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Twin Transition for The Timber Industry

Deliverable 1.1
Initial Descriptions of Use Cases with Expected Outcomes and Impact Projections to 3 Target Domains

5G-TIMBER | Work Package 1, Task 1.1

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5 weeks: 23rd August 2022	Marcello Urgo (POLIMI)	DRP initially freezes the Table of Contents (ToC) in agreement with the WP Leader.
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Glossary of terms and abbreviations

Abbreviation / Term	**Description**
3GPP	3rd Generation Partnership Project
5G	5th Generation
AR	Augmented Reality
BIM	Building Information Modelling
CAD	Computer-Aided Drawing
DT	Digital Twin
eMBB	Enhanced Mobile Broadband
EU	European Union
HMD	Head Mounted Display
I5.0	Industry 5.0
LTE	Long-Term Evolution
mMTC	Massive Machine-Type Communication
MR	Mixed Reality
MTP	Motion-to-Photon
PLM	Product Lifecycle Management
UC	Use Case
URLLC	Ultra-reliable Low-Latency Communication
VR	Virtual Reality
XR	Extended Reality

1. Executive Summary

It is expected that in the next five years, the penetration of 5G technologies in industry and, specifically, in manufacturing will be significant and continuously increasing, positively impacting industry revenues, GDP and the workforce in the sector. The 5G TIMBER project aims to address the challenge of adopting 5G technologies in small and medium size manufacturing industries focusing on the wood sector.

Within this field, the project will demonstrate key implementations of advanced approaches leveraging the specific characteristics of 5G technology to enhance and enable the exploitation of material models for wood, open standards for production data, secure exchange of data, data analytics at the edge, precise indoor localisation, Digital Twin models (DT) augmented reality (AR), industrial IoT.

To support the development of innovative and commercially exploitable approaches based on the described technologies, innovative use cases (UCs) are defined to support the activities of the 5G TIMBER project in the wood value chain. Three categories of UCs have been selected: i) data-driven sawmill and woodworking machine setup; ii) modular wood-house factory; iii) construction and renovation with wooden elements, valorisation of composite waste. Within these three categories, specific UCs have been further defined.

This deliverable provides a structured description of the UC categories and related use cases. This description also addresses general requirements for implementing the UCs and field trials, the actors involved and their central role, the benefits of 5G technologies, possible constraints, and risks.

Besides this, this deliverable also defines structured input and application framework for the solutions and approaches to be developed within the 5G TIMBER project and further addressed in WP2 and WP3.

The final version of this deliverable, due on September 30th 2022, has been updated on December 21st 2022, to take into consideration the technical and operative details related to UC1.1 driven by the interaction with Hekotek and the involved sawmill; and the current status of the availability of 5G technologies, hardware components and related capabilities, emerged in the continuous advancement in this area.

2. Introduction

The objective of this document is to describe the use cases (UCs) within the 5G-TIMBER project supporting the development and demonstration of tools, methodologies and approaches, supporting the reduction of wood waste, the valorisation and efficiency of production processes and systems processing wood, safe-human machine collaboration in the processing of wood.

The UCs can be clustered into three main categories:

1. **Data-driven sawmill and woodworking machine setup**. This category addresses the first part of the value chain of the wood after forestry, starting from the cutting of the logs to their processing in sawmills to obtain lumber. The focus of this category will be on the equipment used in sawmills, specifically on the development, modernisation, setup, monitoring, remote operation and maintenance.
2. **Modular wood-house factory.** This category addresses the use of wood parts in constructing modular pre-assembled modules of wooden buildings. The focus will be on both the production site where the modules are assembled (i.e. the factory) and the module components. Modern technologies will be integrated into the production process to improve assembly efficiency, safety and integration with the product lifecycle management tools.
3. **Construction and renovation with wooden elements, valorisation of composite waste**. This category covers the remaining part of the life cycle of a wooden house, namely the building at the specific site and the monitoring during the use phase. The end-of-life will be focused on wooden composites wastes generated during the service life of the modules.

The described categories, as well as the UCs further detailed in the following Chapters, fit into the overall schema of the project shown in Figure 1.

The schema contains two layers:

4. **Wood value chain.** All the activities in the 5G-TIMBER project are aggregated around the value chain of wood materials and products. Icons in full colours represent physical assets, materials and concepts constituting the whole wood-value chain involved in the project.

5. **Contributions to the 5G-TIMBER project.** During the project, technologies, tools, methodologies, and approaches will be designed, developed and tested, concerning the different UCs, to improve the current state. Icons in blue represent these contributions.

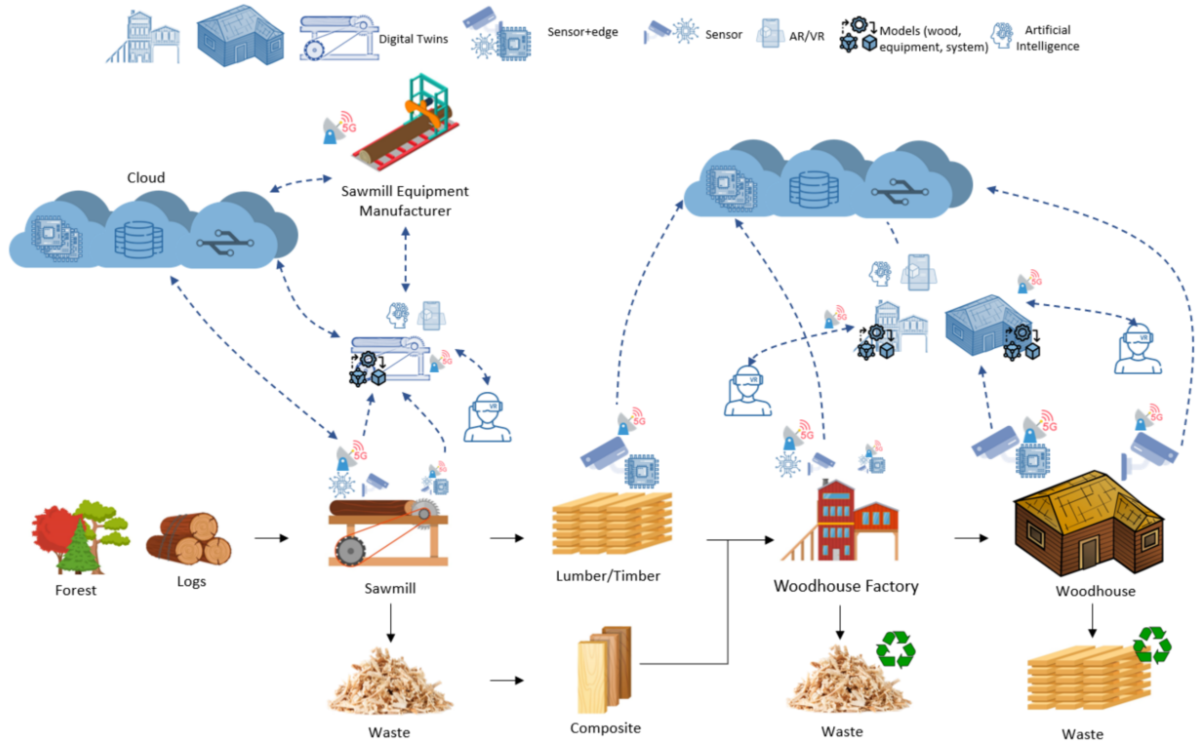

Figure 1 – Overall schema for the activities within the 5G-TIMBER project. The bottom part, in full colour, represents the value chain for wood processing and its use in the construction sector. The top part, in blue, shows the devices, tools and approaches developed in the project. The core of the activities is the digital twin of sawmill equipment, woodhouse factory and the woodhouse. On top of this, sensors (e.g., cameras) are exploited to connect the real system/object with its digital twin and perform analyses through edge/cloud computing. Finally, AR/VR and AI are the core technologies exploited[1].

Furthermore, as the primary objective of the 5G-TIMBER project is to implement field trials leveraging the advanced and unique characteristics and capability of 5G networks, UCs will also be described and structured according to the potential and strategic exploitation of 5G technologies.
To structure this analysis, the starting point is a document of the 3rd Generation Partnership Project (3GPP), an umbrella for organisations which develop standards for mobile telecommunications, identified several

[1] Credits for the icons: Freepik.com and Flaticon.com

potential markets and many use cases for 5G, and grouped them into families that share standard requirements and characteristics [1] :

1. Enhanced Mobile Broadband
2. Massive Machine Type Communications
3. Ultra-reliable Low-latency Communication

Besides these, enhancements are being added to the 5G technology specifications as part of 3GPP Releases 16 and 17[1] , supporting additional functionalities (also known as vertical services). Among these, location services are the ones relevant for the 5G-TIMBER project. It must be noticed that, according to the current availability of 5G hardware and software technologies, only R16 will be supported in the scope of 5G-TIMBER, and, in addition, the actual exploitation of R16 features will also depends on their support in the RU & DU ecosystem.

Below is a concise description of these 5G-related scenarios and services with their main strengths/weak points. A description will be provided for all of them except for Network Operation since it is not relevant to the project. A mapping of the relevance of 5G use cases concerning the use cases in the 5G-TIMBER project is reported in Table 1.

Enhanced Mobile Broadband (eMBB)

Leveraging on higher bandwidth, the eMBB use case calls for a higher data rate than 4G Long-Term Evolution (LTE) cellular networks can provide in terms of the peak data rate in ideal conditions, the expected data rate in more typical conditions, and the minimum in conditions of poor network coverage. Examples are data downloads and real-time video in an indoor environment, traffic hotspots in dense urban environments, public events, and consistent mobile broadband experience in rural areas and public transport.

Strengths: higher network capacity and lower consumption of electrical power.

Weaknesses: LTE can already deliver the data rates required by the most common mobile applications, including industrial use cases.

Massive Machine-Type Communications (mMTC)

The use case related to machine-type communications (MTC) addresses the concept of the Internet-of-Things (IoT) [1] and its derivatives. MTC supports a wide range of industrial applications, e.g., wireless tracking devices and sensors (motion-triggered security cameras, environmental sensors, industrial and building automation sensors). MTC devices must be cheap and low complex, have low power consumption to ensure long battery life, and have a sufficient radio link budget (>150dB).

> **Strengths:** 5G can improve the network density (from 10k of LTE to 1 million devices per square kilometre) and coverage. More frequencies are available for 5G mMTC communication for sub-gigahertz frequencies (extended range) and 3+GHz range (higher network density). 5G standards support unlicensed radio networks (DECT-2020 NR in the 1.9GHz band and the 60GHz ISM band).
>
> **Weaknesses**: Existing technologies like 4G NB-IoT, NB2-IoT, and CAT-M can handle most practical use cases' requirements. 5G hardware components are more expensive.

Ultra-reliable Low-latency Communication (URLLC)

Ultra-reliable low-latency communication (URLLC), also known as critical communication (CriC), is characterised by the need for very low network latency (<10ms), often in conjunction with high reliability (Service Level Agreement >99%).

Low latency and high reliability come together in wireless industrial automation [3] to support the adoption of robotics and intelligent approaches in manufacturing systems [4] . This scenario matches what is commonly addressed with Industry 4.0 and beyond, where industrial robots and machinery equipped with sensors and actuators can be remotely governed. In such a class of factories, wireless technologies could bring advantages over a cable network. Thanks to a lower installation cost and an easy setup, the capability to be reconfigured and extended to add new pieces of equipment or to match changes affecting the production technologies and products makes wireless networks well-suited for dynamic industrial environments.

An additional industrial application class is virtual reality hand-held devices and headsets, requiring very low latencies to avoid feelings of nausea on the part of the user, whose exploitation in an industrial environment is significantly increasing [6] .

Strengths: 5G can offer significantly shorter network latencies and higher quality of service (QoS) levels.

Weaknesses: Conventional URLLC solutions, except DECT-2020, require standalone (SA) cellular network implementations, which are still rare.

Location Services (LCS)

In 3GPP Release 16, 5G supports location services allowing a horizontal positioning accuracy of 50 m for 80% of mobiles, vertical positioning accuracy of 5 m, and end-to-end latency and time to first fix of 30 seconds [5] . Release 16 extends the radio signals-based localisation capabilities of 5G to ±3m (both horizontal and vertical) with (End-to-End) E2E latency for indoor deployment scenarios. Accuracy within 10s of cm is only anticipated in R17/R18.

Strengths: improved positioning accuracy compared to 4G.

Weaknesses: Limited availability of devices supporting these functionalities. 4G does not support these positioning features.

Table 1. 5G Scenarios, vertical services and 5G-Timber Use Case

UC Category	UC	5G Scenarios			Vertical Services
		eMBB	mMTC	URLLC	LCS
1. Data driven sawmill and woodworking machine setup	1.1 - Data and material models driven lumber production and handling	✓✓	✓✓✓		
	1.2 - DTs assisted assembly, remote operation and servicing for woodworking machinery	✓✓✓	✓✓	✓✓✓	
	1.3 - Data and AI driven industrial machine's fault prediction and design support		✓✓✓		
2. Modular wood-house factory	2.1 - Precise localization for production processes optimization and human safety	✓	✓		✓✓✓
	2.2 - DT, AR and Industry 5.0 UX assisted production supported by ZSM 5G data exchange	✓✓		✓✓✓	✓✓
	2.3 - Data driven design to production cycle optimization	✓✓	✓	✓✓✓	
3. Construction and renovation with wooden elements, valorisation of composite waste	3.1 - AR and Industry 5.0 UX assisted assembly and renovation of green buildings	✓✓✓		✓✓✓	
	3.2 - Long term Structural Health Monitoring (SHM) of wooden constructions using IoT and embedded AI		✓✓✓		
	3.3 - Wooden composites waste recycling				

2.1. Mapping 5G-TIMBER Outputs

This section maps the components described in the 5G-TIMBER's Description of Action (DoA)/Grant Agreement (GA), i.e., the description of the deliverable and task description in the DoA/GA, against the chapters included in this deliverable and the justification of the work conducted in the project. See Table 1.

Table 2 Adherence to 5G-TIMBER's GA Deliverable & Tasks Description

5G-TIMBER GA Element	5G-TIMBER GA Element Outline	Respective Document Chapter(s)	Justification
DELIVERABLE			
D1.1	INITIAL DESCRIPTIONS OF USE CASES WITH EXPECTED OUTCOMES AND IMPACT PROJECTIONS TO 3 TARGET DOMAINS	CHAPTERS 3, 4, 5	CHAPTERS 3, 4 AND 5 ADDRESSES THE THREE UC CATEGORIES MATCHING THE THREE TARGET DOMAINS OF THE PROJECT: DATA DRIVEN SAWMILL AND WOODWORKING MACHINE SETUP; MODULAR WOOD-HOUSE FACTORY; CONSTRUCTION AND RENOVATION WITH WOODEN ELEMENTS, VALORISATION OF COMPOSITE WASTES

5G-TIMBER GA Element	5G-TIMBER GA ELEMENT OUTLINE	RESPECTIVE DOCUMENT CHAPTER(S)	JUSTIFICATION
TASKS			
T1.1 DEFINITION RETURN AND SCALABILITY ANALYSIS OF PROJECT UCS OF LOW VOLUME MACHINERY, WOODEN AND CONSTRUCTION INDUSTRY	THE UC ADDRESSED IN THE PROJECT WILL BE ANALYSED WITH THE AIM AT IDENTIFYING THE SPECIFIC REQUIREMENTS AND EXTENT ACCORDING TO (A) SCALABILITY, (B) ROI OF THE ACTORS INVOLVED, (C) TECHNICAL FEASIBILITY. THESE ASPECTS WILL BE ADDRESSED INVOLVING THE OWNERS OF THE UCS (HEKOTEK AND HARMET), TOGETHER WITH TECHNOLOGY PROVIDERS AND RTOS	CHAPTERS 3, 4, 5	CHAPTERS 3, 4 AND 5 ADDRESSES THE THREE UC CATEGORIES MATCHING THE THREE TARGET DOMAINS OF THE PROJECT: DATA DRIVEN SAWMILL AND WOODWORKING MACHINE SETUP; MODULAR WOOD-HOUSE FACTORY; CONSTRUCTION AND RENOVATION WITH WOODEN ELEMENTS, VALORISATION OF COMPOSITE WASTES

2.2. Deliverable Overview and Report Structure

This deliverable addresses a structured description of the UCs of the 5G TIMBER project. This introductory section provides a preliminary framing of the themes addressed in the UCs and the key features of 5G technology. Furthermore, the links with the other activities in the project (working packages and tasks) are briefly sketched. Hence, the structure of the deliverable is organised to cover the three UC categories considered in the project, namely "data-driven sawmill and woodworking machine setup", "modular wood house factory ", and "construction and renovation with wooden elements, valorisation of composite waste". Sections 3, 4 and 5 describe the UC categories 1, 2 and 3, respectively.

Each section follows a standard structure. After framing the context by presenting the pilot's owners and the objective of the UC category, the specific contributions of the use cases (3 per UC category) are described. Each of these descriptions is structured as follows:

- The specific objectives of the UC are defined.
- The "as-is" situation is depicted.
- The "to-be" situation is described as a consequence of the tools, methodologies, and activities to be carried out in the project.
- The technical requirements are listed.
- The 5G roles and benefits are highlighted concerning previous network technology.
- The Return on Investment (ROI) and the scalability of the proposed solution are sketched.
- As some of the solutions proposed might depend on the availability of specific assets or standards, the potential risks are described along with mitigation actions.

Finally, section 6 provides the conclusions and the links with follow-up activities in the project related to the described UCs.

2.3. Other project outputs

This section describes the interdependencies with the other project tasks and activities.

b) Interdependencies between the task of this deliverable and the other WPs:

- **WP2**: the technical developments carried out within the project (WP2) will be derived from D1.1.
- **WP3**: the D1.1 will pave the way for the detailed definition of the UCs and their implementation carried out in WP3
- **WP4**: D1.1. will indirectly (through WP3) also affect the deployment of 5G TIMBER applications into the demonstration sites
- **WP5**: grounding on the description of the UC provided in the D1.1, the activities carried out in WP5 will define commercialisation, innovation management and standardisation initiatives.

c) Interdependencies between the task(s) of this deliverable and the same WP Tasks

- The KPIs identified in **T1.2** will be based on the technical requirements described in D1.1.
- Considering the different case pilots and the involved actors identified here, **T1.3** will sketch the architecture for data exchange concerning different data and information flows.
- Using the input of T.1.1, a software and hardware inventory list to analyse the need for data interoperability and integration among the various applications utilised throughout the UCs and the other work packages will be created in **T1.4**.
- In **T1.5**, grounding on the initial requirements and the design of the case pilots described during T1.1, conditions and specifications (cost, SLA, maintenance complexity) will be broadened, aiming at a long-term and larger-scale adoption of 5G NPN networks in manufacturing.

Table 3 lists the other deliverables that **directly** consume outputs from this deliverable. In addition to the deliverables mentioned explicitly in Table 3, all the deliverables mentioned in the 5G-TIMBER's DoA/GA will benefit from the content of D1.1. In particular, the deliverables related to WP2, WP3 and WP4 will have to consider the description of the UC provided in D1.1.

Table 3 List the other deliverables that produce inputs to this deliverable or consume outputs from this deliverable.

5G-TIMBER GA Element	Contribution and Value of linkage
Input for D1.3 & D1.4	Technical requirements and UC description is provided to derive the KPIs
Input for D1.5 & D1.6	Use case description and actors involved will be the base to describe the data flow architecture
Input for D1.7	Technical requirements and UCs description is needed to derive the inventory list and the blueprint for data sharing
D1.8 & D1.9	Requirements and scenarios described in D1.1 will be used to broaden the application of 5G NPN to other manufacturing domain
D3.7 & D3.8	The development of the "machinery assembly and servicing" UC will start from the description provided in D1.1
D3.9 & D3.10	The development of the "Wooden elements manufacturing pilot use-cases development" UC will start from the description provided in D1.1
D3.11 & D3.12	The development of the "construction" UC will start from the description provided in D1.1

3. Use Case 1 Category - Data-driven sawmill and woodworking machine setup

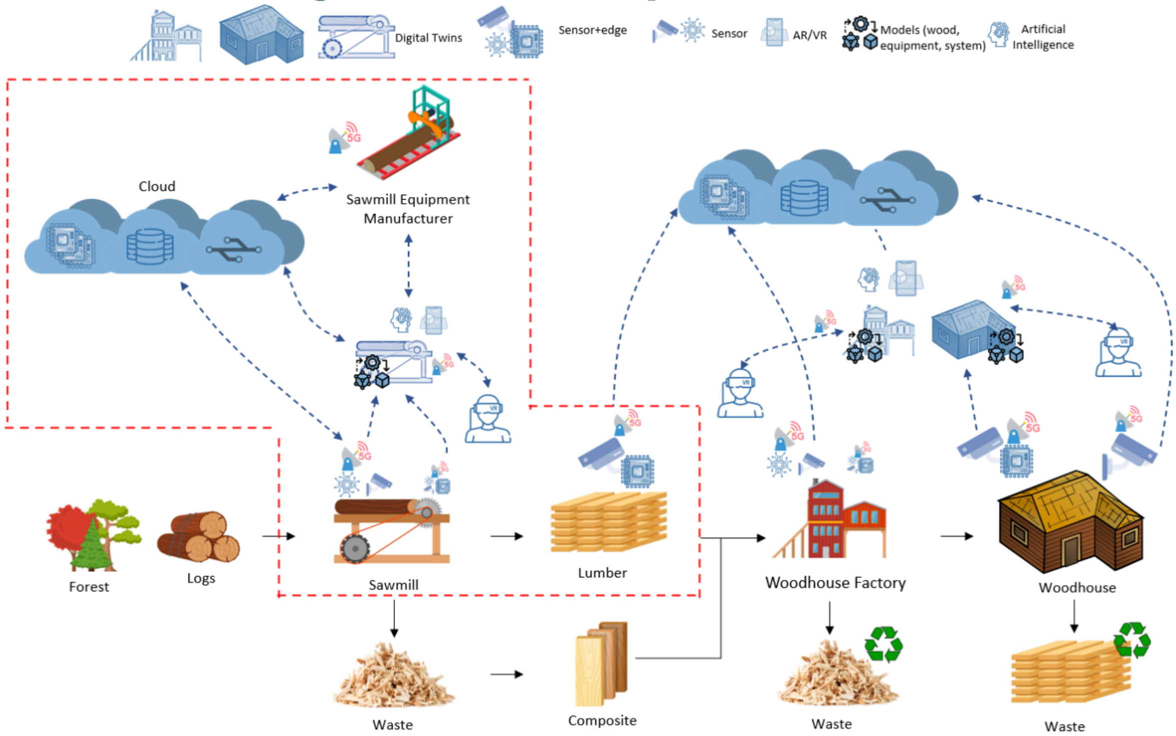

Figure 2. UC1 (dashed red area) focuses on sawmills and machines used for the first selection of the logs for improving timber production[2].

The first use case category (UC1) will focus on sawmills (dashed area in Figure 2) and how machines devoted to the production of timbers can be improved by exploiting I5.0 technologies.
The owners of the UC1 are both Hekotek and Harmet. Hekotek is a company that designs and sells equipment and machines for the sawmill, such as log feeding systems, log sorting lines, sawn timber sorting lines, pellet mills, aspiration systems, boiler houses, and debarking and chipping lines. Harmet, on the contrary, plays the role of the customer for lumbers and other wood components since producing modular wood buildings.

The UC1 category will focus on implementing solutions for specific equipment and processes in sawmills. According to the sawn timber manufacturing process (Figure 3), the sawmill receives the raw materials in the form of unsorted logs. The logs are sorted, and the sawing process is subsequently operated to obtain timbers of the desired sizes and shapes. The obtained logs are then packed for handling, transportation, and storage. This is

[2] Credits for the icons: Freepik.com and, Flaticon.com

operated on the sawn timber handling line. This system comprises a set of conveyors and machines whose primary function is to orient the sawn timber properly to be packed in pallets.

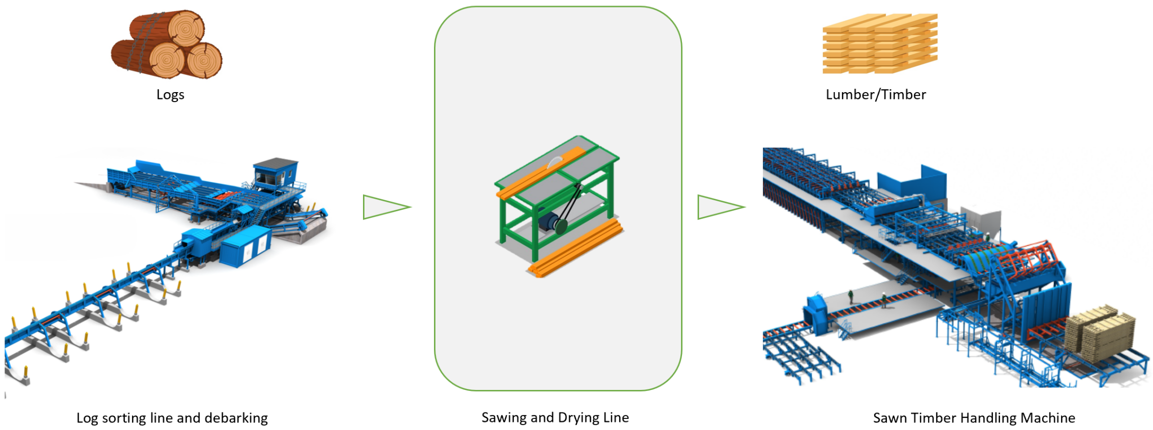

Figure 3. Sawn timber manufacturing process. The first step (left-hand side) is to sort, measure and classify the logs, and debark them. Next (middle), the logs are sawn and dried. Finally (right-hand side), the logs are correctly oriented for being packed in pallets.

The sawn timber handling machine can manage boards with dimensions ranging from 15x60 mm up to 100x28 mm (thickness x width) and from 2000 to 6200 mm (length). Custom design can also be engineered for shorter boards. The throughput of the line can reach up to 160 pieces per minute. Although the line is equipped with advanced measuring systems assisted by computer screen visualisation, quality assessment and control are still challenging. The current solution relies on cameras and human operators monitoring the packing line. Besides the technical parameters, the operator must be aware of and deal with different production schedules (throughput, time, amount of timber, etc.), which put the effectiveness of the operators to the test.

Moreover, the quality of the results is not constant as operators are different, and their performance over the work shift varies. For these reasons and to avoid production downtimes, there is a need to improve the monitoring system of the machine going beyond the simple use of cameras and monitors. In the proposed approach, video streams of the operating environment will be processed by machine vision and AI algorithms, taking advantage of the higher capacity of 5G connectivity to increase responsiveness and reliability. This will provide machine operators with an effective support system and support the improvement of process automation through possible interactions and coupling with the PLC system of the machine being monitored.

Moreover, the initial setup to make the machine work properly is still challenging. Up to 500 parameters (e.g., timing and force of the actuators, synchronisation between different sets of movements, etc.) must be set on the device to optimise the production cycle. The same parameters should be considered when advanced maintenance strategies need to be implemented. A DT-based approach can support these activities and the associated decisions.

UC1 category will leverage 5G network technologies, combined with modern digital twin models, sensorisation and edge/cloud computing, to validate and assess the benefits of these innovative tools and approaches in sawmills addressing sawmill machinery and the obtained wood products. Specifically, UC1.1 will address the use of digital models for wood materials to support decisions in the sawmill and concerning the monitoring of wood products. UC1.2 will implement monitoring approaches for sawmill machinery, taking advantage of 5G-connected sensors to feed and exploit Digital Twin models and approaches. **UC1.2 will focus on the packing machine at the end of the sawn timber handling line**. The same machine will be used for implementing an AI-driven maintenance policy In UC1.3.
Besides the two pilot owners, Hekotek and Harmet, two candidate sawmills (customers of Hekotek) located in Estonia, specifically in Viiratsi and Aegviidu, will also be possibly involved (formal negotiations are currently ongoing) to guarantee the participation of all the actors in the considered portion of the wood value chain.

3.1. Use Case 1.1 – Data- and material-models-driven lumber production and handling

The main aim of UC1.1 is to demonstrate how digital models of wood materials, together with data gathered from the field, aggregated and processed according to an edge or cloud computing architecture, can support decisions in the processing and handling of lumbers. This is addressed as data- and material-model-driven lumber production and handling. The use of digital wood models is applied in two different phases in the processing of wood.

The first relates to the processing of the logs at the sawmill. In this phase, the logs undergo a wide range of measurements, e.g., images, X-ray tomography, etc. The main aim of these measurements is to identify the position of possible defects so that, in the sawmill, the best positioning of the cutting plans can be operated. No specific material model is typically used, just a spatial optimisation of cutting planes and defects. These approaches and the related hardware and software tools are already widely developed and available in sawmills, and the related analyses and decisions are in the hand of the sawmill operators. The focus of UC1.1 will be on the development approaches that could predict the mechanical behaviour of the material and, thus, support cutting decisions and parameters at the sawmill.

The second relates to handling lumbers from the sawmill to the different customers. In this phase, storing the lumbers in critical environments could lead to possible damage resulting in scrap. Thus, a possible approach is leveraging the model of the wood to predict the actual status of the lumbers and either trigger the right time to use a specific lot or raise a warning concerning possible damages.

For both cases, the aim is to increase the yield in wood processing, improve lumbers' quality, and reduce scrap and non-conformities.

3.1.1. As-is

Concerning the first considered phases, as sawmills are becoming more and more modern and digitalised, the pre-processing of the logs usually entails a wide range of measures (x-ray tomography, images, etc.). Currently, the main driver for using this information is the localisation of defects and, consequently, the maximisation of value recovery from each log. Nevertheless, currently, ***no analyses are performed to predict the mechanical characteristics of the wood***, opening the way to approaches trying to trigger and optimise cutting parameters.

Concerning the second considered phase, after the processing in the sawmills, lumbers are packed and, upon need, transported to customers. From this time to the actual use of the lumbers in wood-based products***, no monitoring of the characteristics of the woods is operated***, e.g., temperature and moisture. This could often result in several lumbers presenting cracks and being discarded. Although non-efficient from a material point of view, this is currently considered the easiest and sometimes affordable approach.

3.1.2. To-be

The objective of the activities in the first phase of UC1.1 is to set up a model of the behaviour of the wood to be used to predict its characteristics and support decisions related to its processing. **A physical test, i.e., a scratch test, will be performed in a laboratory** at VTT. In a scratch test, an indenter is loaded against the surface of a wood sample that is moved with constant velocity concerning the tip. Thus, the scratched sample wood is analysed using a computed tomography approach, and **a model of the material scratch resistance will be defined and calibrated**. The **results derived from these analyses on samples will then be extrapolated to match the actual size of the logs**, aiming to make the model available for **possible direct utilisation in the sawmill to assess the optimal interaction between machinery and the pieces of wood analysed**. Concerning the type of wood, softwood and alternative species interesting for Hekotek will be defined.

Notice that, due to the specific characteristics of the different activities, the implementation of this UC will be hybrid, i.e., some of the first activities will be carried out in a laboratory environment (e.g., scratch tests and computed tomography). At the same time, follow-up activities will possibly be carried out at industrial partners' premises (pending negotiations with sawmills mentioned earlier in this document).

Furthermore, addressing the path of the timber after being processed in the sawmill (i.e. transportation to and storage at timber consumers), the **use of 5G-IoT devices to monitor lumbers** will be demonstrated. The aim is to exploit digital models of the material and information coming from the field to identify the risk of damage to the timbers, e.g., cracks. The **main focus will be on moisture models** developed at VTT, requiring to be fed with updated data related to the temperature and humidity of the wood parts. The result is the possibility of **assessing the risk of the wood experiencing cracks**. These activities will be carried out in collaboration with Harmet, focusing on the timber waiting to be used in the production of wooden buildings. The focused wood components will be Laminated Veneer Lumber (LVL), massive wood and cladding boards.

3.1.3. Technical feasibility and requirements

Concerning the definition of digital models for the wood, the described procedures and approaches have already been tested and validated by the partners; this background will provide the partners with the safety to operate in a known area and concentrate on the extension to realistic problems and data in collaboration with Hekotek. VTT will also provide laboratory facilities to use scratch tests and computed tomography.

As detailed in, Scratch resistance of wood is affected by indented tip size, scratch load (constant or increasing), wood species, directions of wood (i.e. radial, tangential, longitudinal), growth ring structure (i.e. earlywood (EW) and latewood (LW)), location of the sample with respect to the wood pith, moisture content (MC), treatment for wood products (impregnation, coatings, etc.).

Figure 4 illustrates the main principle and output of a wood scratch test as typically performed by VTT.
The scratch tests are carried out on small samples, such as 10mm x 10mm x 20 mm. Therefore, it will be necessary to assess an analytical model to scale up the results from small laboratory scale to structural scale. This was already planned, as mentioned in D1.1; however, the LW zones show, for example, penetration depths (elastic deformation) of around 2 times smaller than the EW zones. This is because the EW has lower mechanical properties than the LW, which generally happens for all mechanical properties, such as elastic modulus, strength, etc. For instance, in the pine EW, the elastic modulus in bending can also be less than half compared to the properties of LW, and the bending strength is around 1/3. However, the scratch tests cannot give direct results in terms of bending, but it is possible to see the

differences in terms of scratch resistance (in terms of friction) in samples with different densities. Also, the correlation between scratch behaviour and tensile properties in terms of elastic modulus and strength will be significant, for example, to investigate the effect of moisture variations (especially the drying) on the crack risk. While it is not straightforward to predict by how much the moisture "sensitivity" may differ for different pine samples, the scratch resistance (in terms of friction) will increase with moisture stabilization (in VTT's previous study[10] . polyethylene glycol (PEG)-impregnated samples were tested, and there was no direct correspondence between PEG% and MC%).

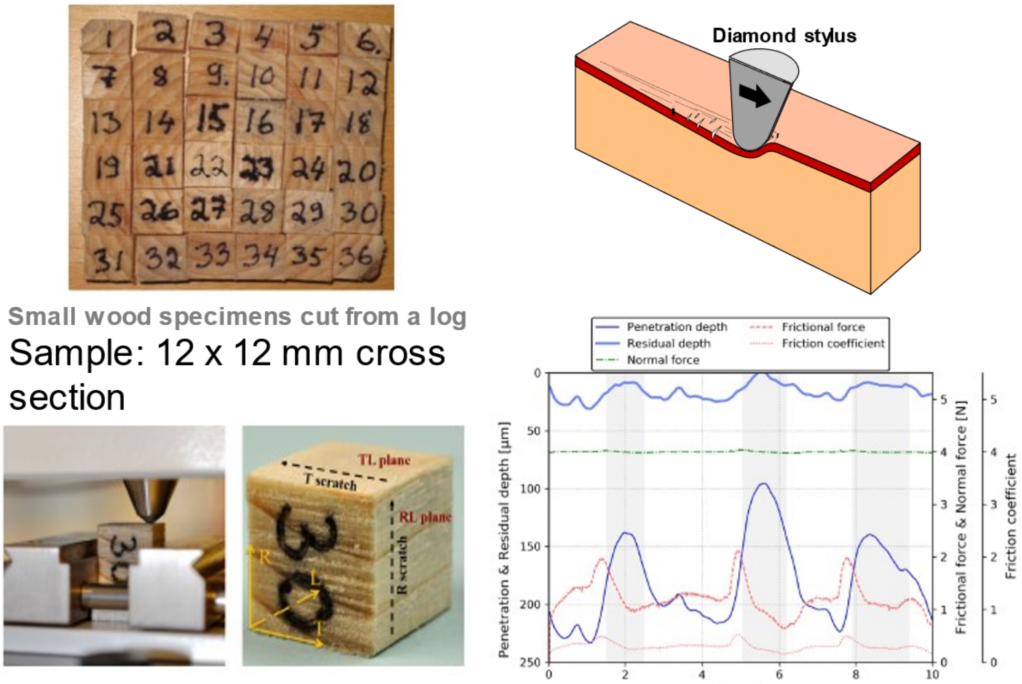

*Figure 4. Illustration of the main principle and output of a wood scratch test as typically performed by VTT (case study: polyethylene glycol (PEG)-impregnated wood sample). **Left**: PEG-impregnated wood sample under scratch test indenter and examples of scratches close to the edges in the T direction (TL plane) and R direction (RL plane). **Right**: normal force [N], residual depth [um], penetration depth [um], frictional force [N], friction coefficient [-] as a function of the scratch length (=10 mm). Approximated locations of latewood (LW) shaded. Compiled from [10] .*

Preliminary tests have already been performed on samples provided by Harmet, and an initial list of required Hygro-thermo-mechanical properties is shown in **Figure 5**.

Several of these initially required properties likely have to be taken from the literature or tested additionally because the material sellers do not have these properties tested for their products.

Regarding Harmet's Kumna production saw centre for the scratch test, they will be ready to be sent to VTT Finland in M8 (Table 4).

<table>
<tr><th>Hygro-thermo-mechanical properties</th><th>Wood products</th></tr>
<tr><td rowspan="3">Density
Average porosity
Moisture diffusion coefficients in the wood directions (transverse and longitudinal), eventually as a function of temperature
Moisture diffusion coefficients in glues for LVL products, if available
Sorption isotherms measured in the temperature range -20 ^{0}C ... +60 ^{0}C
Liquid permeability coefficients in the wood directions
Thermal conductivity coefficients in the wood directions
Elastic moduli in the wood directions
Strength in the wood directions</td><td>LVL (various types)</td></tr>
<tr><td>Massive wood (various types)</td></tr>
<tr><td>Cladding board (various types)</td></tr>
</table>

Figure 5. Initial list of required Hygro-thermo-mechanical properties for Harmet wood house manufacturing

Furthermore, some pieces of these samples will be used to also measure the sorption isotherms by using the dynamic vapour sorption (DVS) method at different temperatures as the sorption isotherms are needed for VTT's numerical hygro-thermal models.

The samples from Hekotek are extracted from boards cut in their customer sawmill (Nordwood) with the following properties, and will be ready to be sent to VTT Finland in M8:

- Wood material: spruce
- Moisture content ≈ 12%
- Dimensions: 150 x 50 x 250 mm (width, thickness, length)
- Two categories of samples will be sent to VTT for scratch testing: acceptable and not acceptable for production processes.

See Figure 6 for an illustrative photograph of such wood samples.

Table 4. Selected wooden components for modular house

Type of sample	Material	Possible cross section measures of samples (mm)	Grade	Additional information
Timber samples without strength class	Conifer (pine or spruce, but mostly pine)	28x45, 28x70, 28x95, 45x45	ABC	No requirement for strength class as this material is not used in load-bearing structures
Timber samples with strength class C24	Conifer (pine or spruce, but mostly pine)	45x70, 45x95, 45x120, 45x170, 45x220, 45x245	C24	Solid strength class C24
Cladding board / Timber samples without strength class (used in exterior)	Conifer (pine or spruce, but mostly pine)	21x95, 21x120, 21x145	-	No requirement for strength class as this material is not used in bearing structures If pre-painted material samples are provided, the type of color will be specified additionally
Kerto LVL	Kerto LVL is produced from 3 mm thick rotary-peeled strength graded softwood veneers. The veneers are bonded with weather- and boil-resistant phenol formaldehyde adhesive to form a continuous billet	Will be specified	-	

Figure 6. Illustrative photograph of the wood samples provided by Hekotek (bottom of the figure) from boards cut in the Nordwood sawmill (top of the figure).

While Hekotek and Harmet are not in a position to provide green wood samples, we are investigating the possibility of using some slices of green wood from VTT's WaterInWood project. In that project, project partner LUKE will cut pine wood for other research purposes and could save a few wood slices for the 5G-TIMBER project. This will be useful for investigating the wood samples in Pilot 1 environment. In contrast, the samples provided by Hekotek and Harmet are useful for the conditions between Pilot 1 and 2 and between Pilot 2 and 3, respectively. Considering the 5G-TIMBER WVC, this is illustrated in Figure 7.

Regarding monitoring the status of wood material, 5G-IoT sensors will be exploited to monitor both temperature and humidity. The models and the activity performed in this UC will be reused In UC category 3. Using existing commercial sensors with embedded 5G technologies will be pursued. However, if they are unavailable, the integration of stand-alone sensors with 5G gateways will be considered. The selection of sensors and their integration will be addressed in T2.6.
5G connectivity to integrate the sensors will be guaranteed since the activities will be carried out at Harmet's premises, where 5G equipment will be installed.

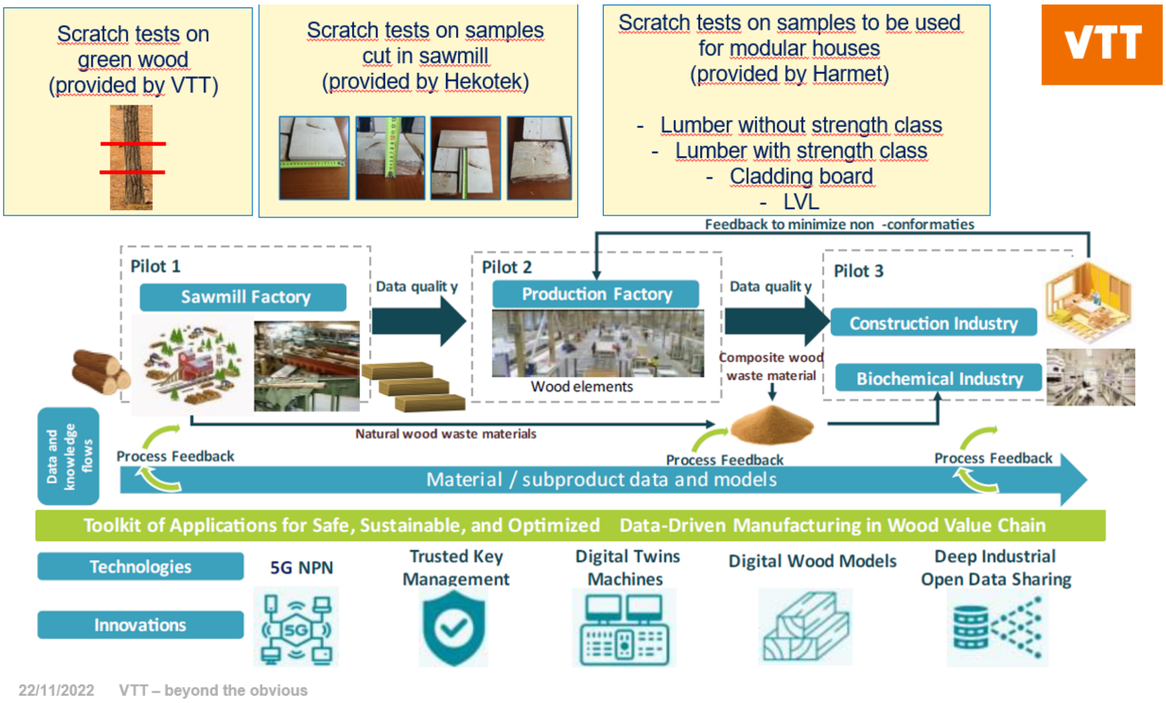

Figure 7. Positioning of the scratch tests in the 5G-TIMBER WVC, i.e. between Pilot 1 (sawmill factory) and Pilot 2 (production factory), as well as between Pilot 2 and Pilot 3 (construction sites).

3.1.4. 5G roles and benefits

The main benefits of 5G technologies are the possibility to connect devices collecting and transmitting information taken from the field (mMTC). Furthermore, also the eMMB is addressed due to the need to make available reasonable mobile broadband experience in rural areas, where sawmills are usually located. Finally, in terms of benefits over 4G and 5G NSA, 5G have much better ways to handle and ensure service quality (slices, E2E quality).

3.1.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in Table 5.

Table 5. ROI of the actors involved in UC1.1.

Stakeholder	ROI
Sawmill Equipment Manufacturers	Possibility to offer additional functionalities to the offered equipment.
Sawmill Owner	Reduce waste lumbers. Improve the quality of the products. Optimize cutting processes. Increase profitability.
End users (timber consumers)	Reduce wasted wood material. Higher quality of the wood material.
RTOs	Exploit research results in real environments.

The scalability of the approaches proposed is twofold. On one side, the possibility to embed digital models of the wood at the pre-processing of logs is a possible additional functionality of sawmill equipment that could be interesting for many customers (owners of a sawmill). Furthermore, besides the proposed models, other models could be added pursuing the same scheme.

3.1.6. Risks and mitigation plan

The main risk to be addressed is the possibility that the developed models for the wood, based on laboratory testing, are not behaving correctly when the results are extrapolated to real-size pieces of wood. To mitigate this risk, the first step is grounding on the existing know-how of the partners who have already exploited this approach. Secondly, a focus on a reduced set of materials (wood species) and type of logs will be operated.

3.2. Use Case 1.2 – DTs assisted assembly, remote operation and servicing of woodworking machinery

The objective of UC1.2 is to support the operation and control of the timber packing machine (Figure 8), leveraging a Digital Twin (DT) of the machine and Machine Learning (ML) models to process data acquired in the operating environment. The packing machine is an automatic machine that collects, moves, and packs sawn timbers. It is designed, manufactured and assembled by Hekotek and delivered to the customers that will operate it.

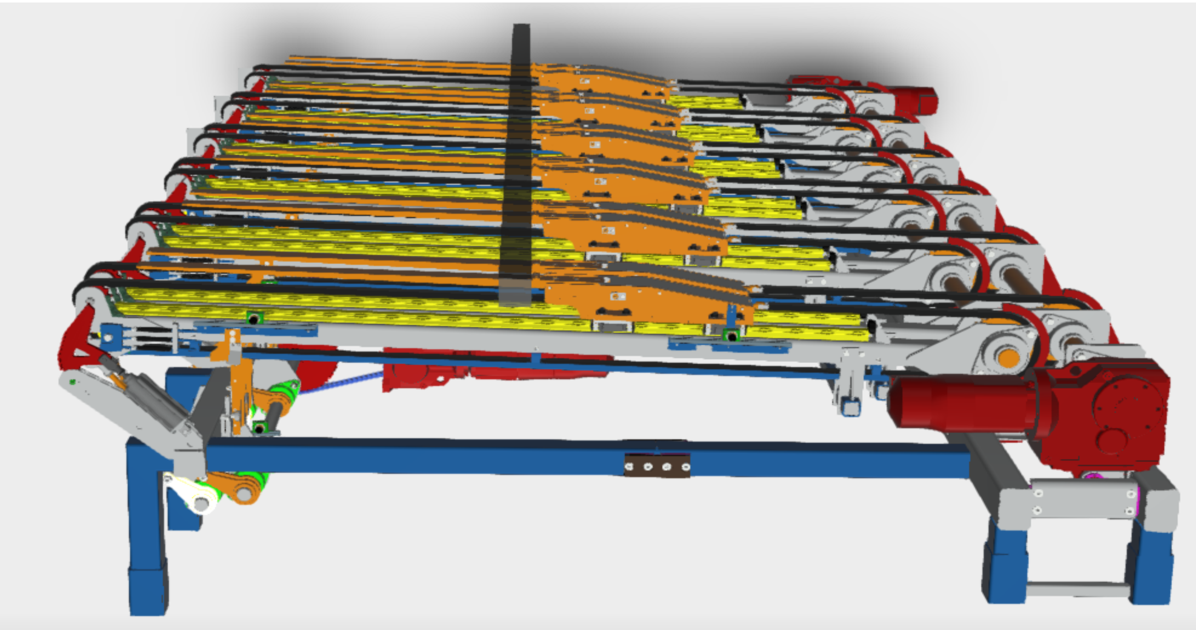

Figure 8. A rendered image of the packing Hekotek machine is addressed in UC1.2 (courtesy of Hekotek).

The DT and the ML models will be used to fine-tune the process parameters, identify and classify anomalous situations and scenarios that would bring to the machine stops, such as jams and misalignments of timbers and *improve the future designs of the machine*. In addition, an AR representation of the machine will be developed to support the operator assembly of the machine and the manual interventions in the service operation.

3.2.1. As-is

The **setup of the machine currently requires about 500 technological parameters** (e.g., timing and force of the actuators) that need to be optimised to guarantee the correct operating conditions. The timbers should be handled and positioned according to specific criteria and orientations without errors or misalignments (Figure 9). In case this is not operated correctly, jams will occur. These events require the machine to be stopped and the manual intervention of an operator assigned to the management of the machine and the related service operations to take care of the issue, solve the jam, and restart the machine. Currently, **the monitoring and supervision of this class of machines are done by an operator through a set of cameras, providing the possibility to check whether the machine is running smoothly and identify anomalies**.

Figure 9. Correct position of timbers on the packing machine. (courtesy of Hekotek)

3.2.2. To-be

The packing machine will be equipped with **IoT sensors and cameras to identify and measure relevant information about the process and to feed the supporting models**. The sensors will collect technical data and measures, allowing to monitor the process in situ and remotely. The cameras mounted on the machine will feed ad-hoc Machine Learning models to classify anomalies in timber handlings, such as misalignments and jams.

The **control logic and algorithm developed will be integrated into a Digital Twin of the packing machine**: the required data models will be designed to

deal with hybrid and heterogeneous data sources. The blueprint for data sharing will rely on open standards-based DTs (ISO 10303). An associated data exchange platform will be implemented to support data collection, management and secure communications.
The Digital Twin of the machine will be developed to model its behaviour grounding on data models, sensors and connections to:

1) Support for the installation and setup of the machine.
2) Monitor machine behaviour and detection of dangerous situations in advance (see also UC1.3)
3) Train the operators to solve jams and common issues on the machine.

To enable the final user to visualise the results, **an Augmented Reality application will be developed to support the installation and the resolution of the issues on the machine**. It will help the operators to be more efficient and avoid dangerous situations. Grounding on the same content, **a Virtual Reality application will be developed to train the operator before working on the machine**. For these reasons, the digital twin shall be granted permission to access 3D models of the machine. A Product Lifecycle Management (PLM) tool will be implemented and integrated to work seamlessly with the different models running in the digital twin and the current IT tools of the company (e.g. CAD, BIM). In this way, UC 1.2 will demonstrate via trials how AR software/tools (compliant with BIM tools of Hekotek) can be used for machine service operations and assembly processes, providing training to the operators when dealing with these new technologies.

3.2.3. Technical feasibility and requirements

The proposed approaches ground on the availability of the Digital Twin of the machine. The DT shall be ground on an open standard, compliant with STEP (ISO 10303), integrated with the IT tools currently employed in the company (CAD, BIM, etc.), and store and process data from the sensors. Moreover, the PLM shall provide dedicated tools to allow the company (i.e. Hekotek) to manage the access policies (e.g. user, user groups, etc.) and track the data over its lifecycle (data ownership, track changes, changes logs, versioning, etc.).
The monitoring approaches will be based on a Machine-Learning model, designed and trained to detect possible issues on the machine. These approaches should be in line with the images captured by the cameras in terms of resolution, point of view, etc.

Concerning sensors to be mounted onto the machine, they shall embed 5G boards and provide the proper hardware/software interface to realise the connection with 5G base stations. Some of the sensors could need to run without a power supply (i.e. with a battery).

Furthermore, sensors shall provide interface and connection to computing boards enabling edge computing. The board's performance shall comply with the specific machine's requirements. For example, if the maximum throughput is 160 pcs/min (2.67 pcs/sec), the end-to-end latency does not need to interfere with the machine throughput (i.e. rate compatible with throughput).

Concerning the 5G connectivity, it shall be available at the testing sites, enabling the visualisation devices to fetch the data needed for the simulation and the rendering. As the strictest requirements are for XR applications, the latency and peak data rate should be suitable to support streaming content in VR and AR. In the literature, the latency requirement is usually referred to as Motion-to-Photon (MTP) latency. The network shall guarantee an MTP latency of less than 20ms for VR and less the 10ms for AR [7] . Concerning the peak data rate for industrial applications and, specifically within the context of 5G-Timber, a data capacity up to 100 Mbps has been Identified as the ideal target [7] . The 5G network end-to-end latency and peak data rate shall comply with the remote operations video/image streaming rate [8] . Although the setup of the network and the performance of devices and approaches will target these performances, the peak data rate and latency requirements are not strict. In case the actual implementation and deployment won't meet them, mitigation actions are described in 3.2.6. The hardware and software requirements for the AR/VR device (tablets) will be detailed for UC1.3 (section 3.3.3).

Finally, both the software and hardware 5G architectures can support secure-by-design features, i.e., security is a built-in feature of the system from the ground up, providing a solution for enforcing proper authentication, privacy, confidentiality and data integrity.

3.2.4. 5G roles and benefits

Considering the massive amount of data this UC deals with (camera and XR content streaming), the 5G network capability (eMBB) enables the solutions devised for this UC to be effectively implemented, potentially avoiding any compression strategy. The URLLC will guarantee a good end-to-end latency for remote operation and the XR applications. Moreover, providing the network architecture with proper "Zero touch network & Service Management" capabilities allows the customer and the manufacturer to deploy this solution in the different operating environments quickly and regardless of the number of machines being monitored (mMTC).

3.2.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in Table 6.

Table 6. ROI of the actors involved in UC1.2

Stakeholder	ROI
Sawmill Equipment Manufacturers	Optimized setup and ramp-up of equipment
Machine Operator	Improved safety. Support to the operation of the machine.
Sawmill Owner	Online process monitoring with advanced automatic approaches (reduce downtimes)
RTOs	Exploitation of DT-based approaches. Development of ML algorithm for industrial monitoring. Testing cutting-edge XR application in real industrial environment

The proposed solution is based on open standards and leverages the 5G unique capabilities (Zero-touch configuration), so it can be easily adapted to different machines and manufacturers. At the moment, no specific requirements are required for deploying the solution. The blueprint for data sharing and the guidelines for developing DTs in SMEs are also helpful in adapting the solution to other manufacturing domains.

3.2.6. Risks and mitigation plan

The risks identified for this sub-UC are the following. Regarding data streaming, if the resolution of the collected images is not manageable from

remote, video compression and buffering strategies will be adopted. The same is valid for streaming the XR experiences.
The availability of sensors with embedded 5G connectivity and implementing the specifications of release 16 cannot be guaranteed at this point in the process. If no off-the-shelf solution is found, ad-hoc implementation will be pursued for demonstration purposes.
5G boards are usually not embedded in Head-Mounted Displays (HMDs). The development of specific boards that, through a standard interface (e.g. USB-C and Microsoft RNDIS driver for Hololens 2), equip the HMD with 5G capability will be desirable (and also exploitable by project partners as the business case). If HMDs are used and embedded 5G connectivity is unavailable, USB-C tethering with a suitable smartphone will be used as a solution.

3.3. Use Case 1.3 – Data and AI-driven industrial machines fault prediction and design support.

Use Case 1.3 is intended to provide a general approach to support modern maintenance approaches in small-volume machinery production. Specifically, the use of IoT data for predictive maintenance and design enhancement of sawmill and woodworking machines will be the focus of the UC, demonstrating this in live operation conditions over the 5G.

Adopting modern maintenance (e.g. predictive or condition-based) approaches enabled by online monitoring of the machine status allows the life and reliability of assets to be extended. Moreover, they can drastically minimise unplanned downtime and repair costs when adequately implemented. By making data available and accessible anytime and from everywhere, the end-user of the machine can access important asset information, such as equipment status, history, manufacturer-recommended guidelines, spare parts, processes and more.

When the same data are accessible not only by the customer but also from the machine manufacturer (Hekotek), they can be elaborated to provide analytics related to maintenance response and performance and certify that the customer has pursued no misuse of the equipment.

Finally, the digitalisation of maintenance is also helpful in pursuing an eco-friendly and paper-free approach.

3.3.1. As-is

At the moment, the **maintenance policy pursued by Hekotek relies mainly on a preventive (scheduled) approach**. The maintenance procedures are described in the "Use and Maintenance Manual" of the machine, which prescribes the set of maintenance activities to be performed on the machine during its lifecycle. There is no feedback mechanism from the field, i.e., **when a machine is operating at the customer facility, neither Hekotek nor the customer can monitor its actual status**.

3.3.2. To-be

For demonstrating the UC, sensors, data and the DT of the machine already developed for UC1.2 will be reused. After identifying the class of failures and modalities, a machine will be equipped with a set of sensors able to directly or indirectly (i.e. through data processing) derive the current status of the machine and signals of possible incipient failures. Also, existing

operation/automation data will be utilised, especially for operation profiling purposes and analytics.
The sensors connected to the 5G network push the collected data to a repository (possibly the PLM) for further computation. The data will feed the digital twin of the machine that, thanks to combined data-driven approaches, e.g. artificial intelligence and a priori knowledge-based hybrid algorithms, will be able to derive the status of the machine (e.g. if a failure is about to happen if the machine is running smoothly, how much residual time to the following maintenance intervention, etc.). A desktop application will be implemented to provide the customer with dashboards summarising the results of the predictive maintenance strategy.
The same data will also be exploited to make some considerations on the design of the machine itself: having access to time history allows the sawmill manufacturer to improve the creation of new releases of the same machine and enhance its procurement strategies for components bought from suppliers. This scenario is made possible by the tight integration between the IoT sensors and the PLM tool enabled and facilitated by 5G connectivity.

3.3.3. Technical feasibility and requirements

The activities concerning this UC require a wide range of present and historical information related to operations, failures and maintenance of the machine under study. Namely concerning system dynamics, failure modes and mechanisms, classes of maintenance interventions, and historical logs for the machine to monitor. Thus, depending on the type of failure *(critical operation performance, failure, maintenance etc. related),* proper sensors will be installed on the machine. The sensor shall embed 5G boards and/or provide the appropriate hardware/software interface to realise the connection with 5G radios. The sensors shall run without the need for a power supply (i.e. with a battery). The data collected (raw data, history data, pre-processed streams) shall be stored in a repository (possibly the PLM tool) and made available through APIs, allowing queries from any device/software.
The visualisation of the results shall be made through the dashboard and be accessible from the remote. Since data travels over a network between the customer and Hekotek, the 5G architecture should be secured by design.
The VR and AR visualisation devices shall be compliant with industrial safety standards. For example, in harsh environments, tablets shall come with drop, shock and dust protection. They shall be equipped with suitable hardware

(high-end cameras, preferably depth sensors, high-resolution displays, enough RAM and storage, 5G connectivity) and software (latest OS and API levels and compliance with OpenXR) to support the development of XR applications. The combination of suitable hardware and software shall allow the XR application to run smoothly. However, the specific requirements set depends on many factors, which are hard to detail at this stage. The selection will be addressed in T3.3.

3.3.4. 5G Role and benefits

The sensors and boards installed on the machine for monitoring purposes shall be able to run with batteries, i.e., without a power supply. As 3GPP's Release 16 is addressing the integration of eMTC and NB-IoT into the 5G system (mMTC service area), the battery (5 Wh) is expected to last for 10 to 15 years (compared to 10 years maximum of previous LTE technologies).

3.3.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in **Table 7**.

Table 7. ROI of the actors involved in UC1.

Stakeholder	ROI
Sawmill Equipment Manufacturers	Improvement of OEE (overall equipment effectiveness). More effective and smart maintenance approaches.
Sawmill Owner	Improved asset management. Improvement of OEE (overall equipment effectiveness). More effective and smart maintenance approaches.
RTOs	Development of 5G-enabled sensors. Deepening of AI-based predictive maintenance approach on real-world case studies.

From a methodological perspective, the proposed solution will outline a general approach to support modern maintenance approaches in small-volume machinery production enabled by 5G technology. Relying on wireless technologies, the setup and installation of monitoring sensors will be facilitated since it avoids the need for complex routing.

3.3.6. Risks and mitigation plan

The availability of sensors with embedded 5G connectivity and implementing the specifications of release 16 cannot be guaranteed at this point in the process. If no off-the-shelf solution is found, ad-hoc implementation will be pursued for demonstration purposes.

The architecture derived for this UC will consider the data collected at the customer facility and the data's trusted and federated access policy. If no agreement is found between the customer and Hekotek, the scenario will be demonstrated with an offline connection between the two stakeholders. The business model will be derived, considering the data ownership.

4. Use Case 2 Category – Modular wood house factory

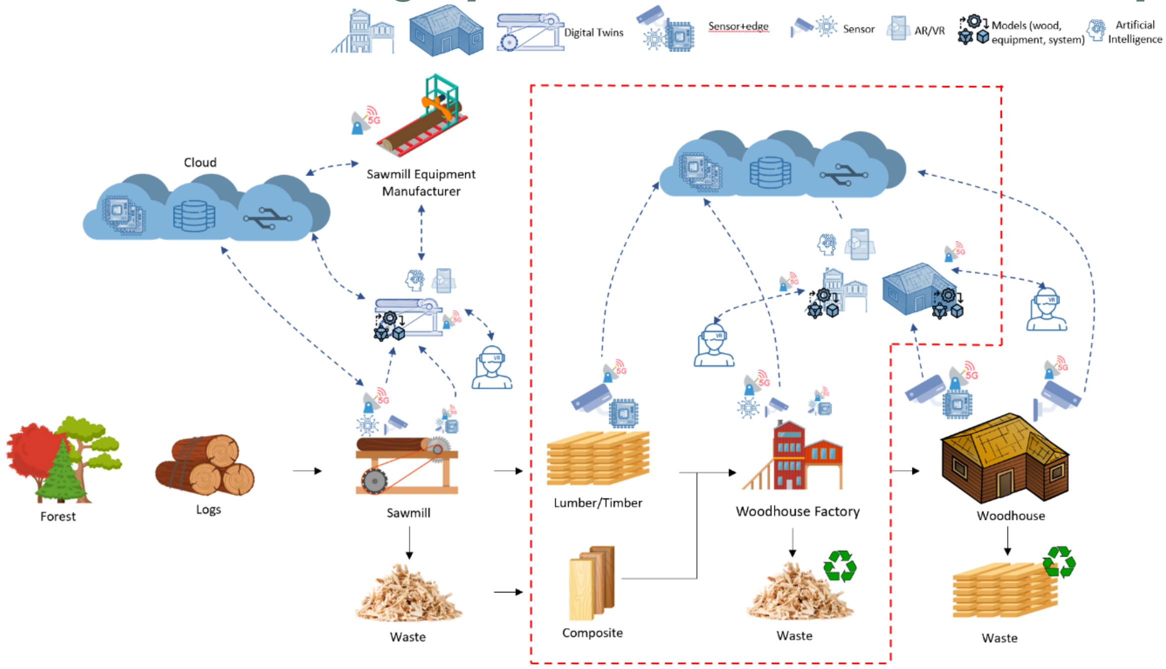

Figure 10. UC2 (dashed red area) focuses on the factory where modular woodhouses are produced. The digital twin of the production system is exploited to support the management and optimisation of activities in the factory. The digital twin of the modular woodhouse is used to support the operators in assembling operation and feedback delivery[3].

The UC2 category (red dashed area in **Figure 10**) will focus on Harmet's wood-house factory to demonstrate and validate the technologies and the integration in a large-scale field trial. The UC2 will focus on the manufacturing process of the wooden house module, ranging from when the lumbers arrive at the woodhouse factory to when the modules leave the factory for the construction site. The UC addresses deploying a 5G private network within a production environment and how it can support integrating different applications and tools. The rest of the chapter will describe how Harmet is currently organised, its commissioning, and the manufacturing process.

Harmet produces modular wood buildings (Figure 11, Figure 17) since 1997. It is the largest exporter of wooden buildings in Estonia and one of the largest in the Nordic region. Harmet counts six factories in Estonia and Finland with an overall production capacity of 600 modules per month. Harmet's product range includes various modular houses, modular on-site facilities, and different types of metal structures. The company covers the whole building

[3] Credits for the icons: Freepik.com and, Flaticon.com

lifecycle, from the design engineering to the final assembly of the buildings. Considering the generic scheduling of the work process for a customer approaching Harmet, the customer can get the wood-house in about ten months[11] .

Figure 11. Examples of modular wood houses (courtesy of Harmet).

Use Case 2 will focus on **the production facility** of Harmet, situated in Kumna village, close to the capital of Estonia. Overall, the objective is to **leverage the 5G capabilities to make introducing innovative technologies within the factory feasible, providing a solution that is easy to maintain and sustainable in the long term.** To reach this goal, the proposed solutions should also consider the design phase and allow a seamless connection between the production floor and the design department. The rest of the section will provide a brief overview of the current situation, paving the way for a detailed description of the innovation actions brought by the specific sub-UCs.

Currently, the assembly process is mainly done in two subsequent phases, namely 2D and 3D assembly. The 2D assembly mainly concern the manufacturing process of the flat components of the module (walls, floor); a big part of the HVAC and auxiliary systems are also installed in this phase (Figure 12).

Figure 12. Example of a 2D-assembly phase at Harmet's (courtesy of Harmet).

The 3D assembly is the assembly of the actual module: the "flat" components previously assembled are put together through lifting, handling, and fastening operations (Figure 13).

Figure 13. Example of a 3D-assembly phase at Harmet's (courtesy of Harmet).

Engineers design the wood-hose modules using 3D modelling techniques (e.g., 3D CAD, BIM), and the technical documentation is provided in the form of 2D drawings of the structural elements, auxiliary and service systems (HVAC, plumbing, electrical routings, etc.). The factory manager and his/her team sketch the production cycle, where inventory stocks and resource availability are also considered. Some loops are needed between the production manager and the design team before the production can begin. At the factory level, the operators rely on technical drawings to assemble the 2D elements and put them together to obtain the final module. However, possible errors are found when the module is assembled: for example, the routing path for the auxiliary system within the 2D elements is correct, but when it comes to the 3D module assembly, they don't fit with one of the adjacent 2D elements. When it occurs, the assembly process cannot be finalised correctly. As of today, there is no feedback mechanism for the design department. One of the reasons is related to how the information flows from the engineering department to the factory floor. The modules are designed in 3D while, for assembling them, technical drawings are used. Often, it happens that the design of the 2D element itself and the 3D model of the module is correct, while their 2D drawings are not. Some attempts to make 3D models available on the shopfloor through tablets and/or displays have been investigated. Still, the main barrier is found to be network performance (latency, peak data rate) and reliability. The 3D models containing the full description of the wood-house module, including the assembly instructions, are too heavy to be managed and delivered factory-wide.

Moreover, the overall management, scheduling, sequencing and orchestration of the production tasks are now addressed manually. Moreover, there is no system tracking how people and materials move around the factory floor. This leads to much waste in men-hours (waiting for the following operations) and, sometimes, security issues. No digital twin of the production system is present, resulting in costly assembly time waste and errors.

The following sections will describe the specific contributions of the use cases. Specifically, UC2.1 will deploy a tracking system in a particular portion of Harmet's facility. Besides demonstrating the feasibility of a 5G-based positioning system, it will also be integrated and reused by UC2.2 and UC2.3.

The UC2.2 will focus on making available 3D data to the operators while assembling the woodhouse module through the XR interface supported by the product digital twin. Moreover, the optimisation of the production cycle will also be addressed with the implementation of a digital twin of the process, taking the operator's safety aspects into consideration. UC2.3 will close the loop between the production and the design phase by implementing a feedback mechanism from the production floor to the design department, grounding on the same DTs previously developed.

4.1. Use Case 2.1 – Precise localisation for production processes optimization and human safety

The activities within UC2.1 aims at demonstrating the benefits of 5G precise localisation methods for indoor logistics and human safety. The idea is to trigger the functionalities provided by the latest release of 5G specifications to be able to localise materials and human operators inside of a production plant.

Indoor Positioning Systems (IPS) are a network of devices able to localise people and/or objects moving inside buildings where the GPS technology fails due to signal attenuation caused by construction materials. A wide range of technologies supporting IPS, both radio and non-radio based. These do not require any wireless infrastructure and provide better accuracy. However, they often need expensive equipment and installations, especially when the coverage area is large (e.g. industrial plant). In radio-based technology, 5G is a promising technology for precise localisation services: positioning users and devices across general indoor environments was a focus area of 3GPP Release 16 [12] . Further improvements are expected in Release 17, targeting 20-30 cm location accuracy for specific deployments [12] .

The UC2.1 will focus on 5G-based localisation testing that would optimise material and human movement trajectories, therefore increasing production efficiency and improving open space safety in GDPR compliant way. Time of Flight (ToF), Uplink time difference of arrival (Ul-TDoA), Angle-of-Arrival (AoA) and imaging techniques will be investigated. Moreover, the results of UC2.1 will also be exploited to optimise the production system, as described in UC2.2.

4.1.1. As-is

Currently, at Harmet's, no localisation technologies keep track of materials and human operators during the production of the wood-house module. Due to production variability, Woodhouse assembly factories suffer from inefficient material and human logistics. Most woodhouse modules are designed on demand, following specific customer requirements. For this reason, the production process can be planned only up to a certain extent: clear material flow and human logistics (e.g. forklift operator movements) need to be designed according to the specific "Work-in-Progress" (WIP) on the production floor. Besides the complex logistics, this situation contributes to possible workplace accidents: for example, material handling and the module liftings are carried out without any system, except for human operators, checking for a possible presence inside the module.

4.1.2. To-Be

A **5G-based Indoor Positioning System will be implemented to localise people and parts within the Harmet Plant**. As the localisation service through 5G radios is still under development by 3GPP, a first attempt will be made by installing private radios in the Harmet plant, developing specific algorithms to derive the location of the assets, and checking its performance in terms of accuracy. Sections 4.1.3 and 4.1.6 describe different architectures if the accuracy does not meet the KPIs.

Specifically, the last phase of the 2D assembly and the rest of the 3D assembly will be considered. Here, possibly dangerous situations can occur due to the lifting and handling the modules' heavy components. Moreover, the logistics of both material and human operators can be intricate. Those aspects make this location within the factory suitable to demonstrate the benefits of the IPS in terms of work efficiency and safety improvements.

4.1.3. Technical feasibility and requirements

The feasibility of the proposed approaches is constrained by the strict requirements related to the overall localisation accuracy, which ranges from 20cm to 500 cm.

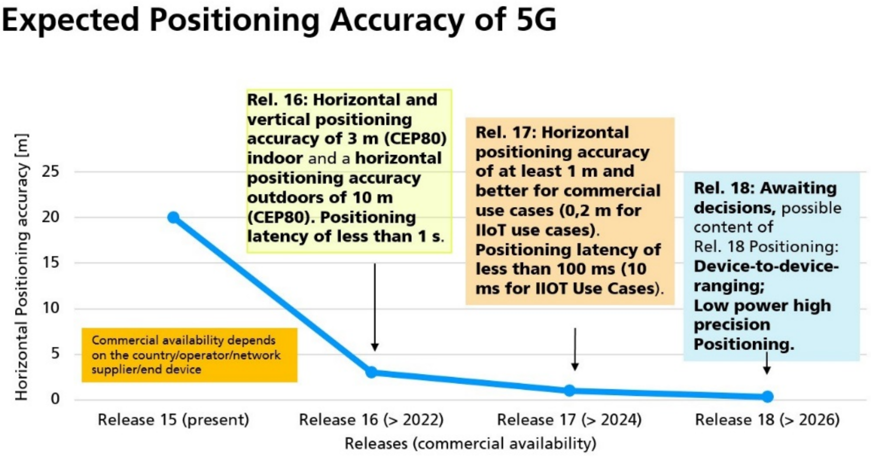

Figure 14. Expected positioning accuracy of 5G releases [Credits: Fraunhofer]

As shown in Figure 14, the capability to stay within this limit using 5G technologies is strictly linked to the availability of hardware and software tools implementing the 3GPP 5G Release 17. The latest release available (R16) can only guarantee 3 m accuracy and 1 ms latecy. The main benefit provided by 5G position systems compared to previous mobile technologies take advantage of the inherent technical performance of 5G. Recent documents also report multiple positioning techniques for different deployment scenarios and use cases (e.g., Figure 15).

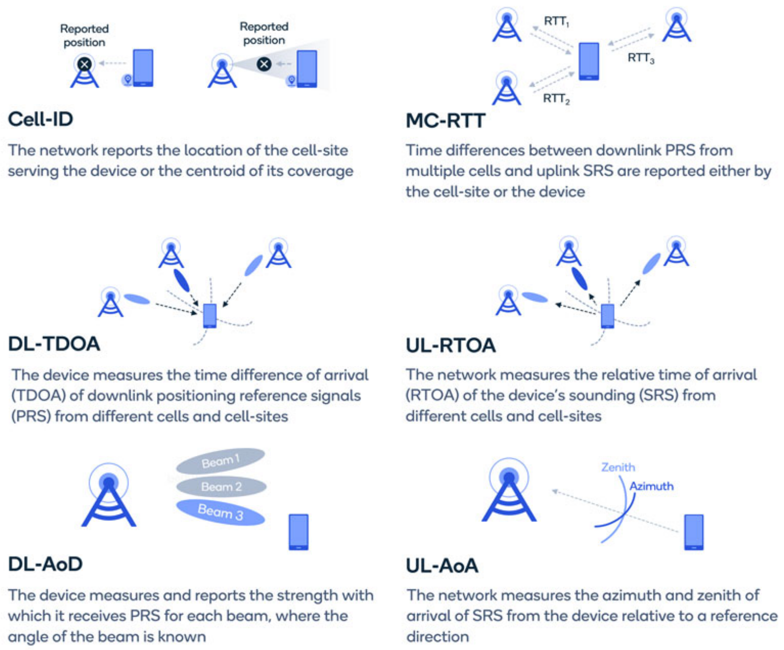

Figure 15. Alternative techniques for localisation using 5G technology cases [15]

For example, the delay error variance decreases in the order of the square of the bandwidth as the bandwidth increases. As 5G provides more bandwidth than LTE (LTE offers a maximum of 20 MHz, 5G can provide 400 MHz in frequency range 2), localisation services can benefit from it. Again, the received power is inversely proportional to all estimated variances [13] .
Furthermore, aiming to develop safety solutions, the 5G network shall work with mm-Wave bandwidth (band of the radio spectrum between 30 GHz and 300 GHz, also known as 5G Frequency Range 2) to improve accuracy. As 5G Frequency Range 2 suffer from more signal attenuation with respect to sub 6 GHz network, a trade-off shall be investigated to allow localisation in

occluded areas (e.g. inside the woodhouse module). The network shall provide less than 10 ms latency.

The 5G radios shall be able to provide signal coverage to the area dedicated to the use case (the overall Kumna factory covers 23000 $m^{2,}$ and the area dedicated to the UC will be about 9000 m^2) and, the positioning algorithm shall provide an accuracy ranging from 20cm to 500 cm depending on the specific area inside the factory[13] .

In case this will not be possible or the 5G network alone won't be ready to provide the required accuracy, alternative solutions will be implemented and tested grounding on the following technologies:

6. Localisation is based on the available 5G technology (R16), leading to lower accuracy. This could be exploited for some of the features, e.g., the capability to check if the position is inside a module or not.
7. Over-the-top positioning strategies (e.g. camera-based localisation tools based on object detection) will be developed. The 5G network will be exploited to stream the data (e.g. images/videos) to the computational units (e.g. on the cloud) and enable the communication with the DTs (see UC 2.2).

Position and gathered data shall be made available in a suitable format (e.g. JSON) and, possibly, stored on a server (cloud or on-premise). These requirements ensure that other UCs can exploit those data for other purposes (see, for example, UC2.2).

4.1.4. 5G roles and benefits

The main benefit of adopting 5G technologies is Localisation services (LCS). Furthermore, Massive Machine-Type Communications (mMTC) is also covered due to the need to manage many localisable items (people, tools, parts, etc.). Finally, 5G technology also provides the capability of very low-power devices, supporting localisation on long time horizons without recharging the tags.

4.1.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in **Table 8**.

Table 8. ROI of the actors involved in UC2.

Stakeholder	ROI
WoodHouse Manufacturers	Improved assembly scheduling capability
Workers	Improved safety on the workplace
5G module manufacturers	Implementation of the latest 5G release
RTO	Development of new 5G-based localization algorithm.

As the solution grounds on 5G radios, the scalability within the factory is guaranteed in terms of area coverage and the number of tracked assets. Those two parameters depend only on the number of radios and the computing capability available. The main criticality for extending the approach beyond the case study (e.g. to the whole manufacturing facility) is related to the cost of each 5G radio.

Regarding the scalability of the proposed solution to other facilities and, even more, to the manufacturing domain in general, general-purpose hardware (available on the market) will be used as much as possible.

4.1.6. Risks and mitigation plan

Due to the uncertainty related to the availability of devices implementing the latest release of 5G technologies (>R16), an alternative scenario has been devised. If the devices are unavailable, or the performance is not enough, existing 5G technology (reduced accuracy, more than 50 cm) will be used, together with alternative IPS technologies (cameras, etc.). Exploiting a sensor fusion approach that leverages the 5G unique capability (latency and reliability), a precise (less than 50 cm) localisation system will be implemented. Besides the network's performance, the 5G radios will also be exploited when other technologies (e.g. cameras) fail due to a lack of line-of-sight (e.g. occlusion).

4.2. Use Case 2.2 – DT, AR and Industry 5.0 UX assisted production supported by ZSM 5G data exchange.

The UC2.2 aims to improve woodhouse assembly quality, efficiency and safety by implementing Augmented Reality (AR) and Industry 5.0-assisted production.

The UC will focus on Harmet's wood-house factory to demonstrate and validate the technologies and the integration in a large-scale field trial. As explained before, the assembly process is mainly done in two subsequent phases, namely 2D and 3D assembly. At the factory level, the operators rely on technical drawings to assemble the 2D elements and put them together to obtain the final module. However, possible errors are found when the module is assembled: for example, the routing path for the auxiliary system within the 2D elements is correct, but when it comes to the 3D module assembly, they don't fit with one of the adjacent 2D elements. When it occurs, the assembly process cannot be finalised correctly.

A digital twin of the product and production system will be developed to address those issues by levering 5G network performance to make data available on the manufacturing floor and provide optimal solutions regarding the manufacturing processes involved. The "3D assembly" will be the focus of the UC2.2.

4.2.1. As-is

One of the reasons is related to how the information flows from the engineering department to the factory floor. The modules are designed in 3D while, for assembling them, technical drawings are used. Often, it happens that the design of the 2D element itself and the 3D model of the module is correct, while their 2D drawings are not. Some attempts to make 3D models available on the shopfloor through tablets and/or displays have been investigated. Still, the main barrier is found to be network performance (latency, peak data rate) and reliability. The 3D models containing the full description of the wood-house module, including the assembly instructions, are too heavy to be managed and delivered factory-wide.

Moreover, the overall management, scheduling, sequencing, and orchestration of the production tasks are now addressed manually, and there is no system tracking how people and materials move around the factory floor. This leads to much waste in person-hours (waiting for the following operations) and, sometimes, security issues. No digital twin of the production system is present, resulting in costly assembly time waste and errors.

4.2.2. To-be

As described before, the focus of UC2.2 will be on two main points.

The first innovation stream will leverage the product's digital twin to support the modules' assembly process by providing the operators with contextual information about the product and the assembly process. Virtual and Augmented reality applications will provide advanced visualisation of the 3D models and additional online and offline information. This will leverage XR technologies and the capability of 5G networks. The DT of the woodhouse will be implemented to provide all the data and information in a structured and modular way. XR applications will be developed to enable the assembly workers to use 3D BIM models while performing the assembly tasks. The device's user interfaces (machine operators, assembly personnel) will be Industry 5.0 compliant (user adaptive): different visualisation devices will be tested for this purpose, such as Head Mounted Displays (glasses) and hand-held devices (tablets). The same XR tools will also be used in personnel training. UC2.2 will include studying human behaviour in XR-augmented factory environments, focusing on worker safety. UI adaptivity occurs in real-time based on how the operator interacts with the system (the interface changes input modality, graphical structure or output channels based on an estimation of what the user does: errors, interactions etc.). Adaptability is based on pre-defined user profiles that the systems can recognise. So far, no data on the safety of AR workspaces has been collected; acquiring it would improve AR acceptability in the industry.

The second stream will ground on the digital twin of the process and production system to optimise the assembly of the modules. The main idea is to have cameras and sensors that monitor what is happening on the shop floor and, grounding on this, feed information to a digital twin that optimises sequencing, human and machine resources and material availability. The digital twin of the production system coupled with a system able to monitor the real-time status of the resources (reused from localisation for parts and people developed in UC2.1) allows the optimisation algorithm to include safety-related aspects. Currently, the production times and Non-Conformities (NC) reports are tracked by the company: they will constitute the ground truth to measure the improvements after the innovations led by 5G-TIMBER.

4.2.3. Technical feasibility and requirements

The proposed approaches ground on the availability of a digital twin of the product (module of the wood-house) and the production system (wood-house factory). The focus will be on the 3D assembly area of the production facility. All the data and information related to the product (3D models) and the process (assembly tasks, production resources, 3D models of the plant) shall be provided.

Within Harmet's plant, 5-10 AR devices (smart glasses and/or tablets) across the factory will be used in the trial. The device should be compliant with industrial safety standards. For example, if a personal safety device must be used (e.g., helmets), the wearability of the smart glasses should be guaranteed[4]. The tablets should be equipped with high-quality hardware (high-end cameras, depth sensors, high-resolution displays, enough RAM and storage, 5G connectivity) and software (latest OS and API levels and compliance with OpenXR) to support the development of XR applications. The suitable hardware and software combination should allow the XR application to run smoothly. However, the specific set of requirements depends on many factors that are hard to detail at this stage. As a reference specification, the devices should meet the ones provided by the major players on the market[5,6]. The software application will then be adapted to the specific device. Both the smart glasses and the tablets shall guarantee the possibility to visualise everything wirelessly, without wired connections. The selection will be addressed in T3.3.

Furthermore, the UI of the XR applications should dynamically adapt depending on what is happening in real-time and how the operator interacts with the system. The interface can change input modality, graphical structure or output channels based on an estimation of what the user does (errors, interactions etc.). The adaptability will be based on pre-defined user profiles that the systems can recognise.

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[4] For example: Trimble XR10 with HoloLens 2 - Full Brim Hardhat (link)
[5] AR Core supported device (link)
[6] Vuforia Engine supported device (link)

Concerning the characteristics of 5G connectivity, as the strictest requirements are for XR applications, the latency and the peak data rate should be suitable to support streaming the content both in VR and AR. In the literature, the latency requirement is usually referred to as Motion-to-Photon (MTP) latency. The network shall guarantee an end-to-end latency of less than 20ms for VR and less the 10ms for AR [7] provided that the hardware devices and approaches involved do not act as the bottleneck. Concerning the peak data rate for industrial applications and, specifically within the context of 5G-Timber, a data capacity up to 100 Mbps has been identified as the ideal target. . Despite the setup of the network will target these performances, the peak data rate and latency requirements are not strict. In case the actual implementation and deployment won't meet them, mitigation actions are described in 4.2.6.
The data gathered from the actual assembly process needed to feed the digital twin of the production system can be derived from the sensors and antenna installed for UC2.1. Therefore, the requirements are the same.

4.2.4. 5G roles and benefits

Based on the technical requirements and the scenario description, the 5G role and its benefit compared to current technology is evident. Regarding the XR application, 5G networks can provide a latency of less than 1ms, leaving enough room for other computational resources needed in the chain (e.g. user motion, object alignments, occlusion and light changes in the surrounding environment, rendering, etc..). Moreover, eMBB and URLCC applications allow hybrid architecture to be implemented. For example, XR applications are known as computational demanding: current devices (HMD or Tablet) provide enough rendering capability at the expense of wearability and comfort, hindering the user's acceptance at the industrial level. Grounding concepts such as remote rendering, the highest quality 3D content and interactive experiences can be provided to the user.
The 5G network will provide suitable performance to devise such interactive and seamless architectures (e.g. streaming high-quality 3D content). Moreover, thanks to the higher peak rate compared to other mobile technology, the 5G network can also support the data exchange with the DTs while keeping a smooth data stream for visualisation purposes.

4.2.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in **Table 9**.

Table 9. ROI of the actors involved in UC2.

Stakeholder	ROI
WoodHouse Manufacturers	Shortening of element assembly time reduction of assembly errors enabling automated feedback of design errors to BIM models reduction of new workers training time
5G module manufacturer	Provide 5G connectivity to XR devices
5G provider	Test 5G performance when streaming XR content
RTOs	Methodologies and approach to develop digital twins.

The proposed solutions will leverage commercial devices and open standards (e.g. OpenXR) for the implementation. The integration with the current IT tools (e.g. CAD, BIM, PLM) will be designed, whenever possible, according to ISO standards or, when none is found, with approaches ensuring the interoperability of the software/hardware. Given the generality of the solution, the scalability toward other manufacturers and/or other industries is only limited to the availability of modern IT tools (e.g. DTs, BIM, PLM, etc.). Cornering, the scalability in terms of the number of users accessing the tools simultaneously, the cost of the devices (HMD, table, servers, etc.) and the network data rate will be the critical factors.

4.2.6. Risks and Mitigation Plan

The main risk is maintaining the MTP latency at an optimal level. Considering a 1 ms latency due to the network, an AR application has about 9 ms to update the frame on display. This means that all the computation and the rendering of the scene should be done in this little amount of time. Suppose the performance of the device (HMD, tablet) does not match this requirement. In that case, different approaches will be attempted, such as prefetching digital assets on the device to reduce the data rate, exploiting edge computing for some part of the XR experience, reduce the resolution/quality of the image.

The user acceptance (willingness of the operator to wear this device while working) can also be critical. Different UIs will be developed in this case to make the user more comfortable. As one of the essential points for user acceptance is the level of interaction, if the users report discomfort from this point of view, different interaction modalities will be investigated (e.g. voice control vs mid-air touch).

The last criticality is the availability of XR devices with 5G connectivity. 5G boards are usually not embedded in HMDs. The development of specific boards that, through a standard interface (e.g. USB-C and Microsoft RNDIS driver for Hololens 2), equip the HMD with 5G capability will be desirable (and also exploitable by project partners as the business case). If such a scenario is not realised, USB-C tethering with a suitable smartphone will be used as a solution.

4.3. Use Case 2.3: Data-driven design to production cycle optimisation

This UC aims to shorten the design to the production cycle and provide automated feedback of discovered non-compliances to initial design and manufacturing steps.

Today, Harmet does not implement a closed loop between the design and manufacturing departments that can report potential issues. Such a mechanism, collecting data on the production floor in real-time and categorising them correctly in the company's PLM tool, would enable a Data-Driven design of the woodhouse. If properly implemented, a data-driven design allows the designer to quickly identify and fix potential issues, limiting their impact along the production chain.

4.3.1. As-Is

Engineers design the wood-hose modules using 3D modelling techniques (e.g., 3D CAD, BIM), and the technical documentation is provided in the form of 2D drawings of the structural elements, auxiliary and service systems (HVAC, plumbing, electrical routings, etc.). The factory manager and his/her team sketch the production cycle, where inventory stocks and resource availability are also considered. Some loops are needed between the production manager and the design team before production can begin.

Once the production begins, the design department has no real-time feedback mechanism regarding possible issues. The same is true for the production process. Production times and **non-conformities reports are done manually by production facility managers and reported to the design department offline**. Therefore, the reporting mechanism suffers from delays and loss of information and the overall quality of the data is no longer guaranteed.

4.3.2. To-Be

Leveraging the DTs developed for UC2.2, a **user interface (UI) will be integrated into the XR application giving human operators the capability to provide feedback on possible non-conformities, design errors and manufacturing/assembly-related issues in real-time.** The UI, deployed on the same devices used in UC2.2, will be able to collect feedback with different modalities, such as voice and video recordings or simple text. Thanks to the coupling between the XR tools and the digital twins, the feedback collected can be easily associated with the digital counterpart of the part/modules the operator is referring to.

The **issues will be pushed in the PLM and associated with the specific part number/job code/project ID**. Conversely, the **engineering department will be provided with a desktop application that reports the feedback**. Thanks to a set of dashboards, the issues will be clustered and categorised, giving a holistic view of the product issues and possible production problems and aiding the design engineers in the decision-making process.

Based on non-conformities and production time now collected by Harmet's, a specific module of a previously manufactured woodhouse will be selected. The same design/manufacturing process will be repeated with the tools implemented (XR tool and desktop application for designer), demonstrating the workflow's feasibility and benefits. Data to be included contains assembly workers' feedback and material models collected during other UCs.

4.3.3. Technical feasibility and requirements

The proposed approaches are grounds on the availability of a PLM implementation for the product, i.e., the modular wood house. The PLM should accommodate all the data and information related to the modules under construction, implement the feedback management mechanisms and role-based access policies, collect the issues coming from the XR application and provide access to the information through a set of APIs. Concerning 5G connectivity, the requirements for UC2.2 also apply to UC2.3.

4.3.4. 5G roles and benefits

Since the technical requirements are almost the same as in UC2.2, the tools and applications developed in this UC will similarly benefit from 5G connectivity. It can provide the network with expected performance (latency, peak data rate and reliability) to support the data streams needed for the XR tools and the connectivity with the PLM.

4.3.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in Table 10.

Table 10. ROI of the actors involved in UC2.3.

Stakeholder	ROI
Manufacturer of the wood house/building	Shortening of element assembly time reduction of customer non-compliances enabling automated feedback of design errors to BIM models
Owner of the wood house/building	Reduction of non-compliances
RTOs	Methodologies and approaches to deal with digital twins in industrial environment

As for the other use cases of the UC2 category, the proposed solutions will leverage commercial devices and open standards (e.g. OpenXR) for the implementation. The integration with the current IT tools (e.g. CAD, BIM, PLM) will be designed, whenever possible, according to ISO standards or, when none is found, with approaches ensuring the interoperability of the software/hardware. Given the generality of the solution, the scalability toward other manufacturers and/or other industries is only limited to the availability of modern IT tools (e.g. DTs, BIM, PLM, etc.). Cornering, the scalability in terms of the number of users accessing the tools simultaneously, the cost of the devices (HMD, table, servers, etc.) and the network data rate will be the critical factors.

4.3.6. Risks and Mitigation Plan

Possible risks and the associated mitigation plan are the same as in UC2.2, check Section 4.2.6.

5. Use Case 3 Category – Construction and renovation with wooden elements, valorisation of composite waste.

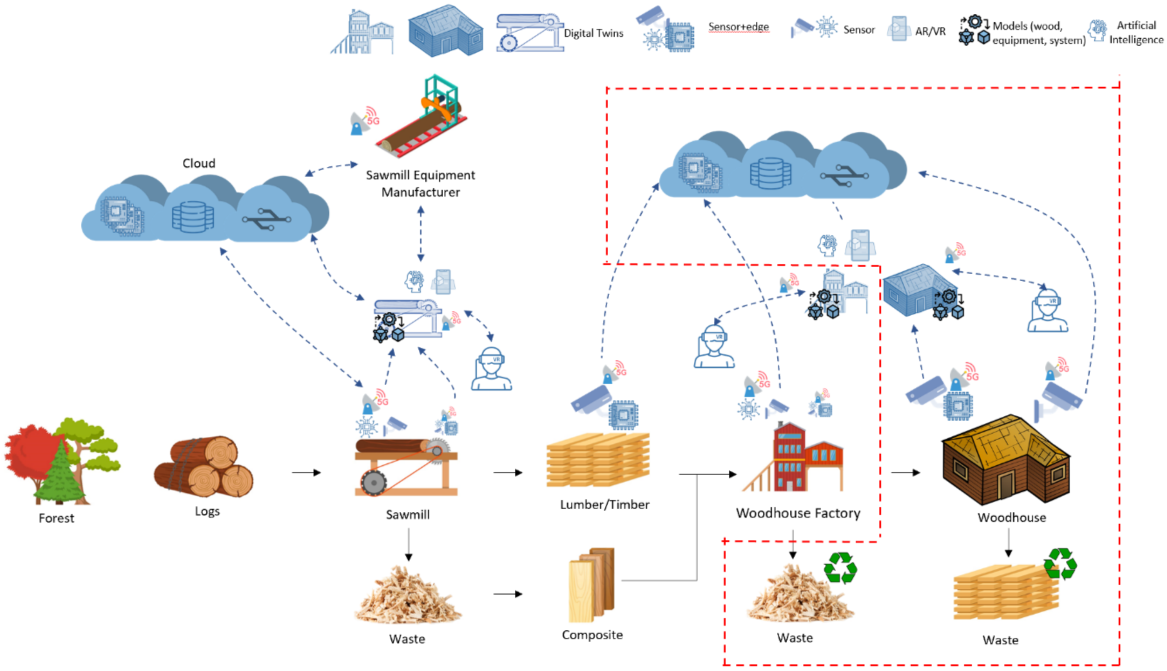

Figure 16. UC3 (dashed red area) focuses on the construction and use phase of a wood house. Furthermore, also recycling aspects for wood composites are taken into consideration.[7]

UC3 category (red dashed area in Figure 16) addresses the following steps in the lifecycle of wooden elements. Specifically, UC3.1 and UC3.2 will focus on the wooden houses' lifecycle. UC3.1 will address the wooden houses' construction phase, ranging from when they leave the factory to when the building modules are assembled at the on-site location. UC3.2, differently, will cover the use phase of the house, thus addressing 5G IoT devices, tools and methodologies supporting the monitoring and maintenance. Finally, UC3.3 takes a different point of view, addressing the analysis of alternative wooden composite materials for the wooden house, aiming to improve waste recycling in the production process.

[7] Credits for the icons: Freepik.com and Flaticon.com

5.1. Use Case 3.1 – AR and Industry 5.0 UX-assisted assembly and renovation of green buildings.

The objective of UC3.1 is to test and validate XR technology to support the assembly of the modules of wooden houses at the construction site. This UC will leverage the tools and technologies developed and tested in UC2.2 during the construction of the modules, extending their use on construction sites. The capability of 5G communication technologies will enable the possibility to exploit these support approaches for human workers grounding on the case of guaranteeing the adequate transfer rate, low latency, and reliability in public spaces. Thus, public 5G networks will be used according to their availability on the construction sites. Candidate construction sites (see Figure 17 for a previous example) will be identified with the project partners in Task 4.1 (M13-M27).

Figure 17. Construction of a modular wooden house (courtesy of Harmet).

Moreover, to support a broader range of demonstration activities and mitigate the risks linked to the availability of the construction sites, the activities linked to this use case will also be able to take advantage of Harmet's mock-up site. In fact, to prototype modular wooden houses and the related construction processes, a mock-up site is available at Harmet's premises. The possibility of testing XR- and Industry 5.0-assisted assembly and renovation approaches in the mock-up site will provide the case for a seamless transfer of the technologies and approaches tested in the production site to the construction site. Moreover, the availability of a private 5G network at Harmet's site will also support the comparison between the performance and reliability of public at the construction site and private 5G networks installed in companies' facilities in the other UCs.

Finally, the activities in UC3.1 will also address a study on human behaviour while using XR technologies. The focus will be on the safety and comfort of the workers and will leverage the involvement of Harmet's personnel.

5.1.1. As is

Currently, the **assembly instructions at the construction sites are available in 2D drawings and written reports**. The operators interpret this instruction set and accordingly organise the handling and lifting operation. There is no connection between what is happening at the construction site and what has been previously designed at the wood house manufacturer facilities. To avoid delays at the construction site, the modules are shipped from Harmet's facility with more spare materials compared to the amount that is supposed to be needed. Digitalising this phase with a connection to a digital twin can mitigate these issues.

The **main limiting factor to providing a 3D model and other information with more advanced visualisation tools (e.g. XR) can be attributed to limited network performance**. Another liming factor affecting the widespread use of XR technologies in the industry is the **lack of interaction intuitiveness and trustworthiness of XR technologies among human workers**.

5.1.2. To be

UC3.1 will test and validate the technologies and tools previously implemented in the UC2 category at the construction site. **An XR application will be developed and connected to the product's digital twin, extending the capability of the one designed for UC2.2**. These integrations will **enable the operators to access data and information (3D models of the modules and the whole wood house, layout of the modules and assembly sequences)**

through augmented reality. The positioning system developed for UC2.1, coupled with more traditional alignment methods (e.g. marker-based), will be reused here as a reference for aligning the digital contents to the physical world. The data and information will be fetched from the PLM implemented in UC2 and adequately adapted to support such a scenario.
Finally, a user behaviour study will be carried out to understand the willingness of the workers to use XR technology in everyday activities.

5.1.3. Technical feasibility and requirements

The feasibility of the described approaches grounds on what has already been designed, implemented and tested for the activities within UC2.2:

- A digital twin/BIM of the wood-house containing all the set of information potentially useful during the construction.
- AR devices (smart glasses and/or tablets) to be used in the trial.

The main difference in comparison with UC2.2 is that these methodologies and devices will be exploited outside the factory. Public 5G connectivity shall be made available at the construction site. As the strictest requirements are for the XR applications, the latency and the peak data rate should be suitable to support streaming the content both in VR and AR, i.e., the network shall guarantee an end-to-end latency of less than 20ms for VR and less than 10ms for AR. Concerning the peak data rate for industrial applications and, specifically, within the context of 5G-Timber, a data capacity of up to 100 Mbps has been identified as the ideal target. Although the setup of the network will target these performances, the peak data rate and latency requirements are not strict. In case the actual implementation and deployment won't meet them, mitigation actions are described in 5.2.6.

5.1.4. 5G roles and benefits

The main benefits of 5G technologies are providing very high data capacity towards the ideal objective of 100 Mbps (emBB) and latency targeting 10ms (URLLC). Both these requirements are fundamental for the use of XR devices.

5.1.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in Table 11.

Table 11. ROI of the actors involved in UC3.1

Stakeholder	ROI
WoodHouse Manufacturers	Shorter building time at the construction site Less assembly errors. Less spare materials at the construction site.
WoodHouse Owner	Less nonconformities Less inspections Full traceability of components
RTOs	Exploitation of BIM/digital-twin real environments

As for the UC2 category, the proposed solutions will leverage commercial devices and open standards (e.g. OpenXR) for the implementation. The integration with the current IT tools (e.g. CAD, BIM, PLM) will be designed, whenever possible, according to ISO standards or, when none is found, with approaches ensuring the interoperability of the software/hardware. Given the generality of the solution, the scalability toward other manufacturers and/or other industries is only limited to the availability of modern IT tools (e.g. DTs, BIM, PLM, etc.). Cornering, the scalability in terms of the number of users accessing the tools simultaneously, the cost of the devices (HMD, table, servers, etc.) and the network data rate will be the critical factors.

5.1.6. Risks and Mitigation Plan

In case the availability of a public 5G network at the construction site is not possible, or if the performance is not matching the requirements at the construction site, the availability of the mock-up site at Harmet's premises guarantees the possibility to carry out all the planned activities.

If the performance of the devices (HMD, tablet) does not match the requirements, i.e., do not guarantee adequate data rates and latency. In that case, different approaches will be attempted, such as prefetching digital assets on the device to reduce the data rate, exploiting edge computing for some part of the XR experience, reduce the resolution/quality of the image. Nowadays, no XR devices are embedding 5G connectivity. The development of specific boards that, through a standard interface (e.g. USB-C and

Microsoft RNDIS driver for Hololens 2), equip the HMD with 5G capability will be desirable (and also exploitable by project partners as the business case). If such a scenario is not realised, USB-C tethering with a suitable smartphone will be used as a solution.

The user acceptance (willingness of the operator to wear this device while working) can also be critical. Different UIs will be developed in this case to make the user more comfortable. As one of the essential points for user acceptance is the level of interaction, if the users report discomfort from this point of view, different interaction modalities will be investigated (e.g. voice control vs mid-air touch).

5.2. Use Case 3.2 – Long term SHM of wooden construction using IoT and embedded AI.

The objective of UC3.2 is to exploit the capability of 5G networks and 5G-based IoT devices to support the structural health management of wooden constructions. The activities within UC3.2 will control the use of energy-efficient 5G IoT devices, connected via a commercial 5G network, to monitor relevant variables as a proxy for the structural health of the wood modules (see Figure 18). The monitoring will cover the lifecycle of the wooden modules immediately after their production, thus, ranging from waiting for the storage, pickup, transfer, and assembly at the construction site to the use phase of the wooden house and its possible reuse. Particular attention will be paid at the various storage timeframes (before shipment, possible intermediate storage and before installation at the construction site) as, during these periods, the moisture damage can be accumulated.

To support the seamless installation of the sensors inside the modules, the possibility of embedding 5G connectivity into the modules will also be pursued to cope with cases where public 5G infrastructure is unavailable or does not match the desired requirements.

Figure 18. A structural module for a wooden house (courtesy of Harmet).

5.2.1. As is

After completing the modules at the production sites, **no automatic monitoring approach has been implemented, apart from the visual inspection steps required for quality-related checks** (before the shipping to the customer) and at the beginning and within the erection at the

construction site. Nevertheless, **unexpected situations can damage the wooden modules in different phases**.
The first case is when the modules are at Harmet's premises, outside the plant, waiting for the pickup and transport to the customer. Due to possible delays occurring at the construction site, this waiting period can range from a couple of weeks to some months.

A second case is the pickup transport and delivery to the customer site, where possible damages to the modules can occur.
Finally, once the wooden house has been completed and is being inhabited, monitoring structural anomalies and deviations from standard humidity conditions is a significant need, with the aim of the early identification of dangerous situations and consequent triggering of maintenance/repair actions.

5.2.2. To be

Activities of UC3.2 will be focused on two main streams.
The first is **monitoring the wooden house's structural health concerning moisture-related aspects**. To this aim, 5G IoT sensors will be installed in selected structural parts of the modules to monitor humidity and temperature. Starting from these data, a moisture model of the wood elements will be instantiated, grounding on what was developed and tested in UC1.1. This approach's objective is to predict situations that could hinder the structural integrity of wooden structural parts, e.g., the generation of cracks and anomalous humidity values that could signal leakages, mould, etc.
The second stream of activities will address the **monitoring of structural variables, e.g., the alignment of structural elements and the load variation in specific spots**. In this case, rather than exploiting the data from monitoring devices to feed a model for the behaviour of wood elements, the trespassing of given thresholds will be monitored to raise the alarm in case of specific events.

Finally, to enable a seamless and fast setup of the 5G IoT sensors, the possibility of **embedding 5G connectivity in the modules of the wooden house will be investigated and possibly demonstrated**. The idea is to embed 5G connectivity technology (5G radios, 5G gateways) in the rigid module, to leverage on self-optimizing network capability of 5G technology and allow an automatic and practical setup of both 5G connectivity, monitoring devices and architecture.

5.2.3. Technical feasibility and requirements

The described approaches' feasibility is based on the availability of hardware devices and software tools.

Specifically, concerning the hardware, 5G IoT sensors will need to be embedded in selected structural wooden parts. Sensors can monitor different variables (temperature, humidity, load, alignment, etc.). Using existing commercial sensors with embedded 5G technologies will be pursued. However, if they are unavailable, the integration of stand-alone sensors with 5G gateways will be considered. The selection of sensors and their integration will be addressed in T2.6.

Furthermore, in the scenario of embedding 5G connectivity in the modules of the wooden houses, 5G connectivity devices will be installed (5G gateways, 5G radios) so that, after the completion of the building, 5G connectivity ranging from could be made available.

Concerning software tools and frameworks, hygro-thermo-mechanical models will be exploited to support the identification of anomalies and the prevention of damages in the wooden structure (e.g., cracks). The specific models will be selected and developed in T2.1.

Moreover, an edge/cloud computing architecture will be implemented to support structural health monitoring approaches. Technical requirements related to data rate and connection reliability for UC3.2 are not binding due to the need to manage/transfer a small amount of data gathered from the sensors. The expected sampling frequency is in the order of 10 measures per day.

5.2.4. 5G roles and benefits

The main advantage of using 5G technologies is the resource efficiency of 5G IoT sensors to support the monitoring of the wooden house modules from the completion to the installation on the construction site.

The second class of advantages is linked to the 5G zero-touch to support the automatic setup of 5G connectivity and monitoring systems. This eliminates the manual configuration of network elements and, by doing so, reduces the lifecycle cost of Installing connectivity in the wooden modules.

5.2.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in **Table 12**.

Table 12. ROI of the actors involved in UC3.2

Stakeholder	ROI
WoodHouse Manufacturers	Monitoring the lifecycle of the woodhouse. Use data to improve the design Implement predictive/preventive maintenance approach Reuse modules for temporary installation (e.g. showcases, hospitals, schools, etc…)
WoodHouse Owner	Embedded 5G capabilities
RTO and Academics	Digital wood models Building maintenance algorithm and approaches

The described approaches can be extended to monitoring a more comprehensive range of variables, only limited by the availability of sensors. Furthermore, the low energy consumption of 5G-IoT devices supports their use over longer time horizons detached from the grid.

This would support an extensive adoption of these approaches in building management, only limited by the amount of data/info the user is willing to monitor/store.

5.2.6. Risks and Mitigation Plan

Using existing commercial sensors with embedded 5G technologies will be mainly pursued. If not possible, the integration of stand-alone sensors with 5G gateways will be considered. The selection of sensors and their integration will be addressed in T2.6. For the wood model to be implemented and validated, at least one year of monitoring data is needed. If the installation/preparation is delayed because of Harmet's customer unavailability, the monitoring will be performed at Harmet's mock-up site.

5.3. Use Case 3.3 – Wooden composites waste recycling.

The objective of UC 3.3 is to validate the feasibility of material models used to drive the selection of suitable wood-based materials (e.g. Oriented Strand Board, solid and engineering wood products) for woodhouse manufacturing and design. The primary goal is to improve waste recycling in the production process.

5.3.1. As-is

Woodhouse manufacturing produces a significant amount of waste containing formaldehyde and other chemicals. Currently, the manufacturing and design process does not take recyclability into account. Thus, decisions about the materials to be used in the modules of the wooden house do not consider the possibility of recycling industrial wastes. Which leaves thermal treatment of Oriented Strand Board (OSB) as current state of the art solution. Thermal treatment implicates either burning to extract energy or pyrolysis to extract both energy and liquid fuels. The former cannot be considered as recycling and the latter constitutes downcycling and not recycling. It is suggested that one could alleviate the problem by partly substituting raw materials of resins used for OSB production with bio-based materials, e. g., bio-oil [16,17]. Today, each woodhouse module can be composed of up to 20% of the OSB, resulting in a significant amount of waste with major recycling difficulties.

5.3.2. To-be

The activities related to UC3.3 will focus on using numerical and/or empirical models to support recyclability aspects in the material selection process. The aim is to provide designers and engineers with quantitative information about the possibility and difficulty of recycling wood and wood-based materials (requirements for separation, exclusions, and pre-processing). Among the alternative options, biochemistry recycling processes [18,19] and the use of novel chemically recyclable adhesives [20] will be considered. In addition to the above-stated methods a new pathway to sustainable adhesive production is envisioned where at least 20% of carbon contained in polymers (said adhesives) is sequestered from CO2 [21], either of atmospheric or anthropogenic origin. Eventually, all carbon composing the polymeric material should be derived from biomass and/or CO2, leading to sustainable and recyclable materials.

5.3.3. Technical feasibility and requirements

The technical feasibility of the declared approaches is based on the availability of appropriate models considering wastes and recycling aspects. Some of them are already available in the literature as well as by the partners in the consortium. Laboratory resources necessary to test the production and properties of sustainable and recyclable materials will be provided by TalTech Virumaa College in collaboration with other departments in the university and consortium partners.

5.3.4. 5G roles and benefits

The IoT sensors used for health monitoring described in UC 2.3 can be beneficial for waste prediction as well. By reusing the same setup, the moisture and (possibly) geometry measurements can be exploited to update the same model to estimate health status of the wood.

5.3.5. Return on Investment and scalability

The ROI of the actors involved in this UC are reported in **Table 13**.

Table 13. ROI of the actors involved in UC3.3

Stakeholder	ROI
Woodhouse Manufacturers	Reduce the waste from wood composites. Improve and ease the recycling of wastes from wood composites. Declare proper waste amounts in product EPD.
RTO and Academics	Validate and test LCA models and circularity indicators for wooden composites, Validate and test recyclability prediction for wooden composites.

The approaches and analyses carried out concerning the construction area can be easily extended to alternative sectors with similar wooden composites.

5.3.6. Risks and Mitigation Plan

N.A.

6. Conclusions

This deliverable describes the use cases that will be addressed in the 5G TIMBER project.

Within WP1, the information provided in this deliverable will serve as an input for T1.2 and, consequently, D1.3 and D1.4, supporting the definition of proper KPIs to measure the impact of the proposed solutions and approaches.
Furthermore, the sketch of the architecture of the approaches to be implemented and the related technical requirements will also support the description of the data flow architecture, addressed in T1.3 and synthesised in D1.5 and D1.6, as well as the inventory list and the blueprint for data sharing covered by T1.4 and reported in D1.7. Finally, the identified requirements for the use cases will drive the definition of long-term strategies for larger-scale adoption of 5G NPN networks in manufacturing, addressed in T1.5, and covering architectural solutions, hardware equipment and software design criteria, to be reported in D1.8 and D1.9.

The information, requirements and specifications provided in this deliverable will also fire up the activities in WP2 and WP3, supporting the design and development of the solutions and approaches of the 5G TIMBER project.

Concerning WP2, specific digital material models will be selected and implemented according to the requirements associated with the use cases and their extent within the life cycle of the products (T2.1). The classes of information and data to be stored, as well as the specific characteristics of the digital twin for products, equipment, and factories, will drive the definition of open standard-based Digital Twin for industrial automation, to be addressed in T2.2.
The requirements related to 5G infrastructure and critical functionalities will support the activities in T2.5, aimed at designing and implementing the 5G architecture and related resource management mechanisms to help demonstrate 5G technologies in the use cases.
Requirements related to the precise localisation of parts, tools and people (UC2.1), together with those related to the AI-based processing of videos and images and data (UC1.2, UC2.2, UC3.2), will be an input for the activities in T2.4.

The sketch of the tools and approaches to be developed and the data to be managed, together with the output of T1.3, will drive security-related reasoning and approaches to be addressed in T2.5.
Finally, specifications related to maintenance and monitoring (UC1.3 and UC3.2) will support the development of the related approaches to be covered in T2.6.

Concerning WP3, the information in D1.1 will be one of the inputs for T3.1 and T3.2, as well as a significant driver for the activities linked to the design and development of the specific solutions related to the UC categories and specific use cases addressed in T3.3, T3.4, T3.5 and T3.6.

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