



BEEYONDERS

Document title: Technical Requirements

D2.2: Technical Requirements WP2, T2.2

Authors: José Carlos Jiménez Fernández (TECNALIA); All partners



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Technical references

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101058548.

1. Executive Summary

BEEYONDERS will develop key specific Breakthrough Technologies (BT) in the following domains: Autonomous vehicles and collaborative robotics, additive manufacturing, workers' safety & wellbeing monitoring devices, digital twin management platform & Artificial Intelligence. These BT will be demonstrated and validated in 6 use-case diverse construction sites in 4 different European countries. The participation of construction site workers will demonstrate the safety and adoptability of these BT.

This document, D2.2 Technical Requirements, is a deliverable of the BEEYONDERS project, which is funded by the European Union's Horizon Europe Programme (2021 – 2027) under Grant Agreement No 101058548.

The deliverable: "Technical Requirements" is related to the technical objectives required and focused on the final technological state that is defined for each technological development. Associated to the task T2.2, it will develop a methodology to measure the technical target level of these developments, to precisely define, measure and control the progress of each technical goal of the project.

Section 1 of this document is referred to this executive summary, where this deliverable is generally described. Section 2 introduces the objectives followed by this document in terms of the objectives are meant to be achieved through the redaction of this document. Section 3 introduces the methodology followed during the task T2.2 – Technical Requirements, and in this deliverable the conclusions reached by all partners.

Section 4 includes the technical requirements identified in this initial phase of the project focusing in BEEYONDER's use cases, and section 5 describes the specific requirements collected among the partners focusing on each technology to be developed in the project. Finally, section 6 presents the references for the elaboration of this deliverable.



2. Objectives

A technical requirement document, also known as a product requirement document, defines the functionality, features, and purpose of a product or methodology to be developed. It is often the first phase of planning for a project development and serves a vital role in communicating with stakeholders and ensuring successful outcomes. Companies may have different technical requirements templates based on the technology and methodology they'll use to complete the project, the needs of internal and external stakeholders, and other factors. However, there are some key items that are often included in requirements documentation:

- **Revision Log:** A record of document updates that designates who is responsible for the updates, to track any changes.
- **Executive Summary:** An overview of the project or product with background information, the business case for pursuing the project, a description of the target audience, and high-level goals. It may also include the scope of the project in this section, detailing what is in-scope and out-of-scope for the current stage of documentation.
- **Requirements:** These should have sufficient detail so that designers can work to meet all requirements and testers can confirm that they all have been satisfied. It may include a numbered and prioritized list of requirements for tracking and reference. There may also be a separate section for non-functional requirements, as it will be described in the following sections, as per example assumptions, risks, and dependencies affecting the project and requirements. These items may include constraints that present limitations to a project, a description or diagram of the context and larger system in which a product exists or is being created, and specific assumptions such as what technology, equipment, or expertise may be available.
- **References:** Create a list of supporting documents and links to relevant artefacts.

Guidelines and methodologies will be developed to effectively measure the accomplishment rate of the requirements defined here.

The main line followed to describe these requirements are focused on the BEEYONDERS' key exploitable results, defined in the proposal, which are the following (also indicated the main related partner for each KER):

1. A methodology to measure the impact of digital and new technologies in construction processes. (TECNALIA, ACCIONA, AISCAT, and FLOWTECH)
2. An autonomous / teleoperated wheel loader. (ITAINNOVA, HIDROMEK)
3. An autonomous UAV / drone tailored to flight in non-GPS areas and adapted to underground works. (FADA CATEC)
4. An autonomous ground mobile platform for inspection and maintenance tasks of large areas. (TECNALIA)
5. Optimized and bio-compatible mortars adapted to 3D-printing for maritime ecosystems. (HOLCIM and SEABOOST)
6. 3D printing equipment capable of working in vertical walls of caisson formworks for maritime construction. (ACCIONA, COBOD, and HOLCIM)
7. An exoskeleton capable of assisting both the lower-back and the arms in a unique device. (IIT)
8. Wearables integrated in Personal Protective Equipment for worker H&S and monitoring. (STAM, VTT)
9. Construction Digital Twin platform and added value services. (TECNALIA, CSTB, DTU)



10. Learning and training platforms incorporating virtual reality and connection with digital solutions. (STAM, DTU and EBC)

It is included as well in this deliverable the Agent – Based Modelling simulations, as these simulations are present and an important aspect for the right development of the use cases.

The reason of defining these requirements is because all these KERS are strictly related during BEEYONDERS technical work packages, coming in the next months. Below it is presented the relational scheme of the mentioned technologies:

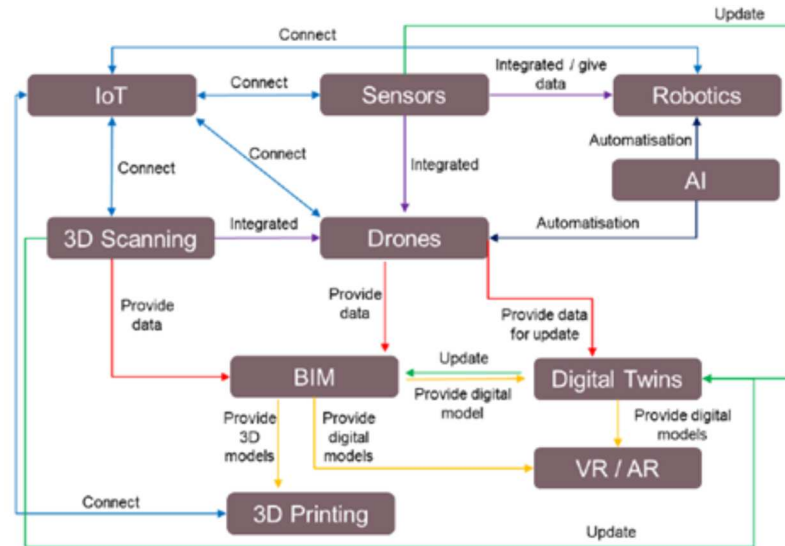


Figure 1. BEEYONDERS technologies relational scheme

In the end, in line with D2.1 – System Requirements, during proposal stage of BEEYONDERS the main objectives of the project were defined. The main objective of this deliverable is the development of the requirements for the consecution of these objectives:

O6: Develop, test, and demonstrate Autonomous & Collaborative Robotics solutions

BEEYONDERS will develop advanced solutions for Tunnel, Road and Building construction and Road maintenance use-cases and demonstrate that is possible to implement unmanned machinery to work in real harsh construction scenarios with autonomous/tele-operated ground and aerial robotic and industrial-machinery vehicles.

- O6.1: An autonomous and tele-operated robotic solution (wheel loader machine and drones) to improve challenges in construction of conventional tunnels with explosives developed, tested, and demonstrated.
- O6.2: A coordinated ground-aerial autonomous and tele-operated solution to improve wheel loader fuel consumption in earthworks activities for road construction developed, tested and demonstrated.
- O6.3: An advanced drone system with non-GPS navigation solution to improve building construction performance developed, tested and demonstrated.
- O6.4: A solution based on autonomous robot to solve production and H&S challenges in a road maintenance scenario developed, tested and demonstrated.

O7: To develop, test and demonstrate new environmental-friendly Additive Manufacturing (AM) solutions



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101058548.

Additive Manufacturing solutions are developed to introduce several benefits to the environment, acting directly on resource optimisation and promoting biodiversity in maritime construction work sites.

- O7.1: An AM solution for printing new types of maritime caissons developed, tested, and demonstrated.
- O7.2: A pilot plant or small factory to chemically/physically optimize mortars to print in any environmental/geographical situation to maintain a robust control of rheological conditions, to ensure quality in structural elements developed, tested, and demonstrated.
- O7.3: A subsea mortar AM element that foster reef biodiversity developed, tested, and demonstrated.
- O7.4: A technology to integrate mortar organic shapes using AM printing in vertical on existing caissons walls, to improve the biodiversity in future maritime works developed, tested, and demonstrated.

O8: To develop, test and demonstrate a Digital Twin with Data Fusion from BT and AI modules

A Digital Twin (DT) platform will bring together data acquisition during the case studies to manage the information of BT developed and demonstrated, with a set of layers and applications based on AI for decision-making and improvement of wellbeing & safety of workers.

- O8.1: DT design, architecture, interfaces, common data formats and communication protocols defined, developed, tested, and demonstrated
- O8.2: AI-capabilities integrated with DT developed, tested, and demonstrated to assess the H&S of workers in collaborative environment with the BT
- O8.3: AI-capabilities integrated with DT developed, tested, and demonstrated to assess the productivity & planning of the construction site with the BT
- O8.4: Integrate LCA&LCC KPIs for analysing all project developments based on BT design and defined

O9: Development, implementation and evaluation of BT around worker's needs

O9 deals with the implementation of previous BTs in workforce, evaluating their impact and consequences for any type of worker, analysing the advantages it can bring considering gender, how it can benefit older construction workers and generating strategies to attract younger ones to construction sector to face the problem of labour shortage. For that, exoskeletons for workers, advanced wearables PPEs and extended reality devices are developed and tested in different scenarios.

- O9.1: BT considering different gender characteristics developed, implemented, and evaluated.
- O9.2: BT for prevention of accidents and well-being for workers developed, implemented, and evaluated.
- O9.3: Effect of BT to attract younger people to construction evaluated.
- O9.4: BT solutions evaluated by users thanks to specific programs and surveys developed in the project.
- O9.5: Advisory groups of construction workers to provide continuous feedback on BTs.



3. Methodology description

Methodology that has been followed in T2.2 – Technical Requirements has been focused in gathering the technical requirements among all the partners of the project, through different cooperative activities performed during this task (M1 – M6). In this initial phase of the project, it is difficult to be able to identify all the requirements, as not all the final use case details can be defined, so upcoming related tasks are meant to redefine, if necessary, the initial requirements definition of this document.

In this document, it can be found that there are two requirement sections: the first one, section 4, are the technical requirements identified at this point focused on the use cases. The reason why has been focused initially on the use cases are due to the importance of starting to highlight the future needs to develop the use cases, as there are many important points to be analysed and treated at this stage of the project, enabling enough time to the consortium to start from the beginning of the project to plan adequately all the use cases details. Following these requirements of the use cases it can be found the requirements gathered among the specific KERS of the project, through a live document template meant to be live during the project and accessible to all partners for consultation and modification. Details of this template are explained below.

To recall, and as it was defined in the Scientific and Technological Methodology defined in D1.1 – Project Management Plan, this task develops the requirements at the initial phase of the project. This activity will be followed, as it can be seen in the scheme below, by defining KPIs (WP2 tasks T2.3 / T2.4) and linked to the testing plan (T2.5, M13) that will start once the technical work packages start to produce their initial specifications. After testing plan accomplished the TRL4 – 5, during use cases these requirements might suffer changes; so T7.1 will develop a methodology to re-adapt and assess if any modification is required. Please refer to the Scientific and Technological Management Plan in D1.1 for more information.

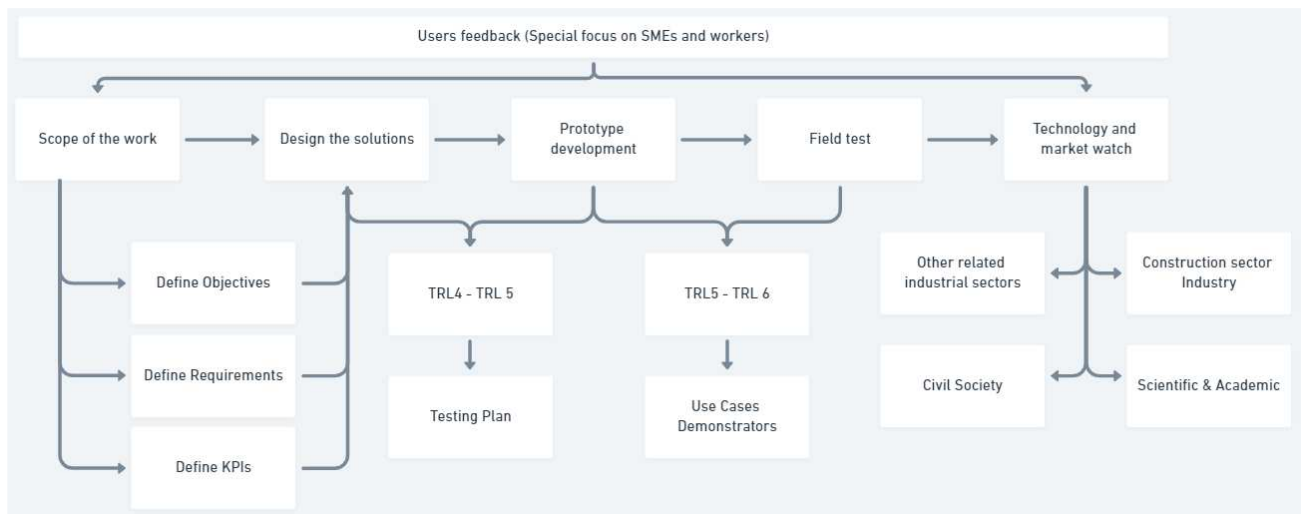


Figure 2. Research & Development methodology (D1.1)

The activities performed during this task have been the following:

- First, it has been required to fill an online tool form that was presented in the context of WP2; both for system requirements (general objectives, D2.1, ALL partners to complete) and the technical requirements (technical objectives, D2.2, technical partners mandatory, others optional). This tool



form presents some technical questions about all the technologies involved in the project, and the answers collected from partners have been used to fill the technical requirements both for use cases and the BTs.

BEEYONDERS
Breakthrough European Technologies Yielding cOnstruction sovereignty,
Diversity & Efficiency of Resources

WP2 – Specifications & Testing

Sección 1 de 12

Personal data (optional)

Descripción del formulario

Name, partner

Texto de respuesta corta

Después de la sección 1 Ir a la sección 3 (O1: Set up the per... for BEEYONDERS.)

Sección 2 de 12

SYSTEM REQUIREMENTS

These sections will be dedicated to the generation and description of the general objectives of the project, which must be present throughout its duration. These requirements, together with T2.2, will serve to guide the developments carried out in the technical WPs. Economical assessment will be performed in combination with KPIs.

Después de la sección 2 Ir a la siguiente sección

Sección 3 de 12

O1: Set up the performance requirements for BEEYONDERS.

O1 sets the requirements for the technologies and solutions, their expected impact for the users, technology and solutions developers, testers, workers, and future professionals

From the point of view of your role/activity as a partner of BEEYONDERS, how do you expect your contribution can impact positively in the reduction of wasted materials and the reduction of CO2 embodied in the processes of the Construction sector?

Texto de respuesta larga

Figure 3. Online tool form.

- Next, as it was agreed during the project kick off meeting among the partners, it has been organised some workshops focused on defining the requirements for the use cases of the project, that will complete the mentioned deliverables D2.1 – 2.2. The initial idea has been involving the related partners to each case study, but allowing any partner to join if might consider appropriate. These workshops have been the following (details of assistants are presented in each use case section):
 - Use case 1: Tunnel Construction. Assistants proposed:
 - ACCIONA, as case study responsible and end – user.
 - TECNALIA, CSTB, as Digital Twin task leaders.
 - ITAINNOVA, FADA, HIDROMEK, as Autonomous Ground vehicle and Autonomous Aerial vehicle task leaders.
 - INFRAPLAN, as KPIs task leader.
 - Use case 2: Road Construction. Assistants proposed:
 - AISCAT, ACCIONA, as case study responsible and end – users.
 - TECNALIA, DTU, CSTB, as Digital Twin task leaders.



- ITAINNOVA, FADA, HIDROMEK, as Autonomous Ground vehicle and Autonomous Aerial vehicle task leaders.
 - INFRAPLAN, as KPIs task leader.
 - VTT, as wearables contributor.
- Use case 3: Building Construction. Assistants proposed:
 - FIRA, ACCIONA, as case study responsible and end – users.
 - TECNALIA, DTU, CSTB, as Digital Twin Task leaders.
 - FADA, as Autonomous Aerial vehicle task leaders.
 - INFRAPLAN, as KPIs task leader.
 - STAM, IIT, VTT, as wearables and exoskeleton task leaders.
- Use case 4: Maritime Construction. Assistants proposed:
 - ACCIONA, HOLCIM, as end – user and case study responsible.
 - TECNALIA, CSTB, as Digital Twin Task leaders.
 - INFRAPLAN, as KPIs task leader.
 - COBOD, SEABOOST, CAIDIO, as case study related tasks leaders.
- Use Case 5: Maritime Construction – JAPAN. Assistants proposed:
 - ACCIONA, INGEOS, as end – user and case study responsible.
 - TECNALIA, CSTB, as Digital Twin Task leaders.
 - INFRAPLAN, as KPIs task leader.
- Use Case 6: Road Maintenance. Assistants proposed:
 - ACCIONA, AISCAT, as case study responsible and end – users.
 - TECNALIA, FADA, as Autonomous Ground Vehicle and Autonomous Aerial Vehicle tasks leaders.
 - CSTB, as Digital Twin Task leader.
- And finally, a document template of each BT is proposed to be used as the basis for the monitoring of the proper development in combination with the methodology that will be developed in T2.5 – Testing Plan. This document has been shared between each KERS' responsible partners, and the results are presented in section 5. A brief explanation for each section:
 - Project Task: Please describe here the tasks to be performed by your device / technology in BEEYONDERS, focused specially on the mission related to the use cases proposed in the project.
 - Functional Requirements: Technical details that the device / tech must comply during the use cases, as per example: physical details (weight, size...), environmental requisites in order to properly be deployed in the use cases or test areas, any other requirement could exist.
 - Interoperability requirements: In order to communicate with other devices / technologies, as per example communication protocols, exchange format data, etc.
 - Security requirements: Required security as digital technologies.
 - Technical process: Scheme of the working process, as well identify the related technologies / devices that might affect your technology.



Figure 4. Technical Requirements template used.

 This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101058548.

4. Technical Requirements for Use Cases

4.1. Use Case 1: Tunnel Construction

4.1.1. Details

DATA LOCATION DETAILS

ACCIONA (use case leader)

Location: Santa Barbara Foundation test tunnel, Leon, Spain.

USE CASE DESCRIPTION

Tunnel works, which are carried out in rocky terrain, often require explosives for their execution, being necessary to use specialized machinery such as jumbos. These types of works are one of the most dangerous ones in the construction sector, implying highest safety measures in the tunnel, including of course, the total absence of workers. The traditional way of executing this process is to use a jumbo to drill the excavation front to introduce explosives. Once the blasting has taken place, it is necessary to wait for the air extraction systems to eliminate the suspended particles and make the tunnel atmosphere breathable and transparent so that workers can enter. There is no possibility of working within the infrastructure if adequate safety conditions are not met. This fact supposes an unproductive waiting time around one hour, not negligible with respect to the total hours worked, even more, when several blasts must be carried out per day if working 24 hours a day.

BEEYONDERS proposes a solution to these unproductive waits through the demonstration in a use case of a test tunnel located in León (Spain), in which it is proposed to use autonomous and teleoperated robotics applied to two construction machinery vehicles, together with a drone. Immediately after the explosion and with an atmosphere without visibility (a cloud of dust), the drone will enter scanning the tunnel and obtaining point clouds and the current state of the tunnel. The main indoor details of topology will be transmitted to the loader and dumper assembly, advancing these vehicles behind the autonomous drone avoiding all of them any kind of obstacles and generating an autonomous location and navigation without GNSS signal. Once the place of the explosion has been reached (excavation front), they will carry out debris removal tasks, evacuating the material to the outside and repeating these tasks as many times as necessary while the atmosphere is unbreathable. A record of the progress of the vehicles and the status of the tunnel through the transmission of information from the machinery and drone to the Digital Twin and to specific Artificial Intelligence applications to control the progress of the work will be kept, getting a current state of the executed excavation tasks vs. planned ones.

USE CASE 1 will integrate and test technologies developed mainly in WP3 and WP4 for reducing idle times in tunnel construction with conventional techniques (drilling & blasting). This will be achieved through the integrated operation of drone and autonomous and tele-operated construction machinery just after the blasting has occurred, when the environmental conditions within the tunnel do not allow the access of human workers. The first step will be the setup of the tunnel demonstration environment, including the communication infrastructure to enable M2M&M2I communication among the UAVs and the construction machinery, and the definition of the procedures for simulating an environment where a blasting has occurred, and rock fragments have to be removed in low visibility conditions. Tasks and challenges are:

- Autonomous drone flight within the tunnel with emulated low visibility conditions and no GNSS.



- Automated scan of the tunnel by the drone and transmission of the scanned information for the update of the DT and for supporting localization and navigation of construction machinery.
- Cooperation of autonomous and tele-operated construction machinery for debris removal based on the assistance of the drone for navigation without GNSS coverage and with low visibility conditions.
- Deployment of a digital platform for enabling seamless visualization, supervision, and intelligent processing of the data flows among the drones, the autonomous and tele operated construction machinery, the tunnel monitoring/communications infrastructure, and the DT, with which the platform will be integrated.

PARTNERS INVOLVED:**ACCIONA (LEAD)****TECNALIA****ITAINNOVA****FADA-CATEC****CSTB****HIDROMEK****INFRAPLAN****ICONS****STAM****WORKSHOP ASSISTANTS (07/11/2022):**

Table 1: Workshop assistants.

PARTNER	NAME
STAM	Cristina Naso Rappis
ICONS	eva.martinez
HIDROMEK	Aslıhan Öztapak
ITAINNOVA	Javier Huarte
TECNALIA	Jimenez Fernandez, Jose Carlos
HIDROMEK	Aykut Dilden
HIDROMEK	Ferhan Ficici
TECNALIA	Armijo Prieto, José Alberto
TECNALIA	Zamora Sanchez, Diego
HIDROMEK	Burcu Aylak
HIDROMEK	Mustafa Karahan



FADA CATEC	Francisco Javier Pérez Grau
HIDROMEK	Tugce Tuncel
INFRAPLAN	Stipanovic, Irina
ITAINNOVA	María Teresa Lázaro
INFRAPLAN	Sandra Skaric
ACCIONA	Alonso Cepeda, Antonio
STAM	Alberto Landini
ACCIONA	Buron Martinez, Jose Luis
CSTB	PICINBONO Guillaume

4.1.2. Operational scheme

It is presented below the operational scheme to be performed in this use case, divided by different phases.

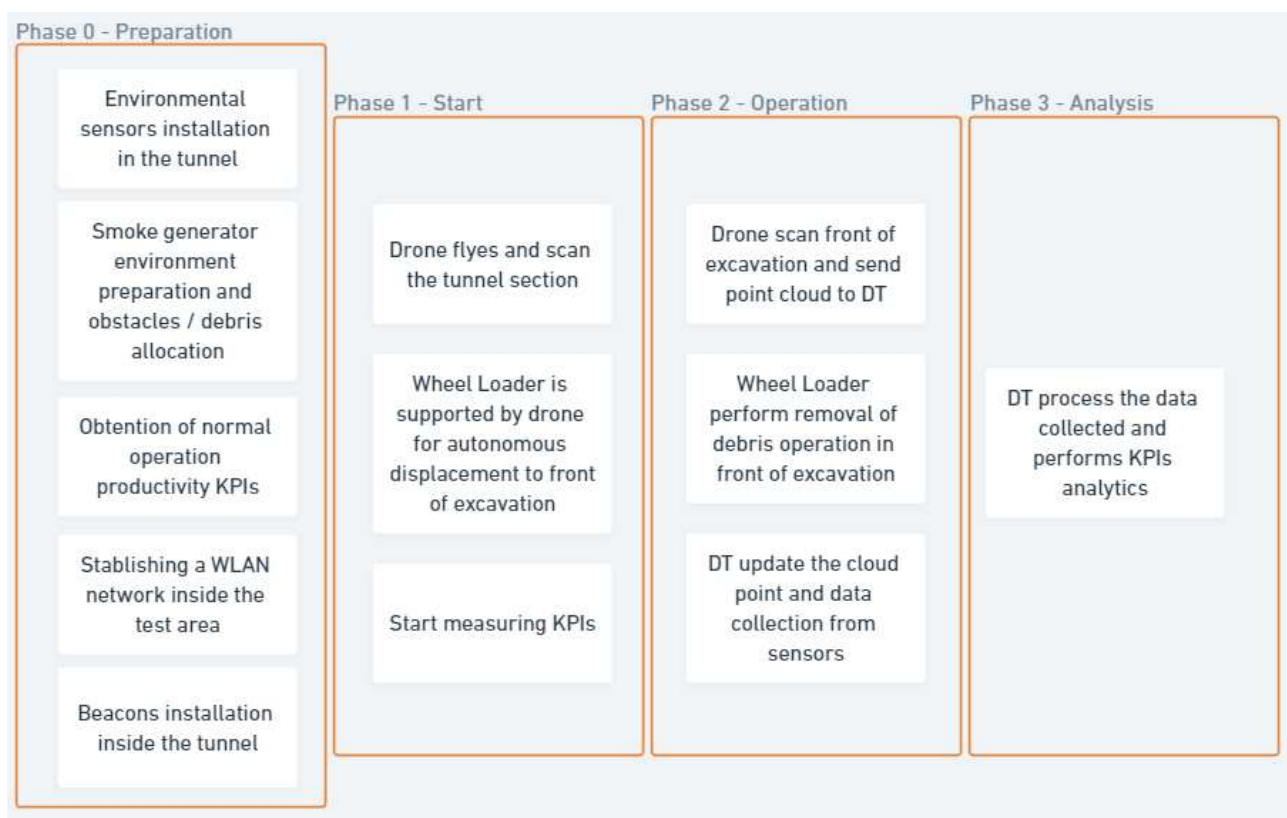


Figure 5. Operational Scheme for tunnel use case.

4.1.3. Requirements

Below are listed the critical aspects identified to perform this use case, with the requirements / actions proposed in order to manage it.



Table 2: Tunnel use case requirements.

Description	Requirement / Action
The tunnel use case foresees the cooperation between drones and autonomous/teleoperated machinery and platforms, with the support of the digital twin, in order to coordinate debris removal activities following the detonation and to avoid obstacles.	Communication protocol and architecture between drone and wheel loader must be defined. ABM simulation of the process is required to control the displacement / operation times and avoid the obstacles (debris mainly) inside the tunnel.
Information between devices, as 3D model obtained from drone, has to be shared with wheel loader.	NDA should be discussed between parties who share information with each other.
Wheel loader performs debris removal operation and loading to a dumper.	Relation and operation details between wheel loader and dumper should be defined. In scenario, the loader will remove the debris inside the tunnel, the operation stages should be defined (If the loader will go out from the tunnel for each time or not).
The tunnel use case aims to reduce idle times between detonation of explosives and removal of debris. This shall have a direct impact on the global productivity of tunnel construction, and thus increase the efficiency of the resources (machinery, workers) involved in the process.	Measuring the productivity and any other variable related to the defined KPIs in a normal situation (no BEEYONDERS technologies) and measure, to allow comparing values, employing drone, wheel loader and DT. DT analyses the data to provide with prognosis information. To be defined as well measuring the productivity (in the same scenario) of a driver, a driver teleoperating a machine and autonomous machine (dumper&wheel-loader)
For the tunnel use case, the following KPI could be defined: % reduction of energy consumption and embodied CO2 emissions associated to a more efficient operation.	Combine data acquisition from the environment (CO2 present in atmosphere, other substances) and data acquired directly from wheel loader or drone (emissions, energy consumption). By means of efficiency (reduction of the idle times) of the operation this could be achieved.
Variables to be monitorised and sent to the DT database: Digital scan of the tunnel excavation front: status after detonation and updates according to the progress of debris removal tasks. Location of resources (drones, autonomous platform, autonomous wheel loader...). Resources usage parameters (tasks performed, distances travelled, idle times, energy consumption, embodied CO2 emissions, etc.).	Define DT architecture. Provide WLAN network inside the tunnel. Define data acquisition methodology from the different identified sources. Resources identification and location algorithms.
Analysis and services expected from the Digital Twin: Automated calculation of KPIs related to the use of BEEYONDERS Technologies in the use case (e.g., reduction of idle times, accuracy of tasks execution by autonomous/teleoperated machinery, increase of efficiency in the use of resources, reduction of	Define DT architecture. Provide WLAN network inside the tunnel. Define data acquisition methodology from the different identified sources (positioning of drone / wheel loader / sensors on site, devices). Stablishing services and calculation algorithms into the DT framework.



energy consumption and embodied CO2 emissions, etc.). Automated update of tunnel excavation status based on scans sent by drones and/or autonomous/tele-operated machinery and platforms.	
Drone energy autonomy is around 15 minutes fly.	Drone is required to perform a scanning of the tunnel section in the same fly, during the 15min maximum energy autonomy.
The use case simulated (dusty environment after the explosion) usually lasts 30 min – 1 hour.	Operational time during the demonstration must be maximum 30 min – 1 hour, to demonstrate an improvement in productivity.
Installation of environmental sensors inside the test area.	Define variables to be measured, related to environmental KPIs. Define sensors and communication protocol with DT. Analyse providing a mobile device platform where check live time sensors data collected.
Data acquisition from wheel loader or drone with sensors installed on board.	Analyse sensors, cameras that can be installed on the wheel loader. By default, the wheel loader will be equipped with cameras (front, rear and maybe on the sides), Lidar's (front and rear) and radar. Define communication protocol sensors – wheel loader – DT.
Workers KPIs definition.	In this use case, workers are not directly related to the operational scheme proposed. These KPIs will be more related to acceptance, indirect benefits, etc.
Tunnel section dimensions can affect the operation of the wheel loader, and tunnel ground surface can affect the movement.	At this point, it is known that the tunnel section is 8m diameter. It is required to obtain detailed drawings of the test area (plan, sections) to analyse the manoeuvrability requirements for the wheel loader. These tunnel dimensions are suitable for the current planned wheel loader, although it is not possible to manoeuvre the machine inside the tunnel, but it can be driven forward and reverse. For every debris removal operation, the machine (dumper) should go outside of the tunnel in order to leave its debris. Tunnel ground surface is asphalt, to be confirmed.
Beacons installation inside the tunnel to support / check autonomous displacement inside the tunnel.	Initially, beacons installation inside the tunnel are not required as drone can fly autonomously, and coordinate with the wheel loader to support its movement. From the tunnel entrance, the front of excavation (place for the debris removal operations) is around 400 meters. Beacons can be used as a ground- truth information to validate if the localization algorithms are working properly.
Dusty environment to be designed.	To generate the dusty environment, it is required to define the equipment to generate the smoke, as well the smoke parameters (as density, dwell time, etc.)



Presence of water inside the tunnel can be a problem for sensors installed on site, drone or wheel loader.	Confirm the presence or absence of water spots inside the tunnel. If there are water spots, sensors must be isolated with the required waterproof solution. Analyse the interest of providing the drone or the wheel loader with thermographic camera to detect water spots.
When an explosion in a tunnel happens, workers are not allowed to approach the entrance of excavation.	For a proper recognition / scan of the front of excavation, drone and wheel loader need to approach the front of excavation the most possible. Confirm this restriction is only for human workers, and not for machinery / devices.
Employ topographic devices to support the 3D maps elaborated from drone / wheel loader.	Analyse the accuracy of the sensors are going to be deployed in the drone and the wheel loader. Initially is not expected to require topographic devices to support 3D maps elaboration, to be confirmed.
Wireless network inside the tunnel to perform communication of drone – wheel loader, and to digital twin.	Installation of WLAN inside the test area. Possibility of installing fibre optic, with major bandwidth capacity. To be confirmed.
Coordination between drone and wheel loader is performed directly between these two devices, without DT in between. DT will receive the data (scanned maps, data acquired, etc.) after coordination between drone and wheel loader.	Define DT architecture and framework for this use case. On the wheel loader machine, a high capacity controlling computer should be required.

4.2. Use Case 2: Road Construction

4.2.1. Details

DATA LOCATION DETAILS

AISCAT (use case leader)

Location: A-1 Milano – Napoli, Firenze sud (Italy)

USE CASE DESCRIPTION

A use case is proposed for the construction of a road located in Italy, part of the AISCAT 5.000 km highway network. For this type of work, the phase that consumes more resources is earthworks, in which different types of construction machinery modify the terrain to adhere to what is planned in the execution project. Site managers must plan how these tasks will be carried out on site: machinery vehicles available, skilled workers, weather conditions, interference with other phases of the site, etc. Once this phase begins in each of the sections of the work, drivers are who make decisions regarding the tasks to be carried out and decide how they are going to drive these vehicles to move the terrain in the best possible way. Although they are experts, they will drive neither performing the best possible trajectories nor in the most efficient conduction mode, because they are human drivers and not optimized algorithms. We can translate this statement in two types of problems to improve. On the one hand, in terms of the subtasks to be carried out, choosing the correct order or the most optimal sequence of steps to achieve a certain configuration of the terrain. On the other hand, in relation to the fact that drivers will not carry out these subtasks achieving the minimum routes to follow. These two circumstances cause more fuel to be consumed than is strictly necessary to achieve the



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construction objectives of the work, consequently emitting more CO₂. As we will see in Impact section, based on other parallel studies for other kind of vehicles, only controlling the way of driving, would be possible to achieve potential savings of 7% to 14%.

The use of breakthrough technologies in this use case could solve the excess CO₂ emissions by implementing several technologies in a coordinated way. On the one hand, incorporating localization and autonomous navigation in vehicles, both terrestrial (construction machinery) and aerial (drones), and on the other hand, an optimized management of the work thanks to the Digital Twin with AI functionalities. Both sets of technologies, working in coordination, could get a current state-of-the-terrain situation and machinery on site by means of drones, transmitting data to the DT, which would contain information on the phases to be executed for that current state. After that, AI algorithms could select the priority tasks to work on, sending precise orders to the earthwork's machinery with optimal trajectories in terms of distance, and these machines, through autonomous and tele-operated navigation would carry out these tasks without the intervention of drivers. Once completed, the drone would be ordered to assess the new situation, starting a new work cycle. Proximity checks that can create a near miss safety situation (human & machinery) will be considered while tasks are performed, deploying and validating the smart wearables into this scenario. A successfully carrying out and demonstrating of this way of working will mean a considerable reduction in CO₂ emissions in road works.

A suitable road construction site will be selected to carry out the demonstration activities.

Objectives:

- Drone operations for advanced photogrammetry calculations and an update of earthworks status.
- Drone application for location of ground earthworks machinery and other construction assets that can be understood as obstacles for machinery displacements in construction site.
- Cooperation of ground autonomous vehicles for implementing advanced coordination strategies, including optimization of tasks sequencing, for a more efficient use of resources.
- Update of the DT with data streams coming from drones and ground machinery to support operations for routes and fuel optimization and earlier detection of deviations.

PARTNERS INVOLVED:

AISCAT (LEAD)

ACCIONA

TECNALIA

ITAINNOVA

FADA-CATEC

CSTB

HIDROMEK

INFRAPLAN

DTU

AISCAT

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101058548.

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FADA	Francisco Javier Pérez Grau
DTU	Jochen Teizer (Guest)
HIDROMEK	Mustafa Karahan

4.2.2. Operational scheme

It is presented below the operational scheme to be performed in this use case, divided by different phases.



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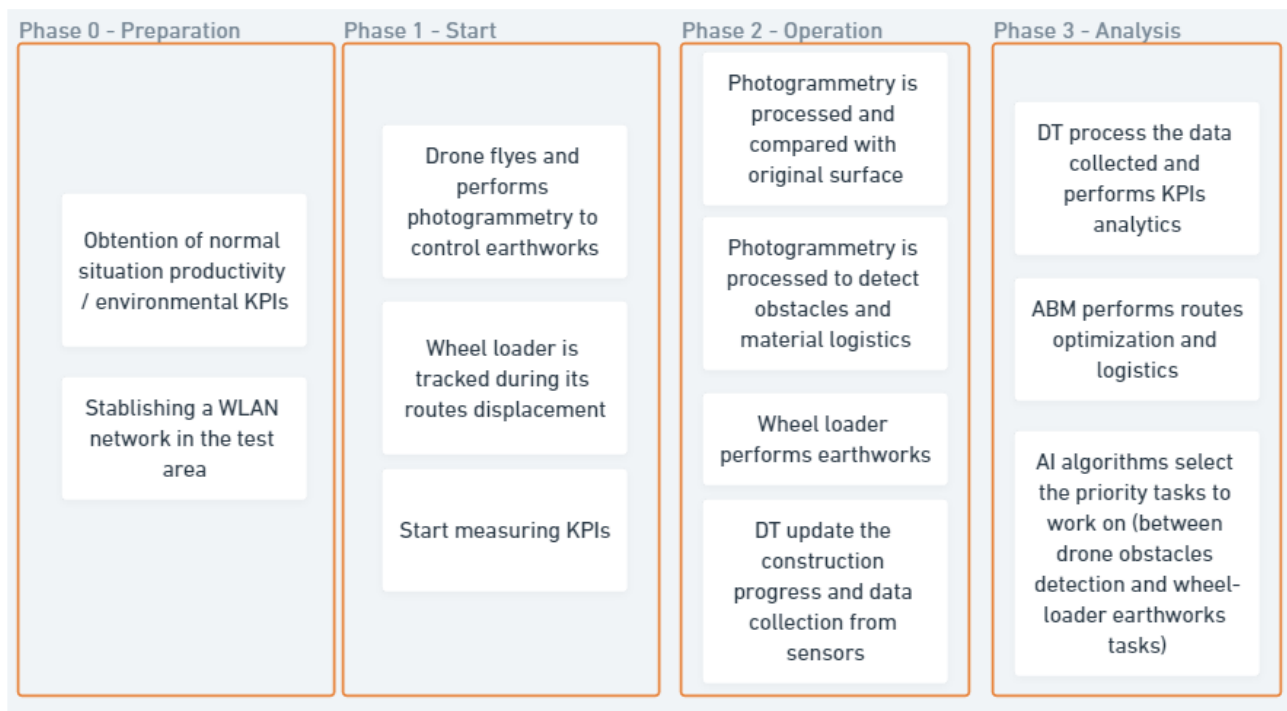


Figure 6. Operational Scheme for road construction use case.

4.2.3. Requirements

Below are listed the critical aspects identified to perform this use case, with the requirements / actions proposed in order to manage it.

Table 4: Road construction use case requirements.

Description	Requirement / Action
Automated 3D mapping using photogrammetry. Cooperation with wheel loader in road construction use case.	Define photogrammetry sensor and specifications. Define communication protocol between drone / wheel loader / DT. Drone sends the map to the DT and/or to a local storage network for this kind of processing, and the wheel loader receives the info.
Identified worker's KPIs: worker's profiles (gender, age, country) / acceptance level / safety / productivity / feedback. O1.5: KPIs: Worker, user and value chain needs / Environmental - Social constraints / Technical constraints. - GDPR issues should be noted.	GDPR must be complied. Define methodology to obtain the initially defined KPIs.
For wearables, analysis and services expected from the Digital Twin: overall/aggregated metrics from activity recognition and fatigue trends (due to GDPR issues person level data can be difficult: data needs to be strictly anonymous and/or aggregated over population).	Define proposed sensor units of wearables. Connection of wearables with DT, architecture and communication protocols to be defined. GDPR must be complied.



Initial proposed use case details: third lane construction of A1 highway.	Analyse viability of flying drone in a highway in service. It has been identified possible complications due to flying drone on an active highway. It has been decided between partners to search for an alternative case study location. Related to drone, analyse flying permits, far from populated areas, and no airports close. The wheel loader operation on an active road is very dangerous even with an operator, with autonomous or remote-control version, it will be more dangerous. Also, the dimensions of the road should be known. It is required to know the loading and unloading scenario in order to evaluate the maneuverability of the machine.
H&S KPIs obtention initially focused on near miss spot location of workers – machines.	Define proximity sensors for wearables. Stablish data collection and DT ingestion. Algorithms to detect proximity and analysis of data in DT. Analyse sensors able to raise an alert on real time in case of a dangerous proximity of a worker to machines.
Workers related injuries, risks, personal protective equipment details.	Wearables require to be integrated into worker's personal protective equipment's. It is proposed to maintain a meeting between related partners and H&S officer related to the use case construction.
Drone performs photogrammetry of the construction area in order to update earthworks progress and to detect obstacles or anomalies on machines routes.	Photogrammetry requires to scan a static area, no worker movements or machines during the scanning. Define shift times to perform the scanning and frequency of scan per day (initially 1 or 2 times per day).
Autonomous wheel loader is supported by drone to optimise its routes.	ABM simulations performs the optimization of the routes from data collected from use case. Define working scenario to perform initial simulations. ABM can support to define optimal logistic of material on site.
Wheel loaders perform earthworks tasks on site as autonomous / semi operated vehicle.	Define the specific earthwork tasks to be performed by the wheel loader, and the sequence of displacements / operations. A visit to the test area to analyze the scenario as soon as possible is a requirement.
Road construction usually has pre-defined routes for machinery on site.	Define a business case to increase the complexity of the use case, as per example when timing on site is not right and in the same area, different tasks and machines are overlapped and present in the same area.
Environmental KPIs definition.	To be defined the specific tasks and use case details in order to define the measurable KPIs, both machines and environmental.
Productivity KPIs in order of time spent to perform different tasks.	Measure normal operation times for the machines on site to obtain the reference values for KPI evaluation.



Wheel loader integrates the map scanned from drone to allow the movement on site until the operations area.	Drone flies initially, obtains the site map updated with identification of presence / absence of obstacles. Wheel loader must recognise the obstacles and be able to recalculate the trajectory. An iterative 3D graph SLAM process will be used to maintain the map updated over time (multiple sessions) keeping the consistency of the data. In order to manage this task, on the wheel loader machine, a high capacity controlling computer should be required. A subscription/publication infrastructure will be also developed to coordinate the data among agents.
Wheel loader and drone tested properly before moving the devices to the use case in Italy.	Perform a previous testing plan simulating as much as possible the future location for the demonstration. Define testing plan. For the wheel loader, this pre-testing activity could be performed in HIDROMEK construction location, Turkey.
Wireless network in the demonstration area available.	4G or similar connection is required on the use case location.
3D model built from drone able to identify elements on site as pipes, materials, etc.	To be analysed in DT automated recognition techniques for drone or wheel loader.
DT will update the 3D surface from the photogrammetry and tracking of wheel loader and workers.	Define the automation degree of obtaining 3D surfaces from photogrammetry. Define GNSS GPSGNSS data obtention from wheel loader and worker's wearables.

4.3. Use Case 3: Building Construction

4.3.1. Details

DATA LOCATION DETAILS

FIRA (FLOWTECH after amendment) (use case leader)

Location: Helsinki region (Greater Helsinki or Helsinki Metropolitan Area), Finland

USE CASE DESCRIPTION

Building construction sites are characterized by being in limited environments in which construction tasks are predominantly vertical and not horizontal, as in the case of roads and tunnels, so their characteristics and the associated challenges are completely different from the above cases. Specifically, it can be said that there is a global increase in the density of workers and construction elements. Therefore, construction challenges will be related, to the safety of the workers, since the activities carried out and tools used for it, must be developed in a smaller space with a greater number of workers, which potentially increases the number of accidents. Additionally, higher construction complexity implies a better control of what is planned and executed. It is essential to perform tasks in proper quality resulting in minimum amount of rework. Consequently, this results in improved productivity and decrease in overall energy and embedded CO₂ as the construction is performed faster than before. To achieve these objectives, a building construction case study in Finland is proposed.

From the safety perspective the focus will be related to wearables that workers will wear, monitoring biometric and kinematic parameters. On the other hand, tasks related to measuring what has been executed



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(acquisition of information on the degree of execution of the construction tasks and whether or not they have been carried out correctly). In the first case, two types will be integrated: Exoskeletons and small wearables. Exoskeletons will be implemented to evaluate how safety conditions can be improved in workers of different ages and gender, to reduce their level of injuries at work, obtaining valuable information on how they could be prevented and how these systems help to improve the wellbeing of workers. In the case of small wearables, to measure occupational health and safety variables, to prevent accidents, whose initial symptoms, if they could have been measured, would have given enough information to avoid serious consequences.

Testing different systems and knowing the feedback of workers, is essential to reduce the rate of accidents in construction.

In the second case, the use of drones inside a building is proposed to capture the information of what has been carried out so far. In this system, as in the use-case of Tunnel, in which GNSS signal was not available, is proposed to start working from the end of the workers' working hours, scanning the interior of each floor of the building to capture the information of the tasks carried out so far, flying autonomously/teleoperated way. Once the flights are finished, the system will upload the information to the DT, so that it can be compared with what was planned, making possible to know the degree of real progress of the workday by day and if there is any deviation from the plan. This building case study will integrate technologies coming mainly from WP3, WP4, and WP5. The first objective of the task will be to demonstrate how BEEYONDERS can improve productivity through the automated indoor scan of building progress using drones. Secondly, the case study will validate the integration of technologies for improvement of safety, health, and well-being of workers, such as exoskeletons and wearables. Expected outcomes are:

- Autonomous flight of drones within the building without or partial GNSS coverage and with low visibility conditions (e.g. sunset or sunrise, even at night if possible).
- Automated scan of the building progress by the drones and subsequent update of the DT.
- Use of exoskeletons, connected with the DT, for reducing the perceived physical effort required to carry out repetitive tasks.
- Use of wearables for collecting data from workers related to safety, health and wellbeing, and subsequent update of the DT.

PARTNERS INVOLVED:

FIRA (FLOWTECH) (LEAD)

ACCIONA

TECNALIA

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Table 5: Workshop assistants.

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INFRAPLAN	Sandra Skaric



4.3.2. Operational Scheme

It is presented below the operational scheme to be performed in this use case, divided by different phases.

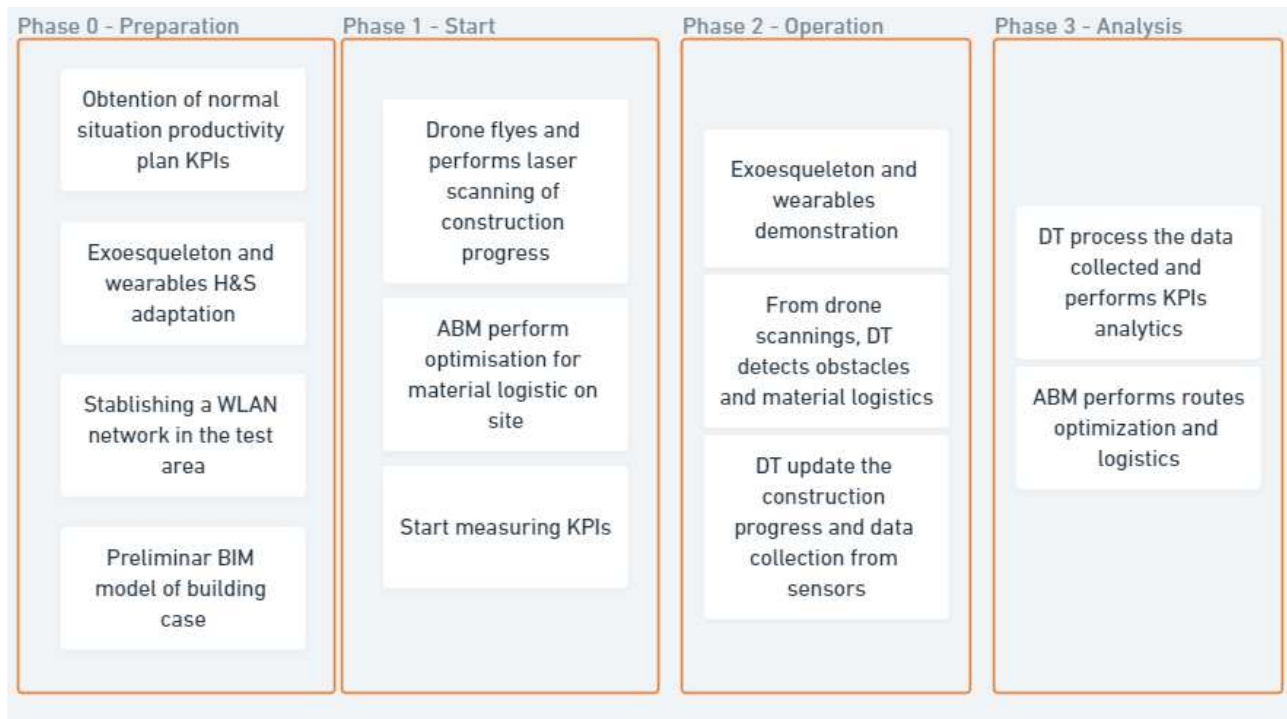


Figure 7. Operational Scheme for building construction use case.

4.3.3. Requirements

Table 6: Building construction use case requirements.

Description	Requirement / Action
Drone will perform automated 3D mapping autonomous navigation in GNSS-denied environments.	3D maps (quite large, and it is recommended using open file formats). To be defined the frequency of flights, initially will be 1-2 times per day. Initially it is planned to use the same platform for the tunnel and the building, but the initial proposal of the building for this use case that were shown in the workshop are from a much smaller building with narrow passages between rooms. To be analysed the exact building use case demonstration to face this narrow spaces problem.
Identified worker's KPIs: worker's profiles (gender, age, country) / acceptance level / safety / productivity / feedback. O1.5: KPIs: Worker, user and value chain needs / Environmental - Social constraints / Technical constraints. - GDPR issues should be noted.	GDPR must be complied. Define methodology to obtain the initially defined KPIs.



For wearables, analysis and services expected from the Digital Twin: overall/aggregated metrics from activity recognition and fatigue trends (due to GDPR issues person level data can be difficult: data needs to be strictly anonymous and/or aggregated over population).	Define proposed sensor units of wearables. Connection of wearables with DT, architecture and communication protocols to be defined. GDPR must be complied. GDPR sets challenging requirements for the data management platform. Data can be also pseudonymized.
The ideal innovation would be to count right after the project development on an advanced hybrid decision-support system combining the use of wearables, data analysis, gamification on workers habits to predict and anticipate accidents and incidents and to optimise workers tasks and working conditions. This would improve health and safety of the workers as well as the effectiveness and efficiency of the whole production process and of the trade-offs within the decision-making (concerning teams, planning, variations on tasks etc.).	DT input / output services definition to comply this statement with a decision-support system integrated, based on data acquired on this use case.
Personal protective equipment regulations.	European Directive 2016/425 for all kind of protective measures to be considered.
Specifications of the human devices (exoskeleton, wearables) that can affect the workers are mainly: weight, comfortability and real contribution to the tasks undertaken.	Sensors and data collection from human devices to acquire data related to these specifications.
Activities concerning the workers KPI (Task 2.4) will provide a measurement framework to assess the impact of the technologies on the workforce, considering technology acceptance and user experience. This will support the uptake of such technologies, therefore contributing to higher efficiency of resources in the sector. Economic, environmental, and technological KPIs are interlinked and therefore will be relevant for the development of workers KPIs.	It could be very useful to develop a standardised methodological framework to measure worker's acceptance that could be applied and replicated in future similar projects. The information that has been covered in this technical requirement section will be relevant for the development of workers KPIs.
Use case building are 6 – 10 floors residential building. FIRA's construction methodology is based on prefabricated walls.	Obtain drawings and all data required in order to design the initial BIM model of the building, where all the information will be provided within DT.
Drone scanning will perform analysis of construction progress.	DT to compare the as-planned with the as-built from the data obtained from drones. To do that, must be confirmed the strategy to be followed in this use case, as how this information is going to be processed (in term of updating construction Gantt planning, visualization on BIM model, etc.). Automatisation of recognition of construction executed elements (as prefabricated walls) is to be analysed.



Exoskeleton and wearables are human devices that will collect data from workers during their tasks.	KPI obtained from these devices are meant to be focused on H&S (as fatigue, hazardous movements, gender dimension, etc) and not on productivity of workers. Productivity will be measured by drone acquisition, and indirectly related to the worker's devices that are going to be employed.
Proposed use case states flying the drone with low visibility conditions.	Perform the scanning flies during sunset/sunrise or even nights, if possible. Analyse the requirements of minimal illumination.
Drone will perform an indoor flying, and data acquisition.	To be defined the specific route for the drone and sensors required according to information required. According to this, different drone platform is required.
Workers related injuries, risks, personal protective equipment details.	Wearables and exoskeleton require to be integrated into worker's personal protective equipment's. It is proposed to maintain a meeting between related partners and H&S officer related to this use case.
Human devices acquisition time of data to be relevant in post-processing.	As human devices are going to measure fatigue on workers, muscular activity, etc. it is required to get data during enough time. Initially 1 – 2 months of data could be enough, to be confirmed.
KPIs on workers related to the usage of wearables and exoskeleton can require some time to get used the workers at the beginning of usage of human devices.	Employing human devices during testing phase of the project, prior to the use case demonstration, to get used the workers using these devices. ABM simulations can be employed to predict, from data acquired during the demonstrations, obtained KPIs related to this usage.
Building constructions usually concerns many different activities.	It will be analysed the possibility of performing different activities, as using wearables and exoskeleton during pouring concrete activities.

4.4. Use Case 4: Maritime Construction

4.4.1. Details

DATA LOCATION DETAILS

HOLCIM (use case leader)

Location: Port of Gijon, Spain

USE CASE DESCRIPTION

Maritime works use-case has been selected because it represents a typology of construction works that has its own characteristics within construction. Its infrastructures are subject to demands that are totally different from the rest of the BEEYONDERS case studies because structural elements are subjected to the action of sea water, chemical reactions and dynamic loads due to waves compared to the mostly static stresses of the rest of construction case studies. This must be strongly considered for its geometrically/structural design and the type of material to be developed to improve the behaviour of the final constructive element to be installed.



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So far, ACCIONA has done something in some way similar and at the level of large-scale production in its Kugira's caissons manufacturing unit. In this context, the real research for findings and alternatives in the field of Additive Manufacturing is proposed to implement solutions in the construction of marine infrastructures, which would mean facing a huge and completely innovative challenge. On the one hand, due to the lack of knowledge in the large-scale handling (tens of meters) of robotized concrete 3D printing systems, on the other hand, due to the lack of knowledge in the precise control of the physical-chemical properties of 3D printable material to be used in Additive Manufacturing processes, to ensure the achievement of desired rheological properties of workability and mechanical resistance that are adapted to marine infrastructures. Finally, total control over the previous variables would allow the generation of new functionally (structural and ecological) optimized. For these reasons, a series of tests and demonstrators will be proposed in Spain (optimized geometries that improve performance by reducing the amount of material that is used or wasted, thereby reducing CO2 emissions. Additionally, we will work to achieve, through different technologies to optimize the surfaces shapes and textures of caisson so that they can favor the settlement of marine species, helpful for promoting marine biodiversity. The results optimizing the properties of materials to achieve the desired properties regardless of the variables of the raw materials or environmental conditions will be demonstrated in a real plant at TRL 6, achieving the right material to be printed in any European location.

PARTNERS INVOLVED:

ACCIONA

HOLCIM

TECNALIA

CSTB

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COBOD

SEABOOST

CAIDIO

WORKSHOP ASSISTANTS (10/11/2022):

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101058548.

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4.4.2. Operational Scheme

It is presented below the operational scheme to be performed in this use case, divided by different phases.

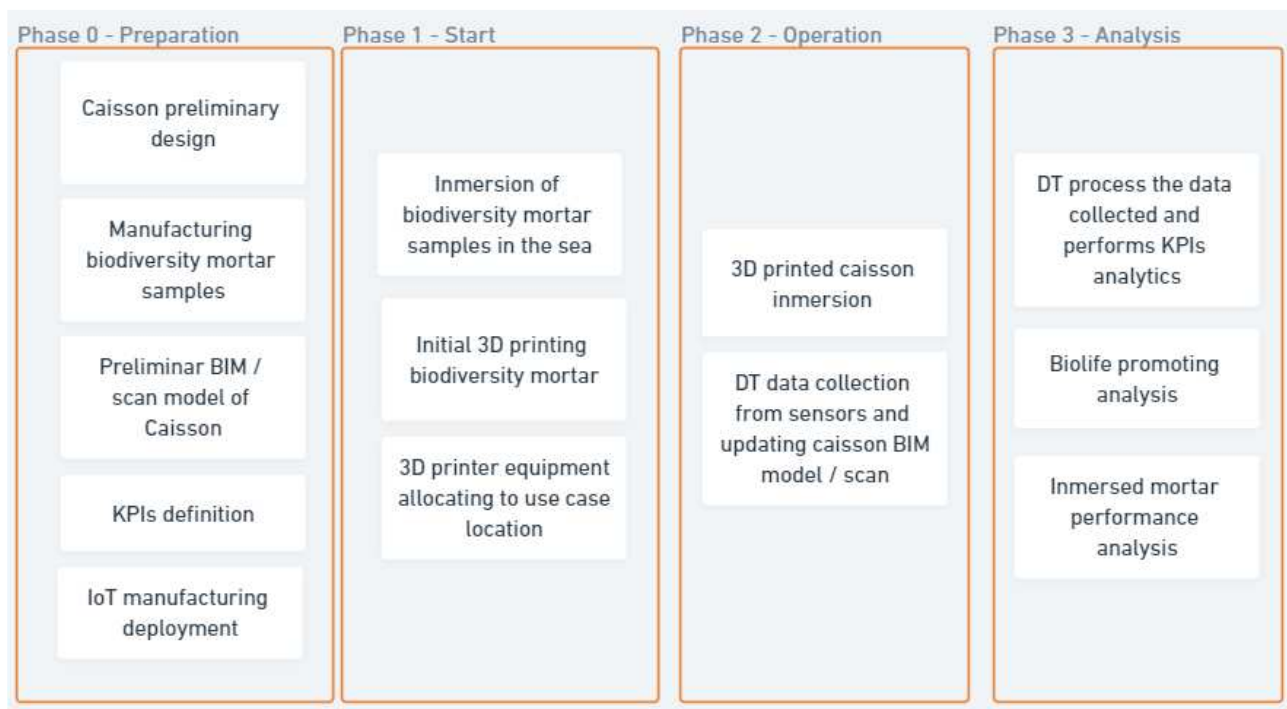


Figure 8. Operational Scheme for Maritime Construction use case.



4.4.3. Requirements

Table 8: Maritime construction use case requirements.

Description	Requirement / Action
Orientation of time required to be immersed in maritime ecosystem the biocompatible mortar samples to evaluate the ecological benefits.	HOLCIM: at least 6 months. SEABOOST: 12 to 24 months. It is required to immerse the initial samples as soon as possible in order to provide more time to biolife to promote. To be defined the metrics for the development of biolife with immersed conditions on top of it.
Variables during the manufacturing of the new materials that are going to be measured (moisture content, consistency, etc.) and after manufactured (rheology, mechanical properties and structural resistance...).	Moisture content of aggregates, temperature evolution of fresh material after mixing with water, wattmeter curves in the concrete mixer, 3D surface as built vs planned, colonization of these surfaces over time (and possibly cracking monitoring). SEABOOST: Complexity, rugosity, moisture, pH. CAIDIO: Moisture of aggregates, temperature of concrete or mortar raw materials.
Types of sensors required to measure the mortar variables during or after the manufacturing.	Moisture probes, wattmeter, temperature and Hygrometry sensors, pressure sensors, LIDAR, etc. A priori not under IoT. HOLCIM: Moisture sensor for aggregate during production of dry mortar mix and concrete, temperature sensor during production of mortar/concrete. SEABOOST: Underwater photography. CAIDIO: Optical moisture sensor, machine vision camera, temperature sensors.
Expected sizes of the caisson and the biocompatible attachments planned to be manufactured.	The idea is to manufacture typically a portion of the scale 1 caisson (typically a few meters long, a few meters high and a few meters wide), typically $\sim < 5m*5m*5m$. Smaller scale boards could be done for bio-life development. HOLCIM: We will work on a scale 1 caisson, but the case study will focus on printing the critical parts of the caisson with typical size of several meter high, several meters long and several meters wide (probably around 4 ± 2 meters for example).
Variables that will be monitored and sent to the DT database of the Digital Twin architecture.	For the caisson: Geometry, colour, crack detection and crack width measurement. COBOD: Layer time, printing speed, buildability, pumpability (3D printing equipment).



	CAIDIO: Moisture of aggregates, temperature of concrete or mortar raw materials. CAIDIO: Moisture (%), Temperature (Celsius), Frequency of data collection max 5 Hz (IoT manufacturing).
Communication protocols that are planned to be employed in your device in order to communicate with other BT technologies (AWL, drones, wearables, etc.).	CAIDIO: To be defined, but currently we use MQTT. During use case: communications will be very punctual, required during checking of biolife promoting and material performance. 3G/4G connection required available on use case location.
Analysis and services that you expect in the Digital Twin related to your technology. Your thoughts if you are end-user:	Store information about production, evolution during service life including monitoring of marine-life development, if required, data related to possible maintenance need, include data for end of life. CAIDIO: Basic statistical analysis such as Max, Min, Average, Std Deviation etc.
Standard caisson size, but printing only a representative part	Standard geometry caisson is around 30m x 30m x 15m, depending on the location. Design of caisson must comply the 3D printable structure with current codes and optimize in the way to use less material would be a challenge.
Advantages of using 3D printing for caissons, and current specifications for standard caisson manufacturing. ACCIONA present Kugira: Floating structure to manufacture concrete caissons directly on seawater. Speed of manufacturing with this structure is 20cm / hour height, and last around 6 days. Mounting formwork takes 1 – 2 months, and after manufacturing has to be displaced to the installation location (worldwide).	3D printing improves the current limitations of caisson's manufacturing; as an example, currently the section has to be constant, so 3D printing will allow variable sections. Also, currently is required around 50 – 60 workers to perform the manufacturing, 3D printing will allow to reduce workers required.
Structural parameters of a normal caisson.	Caisson's wall thickness is around 40 – 20 cm, with a reinforcing steel bars required of around 80 – 120 kg/m ³ of concrete. It can be found designs with up to 200 kg/m ³ . With 3D printing, it is an objective of achieve concrete fibers mixing, reducing reinforcement up to 50 kg/m ³ of concrete. Standards caissons foundations are around 1 – 2 meters thickness of rock bed.
3D printing of promoting biolife material on the caisson's wall.	Directly 3D printing or projection, spraying on vertical position onto the caisson's wall, to be defined the methodology.
Demonstration caisson's 3D printing manufacturing location.	3D printing of demonstration caisson will be printed on use case location, in port of Gijon. To be confirmed if is going to be indoor / outdoor printing. COBOD to allocate the equipment to the use case location.
Environmental KPI's definition.	To be defined. Initially, it is proposed the comparison of time and resources spent on manufacturing



	standard / 3D printed caisson, and the allocation of the structure on installation site. LCA/LCC KPIs to be defined.
Caissons requires of a stable foundation at the bottom of the sea.	Floating caisson is a possibility if foundation in use case location presents a problem. For the placing of the caisson, Kugira's structure can be employed.
Detailed information required of 3D printing, materials, sensors, manufacturing process (both material and caisson), caisson geometry.	WP6 starts in month 7 of the project. A meeting has been organized between partners to define the required information. COBOD has organized a visit to their installations in Copenhagen to check their manufacturing capabilities. Material manufacturing can be performed in Valencia, in Holcim's facilities. Installation of IoT deployment for the manufacturing to be analysed.
Frecuency of biolife promoting variables measures.	Once installed, it is proposed by SEABOOST to be monitored once per season (spring, summer...). It is required to analyse the current maritime biolife in the use case location.
Inmerse of samples / caisson into the seawater requires delivering special permissions from the local authorities.	ACCIONA has already in the port of Gijon a test area to immerse this type of samples; to be confirmed the availability of immersing a structure like a caisson. In case of installation of cameras or sensors, analyse special permmission requirements. To be analysed the availability of information from the port's authorities, as pollution events, water chemical properties, etc.

4.5. Use Case 5: Japanese Maritime Construction

4.5.1. Details

DATA LOCATION DETAILS

INGEO (use case leader)

Location: Port of Rotterdam, Netherlands. Dutch National test site.

USE CASE DESCRIPTION

Uncertainties in soil conditions means that we cannot optimise our designs. Since each foundation is essentially a new investigation point, combining this in real-time with the geotechnical ground model and foundation capacity models will result in enhanced safety and reduced cost.

We will work with the Japanese equipment manufacturer Giken Ltd to develop a Digital Twin of their environmentally friendly (low noise and vibration) push-in pile system. A step beyond the state of the art would include (i) using installation resistances and geotechnical data to provide real-time designs governing pile lengths. These can then be used in the whole-life cycle assessment of the structures behaviour in association with Infraplan Consulting (ii) Using the machine-measured data to verify or improve the geological digital twin created using the site investigation data available before the piling works. The work will be completed using installation data from Giken machinery operating at two demo sites, one at a



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Japanese test site and the second at a Dutch national test site located in the Port of Rotterdam, developed by Dr. Gavin of InGEO. Giken will provide the data and will install a minimum of 3 instrumented piles at each location. InGEO will develop the geological and geotechnical resistance models. The digital twin will be developed with the aid of WP3 partners of the project consortium with advice from Giken and InGEO.

PARTNERS INVOLVED:

ACCIONA

INGEO

TECNALIA

CSTB

INFRAPLAN

WORKSHOP ASSISTANTS (10/11/2022):

Table 9: Workshop assistants.

PARTNER	NAME
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INFRAPLAN	Sandra Skaric
ACCIONA	Buron Martinez, Jose Luis
TECNALIA	Armijo Prieto, José Alberto
INGEO	Kevin Duffy
INGEO	Ken Gavin
TECNALIA	Puente Blanco, Sheila
CSTB	PICINBONO Guillaume
INFRAPLAN	Stipanovic, Irina

4.5.2. Operational Scheme

It is presented below the operational scheme to be performed in this use case, divided by different phases.



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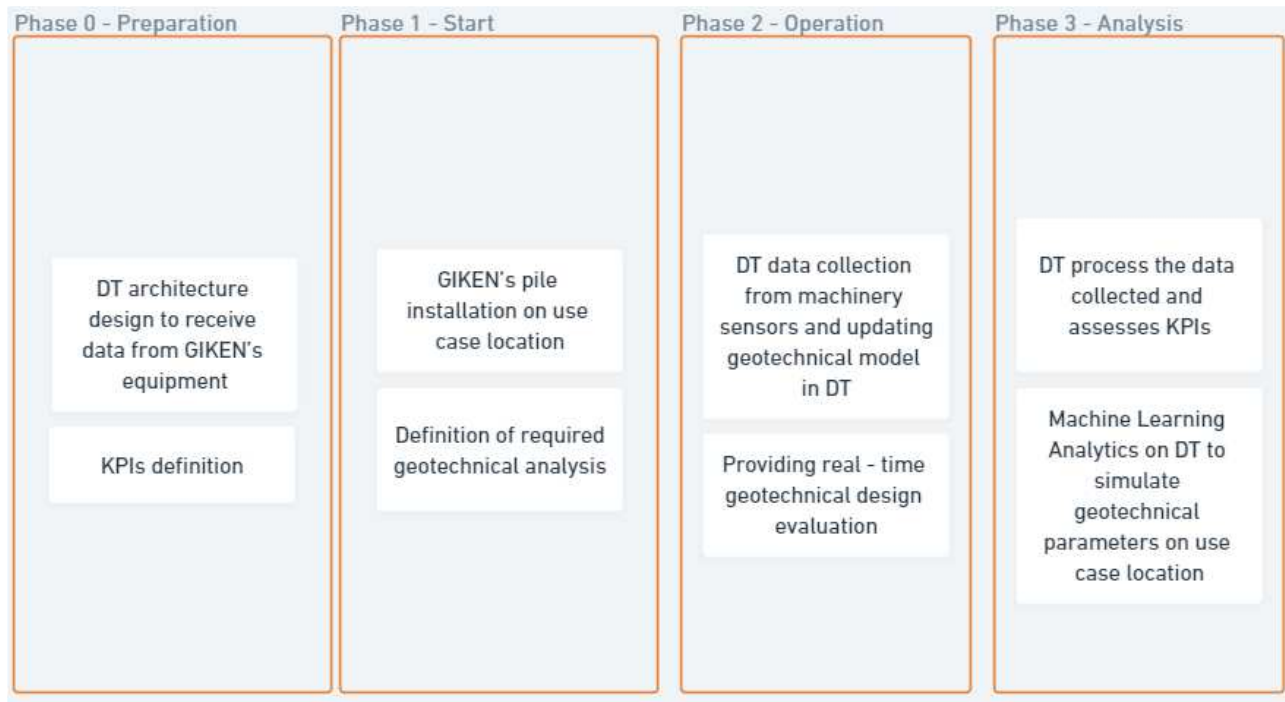


Figure 9. Operational Scheme for Japanese Maritime construction use case.

4.5.3. Requirements

Table 10: Japanese Maritime construction use case requirements.

Description	Requirement / Action
Japanese test site details.	Get test site details and tasks to be performed by the machinery.
DT connection with Giken's machinery.	Communication protocol with DT to be defined. Analyse CANBUS or CANVAS with the machinery, or dataloggers already installed in the machinery. Analyse existing existing's Giken visualization software to be combined with DT.
Data sent frequency from machinery to DT.	Define frequency of measurement data. Analyse what real time data needs to be sent.
Variables to be sent from machinery to DT.	Sensors are already installed in Giken's machinery. Analyse the viability of installing sensors on the installed piles. Some variables to be sent push-in resistance, pile resistance.
Geotechnical analyses to be performed.	To be defined: geotechnical formulation and algorithms from data collected during demonstration. Historical data to be provided by DT.
Piling installation on use case location requires permission from port's authorities.	Giken assesses the compliance of the test site and asking for required permission to perform the piling.
Giken's machinery must be located and installed in use case location.	According to Giken's availability and planning of use case.



To be provided: a ground model with geotechnical information from use case location.	Information to be collected during preparation of use case. Geotechnical model calibration is required.
LCA/LCC KPIs.	To be defined. As an example, material degradation, spent resources, costs, etc. To be provided: non-autonomous operation for pilling installation in order to compare the benefits of autonomous machinery.
Provide a real – time design compliance check during use case demonstration.	The working scheme proposed is to collect data from machinery to DT, and DT will be connected through an API to geotechnical software of INGEO. Programming scripts to re-calculate geotechnical models in the software and send back the re-design to DT. Scripts and data formats have to be defined (.csv, .txt...) Capability of machine learning algorithms for data prediction also to be assessed.
Machine Learning algorithms will require a large amount of data, for example CPT data.	To be provided into database of DT with the geotechnical information provided by INGEO / use case location authorities. The minimum quantity of geotechnical data to provide accurate predictive ML algorithms to be defined
Machine Learning requires a programming language where the algorithms are introduced.	To be defined according to DT architecture, for example Python.
Graphical interface of the DT requirements for Giken.	To be defined: Giken requirements in order to provide with a valuable interface with real time data and post – processing analysis through the different proposed routes.

4.6. Use Case 6: Road Maintenance

4.6.1. Details

DATA LOCATION DETAILS

AISCAT (use case leader)

Location: A24 Italy

USE CASE DESCRIPTION

Road maintenance is based on ensuring that the infrastructure remains in operation, with the minimum number of possible cuts and in the best service conditions for all users, at the lowest possible cost for the concessionaire. Under this premise, different types of elements on the road must pass periodic inspections. Some of them, several times a day, and others semi-annually or annually. At present, concession personnel who drives vehicles along the road, have to check these points several times a day, in daytime and night-time conditions, having to carry out maintenance inspections in adverse weather conditions, with safety concerns for workers themselves and road users. It is proposed to use the technology of autonomous robotics (ground and aerial) to perform certain inspection tasks in road maintenance as:

- Check the retro reflectivity level of vertical traffic signals and check the status of horizontal ones (using a robot/drone and specific perception and analysis software).



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- Check the vegetation status right outside the road carriageway on the external border, measuring the growth and the type of growth, doing predictive analysis (using a robot/drone and its internal sensors and 3D maps to track the environment).

From the previous tasks, prioritizing the intervention based on real needs and extract conclusions giving inputs to legislator to improve maintenance protocols. The autonomous robotic platform, collaborating with autonomous aerial vehicles, will demonstrate their capability to perform these tasks during the operational service of the roads, without affecting the infrastructure users. A case study in Italy, part of the AISCAT 5.000 km highway network, will be used for previous tasks.

PARTNERS INVOLVED:

ACCIONA

AISCAT

TECNALIA

FADA CATEC

CSTB

WORKSHOP ASSISTANTS (10/11/2022):

Table 11: Workshop assistants.

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ACCIONA	Alonso Cepeda, Antonio
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STAM	Alberto Landini
AISCAT	fabrizio.federici

4.6.2. Operational Scheme

It is presented below the operational scheme to be performed in this use case, divided by different phases.



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101058548.

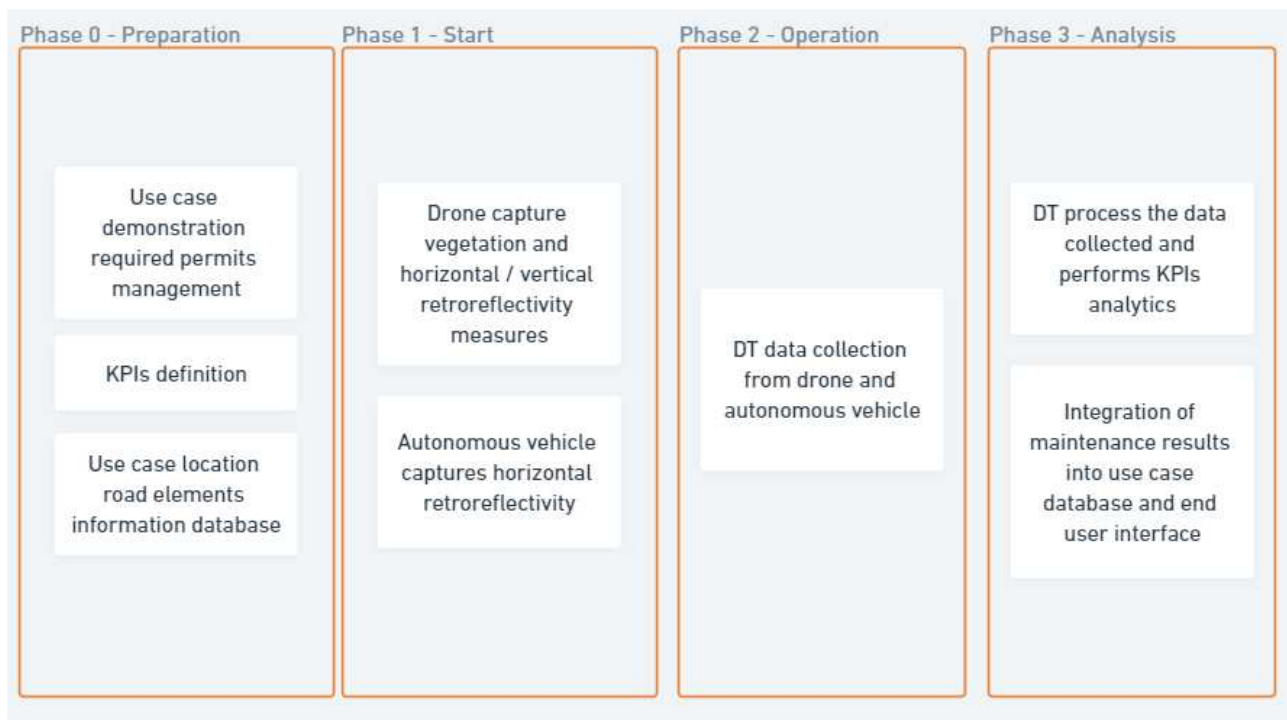


Figure 10. Operational Scheme for Road maintenance use case.

4.6.3. Requirements

Table 12: Road maintenance use case requirements.

Description	Requirement / Action
Autonomous vehicle drive along a road to gather maintenance information, in coordination with drones, and provide this information to a digital twin.	Define elements to be monitored and define length of road maintenance test according to use case location details. ABM simulations to provide the optimal coordination routes of drone / vehicle.
Drone performs automated 3D mapping of road maintenance with inspection and surveillance (traffic signs and vegetation) in road maintenance use case	Define 3D mapping sensor and specifications required. It is proposed a LIDAR sensor, for vegetation detection and maintenance values obtained.
Drone update 3D maps into DT.	3D maps can be quite large, it is recommended that file formats are open (ROS and other open-source libraries).
WLAN network required during demonstrations.	It is a requirement for the demonstration location to provide with 4G or similar network. In case of no existence of network, a local wireless network has to be installed.
Autonomous vehicle can not invade the road lane.	Size is a requirement. Proposed prototype for the use case has the following c: 1100×700×450mm; Weight: 200Kg; Payload 120Kg; Speed: 15 Km/h; Autonomy: 65 Km.



Variables that will be monitored and sent to the DT database of the Digital Twin architecture.	Real time: Telemetry from the autonomous vehicle, road measurements, GPS position. After demonstration, update and processing the 3D map from drone and retro reflectivity values obtained.
Drone fly autonomously and free of obstacles on an open environment.	GPS signal is required at the use case location. To be confirmed with road managers the absence of obstacles that can affect the flying of the drone or the acquisition of 3D models.
Drone flying in a real highway environment requires flying permits from authorities.	Flying permits must comply with the absence of people and vehicles around; even no airports close (aerial space not restricted). It could be required to close a lane where performs the tasks. Weight and dimensions of the drone are crucial as well for this.
Frequency of obtaining data during demonstrations.	Demonstrations must be properly scheduled with road authorities, to reduce as much as possible the possible traffic affections. Initially is proposed to perform the activity once per day as much.
Environmental restrictions during demonstrations taken into account for not to reduce accuracy of sensors in drone and vehicle.	LIDAR sensor can be employed during night with a good accuracy but flying permits during night are usually more complicated to obtain than if flying is during the daytime. To be defined Analyse the obtention of data from control centre of defined road for use case.
Operation and displacement of the autonomous vehicle is autonomous, during normal operation of the road.	Provide with emergency cut-off button in case of any conflict. Semi-operated capabilities are recommended for safety.
Prior to deployment of the drone and the autonomous vehicle on the use case location, testing is required of both devices.	Test facilities are available from related partners of drone and autonomous vehicle. To be defined.
Autonomous recognition of signals and road elements.	Drone has LIDAR and high – resolution camera able to recognise these elements. During preparation phase, provide the DT database with the catalogue of road elements located in the use case road from the road managers. Information obtained from drone is GPS – located, so initially with this information will be linked the recognised elements with the catalogue.
DT services expected from this use case.	DT is meant to provide with alerts to the road managers once the drone or the vehicle detects an anomaly in the status of the maintenance of the road, both traffic signals (vertical and horizontal) and vegetation. To be agreed with road managers and end-users how are they expecting the DT interface.
Data sent to DT during the demonstration.	As this case does not represent a construction scenario, it is proposed to store the data collected locally into the drone and the vehicle, and upload these to DT once the demonstration is finished.



5. Technical Requirements for BTs

5.1. Methodology to measure the impact of digital and new technologies in construction processes.

The methodology to measure the impact of digital and new technologies in construction processes, due to the lack of a strictly technical character of this KER, at this initial stage does not represent any special requirement to be defined. This methodology is intended to be deployed using commercial software, via templates / excel sheets.

In terms of measuring the impact, the methodology aims to collect KPIs results from the use cases of BEEYONDERS, to measure the accomplishment rate of these KPIs, specially focusing on the following pre-defined categories:

- LCA & LCC based indicators and methodology.
 - Environmental impact.
 - Resources consumption and economical assessment.
 - Etc.
- Evaluation of the impact of the BT on workers, focused on:
 - H&S
 - Productivity
 - Etc.

In terms of monitoring the accomplishment of technical target level to be achieved by technologies, to be this methodology will employ the technical templates shared among the partners that are going to be live documents during the technical developments, to monitor the progress of these. Besides, is going to be supported and developed, during the duration of the project, by the following tasks:

- **T2.2 - Technical Requirements. Lead: TEC; Cont.: All. (M1-M6)** Technical objectives will be required focused on the final technological state that is defined for each technological development. In this task, a methodology to measure the technical target level of these developments will be given, to precisely measure and control the progress of each development.
- **T2.5 - Testing Plan. Lead: TEC, Cont.: All tech. developers (M13-M24)** This task will design and establish the methodology for the technologies to be followed, to assure that medium TRL5 is well established prior to the TRL6 validation in WP7. This methodology will be based in designing and assessment of trial tests, in a laboratory environment, and validating the Digital Twin data integration.
- **T5.5 - Monitoring and assessing the impacts of breakthrough technologies on workers. Lead: ICO; Cont.: ACC, TEC, STA, IIT, EBC, CST, AAR, VTT, FIR (M19-M39)** This task will monitor the worker KPIs, focusing on the technologies developed in the project. The methodology to assess the impact of BEEYONDERS technologies on the workers will be developed, e.g., through focus groups with interviews, questionnaires, etc. Workers' perceptions over well-being and safety as well as technology acceptance will be evaluated through dedicated surveys and focus groups (3 are foreseen during the duration of the project) addressed mainly to site workers. The task will also investigate the relation between the performance, well-being, safety and acceptance aspects. Insights from this



task will provide recommendations for fine-tuning BEEYONDERS technologies as well as upscaling and replicating them across EU construction sites.

- **T7.1 – Common methodology for case studies and assessment of breakthrough technologies integration** *Lead: ACC; Cont.: All technology developers (M19-M40)* This task will run in parallel with the case studies to provide a common methodology for ensuring a coherent development of the demonstration and validation activities (T7.2 to T7.7). This methodology will ensure in first place that the detailed specification of the case studies clearly map the technologies from WP3-6 that will be validated, and the adaptations and integrations needed for each of them. Besides, the task will harmonize the validation campaigns of the different case studies, ensuring the availability of all the technological components and of all the needed human and material resources, looking for synergies among case studies sharing applied technologies. Furthermore, common templates will be prepared for the reporting of the demonstration campaigns, and for the collection and analysis of data that will help to assess the impacts of the case studies in task 7.8 and the degree of success of the integration of breakthrough technologies in these case studies.
- **T7.8 – Impact Assessment of technologies deployed on demonstrators.** *Lead: INF; Cont: All (M34-M42)* The main objective of this task is to perform the impact assessment of implementing BEEYONDERS breakthrough technologies in the Case Studies (T7.2-T7.7). The methodology will use KPIs developed in WP2 and integrate them into holistic impact assessment framework that can be used for the assessment of different types of technologies and activities. The methodology will include systematic definition of the infrastructure, environment and organisational components of which the infrastructure or building system is comprised and the types of costs and impacts during the whole life cycle. It will also cohesively unite the many important but often conflicting benefits that should be considered when evaluating digitalization and automation of construction industry, such as the effects on a) costs and reduction of dependence on technology imports b) productivity, c) system efficiency and performance, d) workers wellbeing and safety, and workforce structure (e.g. attraction of younger people, gender balance, etc.) e) environmental impacts, such as CO2 emissions, usage of resources etc., and e) degradation of ecosystems / biodiversity. The evaluation methodology will be developed considering the input from expert surveys and literature study.

The methodology, in this initial state, is focused in gathering the Technical Templates requirement for each technology and these are presented in the next pages. **Please note this information will be updated / completed as long as the project advances and more requirements are identified (supported during the different tasks mentioned before). Testing plan task will be a key task in order to complete this information required.**



5.2. Autonomous / Semi operated Wheel Loader

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 13: Autonomous / Semi operated Wheel Loader Technical Requirements Template

PROJECT TASK		
OVERVIEW: High-level information describing proposed solution, what the project works to achieve, and business reasoning		
This task will develop an autonomous and tele-operated wheel loader system (ATWL) for earth-moving tasks transforming a wheel loader machine in an autonomous vehicle able to perform advanced driving tasks in short or large cycles (tunnel and road construction) and specific earth-moving tasks (loading and dumping).		
TECHNICAL REQUIREMENTS		
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
1.1	A complete set of software modules like path planning, objects avoidance, etc will be developed and the system proposed on T4.2 and T4.3 will be used in combination with the other robots/machines developed in T4.4 and T4.5.	
1.2	LiDAR's and cameras will be integrated on the machine, generating the data to detect objects and localising other machines on the environment.	
1.3	A hierarchical task and motion planning algorithms that combine learning-based techniques (reinforcement learning control) with optimization-based methods will be integrated in parallel to the perception module, considering the multiple parameters that can affect on the loading and dumping process.	
1.4	A combination of multi domain rewards in the learning process will be used while the machine is controlled tele-operated or autonomously.	
1.5	Sensors will be commercial: LIDAR, Radar, Pressure sensors, temperature sensors, cameras, 360 degrees visual systems, integrated potentiometers, electronically controlled brake systems (brake by wire), electronically controlled steering systems (steer by wire), electronic	



	control units, angle sensors, proximity sensors, accelerometers, electronic joysticks, and operator seat station.	
1.6	The AWL will have the specifications as follows: 210 kW engine power, 20600 kg operation weight, 40 kph max. speed, 3,5 m3 bucket capacity, 5 speed transmission.	
1.7	Degree of autonomous operation: AWL will be Level 4.	

INTEROPERABILITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
2.1	Variables to be monitored and sent to the DT database: machine engine rpm, machine speed, pressure and flow values, mechanism positions, dynamic behaviour of the machine, hydraulic cylinders' positions, machine location, pile amount and location, interrelation with surroundings (human around the machine, obstacles).	
2.2	Communication protocols: CANBUS SAE J1939.	

SECURITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
3.1	AWL and human around the machine should interact.	

TECHNICAL PROCESS

As per use case descriptions

ADDITIONAL COMENTS

N/A



5.3. Autonomous aerial vehicles

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 14: Autonomous Aerial Vehicles Technical Requirements Template

PROJECT TASK		
OVERVIEW: High-level information describing proposed solution, what the project works to achieve, and business reasoning		
This task will focus on the design and development of aerial robotic technologies, which involve a system for outdoor inspection, and a system for indoor exploration, which does not make use of satellite-based localization solutions. The operation of aerial robots in GNSS-denied environments or scenarios with high density of obstacles brings an additional complexity to be faced in BEEYONDERS. Advanced functionalities such as the automatic detection and avoidance of obstacles present in the aerial robot surroundings will be considered in this task.		
TECHNICAL REQUIREMENTS		
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
1.1	The UAV must be able to scan the tunnel before workers	
1.2	The UAV must be able to generate a map of the environment with the current state of the tunnel	
1.3	The UAV must be able to operate in 'autopilot' mode, where it explores the tunnel automatically	
1.4	The UAV must be able to fly and localize itself inside the tunnel	
1.5	The UAV must be able to detect obstacles closer than X meters	
1.6	The UAV must take off and land autonomously, always with a safety pilot supervision	



1.7	We expect to have a full autonomous operation from take-off to landing but depending on the final scenario we may need some semi-autonomous operations in the sense of providing high-level motion commands.	
1.8	Sensors will be commercial: RGB camera, 3D LIDAR, IMU.	
1.9	Specifications: there will be different platforms: aerial robots for outdoor use cases will be LARGER than 1.5m diagonal base.	

INTEROPERABILITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
2.1	The UAV must be able to exchange information X with the autonomous wheel loader	
2.2	The UAV must be able to send information X to the DT system	
2.3	Communication protocols: ROS as middleware (Robot Operating System) and Standard IP-based protocols.	

SECURITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
3.1	The risk assessment must consider safety mitigation plan ahead, considering possible collision with obstacles	
3.2	The risk assessment must consider safety mitigation plan ahead, considering possible flight termination of the aerial robot	
3.3	The operation is under supervision of the corresponding health and safety entity	
3.4	The system must incorporate a pure manual control mode to allow the safety pilot to take control of the UAV in any moment	

TECHNICAL PROCESS

Once the requirements are captured, and following the use case design, the functionalities needed to meet the requirements will be identified.



ADDITIONAL COMENTS
N/A

5.4. Autonomous Ground Mobile Inspection Vehicle

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 15: Autonomous Ground Mobile Inspection Vehicle Technical Requirements Template

PROJECT TASK		
OVERVIEW: High-level information describing proposed solution, what the project works to achieve, and business reasoning		
This task will focus on the development of a prototype of mobile robotic platform for the execution of multiple infrastructure maintenance operations, as defined in the associated use case. The prototype will incorporate suitable sensors, a pan-tilt unit and AI unit. This prototype will be used to implement and test the innovative software for this specific and complex scenario (developed in T4.2 & T4.3): autonomous navigation using 3D mapping; obstacle detection and avoidance; teleoperation for complex activities requiring low latency 4G LTE connectivity etc.		
TECHNICAL REQUIREMENTS		
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
1.1	Use case requires a vehicle for road (no off-road capability expected) and outdoor use. It should be capable of traveling several kilometres long road stretches in a reasonable time and without the need for recharging.	
1.2	The vehicle should be operable in both sunny and light rain conditions, though operation in bad weather conditions could be limited by sensors' capabilities.	
1.3	Manoeuvrability is not a priority, so Ackerman or double Ackerman steering should be preferred for higher speeds.	
1.4	It should have enough payload to easily accommodate a variety of equipment and sensors required.	



1.5	Size should be medium-small to easy logistics and transportation.	
1.6	Size: 1100×700×450mm; Weight: 200Kg; Payload 120Kg; Speed: 15 Km/h; Autonomy: 65 Km.	
1.7	Sensors: 3D/2D LiDAR, 2D cameras, GPS, IMU, RADAR, ultrasonic, retro reflectometer. All commercial devices integrated in the platform.	
1.8	Retroreflectometer sensor requires to be adapted to the vehicle and able to provide an API connection to extract the data. Identified sensor is Easylux Retroreflectometer MiniReflecto Horizontal 30-meteri	

INTEROPERABILITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
2.1	Variables to be monitored and sent to the DT database: telemetry from the vehicle, road measurements, GPS position.	
2.2	Communication networks / protocols: Wi-Fi, 4G / ROS based TCP communications through Wi-Fi.	

SECURITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
3.1	Autonomous vehicle requires an emergency stop function.	

TECHNICAL PROCESS

According to use case requirements description

ADDITIONAL COMENTS

N/A



5.5. Optimized and Bio Compatible mortars

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 16: Optimized and Bio Compatible mortars Technical Requirements Template

PROJECT TASK		
OVERVIEW: <i>High-level information describing proposed solution, what the project works to achieve, and business reasoning</i>		
Under the objective of test and demonstrate new, environmental-friendly, additive manufacturing solutions, this task focuses on developing materials for 3D printed caisson. For the construction of caisson, a 3D printable material will be developed. To boost the bio-receptive function of the caisson, a second material and its related applying method will be developed. The material development starts by sourcing raw materials that are available near case study demonstration cite and their characterization. Once the specifications (such as maximum aggregate size, strength level, durability class, bio receptivity etc) are clarified, lab trials will be carried out to for optimizing the recipes. By going through lab trials, for 3D printable material, its fresh properties will be optimized according to the 3D printing process and its long-term properties will be optimized to achieve the requirement. For bio-receptive material, in addition to its own properties, the interaction with 3D printable material and how the impact of apply method will also be accessed and optimized. Once succeeded lab trial, the 3D printable material will go through printing trials through which minor adjustments are possible to fit it with the printing process. Before the demonstration, industrial trial will be carried out so that the performance materials can be validated from factory production, with possible some final adjustments on the recipes.		
TECHNICAL REQUIREMENTS		
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
1.1	For the 3D printable material: - Adapted fresh properties development to ensure the pumping and printing process so and the integrity of printed element during construction phase, measured by yield strength; - adapted hardened properties to assure long term integrity of the caisson structure, measured by compressive and flexural strengths at age of 1 day, 7 days and 28 days, durability indicators such as water porosity and coefficient diffusion of chloride ion; For bio-receptive material: - Adapted fresh properties and applying method to assure its application on the surface of caisson - bio-receptivity adapted to the marine environment of interest	



1.2	Variables during the manufacturing of the new biocompatible 3D printing mortars that are going to be measured (moisture, consistency, temperature, etc.). And after manufactured (Structural behaviour, hardness, biolife implementation): Moisture of aggregates, temperature of concrete or mortar raw materials, wattmeter curves in the concrete mixer, colonization of these surfaces over time (and possibly cracking monitoring), ideally complexity, rugosity and pH.	
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INTEROPERABILITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
2.1	Communication protocols that are planned to be employed during IoT deployment of manufacturing: To be defined, initially MQTT.	

SECURITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
3.1	The following are the major risks which may result in failure to material development: - Risk of insufficient performance: the developed material does not meet the specs; especially long terms performance (can be due to unclear specs or changes in specs during the project due to changes in process and design). - H&S risk: e.g. the material releases hazardous component to its environment during its service life. - IP risk: material developed enters into the patent protection of other companies and we do not have freedom to operate - Lab to production upscale risk: e.g. the recipe cannot be produced with current industrial installation; e.g. the performance of produced material is unsatisfactory (variation is too high, or /and minimum performance cannot achieved) - Cost and environmental impact risk: the material developed has unacceptable cost and/or unacceptable environmental impact	

TECHNICAL PROCESS

The following requirements on technical process are essential to assure the performance of material:

- adapted mixing equipment and mixing process to ensure well mixed, homogenous material;
- adapted pumping system and pumping process to create stable flow of material from mixer to printing head;
- adapted concrete 3D printer and printing process to enable stable extrusion of material out of printing head, in a range of printing speed, and avoid formation of cold joints between printed layers;
- adapted curing environment and curing process to assure acquisition of long term properties of the material.

ADDITIONAL COMENTS

N/A



5.6. 3D printing

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 17: Optimized and Bio Compatible mortars Technical Requirements Template

PROJECT TASK		
OVERVIEW: High-level information describing proposed solution, what the project works to achieve, and business reasoning		
This task focuses on leveraging 3D Concrete Printing (3DCP) technology for marine caisson, optimizing both the design and manufacturing of both the caisson itself but also of artificial reefs to be introduced on caisson's surfaces, to promote bio-marine life development.		
TECHNICAL REQUIREMENTS		
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
	Main performance specifications the 3D printing device will have: Print speed, Layer time, Material open time, Layer dimensions, Buildability, Printability, Pumpability.	
	Number of workers required to operate the 3D printer, which if properly trained is 3-4 people.	
	Caisson building time: A standard caisson can present up to 6000 m3 of concrete. 3D printing equipment to be employed in the project can perform 6m3 per hour.	
	Specifications or requirements identified according to the 3D printing devices: Printing speed: typically 0.4m/s linearly, ~0.5-1.0m/h vertically, material throughput ~ 2-5m3/h, climate: same as for concrete production in standards (usually 5-30°C range, avoid heavy rains, hail storms, high wind conditions), Material specs: to be defined after design study but probably compressive strength from 50 to 90 MPa, Dmax ~10 mm or more, potentially fibered concrete.	
	Specifications for artificial reefs designs: Create complexity, porosity, cavities for marine life.	
INTEROPERABILITY REQUIREMENTS		
ID	DESCRIPTION	COMMENTS



	DT integration of measured marine life promoting into the caisson model.	
	Sensor installation inside / outside seawater to be defined; standard communication protocols apply (as MQTT, HTTP).	
SECURITY REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
	Environmental impact and required permits on submerged caisson has to be assessed with Port authorities.	
TECHNICAL PROCESS		
As per use case requirements description.		
ADDITIONAL COMENTS		
N/A		

5.7. Exoskeleton

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 18: Exoskeleton Technical Requirements Template

PROJECT TASK
OVERVIEW: High-level information describing proposed solution, what the project works to achieve, and business reasoning
Work-related Musculoskeletal Disorders (MSD) are an important cause of functional impairments and disability among civil construction workers with the lower back being the most overloaded body region and the shoulder as the second. A primary goal is to prevent this risk of injury by providing the worker with an assistive exoskeleton for lifting and handling heavy objects (up to 25kg), and therefore by reducing their perceived effort. IIT would provide the required technology, knowhow, and assistive strategies to ergonomically reduce the risk of injury. Thus, the final goal is to enhance workers' working condition, health, and safety by providing a robotic support exoskeleton that will reduce the biomechanical loading during manual handling. The use of exoskeletons could also improve production efficiency by enhancing the workers performance, reducing the execution time, as well as by decreasing absenteeism and related costs. With the adoption of such device, both men, women, and aged workers could benefit by reducing working related difficulties. The use of this device not only reduce the workers fatigue but also, from a health and safety point of view



the companies will not be required to struggle on finding ergonomic solutions to make the specific heavy tasks affordable.

DESIGN AMBITION:

The key innovation in the exoskeleton technology that BEEYONDERS will develop, is the adaptation, customization and enhancement of an active exoskeleton that supports manual material handling and repetitive tasks and aligning these developments and refinements to with the very specialized demands that arise in the construction industry.

We will develop a lightweight active exoskeleton, which will be versatile, modular, and capable of assisting the most fatigue inducing operations found in the construction sector (e.g. fetching of material, static and dynamic operations in uncomfortable/tiring postures, etc.). From a technical point of view, cutting-edge technology including sensors, actuators, and smart concepts will lead to a versatile device suitable for multiple purposes. BEEYONDERS will develop a smart exoskeleton able to understand intuitively and in real-time worker's activities and objectives. This will be achieved by applying bioinspired sensor fusion and cognitive control algorithmsⁱⁱ. These assistive strategies will be studied and designed during the project life to ensure effective assistance in a range of working tasks (i.e. holding, lifting, carrying, pulling, pushing, and walking).

Through the development of these exoskeletons and thanks to its intrinsic mechanical bypass function to reduce the biomechanical overload, we aim to reduce the number of injuries affecting the musculoskeletal system and thereby improve worker safety. When considering the current state of the art in occupational exoskeletonsⁱⁱⁱ, and the highly interactive action of the back and arms while accomplishing manual material handling^{iv}, we noticed that current occupational exoskeletons assist only one unique body segment at a time, and that they are designed to address very specific single goal working tasks. Thanks to the knowhow and experience of IIT, and considering that many activities in manual material handling require coordinated effort from both the arms and back, BEEYONDERS will develop an exoskeleton that will assist both the lower-back and the arms in a unique combined and coordinated device that will support a large variety of working tasks by dynamically recognizing the worker activities: the Arm-Back cOmbined and Versatile Exoskeleton (ABOVE). The ABOVE will be designed with a highly direct focus on reducing the weight of the device (using composite materials), and emphasizing modularity and reconfigurable approaches (providing support for both the back and arms or even independently). While the development of such a system is very challenging, the experience at IIT in onboard CPU, motors, wearable sensors, and control strategies, allows a great level of flexibility and adaptability to the specific user needs.

Because of the unstructured working environment (e.g. rough, uneven and broken ground) and the non-repetitive nature of the tasks within the construction sector, the ABOVE will be an active exoskeleton able to input, on demand, additional energy to the user from external sources (e.g., batteries). Although this will be more complex than with passive commercial exoskeletons^v, the need for flexibility, adaptability and agility means that BEEYONDERS will develop an active smart exoskeleton that is ideally suited to the highly dynamic tasks^{vi} that are common in the construction sector. Thanks to a preliminary analysis conducted with the end-users to determine the needs and objectives, we envisage the following technical solution: the ABOVE will embed electric actuators (high power/weight ratio and high efficiency brushless DC motors and gearing) that will act across the torso and/or across the shoulders of the worker. This will generate about a third of the physiological required torque (30-60 Nm)^{vii}. The system will provide controllable stiffness regulation along the sagittal plane, while allowing free motion along the other directions. The assistance provided to workers while carrying out heavy load activities will be modulated according to the specific needs of the task. These assistive strategies will be based on bioinspired sensor fusion and intelligent cognitive control algorithms^{viii}. The torque provided will generate an assistance that reduces the muscular activation at the lower back and arms by 20%-30%, with a 15%-25% reduction of L5/S1 flexion-extension moments^{ix}.



Critical aspects that characterize the design of these occupational exoskeletons are the: (i) Mechanical structure and body contact points. (ii) Comfort and acceptability. (iii) Effectiveness of the assisting forces. (iv) Proprioceptive sensory strategy. (v) Actuation and control electronics. These five features are the basis of the efficacy of the ABOVE assistive exoskeleton. A final point worth noting is that an active device that includes electric motors, sensors, CPU and batteries will not only provide assistance to workers while carrying out their daily work, but will also improve safety through increased/improved connectivity and data sharing. In fact, the combination of these features will allow bi-directional communication with the device (data from sensors could be transmitted from the exoskeleton, while other information, feedbacks and acknowledgements could be sent back to the worker wearing the device). Safety will definitely be enhanced through at least two improvements: by reducing the risk of injury due to the assistance provided by the exoskeleton, and by sending real-time safety/operational feedbacks to workers using the improved connectivity.

TECHNICAL REQUIREMENTS		
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
1.1	Improve the workers with healthy and safe working conditions Providing a robotic back support exoskeleton that will reduce the biomechanical loading during manual load handling. Providing a robotic shoulder support exoskeleton that will reduce the biomechanical loading during manual load handling and repetitive task of upper limbs. Safety and comfort will be central to the exoskeleton design. The ABOVE has to assist workers during heavy operations and under severe conditions (e.g., rain, dust, humidity, cramped spaces). The ABOVE has to be useful for several activities done by workers (e.g., walking, holding, lifting, carrying, pushing, and pulling), detect the ongoing activity and act consequently to modulate the assistance it offers. The ABOVE has to be comfortable to promote device acceptance. The ABOVE has to be compatible with other personal protective equipment (PPE). The exoskeleton has to reduce musculoskeletal loading by up to 20-40% during manual handling tasks (e.g., holding, lifting, pulling, pushing, and carrying).	



The device has to be usable in unstructured working environments and with unstructured methodologies.

The main objective is to develop a robotic system that can be worn throughout the construction site with minimal/zero discomfort or hindrance, while adapting its level and form of aid to the user defined needs.

The exoskeleton shall not exceed a mass of 10 kg.

The exoskeleton shall support the worker in lifting loads up to 25 kg giving a support to both the back and the shoulders to minimize muscular fatigues.

The exoskeleton shall be designed for heavy-duty use.

The exoskeleton should have autonomy to be used during a whole shift.

The exoskeleton shall be suitable for multiple tasks (lifting and carrying loads and giving support for uncomfortable static postures).

The exoskeleton shall be suitable for multiple tasks, allowing autonomous adaptation between tasks.

The worker shall have the possibility of turning assistance off and adjust the level of assistance.

The exoskeleton shall not constrain worker movements, including bending over, sitting on haunches or raising arms above shoulders.

The overall footprint of the worker wearing the device cannot exceed 60cm to fit in narrow spaces

The exoskeleton shall be easy to use.

The training to use the exoskeleton shall be no longer than 1 hour.

The exoskeleton textile shall be breathable.

The procedure of changing batteries shall take less than 5 minutes.

Time to put on the exoskeleton shall take less than 5 minutes.

Time to take off the exoskeleton shall take less than 1minute.

The exoskeleton shall give the wearer a clear feedback indicating its proper functioning.



	The exoskeleton shall be adaptable to different user body sizes. The exoskeleton shall not produce noise higher than 70dB during its proper working. It shall be possible to share the exoskeleton among workers. The exoskeleton shall be usable by different workers. A user interface for the workers shall be incorporated in the exoskeleton unit. Exoskeleton should be able to provide feedbacks to the worker concerning operational activities and the status of the exoskeleton. The central user interface shall display possible failures of an exoskeleton, its battery level and assistance level. It shall be possible for each user to change the assistive profiles and working assistance level of the exoskeleton.	
INTEROPERABILITY REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
2.1	The exoskeleton shall have the functionality of sending and share data and technical information to the following platforms: 1. Digital twin 2. Wearable systems 3. Training platforms	
SECURITY REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
3.1	The exoskeleton, must be compliant to the safety regulation of machine, thus falling under the Machinery Directive 2014/33/EU which defines essential health and safety requirements when a corresponding hazard exists. The harmonized standard is identified by the safety requirements follows EN ISO 12100:2010 "Safety of machinery – General principle for design – Risk assessment and risk reduction", which imply the following requirements in designing.	



- Geometrical factor and physical aspects: the exoskeleton shall avoid sharp parts and allow suitable position to operate.
- Provision for stability: the exoskeleton shall not alter the balance of the user.
- Ergonomic principles: the exoskeleton shall follow ergonomics as well for the main structure, in particular strength, posture, movement amplitude, as well for positioning of control console.
- Electrical hazard (IEC 60204-1): the electrical circuits of the exoskeleton shall not allow electrical shock.
- Pneumatic and hydraulic hazard: the pneumatic and hydraulic parts of the exoskeleton shall not allow sudden hazardous movements or leakages of hazardous substances in case of failure.

The exoskeleton is used to assist Manual Material Handling (MMH) as regulated by the standard UNI ISO 11228-1:2022 for what concerns the lower back, and it will assist repetitive tasks for upper limbs as in UNI ISO 11228-2:2022 for the shoulders.

Additionally, the exoskeleton will be designed with the safety function for quick releasing the device in case of emergency escape (timing to pull it off less than 1 minute).

The emergency stop of the exoskeletons has to be reachable by others than the wearer.

TECHNICAL PROCESS

The development of the exoskeleton will follow the User Centered Design (UCD) methodology. This method assesses the user's needs and allows work to be structured around those needs. The UCD methodology can be summarized in the following principles:

1. the design is based upon an explicit understanding of users, tasks, and environments.
2. users are involved throughout design and development.
3. the design is driven and refined by user-centered evaluation.
4. the process is iterative.
5. the design addresses the whole user experience.
6. the design team includes multidisciplinary skills and perspectives.

Therefore, we will need to:

- a) Have the opportunity to view worksites and interface with workers by studying their habitual tasks and asking them questionnaires.
- b) Involve workers in the iterative development process and therefore have the possibility to test them in each phase of the device development, collecting physical data and feedbacks about the experiences that they will be involved to.

With the information collected in points above we will be able to define:



- The mechanic design and the ergonomic solutions that better accommodate the needing of the users according to the tasks, the body sections and the movements that will be assisted.
- The electronics components, sensors, motors and actuation units that represent the core of the exoskeleton's intelligence and are needed to control and actuate the device.
- The control strategies that better assist the workers and reduce the physical and biomechanical workload according to the task executed, the body regions involved, the movements and the timing.

ADDITIONAL COMENTS

N/A

5.8. Smart wearables

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 19: Smart Wearables Technical Requirements Template

PROJECT TASK		
OVERVIEW: High-level information describing proposed solution, what the project works to achieve, and business reasoning		
The development of wearable devices is addressed in task T5.2 and belongs to WP5 "Worker-centric technologies to improve health, safety, and well-being". Within this task, a collection of wearables will be applied to workers' clothes to monitor their wellbeing in the working site. To evaluate possible risks for the workers, environmental parameters (temperature, humidity etc.) will be measured and combined with physical parameters of the workers (position, movements, etc.). The collected data will be sent to a cloud platform where they will be stored and analysed through AI algorithms, providing feedback to the workers in case of possible risks.		
TECHNICAL REQUIREMENTS		
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
1.1	Wearability: since the wearable devices will be worn by the workers, they should be designed in such way that they do not prevent or restrict the movements of the workers. This implies that the weight and dimension of the system should not be excessive. Battery: the overall system should have an autonomy of at least 8 hours (one working day).	
1.2	GDPR issues should be noted as these devices are going to be used on humans.	



1.3	Sensors: IMU (Inertial Measurement Unit: acceleration and gyration) and, for ground truth data (not to be used in digital twin), EMG (electromyogram) and EKG (electrocardiogram) are considered at the moment.	
1.4	Innovation: IMU unit analysis of physical activities of the worker relating to wellbeing aspects such as estimation of muscular strain and repetitive movements.	

INTEROPERABILITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
2.1	A SIM module / mobile edge device can be used to send data collected from the sensors to the cloud platform. Depending on the case study and requirements of the Digital Twin, technologies such as Bluetooth and Wi-Fi can be adopted to exchange data.	
2.2	Analysis and services expected from the Digital Twin : overall/aggregated metrics from activity recognition and fatigue trends (due to GDPR issues person level data can be difficult: data needs to be strictly anonymous and/or aggregated over population).	
2.3	Variables to be monitored and sent to the DT database: aggregated activity recognition data from IMU (accelerometer, gyroscope, magnetometer), and other aggregated physiological parameters, if allowed by GDPR.	
2.4	Communication protocols: Bluetooth, TCP/IP, MQTT. The sensors monitor the worker and calculate aggregated data with edge devices.	

SECURITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
3.1	The wearable system will process data collected by the workers in compliance with GDPR law.	

TECHNICAL PROCESS

This technology is strictly related to the Digital Twin, since the data collected by the sensors will be sent to the platform and will be managed by it. For this reason, the scheme of the working process will be finalized after the communication between the wearable system and the platform has been defined.

ADDITIONAL COMMENTS

A GPS sensor will be used to retrieve the position of the workers within the working site. If this is not possible in the project use-cases because no GPS signal is available, alternative solutions will be considered.



5.9. Digital Twin

Following the previous indications in this document, specifications and requirements are presented for each technology (as per Technical Requirements Template explained in section 3 of this document):

Table 20: Smart Wearables Technical Requirements Template

PROJECT TASK		
OVERVIEW: High-level information describing proposed solution, what the project works to achieve, and business reasoning		
To develop a unified, open, data platform to store, gather and analyse all numerical information describing the construction site and produced by all actors and equipment. The core component of this platform will be a digital twin of the construction site. This task develops the functional and user requirements for the Digital Twin system. The user and functional requirements of the Digital Twins will cover the digital workflows required, KPIs to be evaluated from WP2, visualization interface features and characteristics, data capture hardware & software, management of BIM integration modelling and services input/output workflow comprising the intelligence of the system.		
TECHNICAL REQUIREMENTS		
OVERALL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
0.1	User management	Sign up, log in, password recuperation
0.2	Settings management	User roles and access control definition, project management, sensor management (inclusion, removal, configuration)
0.3	Monitoring and actuation	Real time data acquisition, real time data visualization, model visualization, KPI processing and visualization, alert management
FUNCTIONAL REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
1.1	Manage BIM design data model	Overall BIM design Model merging of all discipline models: for example, Infrastructural, Architectural, Structural, Electricity, Plumbing, HVAC, etc



1.2	Get various Bill of Quantities (BoQ)	Feature extraction of the resources required for the construction project
1.3	Manage 4D As Designed	Process
1.4	Create as built model from cloud points	Data importation
1.5	Detect construction deviations	feature
1.6	The platform provides a Standard API (e.g., SPARQL ENDPOINT REST API) to request the knowledge graph.	API
1.7	The platform provides functionalities to visualize 2D and 3D representations of the construction site with built elements and resources.	Visualization
1.8	Indicators of the dashboard should be connected to geometrical representations of entities involved in calculation.	Visualization
1.9	The user can interact with element to get states and details.	Visualization
1.10	The platform provides functionalities to validate input data against expected data schema	Data
1.11	The platform annotates raw data with context information according to metadata defined in the model particularly for non-RDF data such as images, time series or point clouds	Process
1.12	Data are indexed when stored to provide read performances (metadata, geospatial indexes, temporal indexes)	Data
1.13	The platform provides versioning functionalities. In the Raw Data Layer, SOSA approach, should be sufficient to timestamp data and keep history.	Data
1.14	Construction plans and as-build progression need to be versioned. This versioning could be achieved by using named graph.	Process
INTEROPERABILITY REQUIREMENTS		
ID	DESCRIPTION	COMMENTS
2.1	The platform stores raw data as files or times series.	Storage
2.2	Data can be imported, exported according to Linked Data standards (Such as RDF, Turtle and JSON-LD)	Storage



2.3	Raw dataset stored as files are identified by URLs and contextualized by metadata (as JSON-LD files or in a named graph)	Storage
2.4	The data provides ETL and Conversion to RDF capabilities. A mapping language between non-RDF and RDF is implemented such as SPARQL-Generate. As part of the Data Harmonization Processor, the platform implements injectors to convert data standard formats to RDF graphs.	Process
2.5	Graph requesting is provided through a standard language compliant with RDF graphs such as SPARQL.	Process
2.6	OWL is implemented to provide inference on concept extensions relations such as sub-classes and sub-properties.	Process
2.7	Request language provides aggregation functions to perform statistical calculations on groups of data (e.g., SUM, AVERAGE, MIN, MAX...)	Process
2.8	The platform provides web HTML5 (CSS, HTML, SVG, JavaScript) compliance to display user interface such as interactive dashboards.	Visualization
2.9	Data validation rules are formalized with a standard rule language such as SHACL (Shapes Constraint Language) or equivalent.	Data

SECURITY REQUIREMENTS

ID	DESCRIPTION	COMMENTS
3.1	Standard communication protocols are required.	

TECHNICAL PROCESS

As per architecture / framework to be defined in the coming months.

ADDITIONAL COMENTS

N/A



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5.10. Training & Learning modules

This task will develop an interactive training and learning (platform) environment that will allow exposing workers to hazard in a safe training environment in virtual reality (VR) that simulates human-robot interactions. This task will develop a dedicated interface developed for each case study that will introduce the physical digitalised environment built to be employed in WP5 for the learning and training modules proposed.

To do so, involved partners will create and test a first of a kind multiplayer user-centric active and serious gaming learning environment that enhances the understanding of construction trainees or the existing workforce for the identification and mitigation of various risk levels in a construction workplace. The proposed technology will employ real case studies models that will be available from the Digital Twin interface developed in T3.7 and will create a safe virtual training environment. To improve the fidelity of the serious game learning simulations and provide the participants with the most suitable realistic experience during the training, a specific part of the work is set on realizing the next generation level of active learning by integrating body motion sensors, hand tracking, realistic representation of avatars during gameplay, and forced feedback with the use of the exoskeleton.

The produced material will be tailored to each specific project case study, based on how BEEYONDERS solutions are applied in that scenario. Training activities (webinars, expert consultations) will be conducted for each end user to improve the knowledge of traditional workforces on digital construction, with the objective of introducing the workers to the innovative solutions developed in BEEYONDERS and how to use them in their daily activities. Initial feedback will be collected by the workers at this stage, to improve the technologies deployment process on-site.

5.11. HRC assessment through Agent-based modelling

This task will deal with the realization of an agent-based model environment to replicate the use cases scenarios and activities, to evaluate both the impact of the autonomous robot tasks on the human operators and from a safety and robot operation efficiency. Information will be collected from the end-users and from other technical activities (e.g.: robot workspace, autonomous path, tasks plan and cycle times). From this information, the created model will be able to reproduce and simulate the different parallel activities occurring in the working area, providing each modelled agent with a precise behaviour pattern and schedule. An extensive simulation campaign will be performed, to study the interactions between the robot and the other agents involved in the working environment.

Identified main requirements to build a model are the following:

- Description and measurements of the scenario layout
- List of agents involved
 - People
 - Maximum and minimum number of people involved
 - Description of the sequence of tasks they must execute
 - Drones, autonomous machines, etc.
 - Number involved and possible restrictions (for example, in 100m of tunnel only two autonomous machines can be present at the same time)



- Description of the sequence of tasks they must execute
- Possible constraints in the execution of some task (for example, the autonomous machine can only go straight or rotate by a maximum of X degrees)
- Dimensions
- Maximum and minimum velocity
- Security constraints in the interaction with workers

From these simulations, and as has been described in the use cases description and requirements, the possible evaluations and benefits of employing ABM are:

- Find the optimal configuration by simulating a large number of scenarios by varying input parameters (number of people, number of devices, duration of an activity...).
- Change agent trajectories to optimize the time needed to perform a task or meet safety constraints.
- Study human-robot interactions to estimate possible collisions (different areas of collisions can be defined).



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ⁱ <https://easylux.com.br/products/mini-reflecto-horizontal/>

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