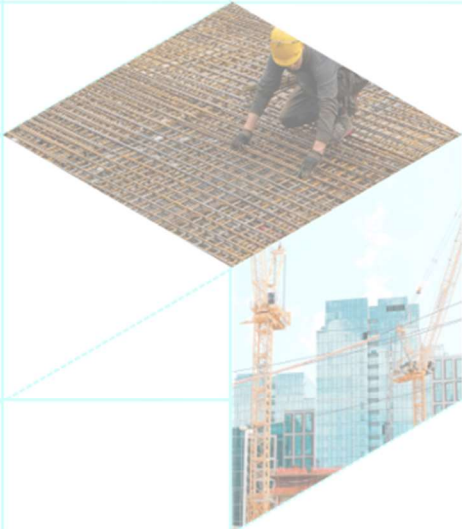




Common Methodology and Specifications for Case Study Development and Technology Integration Assessment

D7.1: Common Methodology and Specifications for Case Study Development and Technology Integration Assessment. WP 7, T 7.1

Authors: Carlos Martín-Portugués Montoliu (ACCIONA) and Antonio Alonso Cepeda (ACCIONA).



Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor the granting authority can be held responsible for them

Technical references

PROJECT ACRONYM	BEEYONDERS
PROJECT TITLE	Breakthrough European tEchnologies Yielding cOnstruction sOvereignty, Diversity & Efficiency of ResourceS
PROJECT COORDINATOR	Antonio Alonso Cepeda antonio.alonso.cepeda@acciona.com
PROJECT DURATION	June 2022 – November 2025 (42 months)

DELIVERABLE NO.	D7.1
DISSEMINATION LEVEL*	
WORK PACKAGE	WP 7 - Case Studies
TASK	T7.1 - Common Methodology and Specifications for Case Study Development and Technology Integration Assessment
LEAD BENEFICIARY	1 (ACCIONA)
CONTRIBUTING BENEFICIARY/IES	1 (ACCIONA), All partners belonging to WP7
DUE DATE OF DELIVERABLE	31 March 2024
ACTUAL SUBMISSION DATE	28 March 2024

* PU = PUBLIC

PP = RESTRICTED TO OTHER PROGRAMME PARTICIPANTS (INCLUDING THE COMMISSION SERVICES)

RE = RESTRICTED TO A GROUP SPECIFIED BY THE CONSORTIUM (INCLUDING THE COMMISSION SERVICES)

CO = CONFIDENTIAL, ONLY FOR MEMBERS OF THE CONSORTIUM (INCLUDING THE COMMISSION SERVICES)

Document versions

V	DATE	BENEFICIARY	AUTHOR
0.1	18/03/2024	ACCIONA	Antonio Alonso Cepeda
0.2	21/03/2024	ACCIONA	Carlos Martín-Portugués Montoliu
0.3	25/03/2024	TECNALIA	Jose Carlos Jimenez Fernandez
0.4	27/03/2024	INFRA PLAN	Daniel Rodik
0.5	27/03/2024	ICONS	Eva Martínez
1.0	28/03/2024	ACCIONA	Antonio Alonso Cepeda



Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them

Table of contents

Executive Summary.....	5
Introduction	6
Methodological approach.....	8
Development of the common methodology framework	8
Planning and Identification of resources required for each use case. Roles distribution.....	15
Preliminary discussions to select the applicability of KPIs for each of the use cases.	15
Creation of use case particularized KPIs lists and guidance to support data collection and impact assessment.....	19
Development of templates for the reporting of the demonstration campaigns and the comparison of BT technologies and reference scenarios as key part of the impact assessment	73
Conclusions.....	78



List of Tables

Table 1 List of the Beeyonders KPIs.....	15
Table 2: Outcomes of the Tunnel Use case:	22
Table 3: Outcomes of the Roads construction workshop	31
Table 4: Outcomes of the Building Construction workshop.....	39
Table 5: Outcomes of the Maritime construction – EU – Japan collaboration workshop	48
Table 6: Outcomes of the Road Maintenance workshop.....	57
Table 7: Outcomes of the Maritime construction workshop	65

List of Figures

Figure 1: Gantt chart of WP7	6
Figure 2 Tunnel construction – baseline scenario workflow	8
Figure 3 Tunnel construction - BT scenario workflow.....	8
Figure 4 Road construction – baseline scenario workflow.....	9
Figure 5 Road construction - BT scenario workflow.....	9
Figure 6 Building construction – installation works – baseline scenario workflow.	10
Figure 7 Building scenario installation works – BT integration of exoskeleton scenario workflow.....	10
Figure 8 Building construction – construction of one floor/building unit – baseline scenario workflow	10
Figure 9 Building scenario – construction of one floor/building unit – BT scenario workflow	11
Figure 10 Maritime caisson construction – baseline scenario workflow	11
Figure 11 Maritime caisson construction – BT scenario workflow	12
Figure 12 Japanese collaboration maritime caisson construction – baseline scenario workflow	12
Figure 13 Japanese collaboration maritime caisson construction – BT scenario workflow.....	12
Figure 14 Road maintenance – baseline scenario workflow	13
Figure 15 Road maintenance – BT scenario workflow	13
Figure 16: The methodological approach proposed	14



Executive Summary

BEEYONDERS' core ambition is to address the current challenges of the European construction sector by producing, commercializing, and integrating beyond the state-of-the art versatile solutions into real construction scenarios.

Deliverable D7.1 is designed with a dual purpose. On the one hand, establish the initial conditions and realistic characteristics of the key points that must be demonstrated in the 6 planned use cases. On the other hand, establish a common work methodology in all use cases, explaining the proposed indicators that will be used in each one, which will have to be completed as WP7 progresses by all participants, and whose values and results, will serve to quantify the achievements of the project in D7.8. These concepts are explained in Introduction section.

In the following section of Methodological approach, the work schemes that were developed in WP2, which established the baseline for each use case, are indicated. It is also explained the BEEYONDERS solution for each of them, and the functional units for its measurement.

The KPIs that were selected in D2.3 and D2.4 are presented. Their scopes of application include Economic, Environmental, Technical and Social performance of the technologies and cases studied. The KPI tables are included, and for each use case, the results on these ones from first discussions carried out in WP7. Additionally, an analysis of the most important technologies of each use case is performed in each one, showing the most relevant KPIs in tables and the value proposition based on the KERs, which are defined until this moment in the project.

Next, the methodology used in the workshops organized for each use case has been explained. Tables of the outcomes per use case are included, incorporating definition & input data for calculation and collection of information.

The deliverable adds a section on development of templates for the reporting of demonstration campaigns, and the comparison of BT technologies and reference scenarios as key part of the impact assessment. The result of the proposed templates is shown and will contain the key information for the measurement and evaluation of each use case during its life in the project and at the end of it.

Finally, the deliverable shows a series of conclusions regarding the work developed and its usefulness for the use cases, focusing specifically on the effort to harmonize a similar methodology and an equivalent way of measuring and evaluating the impact of technologies developed and integrated in use cases.



Introduction

According to the BEEYONDERS Gantt chart, in month 19th of the project, which corresponds to December 2023, WP7 – Case Studies began.

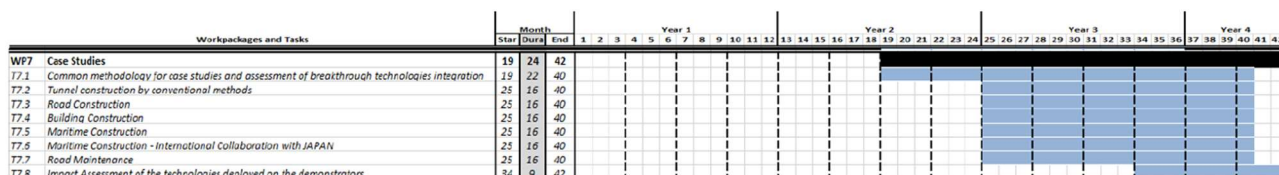


Figure 1: Gantt chart of WP7

This WP is proposed as a natural continuation of the task T2.5 – Testing Plan, and the evolution of the developments of all the technical WPs, which cover: WP3, WP4, WP5, and WP6; in which technology that is going to be implemented in real use cases, is currently being developed (tasks T7.2 to T7.7).

The structure of the WP7 has several peculiarities. On the one hand, it is a broad WP, since it covers 8 tasks; and on the other hand, it is a long WP, since it lasts from month 19 to month 42, which is the end of the project. Within it, it can be observed three very different parts:

- Task T7.1 - Common Methodology and Specifications for Case Study Development and Technology Integration Assessment, which is what this deliverable is about.
- Tasks T7.2 to T7.7 – They correspond to the implementation of the 6 use cases defined in the Grant Agreement: Tunnel construction by conventional methods, Road construction, Building construction, Maritime construction, Maritime construction – International Collaboration with JAPAN, and Road maintenance.
- T7.8 – Impact assessment of the technologies deployed on the demonstrators – This task will measure the results obtained in BEEYONDERS and their impact, in accordance with the established project objectives.

Focusing directly on T7.1, 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). As it was defined, T7.1 also has a triple objective:

1. Definition of a common methodology to ensure that the detailed specification of the case studies clearly map the technologies from WP3-6, that will be validated at the end of the project, as well as the adaptations and integrations needed for each of them.
2. Furthermore, the task will standardize and harmonize the validation campaigns of the different case studies, supervising the availability of all the technological components and the coordination of all needed human and material resources, looking for synergies among case studies, sharing applied technologies.



3. Additionally, to prepare common templates for the reporting of the demonstration campaigns, and for the collection and analysis of data that will support the assessment of the impacts in case studies, as well as the success of the integration of breakthrough technologies in task 7.8.

Task T7.1 remains active until month 40, which is when all the case studies will end, so that the supervision of them is ensured, and the same methodology is used for the generation and development of KPIs.

In the following sections, we will review the evolution of the case study schemes in their baseline and improvement proposal modality, developed in WP2. On the other hand, the workshops that have been carried out to specify the fundamental and transversal aspects to be demonstrated, will be explained. Subsequently, the KPI tables that have been defined to measure indicators of interest for the project, and which are appropriate for each scenario, will be explained. Finally, it will be shown how this information will be concentrated in other summary tables, which will formalize a consolidated tool for monitoring this task.



Methodological approach

Development of the common methodology framework

In WP2 (D2.3), to support the identification and selection of the appropriate Key Performance Indicators, technology processes workflows were developed for all BEEYONDERS use cases, referring to the series of steps and activities that are carried out for the completion of the analyzed task. These workflows were also developed for the reference scenarios referring to traditional procedures before BEEYONDERS. In both cases, functional units were defined to set up the reference and facilitate comparison.

The following figures were elaborated and summarize in a visual way, the different use cases in the project:

• CASE STUDY 1: Tunnel construction:

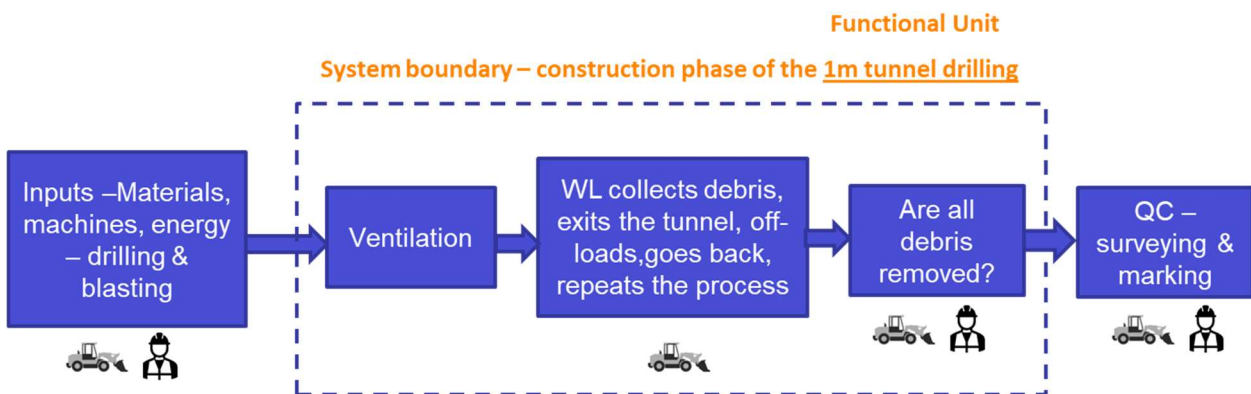


Figure 2 Tunnel construction – baseline scenario workflow

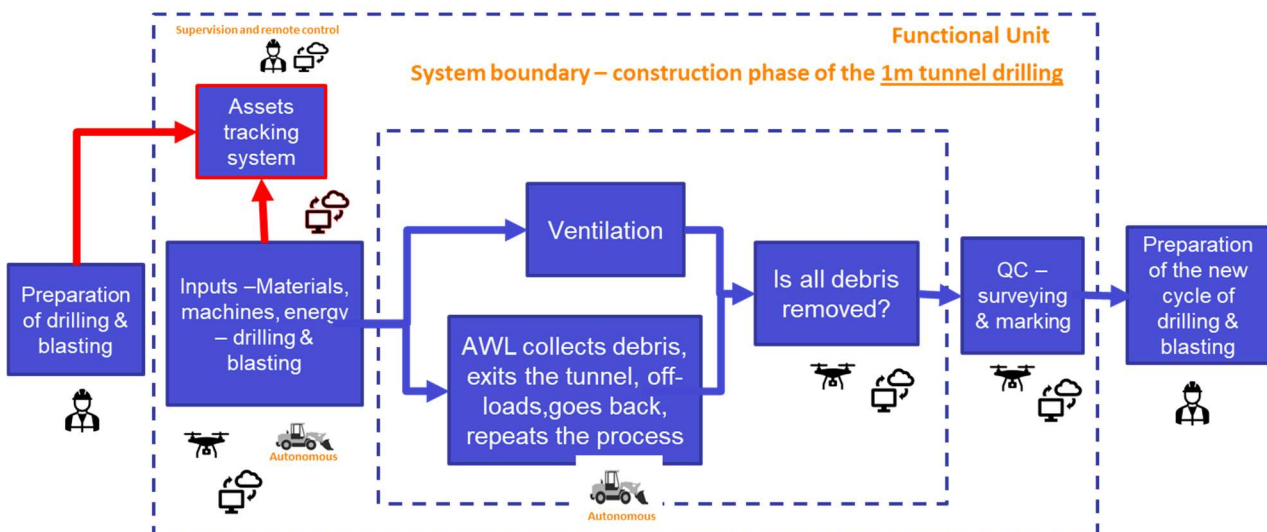


Figure 3 Tunnel construction - BT scenario workflow



• CASE STUDY 2: Road construction:

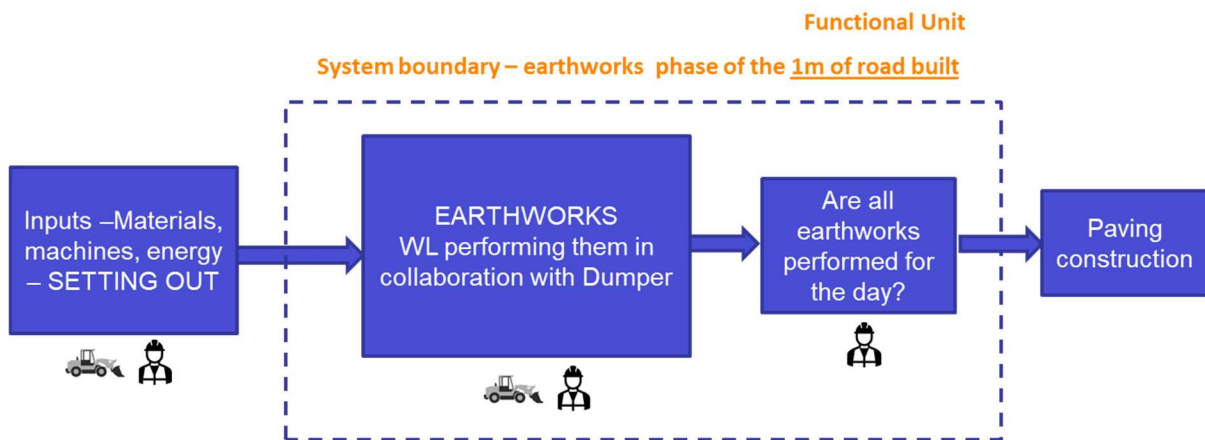


Figure 4 Road construction – baseline scenario workflow

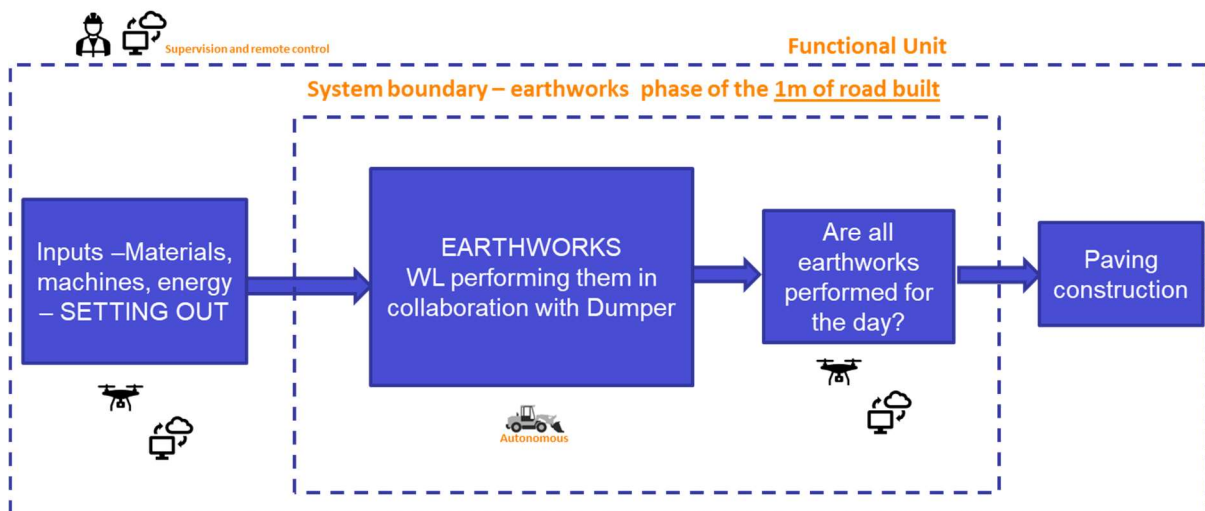


Figure 5 Road construction - BT scenario workflow



• CASE STUDY 3: Building construction:

System boundary – installation works at the building construction site
(FU: installation of 1 building product)

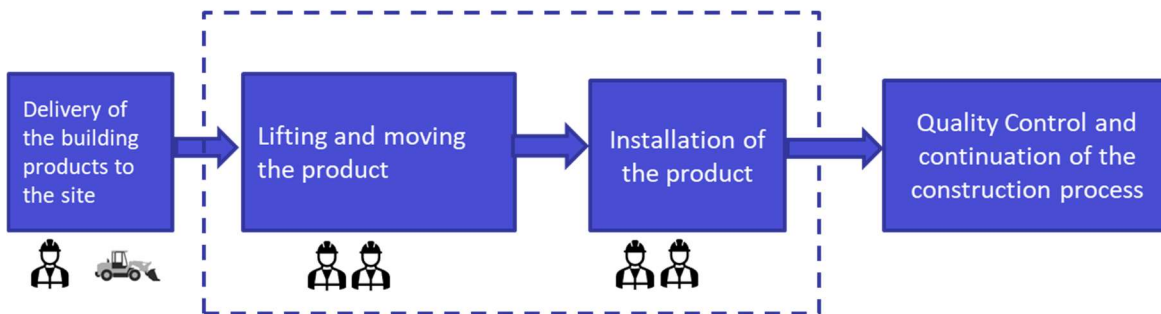


Figure 6 Building construction – installation works – baseline scenario workflow.

System boundary – installation works at the construction site of the building
(FU: installation of 1 building product)

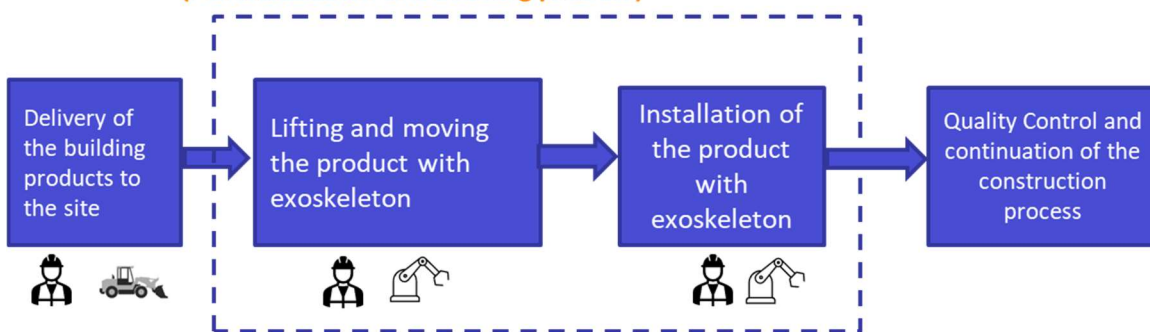
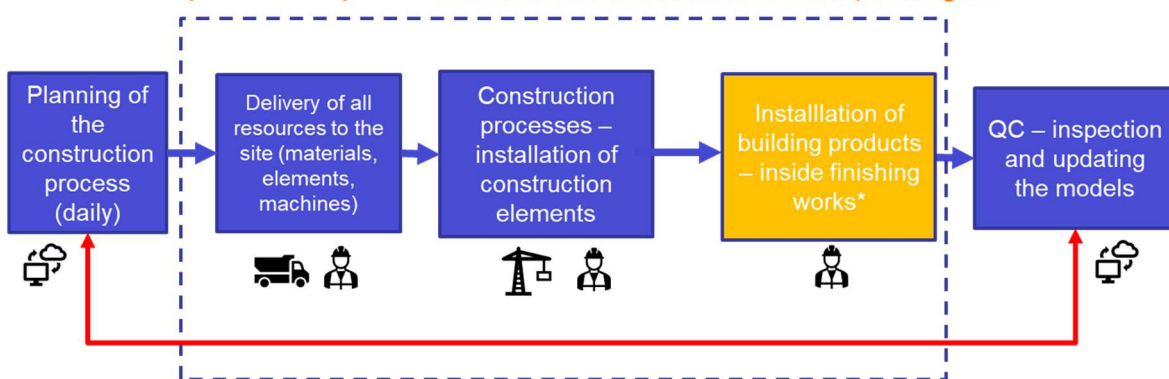


Figure 7 Building scenario installation works – BT integration of exoskeleton scenario workflow

System boundary **Functional Unit: construction of 1 floor / building unit**



* Presented in details before, as separate model for analysis

Figure 8 Building construction – construction of one floor/building unit – baseline scenario workflow



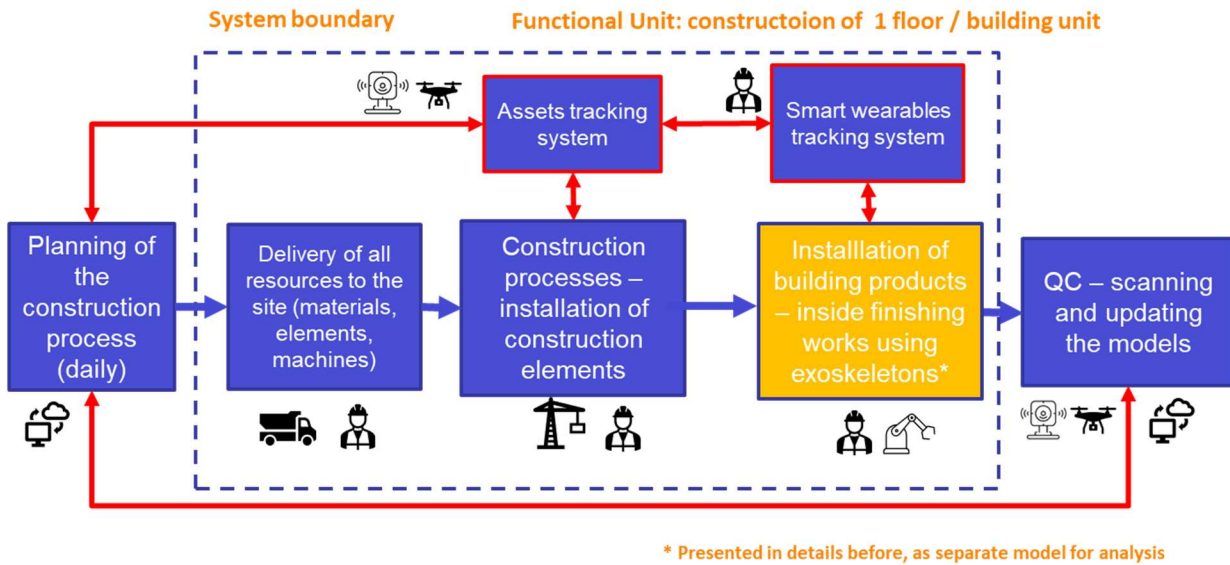


Figure 9 Building scenario – construction of one floor/building unit – BT scenario workflow

• CASE STUDY 4: Maritime construction:

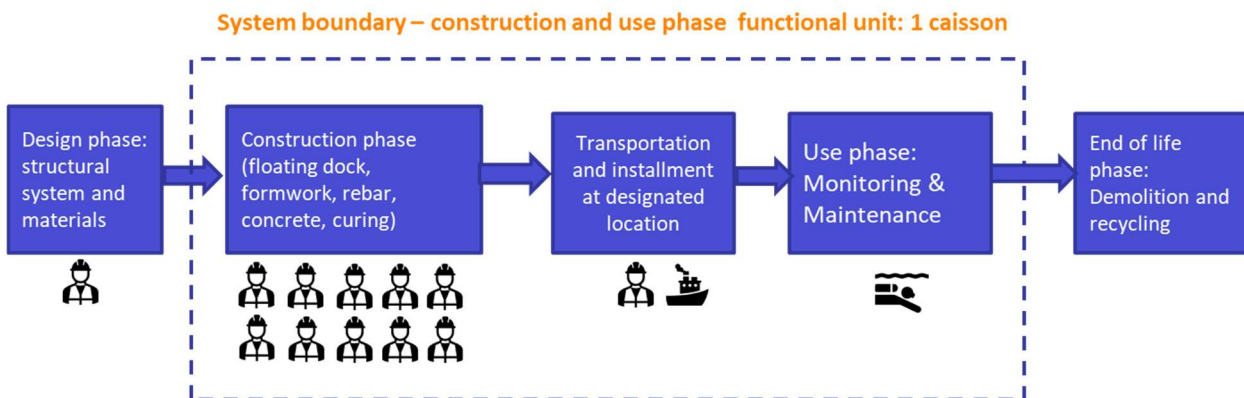


Figure 10 Maritime caisson construction – baseline scenario workflow



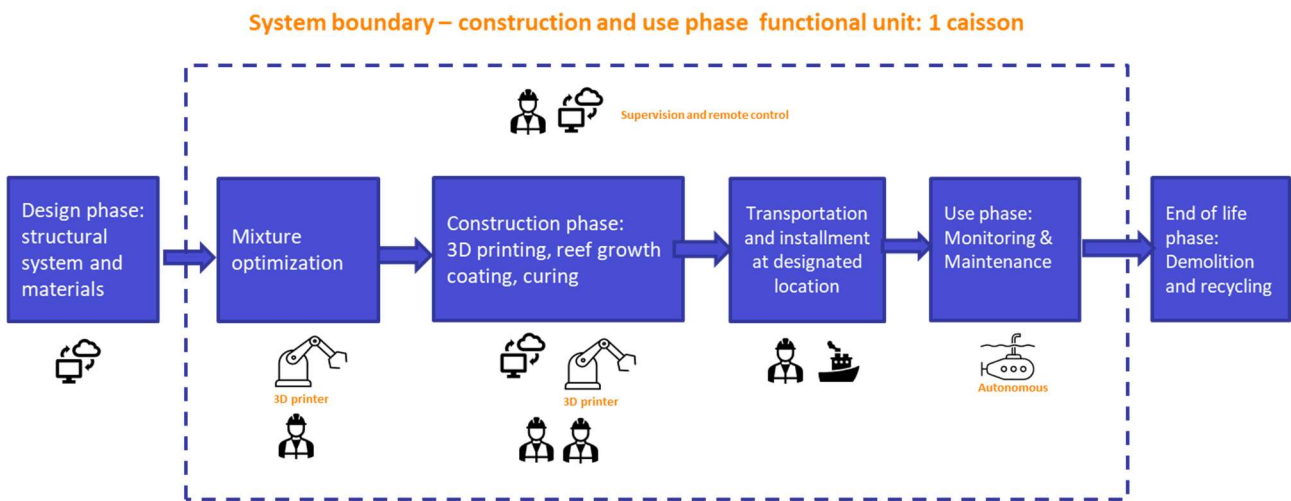


Figure 11 Maritime caisson construction – BT scenario workflow

• CASE STUDY 5: Japanese Maritime construction:

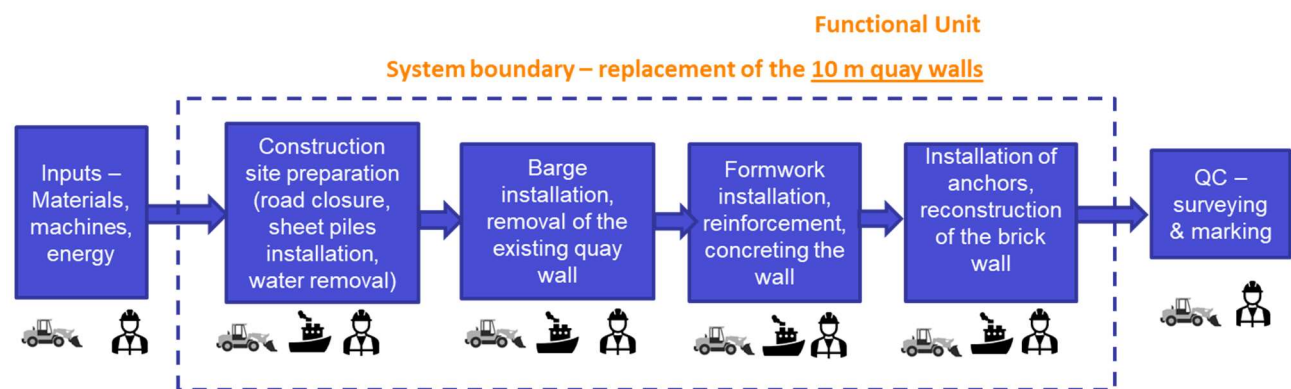


Figure 12 Japanese collaboration maritime caisson construction – baseline scenario workflow

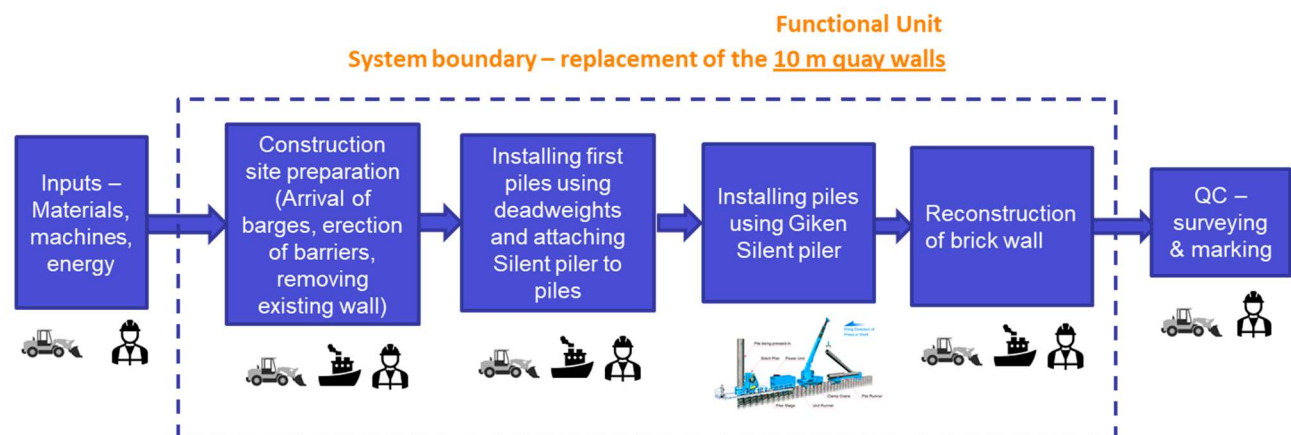


Figure 13 Japanese collaboration maritime caisson construction – BT scenario workflow



• CASE STUDY 6: Road maintenance:

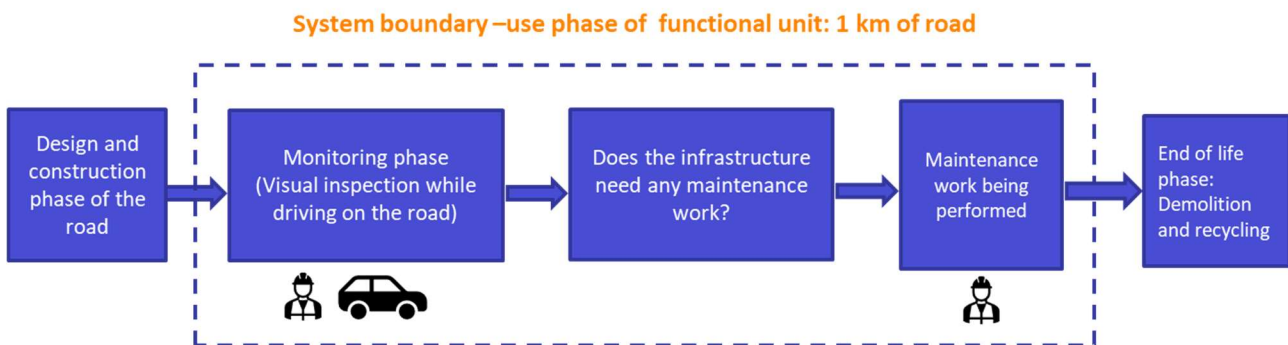


Figure 14 Road maintenance – baseline scenario workflow

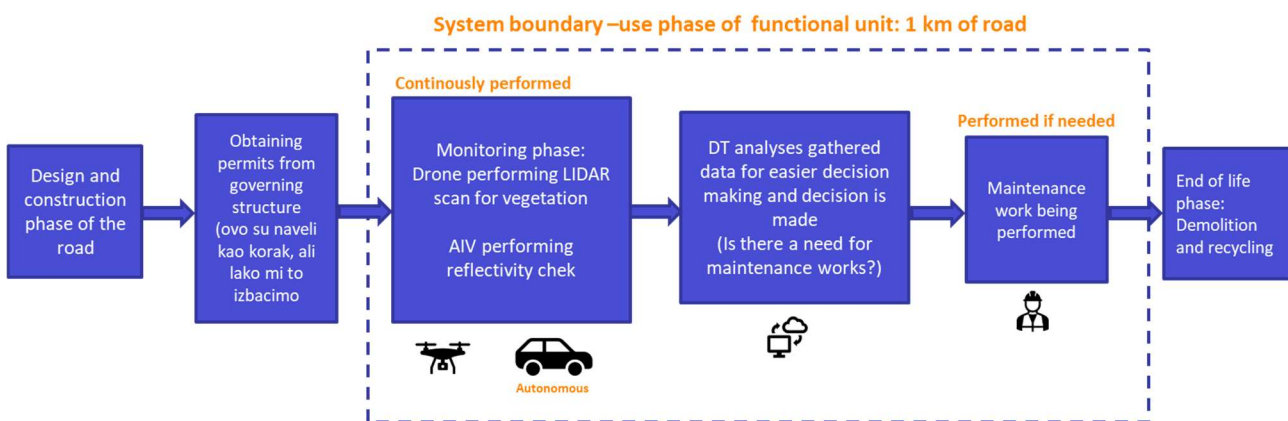


Figure 15 Road maintenance – BT scenario workflow

The analysis of both: baseline and BT scenarios, workflows and associated tasks were crucial for the identification of the BEEYONDERS KPIs (properly classified by the BT impact categories: Social, Environmental and Economy), and for understanding the various stages and activities included in each of the BEEYONDERS use cases.

In T7.1 this understanding was also useful to clearly map the technologies from WP3-WP6 that will be validated, to identify the adaptations and integrations needed for each of them, the associated resources (both human, materials and equipment) required and was valuable to define the common methodology for ensuring a coherent development of the demonstration and validation activities.

After the planning and identification of resources and responsibilities, it will be necessary to define the most suitable KPIs to facilitate the impact assessment. Assessment that will be configured and undertaken in Task 7.8, to quantify the expected impacts on the construction sector if BT are deployed. This includes:

- Increasing productivity in construction works
- Enhancing system efficiency and performance
- Facilitating Safety and wellbeing enhancements



- Reducing the labor shortage targeted (age, gender, disable, acceptance)
- Environmental impact reductions

For this reason, the comparison between reference scenarios following day to day practices and the BEEYONDERS use cases is crucial. Thus, it will be necessary to identify also during the first steps mentioned the pathways to collect the required information for setting up the baseline that will be considered for the impact assessment.

The overall process proposed for identifying the most suitable performance indicators for each use case and for defining the data to be collected and calculation methods for an adequate impact assessment involves the following steps:

- Preliminary discussions to select the applicability of KPIs for each of the use cases.
- Organization of devoted workshops to verify and refine the selection undertaken and identify the data to be collected involving all the actors in the demonstration activities.
- Development of guidance documentation to support data collection and impact assessment (including information on the KPIs selected: definition, calculation methods and data required. Linked to Task 7.8)
- Development of templates for the reporting of the demonstration campaigns and the comparison of BT technologies and reference scenarios as key part of the impact assessment (Linked to Task 7.8).

The process will be implemented on all use cases to track progress, identify areas for improvement, and make data-driven decisions that lead to better outcomes.

Figure 16 summarized the approach followed:

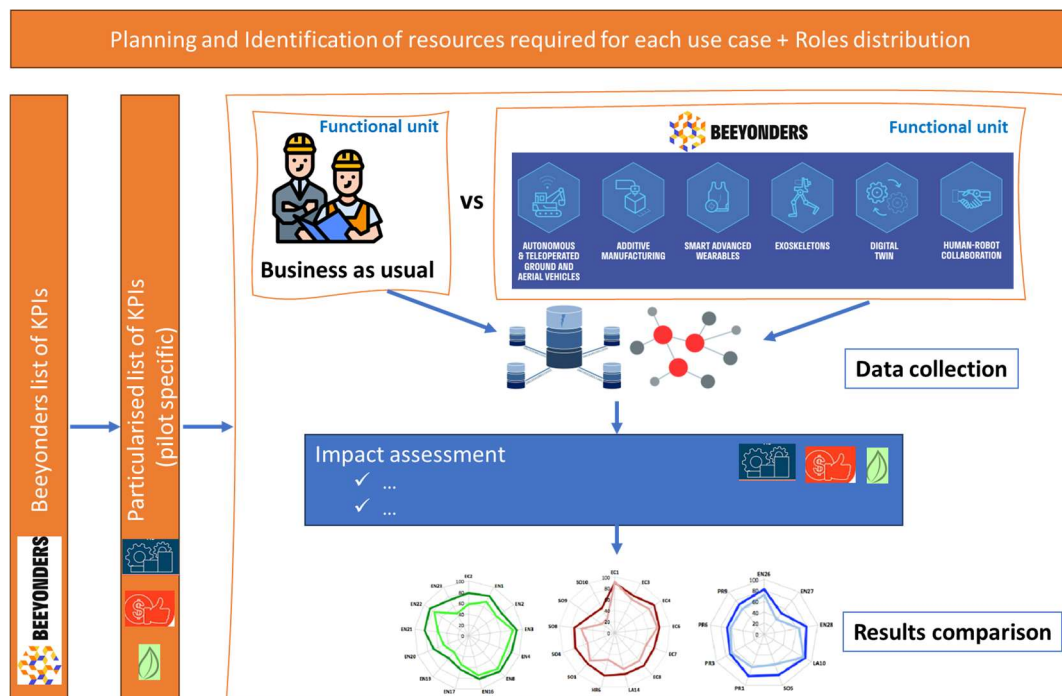


Figure 16: The methodological approach proposed.



Planning and Identification of resources required for each use case. Roles distribution.

The first steps proposed to set up a reliable and replicable methodology for the validation activities in BEEYONDERS, are mainly linked to the organization of activities and resources required for accomplishing the targets fixed for the different use cases. To avoid misunderstandings, errors and bad planning, it is proposed to define from the very beginning responsibilities among partners and mainly within use case leaders. These first step are:

1. Planning of all the use case activities based on the workflows already available for each use case.
2. Identification of all the resources required for undertaken the activities included in each workflow
3. Role's distribution (this includes the identification of Use case and activity leaders, data gathering responsible and quality assuring chief)

Preliminary discussions to select the applicability of KPIs for each of the use cases.

D2.3 - LCA/LCC KPIs and D2.4 - Workers KPIs describe the different key performance indicator selected in BEEYONDERS (Table 1) to describe the **Economic, Environmental, Technical and Social performance** of the BT and to facilitate the impact assessment.

Table 1 List of the BEEYONDERS KPIs

Dimension	Sub dimension	Macro-objective	ID No.	Name
Economy	Cost	Optimized life cycle cost and value	Ec1	Whole life cycle cost
			Ec2	Labour cost
			Ec3	Energy used
			Ec4	Depreciation cost
			Ec5	Materials used
	Maintenance cost	Optimized life cycle cost and value	Ec6	Maintenance cost of non-conventional machinery
			Ec7	Maintenance cost
	Non-compliance cost	Non-compliance economic impact	Ec8	Non-compliance cost
Environmental	Emissions / Environmental Impacts	Greenhouse gas emissions	Env1	Global warming potential (GWP)
		Other impacts on the environment	Env2	Particle matter and human toxicity
			Env3	Other impacts on the environment
			Env4	Photochemical Ozone Creation Potential
			Env5	Ozone Depletion Potential
			Env6	Acidification Potential
			Env7	Eutrophication Potential
			Env8	Ecotoxicity
		Other impacts on the environment and Healthy and	Env9	Noise generated



Dimension	Sub dimension	Macro-objective	ID No.	Name
		comfortable workspaces		
	Resources	Resource efficient and circular material life cycles	Env10	Energy demand
			Env11	Materials used/Materials consumption
			Env12	Water depletion
	Non-compliance impact	Non-compliance impact	Env13	Non-compliance environmental impact
	Biocompatibility	Biocompatibility	Env14	Area of habitat retained/created
Technical	Sub dimension	Macro-objective	ID No.	Name
			T2	Quality of the activities performed
			T3	Cycle Time
			T4	Time needed to prepare floating dock for production
			T5	Distance covered by machinery excluding drones
			T6	Distance covered by drones
			T7	Functional units accomplished
			T8	Failure rate
	Autonomy	Autonomy	T9	Time of full autonomous operation
			T10	Percentage of tasks that use drones
			T11	Percentage of tasks that use autonomous vehicles
	Reliability	Reliability	T12	Accuracy of data
Social	Inclusiveness	Gender inclusion	S1	Women willingness
			S2	Women capability
			S3	Wearables and exoskeleton fit for women's physical traits
			S4	Older workers capability
		Age inclusion	S5	Potential for attraction of younger generations
			S6	Pregnancy Friendly Environment
		Disability inclusion	S7	Usability of BT for people with disabilities
	Workers	Healthy and comfortable space	S8	Motivation Improvement
			S9	Indoor air quality
			S10	Fatigue detection
			S11	Perception of Fatigue reduction
			S12	Muscular strain and back-injuries prevention
			S13	Perception of musculoskeletal loading reduction
			S14	Safety perception
		Safe workers spaces	S15	Alert system detection
			S16	Detection of man down situations



	Performance	S17	Recognition of dangerous locations for workers
		S18	Performance enhancement
		S19	Level of training required
		S20	Compatibility of wearables with other worker tasks performed
	Technology Acceptance	S21	Technology complexity
		S22	Perceived usefulness
		S23	Existing knowledge and confidence about the technology and its use
		S24	Comfort Level
		S25	Perception of control of the technology and own body

Taking into consideration that the nature of each BT and use case is different, the impact expected will be different as well, internal discussions were planned to define in advance the applicability of KPIs and the value proposition of each BEEYONDERS technology linking it with the project Key Exploitable Results (KERs). The following is a summary of the preliminary conclusions for each case study.

Case study 1: Tunnel construction



- ✓ **Most relevant KPIs:** Technical KPIs (e.g., Cycle Time (T3) and Functional units accomplished (T7) and Social KPIs (e.g., Indoor air quality (S9) and S20 Compatibility of BT with the task performed by workers).
- ✓ **Value proposition based on KERs (Part B):** KER 2: An autonomous / teleoperated wheel loader, and KER 3: An autonomous drone tailored to flight in non-GPS areas and adapted to underground works. Discussions during the workshops should be oriented to select the KPIs and data required to facilitate the impact assessment required to accomplish the target of reducing of idle times. So, it is considered that the proposed coordinated use of drones, autonomous vehicles, and tele-operated machinery vs the traditional way to construct tunnels will allow reducing idle times between 10% and 12.5% after detonation for Drilling & Blasting tunnels.

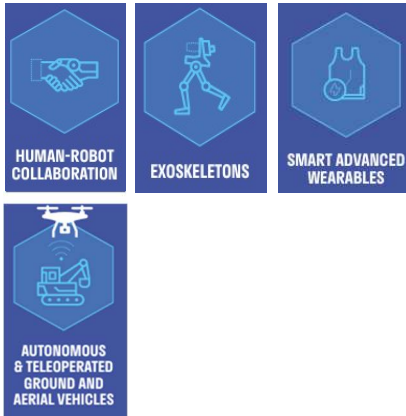
Case study 2: Road construction



- ✓ **Most relevant KPIs:** In this case, the environmental and economic indicators are the key ones to reflect the impact of energy savings (e.g., Ec3 Energy used and Env 1 Global warming potential (GWP))
- ✓ **Value proposition based on KERs (Part B):** KER 2 An autonomous / teleoperated wheel loader. Discussions during the workshops should be oriented to select the KPIs and data required to facilitate the impact assessment required to accomplish the target of reducing fuel consumption. So, it is considered that the collaborative use of drones and autonomous vehicles with real time follow-up progress through the DT will allow process optimization leading to fuel consumption reduction of 10%.



Case study 3: Building construction



- ✓ **Most relevant KPIs:** This is maybe the most complex use case as there is balance between technical performance and social aspects that are enhanced using exoskeletons. However, it is clear that is the case closer to the worker's subdimension KPIs, and as a consequence the indicators linked with health and safety (e.g. S10-S14), inclusiveness (S1-S7) and workers performance (S18 and. Finally, Technical KPIs (e.g. Cycle Time (T3) and Functional units accomplished (T7)) are also quite relevant to this case study.
- ✓ **Value proposition based on KERs (Part B):** KER 3: An autonomous drone tailored to flight in non-GPS areas and adapted to underground, KER 7: An exoskeleton capable of assisting both the lower-back and the arms in a unique device and KER 8: Wearables integrated in Personal Protective Equipment for worker H&S and monitoring. Discussions during the workshops should be oriented to select the KPIs and data required to facilitate the impact assessment required to accomplish the targets of reducing idle times associated to drones scanning functionalities and reducing back injuries and how to deal with the potential of BTs to increase inclusiveness and gender issues. So it is considered that the building case study will demonstrate a reduction of 8.3% in idle times thanks to the integration of drones for scanning tasks executed the day before (at night), finding errors, and forecasting tasks. Related to wearables and exoskeletons, it is estimated a reduction of sick leaves due to lower back injuries, at least of 50% of current ones, increasing any gender/age workers endurance at least, by 20%.

Case study 4: Maritime construction



- ✓ **Most relevant KPIs:** In this case study the most relevant indicators will be the associated to environmental and economic performance. In particular linked to biodiversity promotion and materials consumption (Env 14 Area of habitat retained/created, Ec5 and Env 11 Materials used and Materials consumption). Technical and Economic KPIs such as Cycle Time (T3), Time needed to prepare floating dock for production (T4) and Labour cost (as traditional formworks are super intensive in the use of human resources) are also quite relevant for the maritime case.
- ✓ **Value proposition based on KERs (Part B):** KER 5: Optimized and bio-compatible mortars adapted to 3D-printing for maritime ecosystems, and KER 6. 3D printing equipment capable of working in vertical walls of caisson formworks for maritime.



Discussions during the workshops should be oriented to select the KPIs and data required to facilitate the impact assessment required to accomplish the targets of reducing costs and materials consumption while facilitating biodiversity promotion. So, it is considered that To achieve at least, a net profit of 15% vs traditional formworks systems for maritime caissons construction, considering the amortization of 3D printer and special mortars vs traditional ones.

Case study 5: Japanese maritime construction



- ✓ **Most relevant KPIs:** The most relevant indicators will be the associated to environmental and economic performance. In particular linked to energy consumption (Ec5 and Env 11 Materials used and Materials consumption, and Env 10 and Ec3 Energy demand and Energy used). Technical and Economic KPIs such as Cycle Time (T3), Functional units accomplished (T7) with especial attention to the Accuracy of data (T12) to support the geotechnical analysis.
- ✓ **Value proposition based on KERs (Part B):** KER 9: Construction Digital Twin platform and added value services. Discussions during the workshops should be oriented to select the KPIs and data required to facilitate the impact assessment required to accomplish the target of reducing costs. So, it is considered that The primary advantage in developing improved capacity models is to optimise pile lengths. According to the real case of “Assumptions”, we can expect average savings of 10M€ per similar works.

Case study 6: Road maintenance



- ✓ **Most relevant KPIs:** As in the previous use case, the most relevant indicators will be the associated to environmental and economic performance. In particular linked to energy consumption (Env 10 and Ec3 Energy demand and Energy used)
- ✓ **Value proposition based on KERs (Part B):** KER 4. An autonomous ground mobile platform for inspection and maintenance tasks of large areas. Discussions during the workshops should be oriented to select the KPIs and data required to facilitate the impact assessment required to accomplish the target of reducing energy consumption. So, it is considered that Fuel consumption reduction replacing conventional vehicles by drones for the accomplishment of inspection tasks. Savings as bigger as 50%-70% are expected.

Creation of use case particularized KPIs lists and guidance to support data collection and impact assessment.

Six dedicated workshops have been arranged to assess all case studies, involving those partners involved in each use case. The modality has been online, which has allowed plenty of participation, its correct spacing, and its adequate preparation from the beginning, in month 19 to month 22.

The outcomes of the different workshops arranged were a use case particularized list of KPIs and guidance to support data collection and the impact assessment planned in Task 7.8.



It should be remarked that the applicability of some KPIs is not clear yet considering actual level of development of the use case, thus, at this stage applicability will be marked as “?”. The progress of the different tasks in WP7 (from T7.2 to T7.8) will clarify the uncertainties and will define applicability.

Tunnel construction

This workshop was held on 10th January 2024. Two main objectives were set. On the one hand, determine at a practical and more specific level, what the main demonstration milestones are planned, ensuring that all partners are on the same page. On the other hand, explain the initial KPIs that have been selected at a productive, economic, environmental, and related to the workers level, who will operate the demonstrator.

Three sequential demonstration sub scenarios have been defined: the first will consist of scanning the tunnel using the drone, obtaining a detailed map of the tunnel environment after the simulated explosion. The second will consist of access by the wheel loader using the previously scanned information and its systems until reaching the workplace. Finally, the third will consist of carrying out the task of collecting the debris by the wheel loader and extracting and unloading it to the truck outside.

Some key technical aspects to be considered:

- Use of thermographic camera embedded in the drone to get additional information of the tunnel once the smoke is activated and to potentially detect unexploded explosives or presence of water leakage if the demonstrator allows to test this kind of variables.
- It will be important to be able to see the image of video in relation to what vehicles are “seeing” in almost real time.
- A complete system of alarms is needed to warn about any problem the autonomous vehicles can find.
- It is considered necessary to monitor the level of fuel, presence of gases, and tire pressure, among other variables of the wheel loader machine.
- Position and speed of ground/aerial autonomous vehicles have to be tracked in real time.
- A camera facing the ceiling will be installed in one of the vehicles for detecting instabilities.
- Protected Wi-Fi systems in the tunnel will be installed every 200 meters approximately.

At technical level, the idea of well defining the human machine interface (HMI) of each use case has been emphasized, collaborating with the end users and the rest of the partners, with CSTB partner (responsible for HMIs designing). It is considered very important to have HMIs appropriate to the monitoring and needs of construction managers, being these homogeneous with the rest of the use cases.

Data exchange generated in this use case will be supervised and integrated into a higher-level layer of Digital Twin, which will be common to all case studies of the project.

The second part of the workshop was dedicated to the selection of the most suitable KPIs for the Tunnel construction case study and associated guidance for an accurate data collection and to define a more precise value proposition linked to the associated KERs as described in the previous sub-section.



Value proposition based on KERs (Part B):

The proposed coordinated use of drones, autonomous vehicles, and tele-operated machinery vs the traditional way to construct tunnels will allow reducing idle times between 10% and 12.5% after detonation for Drilling & Blasting tunnels.

The following table summarises the other outcomes of the workshop on KPIs and guidance:



Table 2: Outcomes of the Tunnel Use case:

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec1	Whole life cost	No	Indicator does not apply due to limited boundaries	
Ec2	Labour cost	Yes	Total labour cost per month. Total sum of salaries including benefits and overtime pay for workers on the site including accommodation, insurance, food, allowances etc. (€/month) separated as: No. of workers per month, cost per worker; (€/person month)	Payroll records, Construction logbook, construction management project
Ec3	Energy used	Yes	Cost of total energy used based on all machinery deployed; Electricity used per workday or month (kWh), diesel used per workday, month (lit) gasoline (lit), other etc. Energy prices (€/kWh, €/lit.)	Consumption records for machinery and equipment, load specific energy usage details
Ec4	Depreciation cost	Yes	Average depreciation cost for all machinery (€/month)	Accounting records, Equipment maintenance logs, Vendor and/or manufacturer documentation
Ec5	Materials used	No	Indicator does not apply	
Ec6	Maintenance cost of non-conventional machinery	Yes	Total amount due to maintenance and repairs of the non-conventional machinery, which includes: cost of repairs, cost of non-conventional maintenance activities and cost due to the stop of the site to repair the different BT). Average cost of repairs (€/month), average cost of non-conventional maintenance activities (€/month), average cost due to the stop of the site to repair the different BT (€/month)	Maintenance and repair expenses, Maintenance records, Service provider invoices, Equipment downtime logs, Project management reports

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec7	Maintenance cost	Yes	Total amount due to maintenance and repairs of the asset (it includes cost of repairs and regular maintenance costs). Average cost of repairs and regular maintenance (€/month)	Collection of historical data, Repair invoices, Regular maintenance invoices, bill of quantities from maintenance design project
Ec8	Non-compliance cost	Yes	Average cost of detection, registration and corrective measures (€/month)	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env1	Global warming potential (GWP)	Yes	Is the generally accepted equivalent of greenhouse gas accumulation and represents the cumulative effect of a list of greenhouse gases recognized in ISO/TS 14067 _Annex A.	Total direct and indirect GHG emissions reported as: - GHG inventory - list of GHG sources according to ISO 14064 - category of emissions (combustion, fugitive, indirect, products,...) - GWP tonnes of CO ₂ eq per category and source Emissions data, GWP factors, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env2	Particle matter and human toxicity	Yes	Amount of emitted particle matter (PM) and other non-GH gasses affecting health of living beings and environment (micrograms per cubic meter µg/m ³)	Continuous air pollution monitoring, Meteorological data, Particulate matter samplers or monitors
Env3	Other impacts on the environment	No	Indicator does not apply	

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env4	Photochemical Ozone Creation Potential	TBD ¹	Measure of potential of an activity or a system to contribute to the formation of ozone in the lower atmosphere. Amount of formed reactive substances (mainly ozone) by the action of sunlight which are hazardous to human health and ecosystems and which also may damage crops. ($\mu\text{g}/\text{m}^3$)	Emissions data, Environmental impact assessments, Bill of quantities, GPS tracking devices. Emissions from wheel loader will be obtained by DTU from operational engine datasets obtained.
Env5	Ozone Depletion Potential	TBD	Relative amount of degradation to the ozone layer it can cause. List of ozone depletion substances (ODS) and emissions. (kg CFC-11-eq) (e.g. cooling systems)	Environmental impact assessment, Emissions measurement and product specifications
Env6	Acidification Potential	TBD	Acidifying impacts due to pollutants cause a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) discharge into the environment. (kg mol H^+)	Environmental impact assessment, Emissions measurement and product specifications
Env7	Eutrophication Potential	TBD	Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. Amount of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. kg PO_4 -eq, kg N-eq (marine), mol N-eq (terrestrial)	Environmental impact assessment, Eutrophication factors, Emissions measurement and product specifications
Env8	Ecotoxicity	TBD	Impact on ecosystems, as a result of emissions of toxic substances to air, water and soil. Amount of substances causing the direct or indirect disappearance (e.g., through affecting reproduction) of the animal or vegetable species of an ecosystem. This indicator has three aspects: Freshwater aquatic ecotoxicity, Marine ecotoxicity, Terrestrial ecotoxicity.e.g. chemicals used, explosives (g, kg)	Ecotoxicity factors, Environmental impact assessment

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env9	Noise (and vibration) generated	Yes	Amount of noise generated by construction activities throughout the duration of the process. (dB). Vibrations is also a key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.	Noise and vibration monitoring records, on-site measurements, environmental impact assessment
Env10	Energy demand	Yes	Total demand of energy within the project timeline, encompassing energy consumed by machinery, load-specific requirements, and other energy usage. (see Ec3)	see Ec3
Env11	Materials used/Materials consumption	Yes	KPI measures the total amount of materials utilized in the project, encompassing both construction materials and chemicals. This KPI is essential for assessing resource utilization, tracking inventory levels, and managing costs effectively. Total sum of all materials used (e.g. chemicals used, explosives,...) m3, tons, kg, litres, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Env12	Water depletion	Yes	Total amount of water used in project timeline (m3)	Water usage records
Env13	Non-compliance environmental impact	Yes	See Ec8	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env14	Area of habitat retained/created	Yes	Ecologically valuable habitat created and/or retained within the total area of the site for a completed project. Measure of the changes in soil quality (Biotic production, Erosion resistance, Mechanical filtration). (area km2)	Environmental impact assessment, biodiversity action plans

¹ TBD – to be determined after the impact assesment of the technology deployed (T 7.8)

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
T1	Workers required	Yes	Number of workers required for the defined functional unit (see Ec2)	Project schedules, Construction management project, Input from supervisors, Labor productivity standards
T2	Quality of the activities performed	Yes	Compliance with quality objectives of the activity %	Quality objectives, Inspection criteria, Quality control reports, Expert assessment
T3	Cycle Time	Yes	Total time to finalise 1 functional unit, it includes time to complete the activity + idle time. Detailed dynamic plan of all processes with Cycle times	Time-tracking system, Work log, Daily reports, Observation or direct measurement
T4	Time needed to prepare floating dock for production	No	Indicator applies to maritime use case only	
T5	Distance covered by machinery excluding drones	Yes	Total Distance (meters) covered by the machinery during operation	GPS tracking systems
T6	Distance/surface covered by drones	Yes	Total Distance covered by the drone during operation	Drone telemetry data
T7	Functional units accomplished	Yes	Total functional units accomplished/day	Construction logbook, Work completion report, Quality control records, Project management documentation
T8	Failure rate	Yes	Failure rate completing a task	Quality control records, Work logs, Incident reports
T9	Time of full autonomous operation	Yes	# of tasks failed/ # of tasks attempted	Autonomous systems telemetry data, Human intervention records, Equipment operating schedule
T10	Percentage of tasks that use drones	Yes	Amount of time of autonomous operation/Total amount of time in operation	Project documentation, Drone flight records
T11	Percentage of tasks that use autonomous vehicles	Yes	$(\text{Number of tasks that use drones} / \text{Total number of tasks}) \times 100$	Project documentation, Vehicle tracking systems along with vehicle logs
T12	Accuracy of data	Yes	This KPI measures the accuracy of data collected during the operations. Data accuracy is crucial for making informed decisions, identifying trends and ensuring analytical insights.	Quality control, Third-party audit, Data comparison

			(Number of accurate data points / Total number of data points) x 100	
	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S1	Women willingness	Yes	The extent to which women would be willing to do the job/task before and after the implementation of the BT	Focus group/interview
S2	Women capability	Yes	The extent to which women would feel capable of performing the task/job	Focus group/interview
S3	Wearables and exoskeletons fit for women's physical traits	NO	Women's physical traits integrated into the design of wearables and exoskeleton	Focus group/interview
S4	Olders workers capability	?	The extent to which workers aged +55 would feel capable of performing (or continue performing) this task	Focus group/interview
S5	Potential for attraction of younger generations	Yes	The extent to which young individuals would feel interested in performing this job.	Focus group/ interview
S6	Pregnancy Friendly Environment	Yes	Whether the working environment is safe for pregnant women	Focus groups / interview
S7	Usability of BT for people with disabilities	Yes	BT usability for people/workers with disabilities	Focus groups/ interview
S8	Motivation improvement	Yes	Improvements in motivation to perform the job	Questionnaire with workers
S9	Indoor air quality	Yes	Good quality indoor air. This KPI measures both, subjective and objective parameters of indoor air quality.	Questionnaire with workers and BT generated data
S10	Fatigue detection	NO	Reduction in worker's fatigue	BT generated data
S11	Perception of fatigue reduction	NO	Comparability between worker's fatigue perception and sensor measurements	BT generated data and questionnaire
S12	Muscular strain and back-injuries prevention	NO	Perceived reduction of muscular strains and back-injuries	Questionnaire with workers

S13	Musculoskeletal loading reduction	NO	Workers' perception of musculoskeletal loading reduction	Questionnaire with workers
	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S14	Safety Perception	Yes	The extent to which workers feel safe whilst performing this job	Questionnaire with workers
S15	Alert system detection	Yes	Worker's capacity of hearing BT alerts when in a risky situation/position	Questionnaire with workers
S16	Detection of man down situations	NO	This indicator measures the ability of the technology to detect when a worker has fallen or become incapacitated, and alert others to the situation.	Questionnaire with workers
S17	Recognition of dangerous locations for workers	NO	This indicator measures the ability of the technology to identify and alert workers or supervisors of hazardous areas or situations that could pose a risk to worker safety	Questionnaire with workers
S18	Performance enhancement	Yes	Perception of performance enhancement	Questionnaire with workers
S19	Level of training required	Yes	Level of training required to perform this task	Questionnaire
S20	Compatibility of BT with the task performed by workers	Yes	Perception of compatibility of BT with the task being performed by the worker	Questionnaire with workers
S21	BT complexity	Yes	Perceived ease of use	Questionnaire with workers
S22	Perceived usefulness	Yes	Perceived usefulness of the BT in performing the task	Questionnaire with workers
S23	Existing knowledge and confidence about the BT and its use	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
S24	Comfort level	NO	This KPI is a complex indicator covering aspects such as: • perception of weight, • thermal comfort, • noise level • Perception of fit between body and BT * The worker will give a % weight to each of the aspect in order to calculate the indicator according to the workers' preference	Questionnaire with workers

S25	Being in control of the BT and own body	NO	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
-----	---	----	---	----------------------------

Roads construction

This workshop was held on 19th January 2024. In the same way as in the Tunnel workshop, two main objectives were set. First one related to determine at a practical and more specific level the actions to be demonstrated, and the second one, the explanation of the initial KPIs that have been selected at a productive, economic, environmental, and related to the workers level, who will operate the demonstrator.

Due to the scope of the project (TRL6), as in the Tunnel case study, one of the main aspects that has been decided for the Road demonstrator is not to work in an infrastructure of this type in production, but in a fenced space next to it. Working in this way, developers and technologists can freely carry out tests with autonomous vehicles, so that they are not interfered by personnel and machinery in production. It has been decided that it would be very convenient to have a real road-testing space about 100 meters long by 70 or 80 meters wide.

In this case, communications between vehicles will be simpler than in the previous case, since on the one hand, both vehicles have full GPS capacity, and on the other, communications between them are not physically limited since the space is completely open.

The objective should focus on optimizing the operation of both autonomous systems (drone + wheel loader), to work in coordination, carrying out earthworks tasks, reducing the fuel consumption of the activity. In addition, the set of both vehicles will be equipped with systems to avoid workers and dangerous areas.

The same comment than in Tunnel use case about HMI applies in this case study, considering very important to have HMIs appropriate to the monitoring and needs of road construction managers, and based on the same architectures than in the rest of the use cases.

Data exchange generated in this use case will be supervised and integrated into a higher-level layer of Digital Twin, which will be common to all case studies of the project.

During the workshop, the BT provider: STAM confirmed that their environmental sensors measure PM, Voc, temperature, humidity and NOx (useful for KPI Env2 Particle matter and human toxicity) and that if some hazardous areas in the working site can be defined a-priori, the tracking system for workers developed by STAM could be used to understand if workers are present within those areas.

STAM also remarked that it should be clarified if there is any BT implemented in this scenario that should facilitate the work carried out by women, and how in this scenario BTs should reduce back injuries.

The second part of the workshop was dedicated to the selection of the most suitable KPIs for the Roads construction case study and associated guidance for an accurate data collection and to define a more precise value proposition linked to the associated KERs as described in the previous sub-section.

Value proposition based on KERs (Part B):

The collaborative use of drones and autonomous vehicles with real time follow-up progress through the DT will allow process optimization leading to fuel consumption reduction of 10%.

The following table summarises the other outcomes of the workshop on KPIs and guidance:



Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor the granting authority can be held responsible for them

Table 3: Outcomes of the Roads construction workshop

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec1	Whole life cost	No	Indicator does not apply due to limited boundaries	
Ec2	Labour cost	Yes	Total labour cost per month. Total sum of salaries including benefits and overtime pay for workers on the site including accommodation, insurance, food, allowances etc. (€/month) separated as: No. of workers per month, cost per worker; (€/person month)	Payroll records, Construction logbook, construction management project
Ec3	Energy used	Yes	Cost of total energy used based on all machinery deployed; Electricity used per workday or month (kWh), diesel used per workday, month (lit) gasoline (lit), other etc. Energy prices (€/kWh, €/lit.)	Consumption records for machinery and equipment, load specific energy usage details
Ec4	Depreciation cost	Yes	Average depreciation cost for all machinery (€/month)	Accounting records, Equipment maintenance logs, Vendor and/or manufacturer documentation
Ec5	Materials used	TBD	Total amount of materials used (both construction materials and chemicals, including but not limited to concrete, cement, aggregates, steel, asphalt, bitumen, additives, etc.) Unit of measure: cubic meters, tons, kilograms, liters, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Ec6	Maintenance cost of non-conventional machinery	Yes	Total amount due to maintenance and repairs of the non-conventional machinery, which includes: cost of repairs, cost of non-conventional maintenance activities and cost due to the stop of the site to repair the different BT. Average cost of repairs (€/month), average cost of non-conventional maintenance activities (€/month), average cost due to the stop of the site to repair the different BT (€/month)	Maintenance and repair expenses, Maintenance records, Service provider invoices, Equipment downtime logs, Project management reports

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec7	Maintenance cost	TBD	Total amount due to maintenance and repairs of the asset (it includes cost of repairs and regular maintenance costs). Average cost of repairs and regular maintenance (€/month)	Collection of historical data, Repair invoices, Regular maintenance invoices, bill of quantities from maintenance design project
Ec8	Non-compliance cost	Yes	Average cost of detection, registration and corrective measures (€/month)	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env1	Global warming potential (GWP)	Yes	Is the generally accepted equivalent of greenhouse gas accumulation and represents the cumulative effect of a list of greenhouse gases recognized in ISO/TS 14067 _Annex A.	Total direct and indirect GHG emissions reported as: - GHG inventory - list of GHG sources according to ISO 14064 - category of emissions (combustion, fugitive, indirect, products,...) - GWP tonnes of CO ₂ eq per category and source Emissions data, GWP factors, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env2	Particle matter and human toxicity	Yes	Amount of emitted particle matter (PM) and other non-GH gasses affecting health of living beings and environment (micrograms per cubic meter µg/m ³)	Continuous air pollution monitoring, Meteorological data, Particulate matter samplers or monitors
Env3	Other impacts on the environment	Yes	Indicator to show if the BT have other relevant impacts on the environment apart from contributing to Global Warming Potential and affecting living beings and environment. If high, it must be reported separately the indicator contributing to that higher impact on the environment (e.g., acidification potential, ozone depletion, ecotoxicity, etc.) Environmental impact of Lithium drone batteries?	Pollution monitoring

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env4	Photochemical Ozone Creation Potential	TBD	Measure of potential of an activity or a system to contribute to the formation of ozone in the lower atmosphere. Amount of formed reactive substances (mainly ozone) by the action of sunlight which are hazardous to human health and ecosystems and which also may damage crops. ($\mu\text{g}/\text{m}^3$)	Emissions data, Environmental impact assessments, Bill of quantities, GPS tracking devices. Emissions from wheel loader will be obtained by DTU from operational engine datasets obtained.
Env5	Ozone Depletion Potential	TBD	Relative amount of degradation to the ozone layer it can cause. List of ozone depletion substances (ODS) and emissions. (kg CFC-11-eq) (e.g. cooling systems)	Environmental impact assessment, Emissions measurement and product specifications
Env6	Acidification Potential	TBD	Acidifying impacts due to pollutants cause a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) discharge into the environment. (kg mol H^+)	Environmental impact assessment, Emissions measurement and product specifications
Env7	Eutrophication Potential	TBD	Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. Amount of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. kg PO_4 -eq, kg N-eq (marine), mol N-eq (terrestrial)	Environmental impact assessment, Eutrophication factors, Emissions measurement and product specifications
Env8	Ecotoxicity	TBD	Impact on ecosystems, as a result of emissions of toxic substances to air, water and soil. Amount of substances causing the direct or indirect disappearance (e.g., through affecting reproduction) of the animal or vegetable species of an ecosystem. This indicator has three aspects: Freshwater aquatic ecotoxicity, Marine ecotoxicity, Terrestrial ecotoxicity.e.g. chemicals used, explosives (g, kg)	Ecotoxicity factors, Environmental impact assessment

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env9	Noise (and vibration) generated	Yes	Amount of noise generated by construction activities throughout the duration of the process. (dB). Vibrations is also a key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.	Noise and vibration monitoring records, on-site measurements, environmental impact assessment
Env10	Energy demand	Yes	Total demand of energy within the project timeline, encompassing energy consumed by machinery, load-specific requirements, and other energy usage. (see Ec3)	see Ec3
Env11	Materials used/Materials consumption	Yes	KPI measures the total amount of materials utilized in the project, encompassing both construction materials and chemicals. This KPI is essential for assessing resource utilization, tracking inventory levels, and managing costs effectively. Total sum of all materials used (e.g. chemicals used, explosives,...) m3, tons, kg, litres, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Env12	Water depletion	Yes	Total amount of water used in project timeline (m3)	Water usage records
Env13	Non-compliance environmental impact	Yes	See Ec8	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env14	Area of habitat retained/created	Yes	Ecologically valuable habitat created and/or retained within the total area of the site for a completed project. Measure of the changes in soil quality (Biotic production, Erosion resistance, Mechanical filtration). (area km2)	Environmental impact assessment, biodiversity action plans

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
T1	Workers required	Yes	Number of workers required for the defined functional unit (see Ec2)	Project schedules, Construction management project, Input from supervisors, Labor productivity standards
T2	Quality of the activities performed	Yes	Compliance with quality objectives of the activity %	Quality objectives, Inspection criteria, Quality control reports, Expert assessment
T3	Cycle Time	Yes	Total time to finalise 1 functional unit, it includes time to complete the activity + idle time. Detailed dynamic plan of all processes with Cycle times	Time-tracking system, Work log, Daily reports, Observation or direct measurement
T4	Time needed to prepare floating dock for production	No	Indicator applies to maritime use case only	
T5	Distance covered by machinery excluding drones	Yes	Total Distance (meters) covered by the machinery during operation	GPS tracking systems
T6	Distance/surface covered by drones	Yes	Total Distance covered by the drone during operation	Drone telemetry data
T7	Functional units accomplished	Yes	Total functional units accomplished/day	Construction logbook, Work completion report, Quality control records, Project management documentation
T8	Failure rate	Yes	Failure rate completing a task	Quality control records, Work logs, Incident reports
T9	Time of full autonomous operation	Yes	# of tasks failed/ # of tasks attempted	Autonomous systems telemetry data, Human intervention records, Equipment operating schedule
T10	Percentage of tasks that use drones	Yes	Amount of time of autonomous operation/Total amount of time in operation	Project documentation, Drone flight records
T11	Percentage of tasks that use autonomous vehicles	Yes	$(\text{Number of tasks that use drones} / \text{Total number of tasks}) \times 100$	Project documentation, Vehicle tracking systems along with vehicle logs
T12	Accuracy of data	Yes	This KPI measures the accuracy of data collected during the operations. Data accuracy is crucial for making informed decisions, identifying trends and ensuring analytical insights. $(\text{Number of accurate data points} / \text{Total number of data points}) \times 100$	Quality control, Third-party audit, Data comparison

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S1	Women willingness	Yes	The extent to which women would be willing to do the job/task before and after the implementation of the BT	Focus group/interview
S2	Women capability	Yes	The extent to which women would feel capable of performing the task/job	Focus group/interview
S3	Wearables and exoskeletons fit for women's physical traits	Yes	Women's physical traits integrated into the design of wearables and exoskeleton	Focus group/interview
S4	Olders workers capability	Yes	The extent to which workers aged +55 would feel capable of performing (or continue performing) this task	Focus group/interview
S5	Potential for attraction of younger generations	Yes	The extent to which young individuals would feel interested in performing this job.	Focus group/ interview
S6	Pregnancy Friendly Environment	No	Whether the working environment is safe for pregnant women	Focus groups / interview
S7	Usability of BT for people with disabilities	Yes	BT usability for people/workers with disabilities	Focus groups/ interview
S8	Motivation improvement	Yes	Improvements in motivation to perform the job	Questionnaire with workers
S9	Indoor air quality	No	Good quality indoor air. This KPI measures both, subjective and objective parameters of indoor air quality.	Questionnaire with workers and BT generated data
S10	Fatigue detection	No	Reduction in worker's fatigue	BT generated data
S11	Perception of fatigue reduction	No	Comparability between worker's fatigue perception and sensor measurements	BT generated data and questionnaire
S12	Muscular strain and back-injuries prevention	Yes	Perceived reduction of muscular strains and back-injuries	Questionnaire with workers
S13	Musculoskeletal loading reduction	No	Workers' perception of musculoskeletal loading reduction	Questionnaire with workers

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S14	Safety Perception	Yes	The extent to which workers feel safe whilst performing this job	Questionnaire with workers
S15	Alert system detection	Yes	Worker's capacity of hearing BT alerts when in a risky situation/position	Questionnaire with workers
S16	Detection of man down situations	No	This indicator measures the ability of the technology to detect when a worker has fallen or become incapacitated, and alert others to the situation.	Questionnaire with workers
S17	Recognition of dangerous locations for workers	No	This indicator measures the ability of the technology to identify and alert workers or supervisors of hazardous areas or situations that could pose a risk to worker safety	Questionnaire with workers
S18	Performance enhancement	Yes	Perception of performance enhancement	Questionnaire with workers
S19	Level of training required	Yes	Level of training required to perform this task	Questionnaire
S20	Compatibility of BT with the task performed by workers	Yes	Perception of compatibility of BT with the task being performed by the worker	Questionnaire with workers
S21	BT complexity	Yes	Perceived ease of use	Questionnaire with workers
S22	Perceived usefulness	Yes	Perceived usefulness of the BT in performing the task	Questionnaire with workers
S23	Existing knowledge and confidence about the BT and its use	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
S24	Comfort level	Yes	This KPI is a complex indicator covering aspects such as: • perception of weight, • thermal comfort, • noise level • Perception of fit between body and BT * The worker will give a % weight to each of the aspect in order to calculate the indicator according to the workers' preference	Questionnaire with workers
S25	Being in control of the BT and own body	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers

Building construction

This workshop was held on 14th February 2024. As in previous workshops, the same two main objectives were set for the meeting.

Regarding technical aspects, the Building use case is particular because it brings together various very different technologies to be integrated. Specifically, four possible actions are planned. First, tests with exoskeletons on workers (any gender and age). Test campaigns must be scheduled for a specific duration (yet to be decided) so that the results are representative. Similarly, and secondly, three types of wearables to measure different biometric, environmental and fatigue variables will be tested by workers in different on-site tests. The duration of the trials has yet to be decided. Thirdly, drones will be used flying inside the building under construction to compare what was executed vs. what was planned using the point cloud obtained by drones through a BIM updating service integrated into the Digital Twin. Besides, a security compliance checking is planned with safety rules algorithm comparison with the obtained point clouds. It has been estimated that the first test flights can be carried out during the summer of 2024. Cables hanging from the ceiling will be avoided as much as possible, since they are very difficult for the drone to see. Finally, and fourthly, training tasks will be carried out with workers, which although they are planned within WP5, could potentially be developed within the work environment, depending on the availability of the workers.

The basic conclusion of the technical points discussed was that specific implementation plans for each technology must be made in each of the four types of implementations explained, not being necessary for them all to coincide in time. From the preliminary forecasts, it seems clear that no more than two previous activities will be brought together in time simultaneously.

The same comment than in previous use cases about HMI applies, considering necessary to have HMIs for monitoring and showing the information to building construction managers.

Data exchange generated will be supervised and integrated into the Digital Twin, common layer among all case studies of the project.

As in the previous case study, the BT provider: STAM, confirmed that their environmental sensors measure PM, Voc, temperature, humidity, and NOx (useful for KPI Env2 Particle matter and human toxicity) and if necessary, also noise can be measured to warn workers if relevant for the use case (useful for Env 9 Noise generated).

The second part of the workshop was dedicated to the selection of the most suitable KPIs for the Building construction case study and associated guidance for an accurate data collection and to define a more precise value proposition linked to the associated KERs as described in the previous sub-section.

Value proposition based on KERs (Part B):

The building case study will demonstrate a reduction of 8.3% in idle times thanks to the integration of drones for scanning tasks executed the day before (at night), finding errors, and forecasting tasks. Related to wearables and exoskeletons, it is estimated a reduction of sick leaves due to lower back injuries, at least of 50% of current ones, increasing any gender/age workers endurance at least, by 20%.

The following table summarizes the other outcomes of the workshop on KPIs and guidance:



Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor the granting authority can be held responsible for them

Table 4: Outcomes of the Building Construction workshop

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec1	Whole life cost	No	Indicator does not apply due to limited boundaries	
Ec2	Labour cost	Yes	Total labour cost per month. Total sum of salaries including benefits and overtime pay for workers on the site including accommodation, insurance, food, allowances etc. (€/month) separated as: No. of workers per month, cost per worker; (€/person month)	Payroll records, Construction logbook, construction management project
Ec3	Energy used	Yes	Cost of total energy used based on all machinery deployed; Electricity used per workday or month (kWh), diesel used per workday, month (lit) gasoline (lit), other etc. Energy prices (€/kWh, €/lit.)	Consumption records for machinery and equipment, load specific energy usage details
Ec4	Depreciation cost	Yes	Average depreciation cost for all machinery (€/month)	Accounting records, Equipment maintenance logs, Vendor and/or manufacturer documentation
Ec5	Materials used	No	Indicator does not apply	
Ec6	Maintenance cost of non-conventional machinery	Yes	Total amount due to maintenance and repairs of the non-conventional machinery, which includes: cost of repairs, cost of non-conventional maintenance activities and cost due to the stop of the site to repair the different BT). Average cost of repairs (€/month), average cost of non-conventional maintenance activities (€/month), average cost due to the stop of the site to repair the different BT (€/month)	Maintenance and repair expenses, Maintenance records, Service provider invoices, Equipment downtime logs, Project management reports

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec7	Maintenance cost	TBD	Total amount due to maintenance and repairs of the asset (it includes cost of repairs and regular maintenance costs). Average cost of repairs and regular maintenance (€/month)	Collection of historical data, Repair invoices, Regular maintenance invoices, bill of quantities from maintenance design project
Ec8	Non-compliance cost	Yes	Average cost of detection, registration and corrective measures (€/month)	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env1	Global warming potential (GWP)	Yes	Is the generally accepted equivalent of greenhouse gas accumulation and represents the cumulative effect of a list of greenhouse gases recognized in ISO/TS 14067 _Annex A.	Total direct and indirect GHG emissions reported as: - GHG inventory - list of GHG sources according to ISO 14064 - category of emissions (combustion, fugitive, indirect, products,...) - GWP tonnes of CO ₂ eq per category and source Emissions data, GWP factors, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env2	Particle matter and human toxicity	Yes	Amount of emitted particle matter (PM) and other non-GH gasses affecting health of living beings and environment (micrograms per cubic meter µg/m ³)	Continuous air pollution monitoring, Meteorological data, Particulate matter samplers or monitors
Env3	Other impacts on the environment	TBD	Indicator to show if the BT have other relevant impacts on the environment apart from contributing to Global Warming Potential and affecting living beings and environment. If high, it must be reported separately the indicator contributing to that higher impact on the environment (e.g., acidification potential, ozone depletion, ecotoxicity, etc.) Environmental impact of Lithium drone batteries?	Pollution monitoring

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env4	Photochemical Ozone Creation Potential	TBD	Measure of potential of an activity or a system to contribute to the formation of ozone in the lower atmosphere. Amount of formed reactive substances (mainly ozone) by the action of sunlight which are hazardous to human health and ecosystems and which also may damage crops. ($\mu\text{g}/\text{m}^3$)	Emissions data, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env5	Ozone Depletion Potential	TBD	Relative amount of degradation to the ozone layer it can cause. List of ozone depletion substances (ODS) and emissions. (kg CFC-11-eq) (e.g. cooling systems)	Environmental impact assessment, Emissions measurement and product specifications
Env6	Acidification Potential	TBD	Acidifying impacts due to pollutants cause a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) discharge into the environment. (kg mol H^+)	Environmental impact assessment, Emissions measurement and product specifications
Env7	Eutrophication Potential	TBD	Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. Amount of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. kg PO_4 -eq, kg N-eq (marine), mol N-eq (terrestrial)	Environmental impact assessment, Eutrophication factors, Emissions measurement and product specifications
Env8	Ecotoxicity	Yes	Impact on ecosystems, as a result of emissions of toxic substances to air, water and soil. Amount of substances causing the direct or indirect disappearance (e.g., through affecting reproduction) of the animal or vegetable species of an ecosystem. This indicator has three aspects: Freshwater aquatic ecotoxicity, Marine ecotoxicity, Terrestrial ecotoxicity.e.g. chemicals used, explosives (g, kg)	Ecotoxicity factors, Environmental impact assessment

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env9	Noise (and vibration) generated	Yes	Amount of noise generated by construction activities throughout the duration of the process. (dB). Vibrations is also a key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.	Noise and vibration monitoring records, on-site measurements, environmental impact assessment
Env10	Energy demand	Yes	Total demand of energy within the project timeline, encompassing energy consumed by machinery, load-specific requirements, and other energy usage. (see Ec3)	see Ec3
Env11	Materials used/Materials consumption	No	Indicator does not apply	
Env12	Water depletion	No	Total amount of water used in project timeline (m3)	Water usage records
Env13	Non-compliance environmental impact	Yes	See Ec8	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env14	Area of habitat retained/created	No	Ecologically valuable habitat created and/or retained within the total area of the site for a completed project. Measure of the changes in soil quality (Biotic production, Erosion resistance, Mechanical filtration). (area km2)	Environmental impact assessment, biodiversity action plans

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
T1	Workers required	Yes	Number of workers required for the defined functional unit (see Ec2)	Project schedules, Construction management project, Input from supervisors, Labor productivity standards
T2	Quality of the activities performed	Yes	Compliance with quality objectives of the activity %	Quality objectives, Inspection criteria, Quality control reports, Expert assessment
T3	Cycle Time	Yes	Total time to finalise 1 functional unit, it includes time to complete the activity + idle time. Detailed dynamic plan of all processes with Cycle times	Time-tracking system, Work log, Daily reports, Observation or direct measurement
T4	Time needed to prepare floating dock for production	No	Indicator applies to maritime use case only	
T5	Distance covered by machinery excluding drones	No	Indicator does not apply	
T6	Distance/surface covered by drones	Yes	Total Distance covered by the drone during operation	Drone telemetry data
T7	Functional units accomplished	Yes	Total functional units accomplished/day	Construction logbook, Work completion report, Quality control records, Project management documentation
T8	Failure rate	Yes	Failure rate completing a task	Quality control records, Work logs, Incident reports
T9	Time of full autonomous operation	No	Indicator does not apply	
T10	Percentage of tasks that use drones	Yes	Amount of time of autonomous operation/Total amount of time in operation	Project documentation, Drone flight records
T11	Percentage of tasks that use autonomous vehicles	No	Indicator does not apply	
T12	Accuracy of data	Yes	This KPI measures the accuracy of data collected during the operations. Data accuracy is crucial for making informed decisions, identifying trends and ensuring analytical insights. (Number of accurate data points / Total number of data points) x 100	Quality control, Third-party audit, Data comparison

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S1	Women willingness	Yes	The extent to which women would be willing to do the job/task before and after the implementation of the BT	Focus group/interview
S2	Women capability	Yes	The extent to which women would feel capable of performing the task/job	Focus group/interview
S3	Wearables and exoskeletons fit for women's physical traits	Yes	Women's physical traits integrated into the design of wearables and exoskeleton	Focus group/interview
S4	Olders workers capability	Yes	The extent to which workers aged +55 would feel capable of performing (or continue performing) this task	Focus group/interview
S5	Potential for attraction of younger generations	Yes	The extent to which young individuals would feel interested in performing this job.	Focus group/ interview
S6	Pregnancy Friendly Environment	No	Whether the working environment is safe for pregnant women	Focus groups / interview
S7	Usability of BT for people with disabilities	Yes	BT usability for people/workers with disabilities	Focus groups/ interview
S8	Motivation improvement	Yes	Improvements in motivation to perform the job	Questionnaire with workers
S9	Indoor air quality	No	Good quality indoor air. This KPI measures both, subjective and objective parameters of indoor air quality.	Questionnaire with workers and BT generated data
S10	Fatigue detection	Yes	Reduction in worker's fatigue	BT generated data
S11	Perception of fatigue reduction	Yes	Comparability between worker's fatigue perception and sensor measurements	BT generated data and questionnaire
S12	Muscular strain and back-injuries prevention	Yes	Perceived reduction of muscular strains and back-injuries	Questionnaire with workers
S13	Musculoskeletal loading reduction	Yes	Workers' perception of musculoskeletal loading reduction	Questionnaire with workers

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S14	Safety Perception	Yes	The extent to which workers feel safe whilst performing this job	Questionnaire with workers
S15	Alert system detection	Yes	Worker's capacity of hearing BT alerts when in a risky situation/position	Questionnaire with workers
S16	Detection of man down situations	Yes	This indicator measures the ability of the technology to detect when a worker has fallen or become incapacitated, and alert others to the situation.	Questionnaire with workers
S17	Recognition of dangerous locations for workers	Yes	This indicator measures the ability of the technology to identify and alert workers or supervisors of hazardous areas or situations that could pose a risk to worker safety	Questionnaire with workers
S18	Performance enhancement	Yes	Perception of performance enhancement	Questionnaire with workers
S19	Level of training required	Yes	Level of training required to perform this task	Questionnaire
S20	Compatibility of BT with the task performed by workers	Yes	Perception of compatibility of BT with the task being performed by the worker	Questionnaire with workers
S21	BT complexity	Yes	Perceived ease of use	Questionnaire with workers
S22	Perceived usefulness	Yes	Perceived usefulness of the BT in performing the task	Questionnaire with workers
S23	Existing knowledge and confidence about the BT and its use	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
S24	Comfort level	Yes	This KPI is a complex indicator covering aspects such as: • perception of weight, • thermal comfort, • noise level • Perception of fit between body and BT * The worker will give a % weight to each of the aspect in order to calculate the indicator according to the workers' preference	Questionnaire with workers
S25	Being in control of the BT and own body	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers

Maritime construction – EU – Japan collaboration

This workshop was held on 19th February 2024. As in previous workshops, the same two main objectives were set for the meeting.

This use case is based on the information produced by the machinery of the GIKEN company, which is the Japanese partner that supported BEEYONDERS from its proposal phase, through a letter of support. GIKEN company has a push-pile system that, through controlled pushes and pulls, can introduce piles and sheet piles into the ground without hitting them.

The most obvious advantage of this system is the elimination of noise pollution due to the impacts used by traditional pile driving systems, achieving a very attractive solution to be used in cities without disturbing their citizens.

In the case of BEEYONDERS, the historical data from the continuous monitoring of the forces necessary to carry out the previous actions, allows the terrain to be characterized at a geotechnic level in a very precise way, which is why this study case proposed a potential development of an algorithm, that through a specific training using historic data, it would be possible to predict the precise geotechnical characteristics of the terrain approximately 10 meters ahead. In this way, and depending on the expected resistance, the energy used by this type of machinery can be adapted, optimizing it to the maximum, and therefore reducing the overall energy consumption of the work. On the other hand, the prediction of the ground resistance can reduce the calculated theoretical length of the piles that were planned, thus reducing the amount of concrete or steel used, a fact that minimizes the CO₂ emissions of the process. Finally, it is considered that the biggest advantage would be the time savings in the overall push-pile process.

The case study proposes a demonstrator in which the digital twin, that is being developed in BEEYONDERS, would potentially receive data from the described machinery that may be working at the construction site and, through the application of a learning model, would generate forecasts of the resistance of the terrain ahead. As this process is applied, the model is validated, and in subsequent steps, it can be refined and updated.

There is public information on data from GIKEN machines in the Netherlands published in doctoral thesis, which can serve as a source of information and model verification.

This type of systems arouses great interest at a commercial level, and the application of predictions and representation of the process through the digital twin could increase its interest even more. During the workshop it was also pointed out that silica fume from the grout mixing tank might influence the generation of particle matter (Env 2 Particle matter and human toxicity) but it will be difficult to measure.

The second part of the workshop was dedicated to the selection of the most suitable KPIs for the Maritime construction case study and associated guidance for an accurate data collection and to define a more precise value proposition linked to the associated KERs as described in the previous sub-section.

Value proposition based on KERs (Part B):

The primary advantage in developing improved capacity models is to optimize pile lengths. According to the real case of “Assumptions”, we can expect **average savings of 10M€ per similar works**.



The following table summarises the other outcomes of the workshop on KPIs and guidance:



Table 5: Outcomes of the Maritime construction – EU – Japan collaboration workshop

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec1	Whole life cost	No	Indicator does not apply due to limited boundaries	
Ec2	Labour cost	Yes	Total labour cost per month. Total sum of salaries including benefits and overtime pay for workers on the site including accommodation, insurance, food, allowances etc. (€/month) separated as: No. of workers per month, cost per worker; (€/person month)	Payroll records, Construction logbook, construction management project
Ec3	Energy used	Yes	Cost of total energy used based on all machinery deployed; Electricity used per workday or month (kWh), diesel used per workday, month (lit) gasoline (lit), other etc. Energy prices (€/kWh, €/lit.)	Consumption records for machinery and equipment, load specific energy usage details
Ec4	Depreciation cost	Yes	Average depreciation cost for all machinery (€/month)	Accounting records, Equipment maintenance logs, Vendor and/or manufacturer documentation
Ec5	Materials used	Yes	Total amount of materials used (both construction materials and chemicals, including but not limited to concrete, cement, aggregates, steel, asphalt, bitumen, additives, etc.) Unit of measure: cubic meters, tons, kilograms, liters, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Ec6	Maintenance cost of non-conventional machinery	Yes	Total amount due to maintenance and repairs of the non-conventional machinery, which includes: cost of repairs, cost of non-conventional maintenance activities and cost due to the stop of the site to repair the different BT). Average cost of repairs (€/month), average cost of non-conventional maintenance activities (€/month), average cost due to the stop of the site to repair the different BT (€/month)	Maintenance and repair expenses, Maintenance records, Service provider invoices, Equipment downtime logs, Project management reports

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec7	Maintenance cost	Yes	Total amount due to maintenance and repairs of the asset (it includes cost of repairs and regular maintenance costs). Average cost of repairs and regular maintenance (€/month)	Collection of historical data, Repair invoices, Regular maintenance invoices, bill of quantities from maintenance design project
Ec8	Non-compliance cost	Yes	Average cost of detection, registration and corrective measures (€/month)	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env1	Global warming potential (GWP)	Yes	Is the generally accepted equivalent of greenhouse gas accumulation and represents the cumulative effect of a list of greenhouse gases recognized in ISO/TS 14067 _Annex A.	Total direct and indirect GHG emissions reported as: - GHG inventory - list of GHG sources according to ISO 14064 - category of emissions (combustion, fugitive, indirect, products,...) - GWP tonnes of CO ₂ eq per category and source Emissions data, GWP factors, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env2	Particle matter and human toxicity	Yes	Amount of emitted particle matter (PM) and other non-GH gasses affecting health of living beings and environment (micrograms per cubic meter µg/m ³)	Continuous air pollution monitoring, Meteorological data, Particulate matter samplers or monitors. Note: Difficult to measure releases from grout mixing tank.
Env3	Other impacts on the environment	TBD	Indicator to show if the BT have other relevant impacts on the environment apart from contributing to Global Warming Potential and affecting living beings and environment. If high, it must be reported separately the indicator contributing to that higher impact on the environment (e.g., acidification potential, ozone depletion, ecotoxicity, etc.) Environmental impact of Lithium drone batteries?	Pollution monitoring. Note: Road closures might impact on this KPI as equipment mobilisation affect traffic, but incorporating this into a single metric might be complicated.

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env4	Photochemical Ozone Creation Potential	TBD	Measure of potential of an activity or a system to contribute to the formation of ozone in the lower atmosphere. Amount of formed reactive substances (mainly ozone) by the action of sunlight which are hazardous to human health and ecosystems and which also may damage crops. ($\mu\text{g}/\text{m}^3$)	Emissions data, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env5	Ozone Depletion Potential	TBD	Relative amount of degradation to the ozone layer it can cause. List of ozone depletion substances (ODS) and emissions. (kg CFC-11-eq) (e.g. cooling systems)	Environmental impact assessment, Emissions measurement and product specifications
Env6	Acidification Potential	Yes	Acidifying impacts due to pollutants cause a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) discharge into the environment. (kg mol H^+)	Environmental impact assessment, Emissions measurement and product specifications
Env7	Eutrophication Potential	Yes	Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. Amount of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. kg PO_4 -eq, kg N-eq (marine), mol N-eq (terrestrial)	Environmental impact assessment, Eutrophication factors, Emissions measurement and product specifications. Note: it might be difficult to distinguish between what is construction-related and what comes from different sources (e.g. urban environment)
Env8	Ecotoxicity	Yes	Impact on ecosystems, as a result of emissions of toxic substances to air, water and soil. Amount of substances causing the direct or indirect disappearance (e.g., through affecting reproduction) of the animal or vegetable species of an ecosystem. This indicator has three aspects: Freshwater aquatic ecotoxicity, Marine ecotoxicity, Terrestrial ecotoxicity.e.g. chemicals used, explosives (g, kg)	Ecotoxicity factors, Environmental impact assessment. Note: it might be difficult to distinguish between what is construction-related and what comes from different sources (e.g. urban environment)

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env9	Noise (and vibration) generated	Yes	Amount of noise generated by construction activities throughout the duration of the process. (dB). Vibrations is also a key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.	Noise and vibration monitoring records, on-site measurements, environmental impact assessment. Note: Vibration is key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.
Env10	Energy demand	Yes	Total demand of energy within the project timeline, encompassing energy consumed by machinery, load-specific requirements, and other energy usage. (see Ec3)	see Ec3
Env11	Materials used/Materials consumption	Yes	KPI measures the total amount of materials utilized in the project, encompassing both construction materials and chemicals. This KPI is essential for assessing resource utilization, tracking inventory levels, and managing costs effectively. Total sum of all materials used (e.g. chemicals used, explosives,...) m3, tons, kg, litres, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Env12	Water depletion	Yes	Total amount of water used in project timeline (m3)	Water usage records
Env13	Non-compliance environmental impact	Yes	See Ec8	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env14	Area of habitat retained/created	Yes	Ecologically valuable habitat created and/or retained within the total area of the site for a completed project. Measure of the changes in soil quality (Biotic production, Erosion resistance, Mechanical filtration). (area km2)	Environmental impact assessment, biodiversity action plans

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
T1	Workers required	Yes	Number of workers required for the defined functional unit (see Ec2)	Project schedules, Construction management project, Input from supervisors, Labor productivity standards
T2	Quality of the activities performed	Yes	Compliance with quality objectives of the activity %	Quality objectives, Inspection criteria, Quality control reports, Expert assessment
T3	Cycle Time	Yes	Total time to finalise 1 functional unit, it includes time to complete the activity + idle time. Detailed dynamic plan of all processes with Cycle times	Time-tracking system, Work log, Daily reports, Observation or direct measurement
T4	Time needed to prepare floating dock for production	No	Indicator applies to maritime use case only	
T5	Distance covered by machinery excluding drones	No	Total Distance (meters) covered by the machinery during operation	GPS tracking systems
T6	Distance/surface covered by drones	No	Indicator does not apply	
T7	Functional units accomplished	Yes	Total functional units accomplished/day	Construction logbook, Work completion report, Quality control records, Project management documentation
T8	Failure rate	Yes	Failure rate completing a task	Quality control records, Work logs, Incident reports
T9	Time of full autonomous operation	No	Indicator does not apply	
T10	Percentage of tasks that use drones	No	Indicator does not apply	
T11	Percentage of tasks that use autonomous vehicles	No	Indicator does not apply	
T12	Accuracy of data	Yes	This KPI measures the accuracy of data collected during the operations. Data accuracy is crucial for making informed decisions, identifying trends and ensuring analytical insights. (Number of accurate data points / Total number of data points) x 100	Quality control, Third-party audit, Data comparison

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S1	Women willingness	Yes	The extent to which women would be willing to do the job/task before and after the implementation of the BT	Focus group/interview
S2	Women capability	Yes	The extent to which women would feel capable of performing the task/job	Focus group/interview
S3	Wearables and exoskeletons fit for women's physical traits	No	Women's physical traits integrated into the design of wearables and exoskeleton	Focus group/interview
S4	Olders workers capability	?	The extent to which workers aged +55 would feel capable of performing (or continue performing) this task	Focus group/interview
S5	Potential for attraction of younger generations	Yes	The extent to which young individuals would feel interested in performing this job.	Focus group/ interview
S6	Pregnancy Friendly Environment	Yes	Whether the working environment is safe for pregnant women	Focus groups / interview
S7	Usability of BT for people with disabilities	Yes	BT usability for people/workers with disabilities	Focus groups/ interview
S8	Motivation improvement	Yes	Improvements in motivation to perform the job	Questionnaire with workers
S9	Indoor air quality	No	Good quality indoor air. This KPI measures both, subjective and objective parameters of indoor air quality.	Questionnaire with workers and BT generated data
S10	Fatigue detection	No	Reduction in worker's fatigue	BT generated data
S11	Perception of fatigue reduction	No	Comparability between worker's fatigue perception and sensor measurements	BT generated data and questionnaire
S12	Muscular strain and back-injuries prevention	No	Perceived reduction of muscular strains and back-injuries	Questionnaire with workers
S13	Musculoskeletal loading reduction	No	Workers' perception of musculoskeletal loading reduction	Questionnaire with workers

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S14	Safety Perception	Yes	The extent to which workers feel safe whilst performing this job	Questionnaire with workers
S15	Alert system detection	No	Worker's capacity of hearing BT alerts when in a risky situation/position	Questionnaire with workers
S16	Detection of man down situations	No	This indicator measures the ability of the technology to detect when a worker has fallen or become incapacitated, and alert others to the situation.	Questionnaire with workers
S17	Recognition of dangerous locations for workers	No	This indicator measures the ability of the technology to identify and alert workers or supervisors of hazardous areas or situations that could pose a risk to worker safety	Questionnaire with workers
S18	Performance enhancement	Yes	Perception of performance enhancement	Questionnaire with workers
S19	Level of training required	Yes	Level of training required to perform this task	Questionnaire
S20	Compatibility of BT with the task performed by workers	Yes	Perception of compatibility of BT with the task being performed by the worker	Questionnaire with workers
S21	BT complexity	Yes	Perceived ease of use	Questionnaire with workers
S22	Perceived usefulness	Yes	Perceived usefulness of the BT in performing the task	Questionnaire with workers
S23	Existing knowledge and confidence about the BT and its use	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
S24	Comfort level	No	This KPI is a complex indicator covering aspects such as: • perception of weight, • thermal comfort, • noise level • Perception of fit between body and BT * The worker will give a % weight to each of the aspect in order to calculate the indicator according to the workers' preference	Questionnaire with workers
S25	Being in control of the BT and own body	No	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers

Road maintenance

This workshop was held on 21st February 2024. As in previous workshops, the same two main objectives were set for the meeting.

In the same way that in the Road construction use case, it was decided to use a space adjacent to the road that was not in production, in this case study a closed road will have to be used to test the technology.

The objective of this use case is to automate the retroreflectance measurement tasks of vertical and horizontal signals on the road. On the other hand, vegetation invading the road will be detected and informed, as well as the potential detection of big elements on the road, generating alarms to inform infrastructure managers.

Achieving success in this case study would mean eliminating risk for workers, who have to constantly carry out this type of activities on the road.

Two types of autonomous vehicles will be used: drones and a robotic mobile platform.

In the case of drones, it has been established that for safety, they must fly on the side of the road. They will have a Lidar scanner on board. Drone will fly along the road under study and will select some points where the signals, from the distance and vision of the drone, may be of interest as possible candidates for precise measurements. The position information of these points will be sent to the mobile robotic platform for inspection.

The ground autonomous platform has embedded, apart from all the sensors necessary for its correct positioning, and hardware & software navigation and communications systems; one retroreflectometer device, which will measure retroreflectivity in both vertical and horizontal signals. The measurement of this variable is standardized and must be carried out with devices specially designed and calibrated for this purpose, which must also perform the measurement while in contact with the surface to be measured. For this reason, the measurement cannot be carried out from air through drones, since other types of radiation and wavelengths could disturb the measurement.

This being so, the possibility of detecting vertical signals and sections of horizontal ones that could be in poor condition from the air, will be tested in the demonstrator. By comparing the measurements of drones with the calibrated and correct measurement of the mobile platform, the degree of reliability of these measurements can be determined, and it will be evaluated if it is possible to generate a new remote measurement model that ensures a certain degree of precision.

Tecnalia (ground platform owner) and Catec (air platform owner) will test the technology until it is functional in Spain, since both partners belong to the same country, and then they will go to Italy for the time determined, to carry out road tests.

The second part of the workshop was dedicated to the selection of the most suitable KPIs for the Road Maintenance case study and associated guidance for an accurate data collection and to define a more precise value proposition linked to the associated KERs as described in the previous sub-section.



Value proposition based on KERs (Part B):

Fuel consumption reduction replacing conventional vehicles by drones for the accomplishment of inspection tasks. Savings as bigger as 50%-70% are expected.

The following table summarises the other outcomes of the workshop on KPIs and guidance:



Table 6: Outcomes of the Road Maintenance workshop

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec1	Whole life cost	No	Indicator does not apply due to limited boundaries	
Ec2	Labour cost	Yes	Total labour cost per month. Total sum of salaries including benefits and overtime pay for workers on the site including accommodation, insurance, food, allowances etc. (€/month) separated as: No. of workers per month, cost per worker; (€/person month)	Payroll records, Construction logbook, construction management project
Ec3	Energy used	Yes	Cost of total energy used based on all machinery deployed; Electricity used per workday or month (kWh), diesel used per workday, month (lit) gasoline (lit), other etc. Energy prices (€/kWh, €/lit.)	Consumption records for machinery and equipment, load specific energy usage details
Ec4	Depreciation cost	Yes	Average depreciation cost for all machinery (€/month)	Accounting records, Equipment maintenance logs, Vendor and/or manufacturer documentation
Ec5	Materials used	No	Indicator does not apply	
Ec6	Maintenance cost of non-conventional machinery	Yes	Total amount due to maintenance and repairs of the non-conventional machinery, which includes: cost of repairs, cost of non-conventional maintenance activities and cost due to the stop of the site to repair the different BT). Average cost of repairs (€/month), average cost of non-conventional maintenance activities (€/month), average cost due to the stop of the site to repair the different BT (€/month)	Maintenance and repair expenses, Maintenance records, Service provider invoices, Equipment downtime logs, Project management reports

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec7	Maintenance cost	TBD	Total amount due to maintenance and repairs of the asset (it includes cost of repairs and regular maintenance costs). Average cost of repairs and regular maintenance (€/month)	Collection of historical data, Repair invoices, Regular maintenance invoices, bill of quantities from maintenance design project
Ec8	Non-compliance cost	Yes	Average cost of detection, registration and corrective measures (€/month)	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env1	Global warming potential (GWP)	Yes	Is the generally accepted equivalent of greenhouse gas accumulation and represents the cumulative effect of a list of greenhouse gases recognized in ISO/TS 14067 _Annex A.	Total direct and indirect GHG emissions reported as: - GHG inventory - list of GHG sources according to ISO 14064 - category of emissions (combustion, fugitive, indirect, products,...) - GWP tonnes of CO ₂ eq per category and source Emissions data, GWP factors, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env2	Particle matter and human toxicity	No	Amount of emitted particle matter (PM) and other non-GH gasses affecting health of living beings and environment (micrograms per cubic meter µg/m ³)	Continuous air pollution monitoring, Meteorological data, Particulate matter samplers or monitors. Note: Difficult to measure releases from grout mixing tank.
Env3	Other impacts on the environment	TBD	Indicator to show if the BT have other relevant impacts on the environment apart from contributing to Global Warming Potential and affecting living beings and environment. If high, it must be reported separately the indicator contributing to that higher impact on the environment (e.g., acidification potential, ozone depletion, ecotoxicity, etc.) Environmental impact of Lithium drone batteries?	Pollution monitoring. Note: Road closures might impact on this KPI as equipment mobilisation affect traffic, but incorporating this into a single metric might be complicated.

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env4	Photochemical Ozone Creation Potential	TBD	Measure of potential of an activity or a system to contribute to the formation of ozone in the lower atmosphere. Amount of formed reactive substances (mainly ozone) by the action of sunlight which are hazardous to human health and ecosystems and which also may damage crops. ($\mu\text{g}/\text{m}^3$)	Emissions data, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env5	Ozone Depletion Potential	TBD	Relative amount of degradation to the ozone layer it can cause. List of ozone depletion substances (ODS) and emissions. (kg CFC-11-eq) (e.g. cooling systems)	Environmental impact assessment, Emissions measurement and product specifications
Env6	Acidification Potential	TBD	Acidifying impacts due to pollutants cause a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) discharge into the environment. (kg mol H^+)	Environmental impact assessment, Emissions measurement and product specifications
Env7	Eutrophication Potential	TBD	Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. Amount of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. kg PO_4 -eq, kg N-eq (marine), mol N-eq (terrestrial)	Environmental impact assessment, Eutrophication factors, Emissions measurement and product specifications. Note: it might be difficult to distinguish between what is construction-related and what comes from different sources (e.g. urban environment)
Env8	Ecotoxicity	TBD	Impact on ecosystems, as a result of emissions of toxic substances to air, water and soil. Amount of substances causing the direct or indirect disappearance (e.g., through affecting reproduction) of the animal or vegetable species of an ecosystem. This indicator has three aspects: Freshwater aquatic ecotoxicity, Marine ecotoxicity, Terrestrial ecotoxicity.e.g. chemicals used, explosives (g, kg)	Ecotoxicity factors, Environmental impact assessment. Note: it might be difficult to distinguish between what is construction-related and what comes from different sources (e.g. urban environment)

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env9	Noise (and vibration) generated	No	Amount of noise generated by construction activities throughout the duration of the process. (dB). Vibrations is also a key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.	Noise and vibration monitoring records, on-site measurements, environmental impact assessment. Note: Vibration is key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.
Env10	Energy demand	Yes	Total demand of energy within the project timeline, encompassing energy consumed by machinery, load-specific requirements, and other energy usage. (see Ec3)	see Ec3
Env11	Materials used/Materials consumption	Yes	KPI measures the total amount of materials utilized in the project, encompassing both construction materials and chemicals. This KPI is essential for assessing resource utilization, tracking inventory levels, and managing costs effectively. Total sum of all materials used (e.g. chemicals used, explosives,...) m3, tons, kg, litres, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Env12	Water depletion	No	Total amount of water used in project timeline (m3)	Water usage records
Env13	Non-compliance environmental impact	Yes	See Ec8	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env14	Area of habitat retained/created	Yes	Ecologically valuable habitat created and/or retained within the total area of the site for a completed project. Measure of the changes in soil quality (Biotic production, Erosion resistance, Mechanical filtration). (area km2)	Environmental impact assessment, biodiversity action plans

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
T1	Workers required	Yes	Number of workers required for the defined functional unit (see Ec2)	Project schedules, Construction management project, Input from supervisors, Labor productivity standards
T2	Quality of the activities performed	Yes	Compliance with quality objectives of the activity %	Quality objectives, Inspection criteria, Quality control reports, Expert assessment
T3	Cycle Time	Yes	Total time to finalise 1 functional unit, it includes time to complete the activity + idle time. Detailed dynamic plan of all processes with Cycle times	Time-tracking system, Work log, Daily reports, Observation or direct measurement
T4	Time needed to prepare floating dock for production	No	Indicator applies to maritime use case only	
T5	Distance covered by machinery excluding drones	Yes	Total Distance (meters) covered by the machinery during operation	GPS tracking systems
T6	Distance/surface covered by drones	Yes	Total Distance covered by the drone during operation	Drone telemetry data
T7	Functional units accomplished	Yes	Total functional units accomplished/day	Construction logbook, Work completion report, Quality control records, Project management documentation
T8	Failure rate	Yes	Failure rate completing a task	Quality control records, Work logs, Incident reports
T9	Time of full autonomous operation	Yes	# of tasks failed/ # of tasks attempted	Autonomous systems telemetry data, Human intervention records, Equipment operating schedule
T10	Percentage of tasks that use drones	Yes	Amount of time of autonomous operation/Total amount of time in operation	Project documentation, Drone flight records
T11	Percentage of tasks that use autonomous vehicles	Yes	$(\text{Number of tasks that use drones} / \text{Total number of tasks}) \times 100$	Project documentation, Vehicle tracking systems along with vehicle logs
T12	Accuracy of data	Yes	This KPI measures the accuracy of data collected during the operations. Data accuracy is crucial for making informed decisions, identifying trends and ensuring analytical insights. $(\text{Number of accurate data points} / \text{Total number of data points}) \times 100$	Quality control, Third-party audit, Data comparison

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S1	Women willingness	Yes	The extent to which women would be willing to do the job/task before and after the implementation of the BT	Focus group/interview
S2	Women capability	Yes	The extent to which women would feel capable of performing the task/job	Focus group/interview
S3	Wearables and exoskeletons fit for women's physical traits	No	Women's physical traits integrated into the design of wearables and exoskeleton	Focus group/interview
S4	Olders workers capability	?	The extent to which workers aged +55 would feel capable of performing (or continue performing) this task	Focus group/interview
S5	Potential for attraction of younger generations	Yes	The extent to which young individuals would feel interested in performing this job.	Focus group/ interview
S6	Pregnancy Friendly Environment	Yes	Whether the working environment is safe for pregnant women	Focus groups / interview
S7	Usability of BT for people with disabilities	Yes	BT usability for people/workers with disabilities	Focus groups/ interview
S8	Motivation improvement	Yes	Improvements in motivation to perform the job	Questionnaire with workers
S9	Indoor air quality	No	Good quality indoor air. This KPI measures both, subjective and objective parameters of indoor air quality.	Questionnaire with workers and BT generated data
S10	Fatigue detection	No	Reduction in worker's fatigue	BT generated data
S11	Perception of fatigue reduction	No	Comparability between worker's fatigue perception and sensor measurements	BT generated data and questionnaire
S12	Muscular strain and back-injuries prevention	No	Perceived reduction of muscular strains and back-injuries	Questionnaire with workers
S13	Musculoskeletal loading reduction	No	Workers' perception of musculoskeletal loading reduction	Questionnaire with workers

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S14	Safety Perception	Yes	The extent to which workers feel safe whilst performing this job	Questionnaire with workers
S15	Alert system detection	No	Worker's capacity of hearing BT alerts when in a risky situation/position	Questionnaire with workers
S16	Detection of man down situations	No	This indicator measures the ability of the technology to detect when a worker has fallen or become incapacitated, and alert others to the situation.	Questionnaire with workers
S17	Recognition of dangerous locations for workers	No	This indicator measures the ability of the technology to identify and alert workers or supervisors of hazardous areas or situations that could pose a risk to worker safety	Questionnaire with workers
S18	Performance enhancement	Yes	Perception of performance enhancement	Questionnaire with workers
S19	Level of training required	Yes	Level of training required to perform this task	Questionnaire
S20	Compatibility of BT with the task performed by workers	Yes	Perception of compatibility of BT with the task being performed by the worker	Questionnaire with workers
S21	BT complexity	Yes	Perceived ease of use	Questionnaire with workers
S22	Perceived usefulness	Yes	Perceived usefulness of the BT in performing the task	Questionnaire with workers
S23	Existing knowledge and confidence about the BT and its use	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
S24	Comfort level	No	This KPI is a complex indicator covering aspects such as: • perception of weight, • thermal comfort, • noise level • Perception of fit between body and BT * The worker will give a % weight to each of the aspect in order to calculate the indicator according to the workers' preference	Questionnaire with workers
S25	Being in control of the BT and own body	No	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers

Maritime construction – Additive manufacturing

This workshop was held on 4th March 2024. As in previous workshops, the same two main objectives were set for the meeting.

A mock-up will be made on the scale of a cell of the new caisson that has been designed, with criteria of material efficiency and biodiversity promotion. It will be carried out through additive manufacturing technology in concrete.

The demonstrator will take place in an area designated for this purpose in a port. Initially, the port is planned to be in Spain, although other options are being considered in Denmark, as a contingency measure.

Due to the intense workload that the design is entailing, the demonstrator's approach is more delayed than the rest, so successive meetings must be planned.

As in previous cases, the second part of the workshop was dedicated to the KPIs of the Maritime construction – Additive manufacturing case study, which will be explained in more detail in the next section.

The second part of the workshop was dedicated to the selection of the most suitable KPIs for the Maritime construction case study and associated guidance for an accurate data collection and to define a more precise value proposition linked to the associated KERs as described in the previous sub-section.

Value proposition based on KERs (Part B):

To achieve at least, **a net profit of 15% vs traditional formworks systems** for maritime caissons construction, considering the amortization of 3D printer and special mortars vs traditional ones.

The following table summarizes the other outcomes of the workshop on KPIs and guidance:



Table 7: Outcomes of the Maritime construction workshop

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec1	Whole life cost	No	Indicator does not apply due to limited boundaries	
Ec2	Labour cost	Yes	Total labour cost per month. Total sum of salaries including benefits and overtime pay for workers on the site including accommodation, insurance, food, allowances etc. (€/month) separated as: No. of workers per month, cost per worker; (€/person month)	Payroll records, Construction logbook, construction management project
Ec3	Energy used	Yes	Cost of total energy used based on all machinery deployed; Electricity used per workday or month (kWh), diesel used per workday, month (lit) gasoline (lit), other etc. Energy prices (€/kWh, €/lit.)	Consumption records for machinery and equipment, load specific energy usage details
Ec4	Depreciation cost	Yes	Average depreciation cost for all machinery (€/month)	Accounting records, Equipment maintenance logs, Vendor and/or manufacturer documentation
Ec5	Materials used	No	Total amount of materials used (both construction materials and chemicals, including but not limited to concrete, cement, aggregates, steel, asphalt, bitumen, additives, etc.) Unit of measure: cubic meters, tons, kilograms, liters, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Ec6	Maintenance cost of non-conventional machinery	Yes	Total amount due to maintenance and repairs of the non-conventional machinery, which includes: cost of repairs, cost of non-conventional maintenance activities and cost due to the stop of the site to repair the different BT). Average cost of repairs (€/month), average cost of non-conventional maintenance activities (€/month), average cost due to the stop of the site to repair the different BT (€/month)	Maintenance and repair expenses, Maintenance records, Service provider invoices, Equipment downtime logs, Project management reports

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Ec7	Maintenance cost	TBD	Total amount due to maintenance and repairs of the asset (it includes cost of repairs and regular maintenance costs). Average cost of repairs and regular maintenance (€/month)	Collection of historical data, Repair invoices, Regular maintenance invoices, bill of quantities from maintenance design project
Ec8	Non-compliance cost	Yes	Average cost of detection, registration and corrective measures (€/month)	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env1	Global warming potential (GWP)	Yes	Is the generally accepted equivalent of greenhouse gas accumulation and represents the cumulative effect of a list of greenhouse gases recognized in ISO/TS 14067 _Annex A.	Total direct and indirect GHG emissions reported as: - GHG inventory - list of GHG sources according to ISO 14064 - category of emissions (combustion, fugitive, indirect, products,...) - GWP tonnes of CO ₂ eq per category and source Emissions data, GWP factors, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env2	Particle matter and human toxicity	TBD	Amount of emitted particle matter (PM) and other non-GH gasses affecting health of living beings and environment (micrograms per cubic meter µg/m ³)	Continuous air pollution monitoring, Meteorological data, Particulate matter samplers or monitors. Note: Difficult to measure releases from grout mixing tank.
Env3	Other impacts on the environment	TBD	Indicator to show if the BT have other relevant impacts on the environment apart from contributing to Global Warming Potential and affecting living beings and environment. If high, it must be reported separately the indicator contributing to that higher impact on the environment (e.g., acidification potential, ozone depletion, ecotoxicity, etc.) Environmental impact of Lithium drone batteries?	Pollution monitoring. Note: Road closures might impact on this KPI as equipment mobilisation affect traffic, but incorporating this into a single metric might be complicated.

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env4	Photochemical Ozone Creation Potential	TBD	Measure of potential of an activity or a system to contribute to the formation of ozone in the lower atmosphere. Amount of formed reactive substances (mainly ozone) by the action of sunlight which are hazardous to human health and ecosystems and which also may damage crops. ($\mu\text{g}/\text{m}^3$)	Emissions data, Environmental impact assessments, Bill of quantities, GPS tracking devices
Env5	Ozone Depletion Potential	TBD	Relative amount of degradation to the ozone layer it can cause. List of ozone depletion substances (ODS) and emissions. (kg CFC-11-eq) (e.g. cooling systems)	Environmental impact assessment, Emissions measurement and product specifications
Env6	Acidification Potential	TBD	Acidifying impacts due to pollutants cause a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) discharge into the environment. (kg mol H^+)	Environmental impact assessment, Emissions measurement and product specifications
Env7	Eutrophication Potential	TBD	Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. Amount of macro-nutrients (nitrogen and phosphorous) in the environment caused by emissions of nutrients to air, water and soil. kg PO_4 -eq, kg N-eq (marine), mol N-eq (terrestrial)	Environmental impact assessment, Eutrophication factors, Emissions measurement and product specifications. Note: it might be difficult to distinguish between what is construction-related and what comes from different sources (e.g. urban environment)
Env8	Ecotoxicity	Yes	Impact on ecosystems, as a result of emissions of toxic substances to air, water and soil. Amount of substances causing the direct or indirect disappearance (e.g., through affecting reproduction) of the animal or vegetable species of an ecosystem. This indicator has three aspects: Freshwater aquatic ecotoxicity, Marine ecotoxicity, Terrestrial ecotoxicity.e.g. chemicals used, explosives (g, kg)	Ecotoxicity factors, Environmental impact assessment. Note: it might be difficult to distinguish between what is construction-related and what comes from different sources (e.g. urban environment)

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
Env9	Noise (and vibration) generated	Yes	Amount of noise generated by construction activities throughout the duration of the process. (dB). Vibrations is also a key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.	Noise and vibration monitoring records, on-site measurements, environmental impact assessment. Note: Vibration is key consideration (i.e. damage to nearby buildings). This is measured in mm/s along with the duration of the vibrations.
Env10	Energy demand	Yes	Total demand of energy within the project timeline, encompassing energy consumed by machinery, load-specific requirements, and other energy usage. (see Ec3)	see Ec3
Env11	Materials used/Materials consumption	Yes	KPI measures the total amount of materials utilized in the project, encompassing both construction materials and chemicals. This KPI is essential for assessing resource utilization, tracking inventory levels, and managing costs effectively. Total sum of all materials used (e.g. chemicals used, explosives,...) m3, tons, kg, litres, etc.	Delivery receipts, Material requisition forms, Chemical materials inventory management log, Supplier invoices
Env12	Water depletion	Yes	Total amount of water used in project timeline (m3)	Water usage records
Env13	Non-compliance environmental impact	Yes	See Ec8	Compliance tracking records, Regulatory documentation, Third-party audits, incident reports
Env14	Area of habitat retained/created	Yes	Ecologically valuable habitat created and/or retained within the total area of the site for a completed project. Measure of the changes in soil quality (Biotic production, Erosion resistance, Mechanical filtration). (area km2)	Environmental impact assessment, biodiversity action plans

	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
T1	Workers required	Yes	Number of workers required for the defined functional unit (see Ec2)	Project schedules, Construction management project, Input from supervisors, Labor productivity standards
T2	Quality of the activities performed	Yes	Compliance with quality objectives of the activity %	Quality objectives, Inspection criteria, Quality control reports, Expert assessment
T3	Cycle Time	Yes	Total time to finalise 1 functional unit, it includes time to complete the activity + idle time. Detailed dynamic plan of all processes with Cycle times	Time-tracking system, Work log, Daily reports, Observation or direct measurement
T4	Time needed to prepare floating dock for production	Yes	Total time needed to put up floating dock for production. It includes time spent on mobility, assembly of 3D printer or formwork and all other activities needed before production can start.	Observation or direct measurement, Project documentation
T5	Distance covered by machinery excluding drones	No	Indicator does not apply	
T6	Distance/surface covered by drones	No	Indicator does not apply	
T7	Functional units accomplished	Yes	Total functional units accomplished/day	Construction logbook, Work completion report, Quality control records, Project management documentation
T8	Failure rate	Yes	Failure rate completing a task	Quality control records, Work logs, Incident reports
T9	Time of full autonomous operation	No	Indicator does not apply	
T10	Percentage of tasks that use drones	No	Indicator does not apply	
T11	Percentage of tasks that use autonomous vehicles	No	Indicator does not apply	
T12	Accuracy of data	Yes	This KPI measures the accuracy of data collected during the operations. Data accuracy is crucial for making informed decisions, identifying trends and ensuring analytical insights.	Quality control, Third-party audit, Data comparison

			(Number of accurate data points / Total number of data points) x 100	
	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S1	Women willingness	Yes	The extent to which women would be willing to do the job/task before and after the implementation of the BT	Focus group/interview
S2	Women capability	Yes	The extent to which women would feel capable of performing the task/job	Focus group/interview
S3	Wearables and exoskeletons fit for women's physical traits	No	Women's physical traits integrated into the design of wearables and exoskeleton	Focus group/interview
S4	Olders workers capability	?	The extent to which workers aged +55 would feel capable of performing (or continue performing) this task	Focus group/interview
S5	Potential for attraction of younger generations	Yes	The extent to which young individuals would feel interested in performing this job.	Focus group/ interview
S6	Pregnancy Friendly Environment	Yes	Whether the working environment is safe for pregnant women	Focus groups / interview
S7	Usability of BT for people with disabilities	Yes	BT usability for people/workers with disabilities	Focus groups/ interview
S8	Motivation improvement	Yes	Improvements in motivation to perform the job	Questionnaire with workers
S9	Indoor air quality	No	Good quality indoor air. This KPI measures both, subjective and objective parameters of indoor air quality.	Questionnaire with workers and BT generated data
S10	Fatigue detection	No	Reduction in worker's fatigue	BT generated data
S11	Perception of fatigue reduction	No	Comparability between worker's fatigue perception and sensor measurements	BT generated data and questionnaire
S12	Muscular strain and back-injuries prevention	No	Perceived reduction of muscular strains and back-injuries	Questionnaire with workers

S13	Musculoskeletal loading reduction	No	Workers' perception of musculoskeletal loading reduction	Questionnaire with workers
	KPI	KPI applicability	Definition & Input Data for calculation	Collection of data
S14	Safety Perception	Yes	The extent to which workers feel safe whilst performing this job	Questionnaire with workers
S15	Alert system detection	No	Worker's capacity of hearing BT alerts when in a risky situation/position	Questionnaire with workers
S16	Detection of man down situations	No	This indicator measures the ability of the technology to detect when a worker has fallen or become incapacitated, and alert others to the situation.	Questionnaire with workers
S17	Recognition of dangerous locations for workers	No	This indicator measures the ability of the technology to identify and alert workers or supervisors of hazardous areas or situations that could pose a risk to worker safety	Questionnaire with workers
S18	Performance enhancement	Yes	Perception of performance enhancement	Questionnaire with workers
S19	Level of training required	Yes	Level of training required to perform this task	Questionnaire
S20	Compatibility of BT with the task performed by workers	Yes	Perception of compatibility of BT with the task being performed by the worker	Questionnaire with workers
S21	BT complexity	Yes	Perceived ease of use	Questionnaire with workers
S22	Perceived usefulness	Yes	Perceived usefulness of the BT in performing the task	Questionnaire with workers
S23	Existing knowledge and confidence about the BT and its use	Yes	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
S24	Comfort level	No	This KPI is a complex indicator covering aspects such as: • perception of weight, • thermal comfort, • noise level • Perception of fit between body and BT * The worker will give a % weight to each of the aspect in order to calculate the indicator according to the workers' preference	Questionnaire with workers

S25	Being in control of the BT and own body	No	Worker's existing knowledge and confidence about the BT and its use	Questionnaire with workers
-----	---	----	---	----------------------------

Development of templates for the reporting of the demonstration campaigns and the comparison of BT technologies and reference scenarios as key part of the impact assessment

The applicability of indicators, uncertainties, open questions and guidance on data collection, were detail in previous subsection. In this last section, the Beeyonders team has created templates to facilitate data compilation, results reporting and the future comparison of reference scenarios versus BTs during the impact assessment planned in Task 7.8.

The template is divided in sections and annexes:

The fist section is the presentation of the pilot at a glance, it includes:

- The operational scheme+ activities planned.
- BT partners involved + their role.
- Value proposition

Detailed information on the activities planned and stages covered during the validation might be detailed in Annex 1 (for both reference and BT scenarios)

Section 2 includes the final and refined use case particularised list of KPIs (based on the applicability described in this deliverable and the future discussions to clarify the uncertainties identified). The level of relevance for the use case and for the impact assessment and the results.

Calculations and information on the surveys and interviews undertaken (social KPIs) should be included in Annex 2.

Finally, Section 3 is devoted to Conclusion of the pilot deployment and impact assessment and to include any potential deviation or incident that might have influenced any of the activities planned.

Ideally the templated will be used in Excel .xlsx format but Use case leader can decide if it is better to gather all the information in .doc Word format.

These templates will be refined as part of the development of the different use cases and will be finalized and refined (if necessary) in Task 7.8.



Template Section 1:

		Picture of the pilot
PILOT No_: Pilot name		
Impact assesement date: Pilot scope: Location; Overall scope; Functional unit; Main specifications/objectives. Phases of the pilot (if more that one)		
Operational scheme and activities included in the pilot:		
Operational scheme	Activities: - - - -	
Target in Beeyonders: Value proposition		
Main BT involved & Role		
Use case leader:		
Partner name:	Partner name:	
Partner name:	Partner name:	



Template Section 2:**Use case particularised list of KPIs**

Social	Economy	Environmental	Technical

RESULTS**Economy KPIs**

Name of the KPI	Unit	Relevance for the pilot (low, mid, high)	Result of the reference scenario if applicable, (low, mid, high)	Result of the pilot scenario	Notes

Environmental KPIs

Name of the KPI	Unit	Relevance for the pilot (low, mid, high)	Result of the reference scenario if applicable, (low, mid, high)	Result of the pilot scenario	Notes

Technical

Name of the KPI	Unit	Relevance for the pilot (low, mid, high)	Result of the reference scenario if applicable, (low, mid, high)	Result of the pilot scenario	Notes

Social KPIs

Name of the KPI	Unit	Relevance for the pilot (low, mid, high)	Result of the reference scenario if applicable, (low, mid, high)	Result of the pilot scenario	Notes



Template Section 3:**Conclusions*****Template Annex 1:*****Annex 1:****Detailed scenarios description:****Extended operational scheme and activities included**

Operational scheme

-
-
-
-

Template Annex 2:

Calculations, results, boundary conditions, assumptions and cut off rules applied.							
For quantitative KPIs							
Name of the KPI	Timeline of data collection	Source of data & Responsible for data collection		Calculation formula	Result	Boundary conditions, assumptions and cut off rules applied	Other information

For qualitative KPIs (e.g. questionnaires)	
Name of the KPI	
Question	
Answer	



Conclusions

The main conclusions of deliverable D7.1 are presented below.

1. It is considered positive to have defined task T7.1 to develop a common methodology to work, measure, and evaluate all use cases of the project.
2. The arrangement of 6 workshops dedicated to the use cases has allowed all the participants to meet to discuss important details of their future execution, resolve doubts, and receive an explanation from the partners responsible for defining the KPIs of each use case, regarding its operation and mode of future evaluation.
3. The creation of different detailed and summarized KPI tables, and the templates for the detailed scenarios definition, represent a set of valuable tools for the evaluation of use cases at the end of the project.
4. For the moment, several KPIs have been established for the different scenarios, hoping to be able to measure most of them from an ambitious perspective in achieving objectives, but it will be at the time of the demonstration when the feasibility of each of them can be validated, due to site conditions or availability of the necessary equipment. All of this will be specifically defined in the templates developed for this purpose.
5. As T7.1 is an umbrella task for the use cases that begins/ends before/after them, it is understood that it will be constantly evolving and will serve as a common framework for communication between the use cases. For this reason, the possibility of making a second version of this deliverable in the final part of WP7 that includes new features that emerged during the demonstrators, is not ruled out and is even considered very positive.

