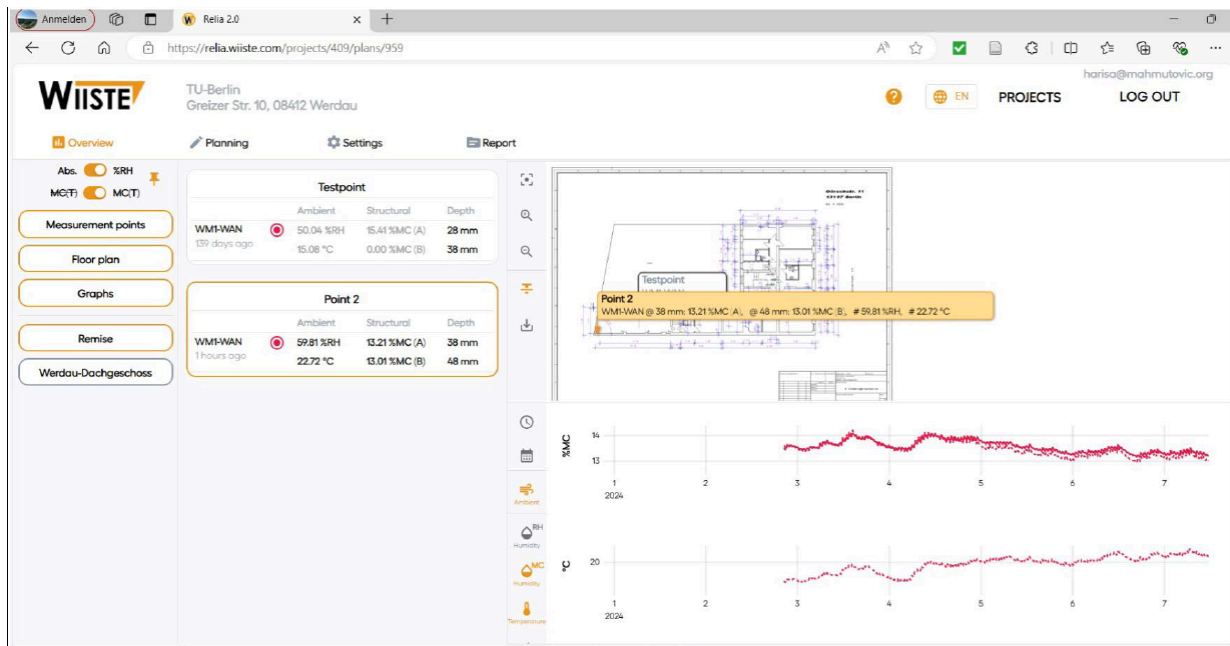


Figure 2. Structural Health Monitoring Platform from the sensor provider

2. Context and objectives

The condition assessment of existing timber structures is an important aspect of extending their service life and supporting circular construction practices. Timber roof trusses are particularly sensitive to environmental influences, especially moisture variations, which can lead to progressive degradation and reduced structural performance over time. Early identification of such degradation processes is therefore relevant to enable timely maintenance and avoid further deterioration.

Conventional inspection methods are primarily based on visual assessment, which may not capture internal or time-dependent changes in material condition. This limitation is particularly relevant in timber structures, where moisture content plays a significant role in degradation processes. As a result,

there is a need for approaches that allow continuous monitoring and improved interpretation of environmental and material conditions.

The objective of this work is to investigate the application of NDT methods for the assessment of timber roof truss serviceability, with a specific focus on moisture-related degradation. The study aims to evaluate how sensor-based monitoring, combined with manual inspection, can support a more informed understanding of structural condition over time. In addition, the work explores the potential of such data-driven approaches to contribute to predictive lifecycle assessment and maintenance decision-making within the REINCARNATE framework.

3. Innovation description

The innovation presented in this work consists of the application of a non-destructive, sensor-based monitoring approach for assessing the serviceability of timber roof structures. The method combines continuous measurement of wood moisture content with environmental parameters, enabling the evaluation of material behaviour under real operating conditions.

The core of the approach is a monitoring system based on electrical resistance measurements, where electrodes are embedded in the timber to capture internal moisture conditions. This is complemented by integrated measurements of ambient temperature and relative humidity, allowing the interaction between environmental exposure and material response to be analysed. The system enables continuous data acquisition and remote access via a cloud-based platform, providing time-resolved information on the condition of structural elements.

Within the REINCARNATE framework, the innovation contributes to the "Building Inspection & Valuation" and "Predictive Life-Cycle Information" domains by introducing a data-driven method for condition assessment of

existing structures. The approach supports the identification of moisture-related risks and provides a basis for informed decision-making regarding maintenance and service life, without requiring destructive intervention.

The innovation lies in the integration of continuous monitoring with conventional inspection practices, allowing condition assessment to move from isolated observations towards time-dependent evaluation. This enables a more consistent interpretation of environmental influences on timber structures and supports the development of monitoring-based assessment strategies.

4. Demonstration Setup

The demonstration was carried out in two real-world timber roof structures located in Werdau (Saxony, Germany) and Berlin-Pankow (Berlin, Germany). Both structures consist of spruce wood roof trusses with similar structural configurations but different conditions in terms of maintenance, environmental exposure, and renovation status.



Figure 3. Positioned moisture measurement sensor at the support point in Pankow



Figure 4. Positioned moisture measurement sensor at the support point in Werday

In Werdau, the investigated structure is part of an uninhabited multi-family residential building with an undeveloped attic. The roof structure exhibits visible signs of moisture ingress, including discolouration and local damage associated with insufficient roof waterproofing. The sensor was installed at a structurally relevant location identified during a preliminary inspection, specifically at a connection point in the collar beam area on the gable side adjacent to a neighbouring building, where moisture accumulation was observed.

Due to the absence of a permanent power supply at the Werdau site, the monitoring system was operated using a temporary energy solution. This limited the data acquisition period to approximately three days, which constrained the duration of the measurements.

In Pankow, the investigated structure is a renovated barn roof located in a courtyard environment. The roof structure has undergone refurbishment, including roof waterproofing and partial replacement of structural elements. The sensor was installed at a comparable critical location within the structure to enable a consistent assessment approach. In contrast to Werdau, the Pankow site provided stable power supply conditions, allowing continuous monitoring over a period of approximately three months, from March to June 2024.

In both case studies, the monitoring system recorded wood moisture content, ambient temperature, and relative humidity. The sensors were installed directly in the timber elements, enabling in-situ measurement of material conditions. Data was transmitted via a remote router to a cloud-based platform, allowing real-time access and storage of the collected measurements.

5. Results and Innovation

The monitoring results show distinct differences in moisture behaviour between the two investigated roof structures. In the Werdau case study, wood moisture values reached up to approximately 17-18%, with short-term variations influenced by changes in ambient temperature and relative humidity. These

elevated values are consistent with the observed structural condition, including moisture ingress due to insufficient roof waterproofing and visible surface alterations.

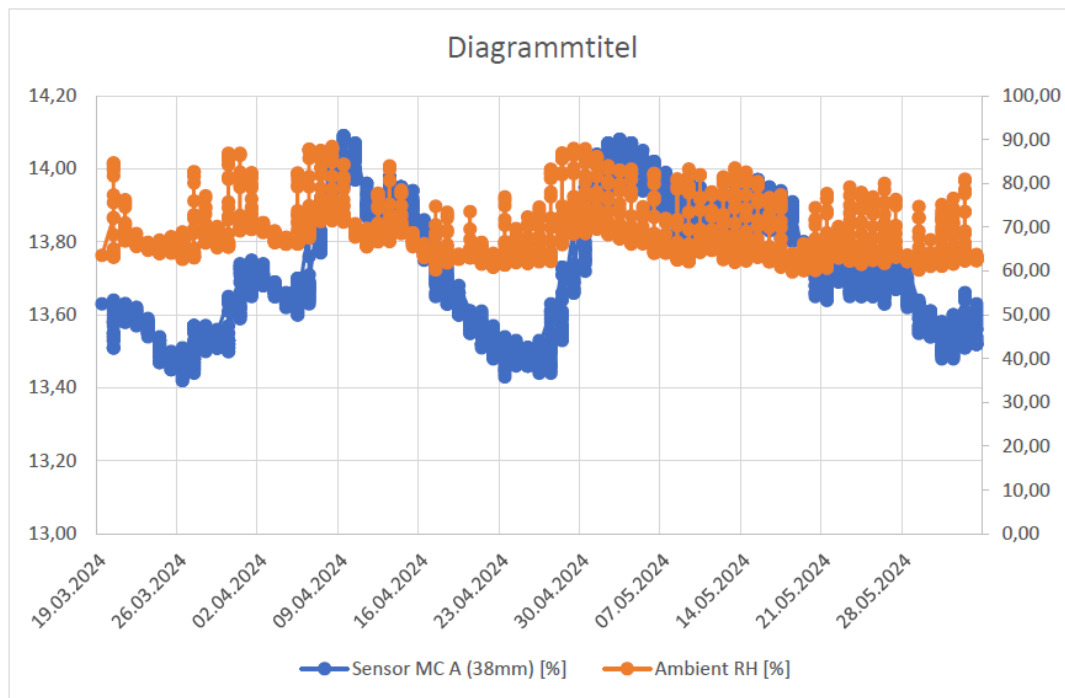


Figure 5. Relative humidity as a function of wood moisture content of Sensor A, Pankow

In the Pankow case study, the monitored timber elements exhibited more stable moisture conditions over the observation period. Wood moisture values generally ranged between approximately 13% and 19%, with moderate fluctuations over time. These variations followed the progression of ambient temperature and relative humidity, indicating a consistent interaction between environmental conditions and material response.

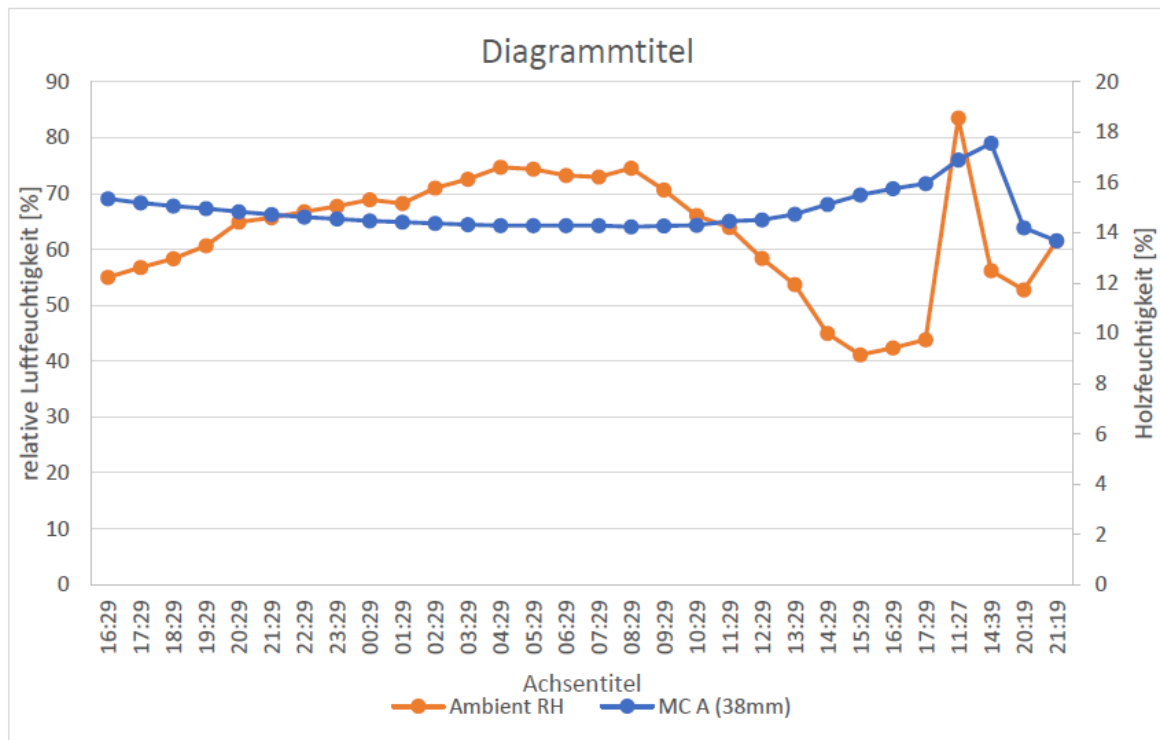


Figure 6. Relative Humidity as a function of the wood moisture content of the Sensor A (Werdau)

Across both case studies, the time-series data show a direct relationship between relative humidity and wood moisture content. Periods of increasing humidity correspond to rising moisture levels, while decreasing humidity is associated with reduced moisture content. This behaviour was observed in both short-term and long-term measurements.

From an evaluation perspective, the monitoring system provides continuous information on moisture development and allows the identification of periods in which moisture levels exceed approximately 15%. These conditions are associated with an increased likelihood of moisture-related degradation processes, although no direct verification of such processes was performed within the scope of this study.

The results also highlight the influence of boundary conditions on data interpretation. The short monitoring period in Werdau limits the representativeness of the observations, while the longer measurement period in Pankow provides a more stable basis for analysing temporal behaviour. In both

cases, the limited number of measurement points restricts the ability to generalise the findings to the entire roof structure.

Monitoring results summary

Case Study	Monitoring Period	Moisture Range	Monitoring Feature	Evaluation
Werdau	Approx. 3 days	Up to approx. 17-18%	Cloud alert above 15% moisture	Higher values linked to visible roof defects and moisture ingress
Pankow	Approx. 3 months (Mar-Jun 2024)	Approx. 13-19%	Continuous hourly monitoring	More stable behaviour under improved roof sealing and prior renovation
Both sites	Short-term and long-term datasets	Humidity and moisture move consistently	Hourly time-series transmission to Wiiste cloud	Environmental conditions influence internal moisture state

6. Contribution to Impacts

The presented work contributes to the REINCARNATE impacts in the areas of scientific advancement, societal relevance, and techno-economic potential, with varying levels of contribution based on the scope and results of the study.

From a scientific perspective (High), the work demonstrates the application of continuous, sensor-based monitoring for assessing the serviceability of timber structures under real operating conditions. The results provide empirical evidence of the relationship between environmental parameters and wood moisture behaviour.

From a societal perspective (Medium), the approach supports improved assessment of structural condition by enabling the identification of moisture conditions that may lead to degradation. This contributes indirectly to building safety and maintenance planning.

From a techno-economic perspective (Medium), the use of sensor-based monitoring introduces a data-driven approach to condition assessment, although large-scale deployment and cost validation were not addressed.

Impact contribution matrix

Category	Level	Justification
Scientific	High	Empirical validation of continuous monitoring for timber condition assessment under real operating conditions
Societal	Medium	Supports earlier identification of unfavourable moisture conditions and more informed maintenance planning
Techno-economic	Medium	Introduces a data-driven inspection approach but without large-scale deployment or cost validation

7. Replication and Next Steps

The methodology demonstrated in this work can be replicated in other timber structures where moisture-related degradation is a relevant factor. The application requires the installation of embedded moisture sensors at structurally relevant locations, combined with continuous monitoring of environmental parameters.

The transferability of the method depends on the availability of measurement infrastructure and appropriate sensor placement. Further development would require longer monitoring periods and a higher number of measurement points to improve representativeness.

Future work may include integration with data-driven analysis methods, although such developments require additional validation.

8. References and Links

Research Document:

Application of Non-Destructive Testing Methods for the Assessment and Prediction of Wooden Roof Truss Serviceability, TU Berlin, 2025

<https://www.reincarnate-project.eu/>