ROADMAP FOR THE 5G/6G EMPOWERED DECONSTRUCTION ROBOTIC PLATFORM

Deliverable D5.1

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CONTRIBUTOR(S)	Marit Zöcklein, Victoria Jung

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Executive Summary

While 5G has become a familiar term when speaking of private and public networks for communication, the use of 5G technologies in manufacturing, energy, construction, or automotive is only at the beginning. This is the starting point for the TARGET-X project to take off. In a joint approach, research partners from these industries explore new use cases and applications. In the construction vertical, we will explore the potentials of 5G as a communication standard for construction machines to perform selected deconstruction activities and move towards a more circular economy.

In this deliverable, the roadmap for a 5G/6G empowered robotic deconstruction platform will be outlined. The outline includes a description of the construction testbed, the planned setup, and the envisioned implementations, including scheduling.

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List of Acronyms and Abbreviations

SDGs	United Nations Sustainable Developments Goals
CDW	Construction and Demolition Waste
FSTP	Financial Support to Third Parties
URLLC	Ultra-reliable low-latency communication
EMBB	Enhanced mobile broadband
ROS	Robot operating system
LPWAN	Low-power wide-area network

1 Introduction

With the announcement of the "2030 climate action plan", the European Commission has expressed its intention to reduce greenhouse gas emissions by 55% by 2030 [1]. By accounting for 37% of all energy and process-related CO_2 emissions, the construction sector is one of the largest emitters of greenhouse gases according to the 2022 Global Status Report for Buildings and Construction [2]. At the same time, Construction and Demolition Waste (CDW) caused by the construction industry is one of the major waste streams in the EU [3]. To meet these two challenges, development must necessarily abandon linear value chains and move towards closed-loop value chains in the sense of the circular economy [4]. This requires rethinking and reengineering traditional construction processes [5, 6]. The research within the construction vertical of the TARGET-X project builds on this initial situation. Using 5G technology already established in the communications industry, construction processes will be recorded, documented, and analyzed for their potential with regard to the circularity. In addition, the conversion of conventional construction machines for the demolition of buildings into intelligent robotic platforms for controlled, minimally invasive, and partially automated construction and deconstruction will play a key role in this research project. The goal is to recover as many of the used building materials as possible for reuse and thus keep them in the value chain instead of adding them to the waste stream. Finally, the research results and learnings from the TARGET-X project can contribute to advancing towards meeting the Sustainable Development Goals (SDGs) formulated by the UN in 2015 [7] in areas “9 – Industry, Innovation, Infrastructure”, “11 – Sustainable cities and communities”, “12 – responsible consumption and production” and “13 – Climate action” in the near future.

1.1 Circular economy in construction

Circular economy is defined as a closed-loop production and consumption model. It comprises the principles of reusing, repairing, refurbishing, and recycling existing materials and products to keep materials within the economy wherever and as long as possible [8]. Circular economy is often associated with the cradle-to-cradle principle in which the remaining components at the end of life of an object or product serve as the resources for a new lifecycle. These principles have manifested themselves as the "9R Framework" on circular economy [9, 10]. In opposition to the circular economy principles, stand almost one billion tons of waste from the European construction sector every year [5]. A large fraction of this number comes from the demolition of buildings without any concepts for reusing or recycling materials. However, for building materials to qualify for reusing and recycling, not only the buildings’ design and the exchange of building information needs adaption but also the construction and demolition processes demand rethinking. In demolition processes, heavy-duty machinery plays a decisive role. Thus, concepts towards a more circular economy in construction cannot neglect the necessary empowerment of conventional demolition machines to platforms for controlled deconstruction. To comprehend the importance of this step towards closing the loop of a buildings’ lifecycle, it is essential to understand the fundamental difference between traditional demolition and controlled deconstruction. While demolition is defined as the act of destroying something irrevocably, controlled deconstruction describes the dismantling of a built structure in such a way as to preserve its structural components. Hence, by controlled deconstruction building materials and components can be recovered for a secondary building. The targeted reuse of components holds great potential for greenhouse gas savings [11], since emissions-intensive component production can be skipped in the case of reuse. Additionally, a controlled, less invasive deconstruction process generates potentially less air and noise pollution than the conventional demolition of a building. As a result, it is less harmful to both the environment in general as well as the health of construction workers on site because they are less exposed to pollutants. Consequently, empowering conventional demolition machines to become robotic platforms for controlled deconstruction can not only improve the immediate working conditions at construction sites but also help meet the goals of the European “2030 Climate Target Plan” [1]. While this transformation opens up many opportunities, it also brings numerous challenges. One of the most challenging tasks to be solved is a sustainable, secure, reliable, and preferably wireless communication concept for construction sites in which people and machines can exchange information with each other. For more circularity, this would mean, for example, documenting the planning as well as the construction process. The collected data for the deconstruction process should be processed in such a way that deconstruction can be carried out in a minimally invasive way that preserves building components. Currently, fifth-generation communications technology is being seen as a promising candidate to meet this challenge. TARGET-X will be addressing this issue by researching to what extent 5G is suitable for communication on construction sites and which new processes are enabled by this technology. At the same time, the limitations of 5G and the characteristics of its potential successor, 6G, will be explored.

1.2 Document overview

The first chapter introduces the concept of circular economy as an answer to current challenges of decarbonization and waste management in the construction industry. Furthermore, it describes the necessity of developing new methods for the controlled deconstruction of built structures for the actual implementation of this concept. In this context, there is also an outline of the role of robotic platforms for the developed deconstruction methods. In addition to that, the first chapter explaines the relations to other activities within the TARGET-X project. In the following, the second chapter will portray the large-scale testbed for the construction vertical and present the planned (de-)construction activities. The third chapter provides an overview of the state of the art in the use of robotic platforms for controlled (de-)construction processes. Chapter four then describes the expected data streams and requirements for the communication network. The fifth chapter depicts the planned developments including the time schedule. This document ends with a conclusion in the last chapter.

1.3 Relations to other activities

The activities in work package 5 construction overlap with the work package 3 energy. Partly, the same testbed will be used and joined tests will be carried out to better understand the individual energy consumption on the construction site. Apart from that, there is overlap with the activities in work package 1 methodological assessment framework. Data obtained in work package 5 activities will also be used as input for the methodological assessment framework that will be built in work package 1 of TARGET-X. The assessment of the sustainability aspects of the use cases to be implemented is one of the key components of the methodological assessment framework. The data from work package 5 use cases will therefore be used in the design and application of the assessment framework. Moreover, the scope and feasibility of the use case developed in work package 5 is highly dependent on the results of the projects from financial support to third parties (FSTP) projects. Depending on which construction activities will be realized within the FSTP projects and the framework of the cascade funding, the feasible deconstruction processes differ. Consequently, if the FSTP projects fall short of delivering the expected results, the planned use case will be implemented with necessary adjustments. Likewise, the effectiveness of the use case can still be maintained.

2 Large scale testbed for research in construction

This chapter provides a description of the construction vertical's testbed. Furthermore, the chapter will also outline the planned construction activities. Since this deliverable was written at an early stage in the TARGET-X project, the planned activities may change in the further course of the project.

2.1 Reference Construction Site at Campus Melaten, Aachen

The Reference Construction Site at RWTH Aachen University operated by the Center Construction Robotics at Campus Melaten in Aachen, Germany is the designated large-scale testbed of the construction vertical of the TARGET-X project. Outside of the TARGET-X project, the site serves students, research partners and industry partners as a living lab for research in construction under a fair use principle. At the moment, the Reference Construction Site hosts four construction site containers which serve as temporary workspaces and prototype labs, a server room as control center, a large tower crane and several other construction machines. As part of a previous project, the Reference Construction Site became part of the 5G-Industry Campus Europe, see Figure 2.1. During the same project, the tower crane was converted for use as a 5G antenna, see Figure 2.2.

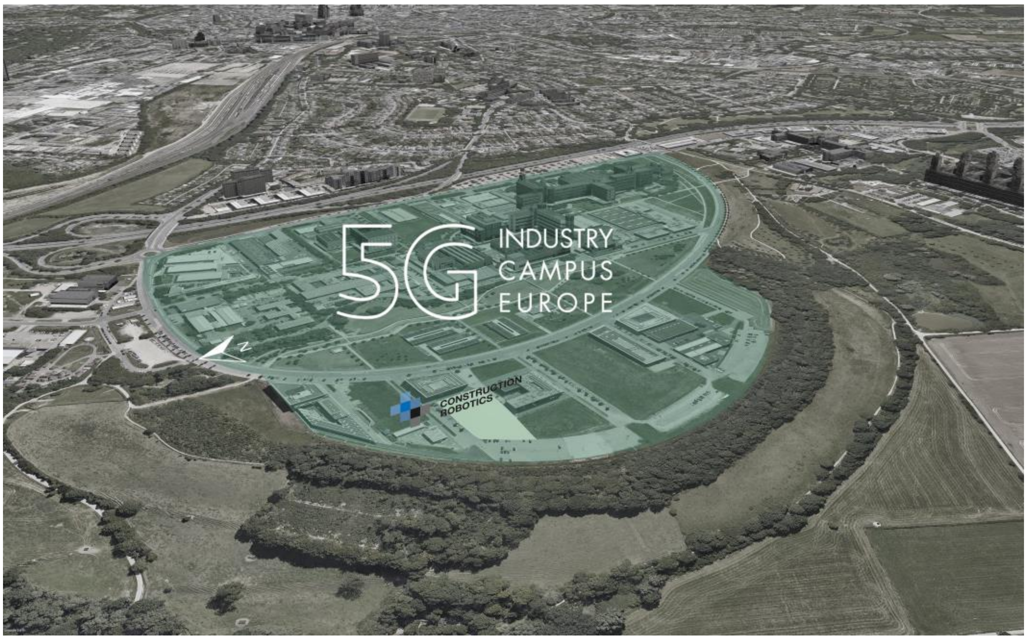


Figure 2.1 Location of the Reference Construction Site within the 5G-Industry Campus Europe at Aachen Melaten.

By transferring the concepts of IoT and Industry 4.0 to the construction industry, a need arose for a highly reliable wireless network that could support many participants with a wide range of requirements. The requirements to the communication service vary strongly depending on the specific use case. Whenever the safety of people could be compromised, real time data with minimal latency and maximal reliability is needed. Other use cases may require large data volumes due to the transfer of big datasets but only at specific occasions. 5G networks can meet these different categories of needs by design as shown in Figure 2.3.

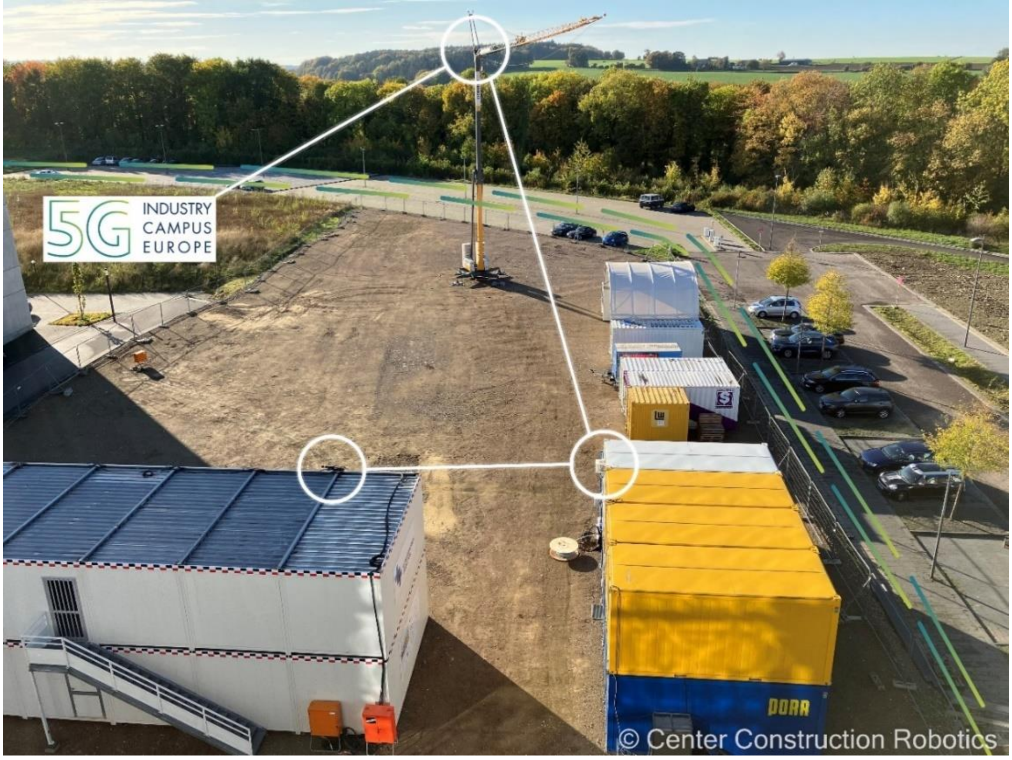


Figure 2.2 Bird view of the Reference Construction Site.

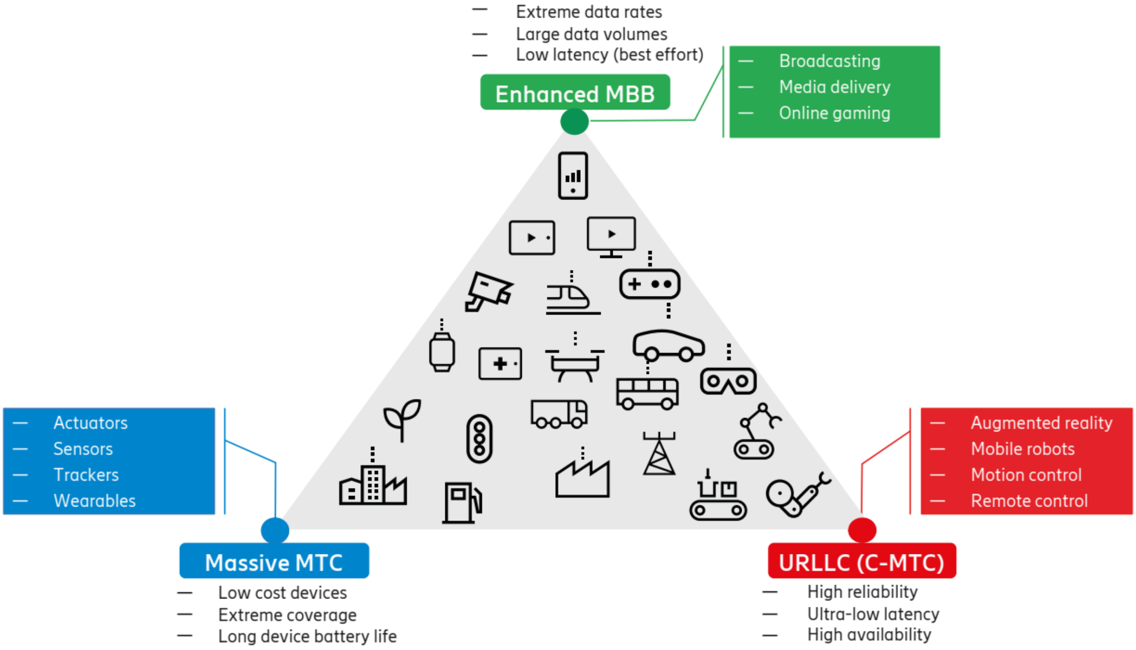


Figure 2.3 5G characteristics as in [12].

2.2 Description of planned demonstrator structure

As part of the TARGET-X project, a multi-material demonstrator structure will be created at the Reference Construction Site. The demonstrator will be a modular, architectural structure. This structure will be used to investigate the real and technical feasibility of the cradle-to-cradle principle and circularity in construction. For this purpose, the structure will consist of different materials, which will be assembled in different ways. However, already in the planning it will be considered that all connections qualify for minimally invasive, module conservative deconstruction and accordingly be detachable. On the one hand, this will provide the possibility to investigate which building materials are already suitable for a circular deconstruction process. On the other hand, the construction of the demonstrator structure will reveal how information and building data need to be exchanged along with the building processes on site and stored for disassembly. Apart from this, the influence of different materials and components on the wireless 5G network quality of service and signal quality can be analyzed due to the multi-material nature of the planned demonstrator structure. For example, signal shadowing in partially enclosed spaces can be studied or the effects of various building materials on signal strength.

Figure 2.4 Example of a Demonstrator structure of the BMBF funded Project "Internet of Construction" at the previous testbed at RWTH Aachen Campus West [13].

3 Robotic platforms for deconstruction

This chapter introduces robotic platforms for deconstruction processes. The first section describes the transition from conventional, remote-controlled demolition machines to intelligent robotic platforms. An explanation of their capabilities in terms of machine-to-machine communication, human-machine-interaction and semi-autonomous working follows. The second section describes the construction machine for the planned deconstruction process regarding technical features, tools, sensors, network devices, implemented functionalities and planned extensions. Section three depicts which mobile robot platform will be incorporated in the planned deconstruction process. In alignment with the previous section about the construction machine this includes technical features, sensors, network devices, implemented functionalities and planned extensions. The chapter ends with a statement about the use of other assistant machines.

3.1 State of the art

Remote teleoperation of heavy-duty construction machinery promises to eliminate many risks that arise from the often dangerous working environment at demolition sites. Yet, while remote control lets the operator control the machine from a safe distance, it also deprives him of direct awareness of the work space. To restore perception, it is necessary to monitor the construction machine and the work space with a variety of sensors. These include cameras for visual feedback. LiDAR, radar scanners, and 3D depth cameras to deliver the depth information [14, 15]. In addition, mobile platforms equipped with cameras and LiDAR scanners are used to observe the work area from a wider perspective and allow the operator to change his viewpoint. The combined sensor data can provide a more holistic picture of the work space. To ensure that the bundled information reaches the operator securely, reliably, and without delay, communication networks that meet these requirements are needed. As demonstrated in [15] 5G networks can be used for that purpose since by design they fulfill the necessary criteria shown in Figure 2.3

3.2 BROKK 170 demolition robot

Based on the findings from [16] and [14], the automation of a conventional, commercially available demolition machine will be further developed. The previously used machine is a BROKK 170 from the manufacturer Brokk AB [17]. In order to continue the previous work, the same demolition machine will be used in the TARGET-X project.

3.2.1 Technical specifications

The BROKK 170 demolition robot weighs $m_{BROKK} = 1.6\,t$ and has a width of 1.08 m in transport mode. In working mode with the supports folded out, the BROKK 170 requires approx. 2.2 m of space in width and length $r_{BROKK} < 4\,m$ depending on the selected end effector, see Figure 3.2. While the machine is hydraulically driven, an electric motor is responsible for powering the hydraulic pump. This arrangement allows efficient power transmission and facilitates indoor usage by providing emission-free operation.

Figure 3.1 BROKK 170 demolition robot

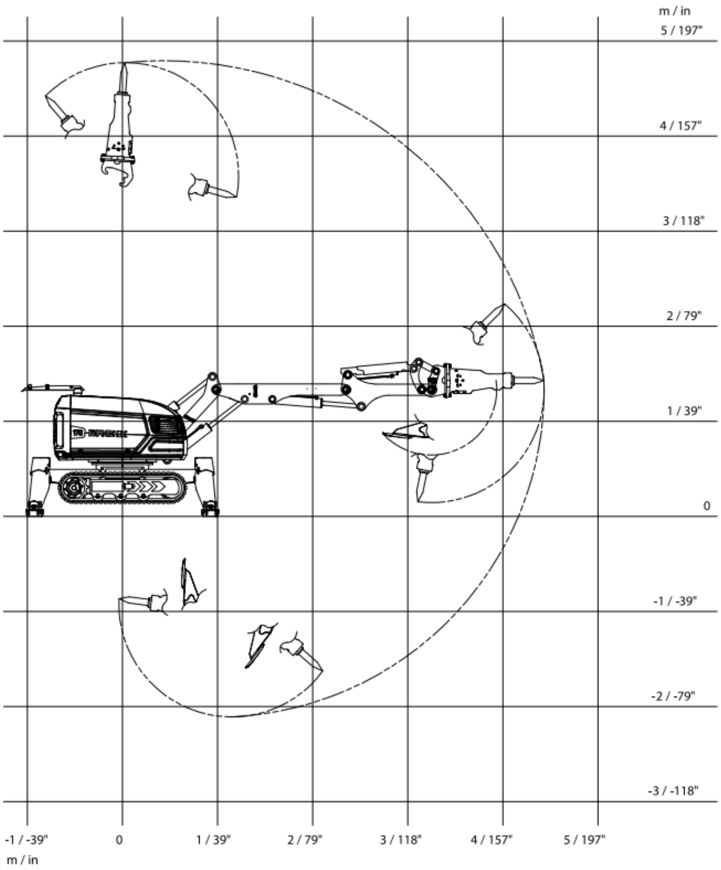


Figure 3.2 Working circle of the BROKK 170 with chisel as end effector.

3.2.2 Tools

The manufacturer offers an extensive repertoire of attachments for the BROKK 170, including hydraulic breakers, cutters, demolition grapples and concrete tongs. In previous projects, a hydraulic breaker from Brokk AB and a concrete saw from Hilti were used [14, 18].

3.2.3 Sensors

The demolition robot is equipped with motion sensors such as rotary encoders for status reporting in particular to estimate the deviation between planned and executed movement. Aside from that, the demolition robot incorporates various sensors to detect its status, including on-board and proprioceptive sensors. It is also equipped with an embedded Nvidia Jetson AGX Xavier PC, which is seamlessly integrated into the control unit. This integration facilitates communication between the host PC and the actuators of the robot. Additionally, the robot features a 3D depth camera and a 2D LiDAR scanner, which are installed to capture and analyze its surrounding environment.

3.2.4 Network devices

As part of the 5G.NAMICO project [19], the BROKK 170 is empowered to communicate via private 5G networks. For this purpose, an industrial 5G router has been equipped. The exact model is “Milesight – UR75-500GL-G-W”, see [20]. This router has six external antennas for cellular, GPS and WLAN. It has two SIM slots for switching between different operator networks. According to the manufacturer, the transfer rate is 1733 MBit/s (2.4 / 5 GHz WLAN). Moreover, the router is relatively cost-effective. For the TARGET-X use cases, this setup will remain unchanged.

Figure 3.3 Milesight Router.

3.2.5 Functionalities

The current setup allows remote teleoperation of the BROKK 170 as well as high-level programming for automated and partially automated deconstruction processes. For example, a concrete sawing process is partially being automated within the scope of the ROBETON project [14].

3.2.6 Planned extensions, additions

As part of the TARGET-X project, the range of materials that can be processed with the BROKK 170 is to be expanded. Previous work has dealt with various forms of concrete processing [14, 18]. The findings from this work will be transferred to the machining of other materials. One previous finding has been that different materials and building elements require different tools for their respective joining methods. Consequently, the selection of materials and joining methods for the use case determines the necessary properties of the machining tools. These properties can be of a physical, mechanical, or functional nature. Based on the defined requirements, suitable end effectors such as grippers or grinders will be chosen and tested for use with the robotic platform for deconstruction. A further extension will be the installation of measuring devices for the purpose of energy monitoring. The corresponding measuring device together with its properties and planned tests were described in detail in Deliverable 3.1. For this reason, only reference is made to it here.

3.3 Innok Heros mobile robot platform

For this project a mobile robot based on a commercially available platform by *Innok Robotics* is used. The platform possesses proprioceptive sensors for tracking of system states by design and has been updated with exterior sensors for observation of the environment.

3.3.1 Technical specifications

The mobile robot platform is available in the four-wheeled version. Without any additional equipment the platform has the dimensions $920 \text{ x } 720 \text{ x } 440 \text{ mm}$. The electric motor allows maximum speeds of $v_{max} = 0.9\, {}^{m}/_{s}$ with a battery life of up to 6 hours. The platform has a maximal loading capacity of $m_{max} = 400\ kg$ [21].

Figure 3.4 Four-wheel, mobile robot platform by Innok Robotics with additional equipment for environment capture.

3.3.2 Tools

The manufacturer offers various attachments, add-ons, and superstructures for this specific platform. For example, it is possible to extend the platform with a gripper arm or a storage container. In the existing setup, none of the likes were used.

3.3.3 Sensors

By design, the Innok Heros is equipped with the inertial measurement unit (IMU) Xsens Mti-30-2A8G4 as well as wheel encoders for the purpose of odometry, a 2D LiDAR scanner and a radio remote controller. In addition to these in-house sensors, the mobile robotic platform was equipped with additional sensors for 3D mapping of its environment as well as the generation of point cloud scans. The current setup consists of an RGB-D camera, Microsoft Azure Kinect DK and the LiDAR scanner Ouster OS-1.

3.3.4 Network devices

The mobile robot platform carries an onboard PC for the handling of basic functionalities like wheel controlling or sending IMU data. An additionally mounted Jetson Xavier NX PC serves for processing of sensor data. To enable communication with other PCs a 5G- and WLAN-capable router has been equipped.

3.3.5 Functionalities

The mobile robot platform can navigate to a predefined location in two different ways. The first option is manual commands sent with a joystick-like remote control by the operator. The second option involves the Robot Operation System (ROS). In this case, the operator generates the control commands in ROS and sends them via a WLAN connection to the Innok. With the currently mounted sensors the mobile robot can capture the remote working scene as 3D point cloud. Also, it can transmit the captured information to the operator via standard WLAN-networks.

3.3.6 Planned extensions, additions

Like the demolition robot, the mobile robot platform is empowered to communicate via a 5G network as part of 5G.NAMICO. Therefore, it is equipped with the same type of 5G router as the demolition robot. Furthermore, the mobile robotic platform will be equipped with a stereo depth camera for improved outdoor performance in harsh environments. Currently, the ZED X camera by Stereolabs is the preferred model since it fulfills the IP66 standard and GMSL2 [22]. As the TARGET--X project progresses, further development will be carried out based on the specific requirements of the use case, which may include the integration of additional sensors and extension of the perception software pipeline.

4 Data and network

This chapter addresses the communication network for the planned use case. For this purpose, the first section contains a sketch of the planned setup along with a description of the network participants and their communication methods. The second section describes the expected data streams. Furthermore, the individual data streams will be assigned to the different categories of 5G networks. Lastly, the requirements to the underlying 5G network are derived.

4.1 Communication setup

The communication setup as depicted in Figure 4.1 provides the basis for the planned implementation.

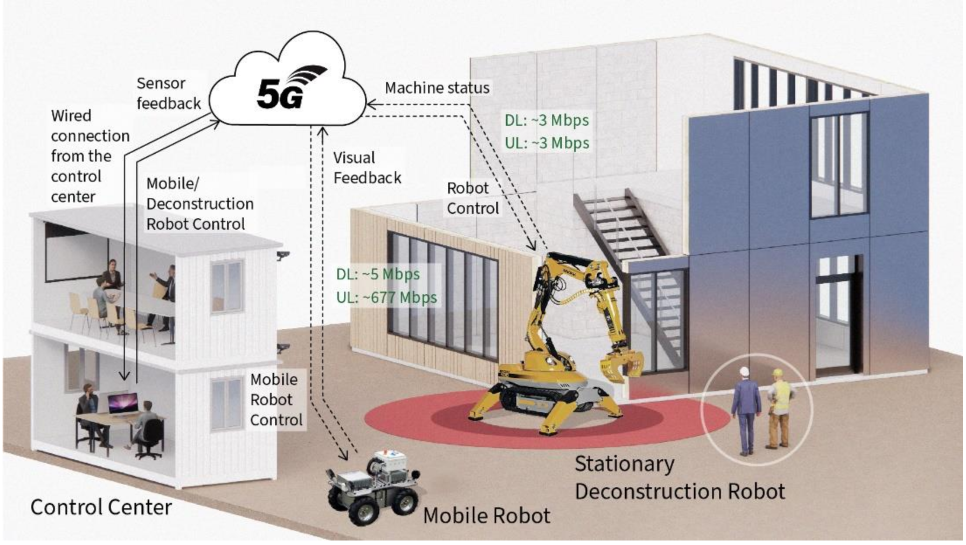


Figure 4.1 Planned communication setup at the TARGET-X construction testbed.

The operator in the control center sends machine control commands to the server via a wired connection. From there, the control commands are transmitted wirelessly to the deconstruction machine. The deconstruction machine is equipped with a 5G router to receive the control commands. The 5G router is connected to an on-board PC which has been mounted on the deconstruction machine. This on-board PC processes the control signals and forwards them to the machine's control unit. Reversely, the measurements of the internal sensors are sent to the onboard PC and from there first to the server via a 5G network connection and second to the operator's PC through a wired connection. Similarly, the measured values of the external sensors are sent to the additionally equipped PC, preprocessed there, and sent wirelessly to the server and then again through a hardwired connection to the operator's PC.

Figure 4.2 Tower crane converted to 5G antenna [18]

Figure 4.3 5G Antenna and Radio unit mounted to the tower crane.

4.2 Data streams and requirements to the communication network

There are three main data streams in the described setup, see Figure 4.1. Firstly, the operator sends control commands to the machines (data stream). Secondly, the status of the machines is detected by proprioceptive sensors and reported to the operator. This data includes odometry, encoder values and vital data such as battery status (data stream). The third and largest data stream is caused by the environment capture system. This category includes 3D point cloud scans, RGBD camera scans, and RGB video streams (data stream). In [18] the communication streams of a demolition robot and a mobile robot platform in the described setup have been analyzed under the assumption of both machines not exceeding velocities of $v < 1\ {}^{m}/_{s}$ while moving. For the motion planning and status reporting the transfer interval corresponds to the time between two consecutively sent commands. For the additional sensors, the displayed transfer interval and average data rate are theoretical values calculated from the maximal network load that could occur if all sensors were used simultaneously at maximum resolution. In this case the end-to-end latency is the time difference between sending and arrival of an environmental scan. Table 4.1 and Table 4.2 show the results of this analysis separately for each 5G device in the planned setup. The reason for this type of summary is that depending on their purpose of use, the initial conditions for the transfer of individual data types differ. All data collected under a safety aspect or form the basis for assistance systems require an ultra-reliable low-latency communication (uRLLC). Partially and fully automated (de-)construction tasks also fall in this category. Hence, also the BROKK 170 will demand a uRLLC. In contrast, detailed environmental recordings as planned with the mobile robot platform require extreme data rates, but are less time-critical. Therefore, they fall into the enhanced mobile broadband (eMBB) category.

In addition to the conversion of conventional construction machines to robotic platforms and the partial automation of their respective tasks, a large part of the research project will deal with the collection, processing, and analysis of construction process data. In order to optimize construction processes for controlled deconstruction, they must first be recorded and digitalized in their entirety. Then, they can be broken down into sub-processes in order to determine possible dependencies. Besides that, the collected data must be processed and stored to be available for planning the deconstruction later on. Only then the reengineering or remodeling of the dismantling processes can be started with regard to their suitability for circular economy. For the purpose of exchanging, processing, and storing process data, other communication technologies like low-power wide-area networks (LPWAN) or WLAN will be tested in addition to the 5G network. Thereby, it will be possible to study which communication technology is best suited for which type of data. At the same time, the simultaneous existence of different communication networks will make it possible to analyze their mutual influences.

Table 4.1 Data profile for the BROKK 170 deconstruction machine

COMMUNICATION STREAM	TRANSVER INTERVAL	END-TO-END (E2E) LATENCY	AVERGAE DATA RATE	REMARKS
2D LiDAR Scans	40ms	< 20ms	DL < 1000 kbit/s UL < 1000 kbit/s	
Motion planning	20-50ms	< Transfer interval	DL < 1000 kbit/s UL < 1000 kbit/s	
Status reporting	25ms	< Transfer interval	DL < 1000 kbit/s UL < 1000 kbit/s	BROKK – Rotary encoder
		Total data rate	**DL ~ 3000 kbit/s** **UL ~ 3000 kbit/s**	

Table 4.2: Data profile for the Innok 444 mobile robotic platform

COMMUNICATION STREAM	TRANSVER INTERVAL	END-TO-END (E2E) LATENCY	AVERGAE DATA RATE	REMARKS
3D LiDAR Scans	50ms	< Transfer interval	DL < 1000 kbit/s UL < 100.000 kbit/s	For 128 channel Ouster LiDAR scanner
RADAR Scans	200ms	< Transfer interval	DL < 1000 kbit/s UL < 50.000 kbit/s	Operating frequency: 77GHz
RGBD Camera Scans	45ms	< Transfer interval	DL < 1000 kbit/s UL < 200.000 kbit/s	Point cloud compression: 0.2cm @ 22fps
RGB Streams	45ms	< Transfer interval	DL < 1000 kbit/s UL < 10.000 kbit/s	RGB streams: 640x576 @ 22fps
Motion planning	20-50ms	< Transfer interval	DL < 1000 kbit/s UL < 1000 kbit/s	-
Status reporting	25ms	< Transfer interval	DL < 1000 kbit/s UL < 1000 kbit/s	IMU/Odometry

	Total data rate	**DL ~ 5000 kbit/s** **UL ~ 360.000 kbit/s**

5 Implementation plan and timeline

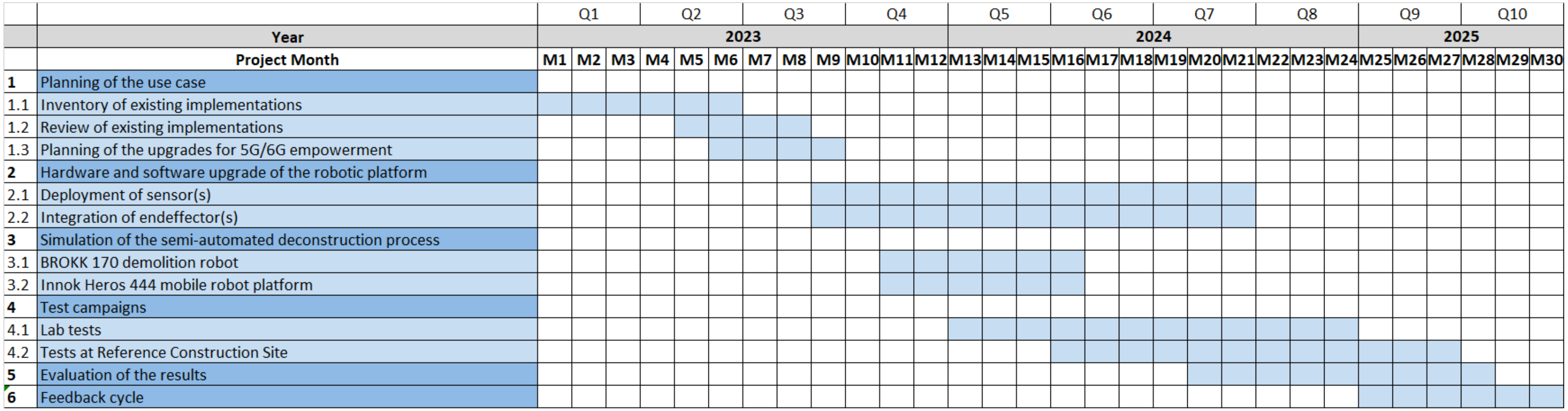
This chapter explains the preliminary implementation plan. While the first part presents the time schedule involving a preliminary Gantt chart for visualization purposes, the second part describes possible dependencies.

5.1 Time schedule

The Gantt chart lists the steps of the roadmap for the 5G/6G empowered deconstruction robotic platform in chronological order, see Figure 5.1. By the due date of this deliverable, the preparatory work for the use case will be largely complete and detailed planning phase will have begun. Once the planning phase is complete, hardware and software upgrades will begin. For this purpose, the new sensors will be mounted and connected. The new end effectors will also be integrated into the existing setup. Largely in parallel, the new processes for the demolition robot and the mobile robotic platform will be simulated. After the successful process simulations, extensive test campaigns will take place, first in a protected laboratory environment and then outside on the testbed. Finally, the test results will be evaluated and, if possible, a feedback cycle will take place.

5.2 Dependencies and challenges

The use cases in work package 5 depend mainly on three factors. The first and most significant factor is the dependency on the performance of the 5G network since communication via 5G is the key element of the planned activities. The second factor is related to the procurement of new sensor technology and tools. Even with early planning and ordering, delivery bottlenecks on the manufacturer side or customs restrictions cannot be ruled out. The third also very serious factor is the cascade funding program, as a result of which the demonstrator structure is to be constructed. Only if the selected companies work successfully on the research topics proposed in the open calls there will be a true-to-life physical and digital basis for implementing the planned deconstruction use case. Therefore, the work package leader and project management team will carefully monitor all third-party activities and act proactively when necessary to ensure the success of the project. Note that, as explained in the first section, the use case can also be adapted in the case of the FSTP projects falling short.



		Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8			Q9			Q10		
	Year	**2023**												**2024**												**2025**					
	Project Month	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**M19**	**M20**	**M21**	**M22**	**M23**	**M24**	**M25**	**M26**	**M27**	**M28**	**M29**	**M30**
1	Planning of the use case																														
1.1	Inventory of existing implementations	■	■	■	■	■	■																								
1.2	Review of existing implementations					■	■	■	■																						
1.3	Planning of the upgrades for 5G/6G empowerment						■	■	■	■																					
2	Hardware and software upgrade of the robotic platform																														
2.1	Deployment of sensor(s)									■	■	■	■	■	■	■	■	■	■	■	■	■									
2.2	Integration of endeffector(s)									■	■	■	■	■	■	■	■	■	■	■	■	■									
3	Simulation of the semi-automated deconstruction process																														
3.1	BROKK 170 demolition robot											■	■	■	■	■	■														
3.2	Innok Heros 444 mobile robot platform											■	■	■	■	■	■														
4	Test campaigns																														
4.1	Lab tests													■	■	■	■	■	■	■	■	■	■	■	■						
4.2	Tests at Reference Construction Site																■	■	■	■	■	■	■	■	■	■	■	■			
5	Evaluation of the results																				■	■	■	■	■	■	■	■	■		
6	Feedback cycle																									■	■	■	■	■	■

Figure 5.1 Gantt chart visualizing the planned actions for the 5G/6G empowerment of a robotic deconstruction platform

6 Conclusions

In summary, TARGET-X offers the opportunity to test 5G technology as a new means of communication in four verticals representing four industries. The socio-economic relevance of the planned use cases will be tested on the large-scale testbeds. In particular, the use cases of the construction vertical will explore which possibilities the new technology offers with regard to a more sustainable design of (de-)construction processes in order to progress towards the goal of a circular economy in construction. In particular, 5G technologies will be exploited to empower traditional construction and demolition machines to become intelligent robotic platforms for minimally invasive, partially automated (de-)construction processes.

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