Robotics and AI as Enablers for Greener Dismantling, Remanufacturing and Recycling

-ROB4GREEN-

HORIZON-CL4-2024-DIGITAL-EMERGING-01-04 – Industrial leadership in AI, Data and Robotics boosting competitiveness and the green transition (AI Data and Robotics Partnership) (IA)

Grant Agreement No. 101189665

Annex 2: ROB4GREEN Technical Description

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. **101189665**.

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1 INTRODUCTION

This guide presents the **challenges of the Open Call** and elaborates on the ROB4GREEN functionalities that can be provided to the applicants to enhance the capabilities of their solutions. The guide provides material and technical details to take into consideration while preparing your proposal for the ROB4GREEN 1st Open Call.

More specifically, you can find:

a. the objectives of the ROB4GREEN project (refer to Section 2),
b. the technologies that fit the call and must be delivered through the **proposed challenges (refer to Section 3)**,
c. an overview of the ROB4GREEN architecture and the technology **blocks that will be available for use** during the FSTP project period **(refer to Section 4).**

For more information regarding the structure of the open call, evaluation criteria, contact, etc. refer to Guide for Applicants.

2 ROB4GREEN PROJECT

2.1 Project overview and core mission

ROB4GREEN is an EU-funded project under the Horizon Europe Programme that aims to bridge the current gap between labor-intensive Re-X processing and automated circularity. By developing easy-to-use, collaborative, and AI-driven robotic systems, the project enables industries to reason and adapt to key “R-strategies” for processing products after their first life. More specifically, ROB4GREEN addresses gaps that currently limit the wider adoption of flexible robotics in the circular economy, including limited cognitive intelligence, insufficient perception of product states, and restricted decision-making at the value-chain level.

To overcome these, ROB4GREEN focuses on the development, deployment and validation of:

- Cognitive and intelligent mechatronics for automating advanced manufacturing processes: Development and enhancement of mechatronic systems, including robots and specialized tooling, to enable autonomy through advanced perception, reasoning, and cognitive capabilities. These advancements allow systems to "understand" product conditions and material compositions in real time.
- AI-based robot programming, continuous learning, and decision-making: Development of AI-driven modules and interfaces to facilitate efficient interaction and decision-making between various robot types and human operators within the high-variability contexts of the foreseen applications.
- Multi-level optimization of Re-X processes and systems: Creation of an integrated, modular architecture for information exchange, analysis, and AI-driven decision-making. This involves scaling optimizations from the individual robotic "cell" level up to the entire value chain, ensuring that lifecycle data is utilized to enhance circular decision-making.

ROB4GREEN technologies, methodologies, and integrated frameworks will be tested and validated in three pilots from the energy infrastructure, automotive, and electronics industries. These pilots target key R-strategies for infrastructure decommissioning and material recycling (wind blade composites), remanufacturing (tire retreading), and the harvesting of high-value components (PCBA components), respectively. To maximize impact on the European economy and validate the rapid technology deployment of the project’s solutions, ROB4GREEN incorporates a Financial Support to Third Parties (FSTP) program. With a total budget of €4 million, this program will allow the verification of: a) the project’s framework in additional real-world scenarios (external pilots), and b) the interoperability of the ROB4GREEN architecture by attracting external RTOs for the co-development of solutions for the project’s pilot cases.

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2.2 Meet the consortium

LMS Laboratory for Manufacturing Systems & Automation	**LMS** is a leading European laboratory, specializing on industrial and collaborative robots, HRI, task planning for autonomous HRC, development of Service Oriented Architectures at the shop floor etc. LMS has proven experience in coordination, technical contribution and management of EU-funded projects (Project coordinator: THOMAS, SHERLOCK, ODIN, CONVERGING, JARVIS, Node leader in AI Testing and Experimentation Facilities of AI-MATTERS, Project manager in X-act and ROBO-PARTNER). LMS is the coordinator of the ROB4GREEN project, leading user-centric design for Human-Robot Interaction, Robot behavior adaptation to human needs and social interaction, and learning of social skills for the robots by observation.
TNO	**TNO**, as an independent and pioneering applied science and technology organisation, is the innovation engine of The Netherlands. Our mission is to create impactful innovations for the sustainable wellbeing and prosperity of society. We innovate, investigate, and orchestrate, collaborating closely with governments, universities and the private sector. By building national and international consortia and ecosystems, we drive technological and methodological breakthroughs that help to realise a secure, sustainable, healthy, and digital society.
tecnalia MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE	**TECNALIA** is the largest centre of applied research and technological development in Spain, a benchmark in Europe and a member of the Basque Research and Technology Alliance. We collaborate with companies and institutions to improve their competitiveness, people's quality of life and achieve sustainable growth. We do it thanks to a team of more than 1,500 people (44% women – 56% men) who are passionate about technology and committed to building a better society. Our main scopes of action are: smart manufacturing, digital transformation, energy transition, sustainable mobility, health and food, urban ecosystem and circular economy. Our mission is to transform technological research into prosperity; TECNALIA's research has a real impact on society and generates benefits in the form of quality of life and progress. And we work with the purpose of building a better world through technological research and innovation.
FLANDERS MAKE	**Flanders Make** is the strategic research centre for the manufacturing industry. From our sites all over Flanders, we stimulate open innovation through excellent research. In addition, companies can work together with us in a custom innovation trajectory. Finally, we also offer an extensive range of testing and validation infrastructure for your products or production. Our goal is to contribute to the technological development of the vehicles, machines and factories of the future. Flanders Make has been an active contributor to EU R&D projects since FP7 with a total grant amount of almost 100M EUR and currently has more than 70 running EU projects.
COMAU	**COMAU** is a worldwide leader in manufacturing flexible, automatic systems and integrating products, processes and services. Headquartered in Turin, Italy, with an international network that spans 17 countries that employ more than 4,000 employees, Comau uses the latest technology and processes to deliver advanced turnkey systems

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	that consistently exceed the expectations of its customers. Comau specializes in body joining & assembly, powertrain machining & assembly, robotics, and maintenance, as well as advanced production systems and environmental services for a wide range of industrial sectors. In particular, the unit of Robotics and Automation Products is mainly focused on the development and commercialization of robotics solutions and products for a very wide range of applications and processes. The product portfolio includes a large family of anthropomorphic robots, AGV, robots and exoskeletons.
netcompany intrasoft	**Netcompany-Intrasoft** is a leading European IT Solutions and Services Group headquartered in Luxembourg (2b rue Nicolas Bové, L-1253 Luxembourg). It employs 3,200+ highly skilled professionals from 50+ nationalities, speaking 30+ languages. The company operates through branches, subsidiaries, and offices in 10 countries: Belgium, Cyprus, Greece, Jordan, Luxembourg, Romania, RSA, Scandinavia, UAE, and USA.Netcompany-Intrasoft serves 500+ organizations across 70+ countries, spanning EU institutions and agencies, national governments, public agencies, financial institutions, telecom organizations, and private enterprises. Its strength is delivering complex, mission-critical projects, combining strong technical expertise with deep understanding of customer business needs, supported by a skilled, flexible, internationally minded workforce.
Teaching Factory	**TEACHING FACTORY COMPETENCE CENTER (TF CC)** mission is to create added value for the services and products of manufacturing companies, through innovative technologies and research activities. TF CC is involved in a number of research projects funded by the industry as well as by the CEU. It has been established through the collaboration of universities and several large industrial companies and SMEs in Greece.
F6S	F6S is a global network that helps founders and startups grow. It supports public and private entities in promoting and communicating research and innovation projects. F6S connects startups with resources like grants, funding, investment, partnerships, and talent. Their tools help solve social, economic, environmental, and sustainability challenges. F6S collaborates with various organizations in the global startup ecosystem, including governments, corporations, investors, and universities.
acciona BUSINESS AS UNUSUAL	Acciona specializes in developing regenerative infrastructure to promote people's well-being and protect the planet. It offers comprehensive solutions in waste management, with expertise in recycling composite materials and manufacturing both recycled and non-recycled components, particularly for the construction and wind energy sectors. Present in over 40 countries, Acciona drives innovation and digital transformation to improve performance, productivity, and sustainability, contributing to a zero-emission world.
MICHELIN	**MICHELIN** is building a world-leading manufacturer of life-changing composites and experiences. Pioneering engineered materials for more than 130 years, Michelin is uniquely positioned to make decisive contributions to human progress and to a more sustainable world. Drawing on its deep know-how in polymer composites, Michelin is

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	constantly innovating to manufacture high-quality tires and components for critical applications in demanding fields as varied as mobility, construction, aeronautics, low-carbon energies, and healthcare. As specialist in multi-life tires for over a century, Michelin has been innovating to improve the mobility of heavy vehicles by offering high-performance tires and services tailored to the needs of its customers. In 1923, Michelin introduced tire retreading, allowing the reuse of tire carcasses. An innovation that remains more than ever relevant today.
	VALEO is an automotive Tier 1 supplying all automakers worldwide, enjoying technological and industrial leadership in electrification, driving assistance, interior experience and light. 2023 Sales were at € 22 B and headcount at 110 000, all over the world. Since 2022, Valeo has its "Circular Electronics Lab" in Nevers: in collaboration with car manufacturers and new mobility fleet operators, Valeo was able to launch a range of remanufactured electronics components, using much fewer natural resources compared to a new part.

3 ROB4GREEN Open Call #1 Challenges

3.1 Requirements applying to all of the four ROB4GREEN challenges

a. **Existing Pre-Conditions:** the applicants should justify their ability to deploy the solution on-site for testing or their ability to create a relevant testbed. In cases where relevant, the applicants must provide their own robot(s).
b. **Prototypes:** must be designed to operate effectively in the potentially challenging conditions set by the selected use case (e.g., human presence, harsh environments, etc.).
c. **Use of open source:** applicants are encouraged to use open-source technologies where feasible to accelerate development, reduce costs, and ensure interoperability by following the corresponding permissions of use.
d. **Security, privacy and safety:** should be taken into account to minimize risks to users both in terms of physical harm and in terms of digital privacy and security.
e. **User studies:** where relevant, these studies should be conducted to evaluate operators' acceptance of the proposed solutions. Where not relevant, the case should be properly discussed and motivated.
f. **Business case benefit/cost performance:** should emphasize the added value of the proposed solution and fit for market and European Economy.

3.2 ROB4GREEN challenges

The first round of ROB4GREEN Open Calls involves four **distinct challenges**. As depicted in Figure 1, each one corresponds to a different hierarchy level of the circular economy's "butterfly diagram", aiming to address barriers that hinder its uptake in Europe.

Every application **must be assigned to one specific challenge** (e.g., *Challenge #1: AI, Data and Robotics for Life Extension*). This selection must be justified by explaining its relevance to at least one of the corresponding focus areas of that challenge (e.g., *"Inspection and Condition Checking"* and/or *"Repairing"*).

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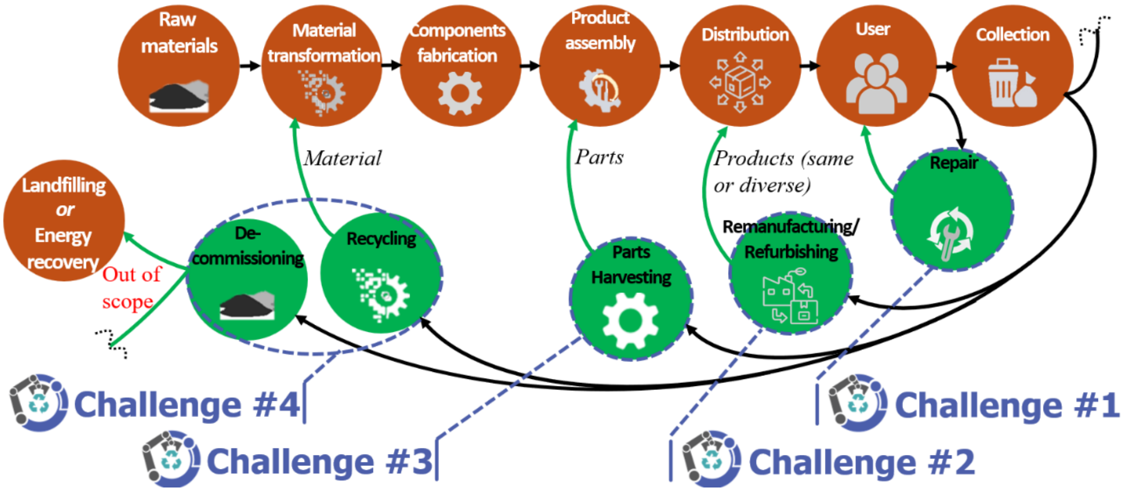

Figure 1. Simplified circular economy butterfly diagram and positioning of the ROB4GREEN Open Call Round #1 challenges

An alternative representation, based on the 9R framework depicted in Figure 2, showcases the aim of ROB4GREEN for generating impact through its first round of Open Calls in key R-strategies. In summary, the applicants are challenged to provide AI, Data and Robotics solutions for:

- ✓ **Challenge #1: AI, Data and Robotics for Life Extension**
  - o R4 Repair
- ✓ **Challenge #2: AI, Data and Robotics for Value Retention**
  - o R5 Refurbish
  - o R6 Remanufacturing
  - o R7 Repurposing
- ✓ **Challenge #3: AI, Data and Robotics for Parts Harvesting**
  - o Mass part harvesting for supplying conventional assemblies, or R(4 to 7) strategies
- ✓ **Challenge #4: AI, Data and Robotics for Decommissioning and Recycling**
  - o Decommissioning and material sorting techniques for supporting R8 Recycle

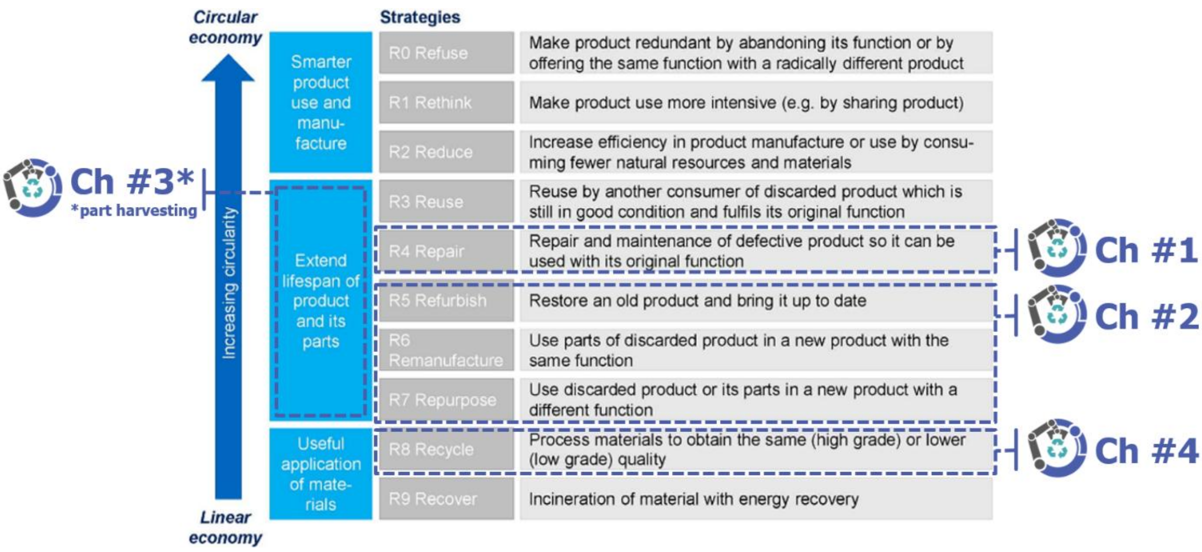

Figure 2. 9R Frameworks suggested by the PBL Netherlands Environmental Assessment Agency (2017), source: CE Grow circular

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<u>Challenge #1:</u> AI, Data and Robotics for Life Extension

Positioning & Strategic Context: Within the hierarchy of circular economy strategies, Life Extension is positioned as the most resource-efficient strategy. It focuses on maintaining a product in its original use phase for the maximum possible duration, thereby preventing it from becoming waste or entering energy-intensive recycling streams prematurely. The strategic goal is to return a used product to its <u>original user or market</u> without altering its core purpose, functionalities, or technical attributes, effectively "resetting" its operational clock while preserving the energy and materials already embedded in it. Under this challenge, there are two priority areas for development which represent the functional requirements needed to bridge the current gap between manual labor and automated circularity:

a. Inspection and Condition Checking: As part of the life extension cycle, the "Diagnostic" phase serves as the critical entry point for keeping high-value products in their primary use cycle for as long as possible. The core objective is to utilize **high-precision inspection, metrology and diagnostic tools** to identify both visible aesthetic defects and/or internal operational wear. This process is governed by the requirement to achieve a "Verified Condition Profile" -an objective, data-driven assessment of component wear and structural integrity that provides the necessary justification for the decision to extend a product's life.

b. R4 - Repairing: As part of the life extension cycle, the "Corrective" phase represents the physical intervention stage aimed at restoring a product's operational integrity and original function. The core objective is to perform high-precision **<u>physical interventions using robots</u>**, ranging from the **targeted replacement of defective sub-components to the specialized processing of materials to reverse degradation**. This phase is governed by the requirement that all actions must ensure the product retains its original safety specifications and performance warranties, effectively making the repaired version indistinguishable from a new unit in terms of reliability and long-term functional performance.

The proposed solutions should improve productivity and operators' wellbeing besides throughput for product life extension while reducing costs and reliance from operator expertise. In this direction, applicants should propose solutions for:

i. at least two (x2) of the following "Inspection and Condition Checking" areas:

- *High-Precision Automated Metrology:* Development of robotic-integrated sensing systems (e.g., laser scanning, 1D/2D/3D metrology) capable of capturing sub-millimeter defects on complex surfaces.
- *Multispectral & NDT Diagnostics:* Integration of Non-Destructive Testing (NDT) such as X-ray, ultrasound, or multispectral imaging to identify internal structural wear, cracks, or fatigue without disassembling the product.
- *Cognitive AI for Defect Classification:* AI models that go beyond simple detection to classify defects by severity and type, utilizing "Digital Product Passport" (DPP) data to compare the current state against original manufacturing specs.
- *Digital Twin-Based Condition Assessment:* Real-time synchronization between physical inspection data and a Digital Twin to visualize wear patterns and simulate "Residual Useful Life" (RUL).

ii. at least two (x2) of the following "repairing" areas:

- *Adaptive Robotized Processing:* Robotic systems that can automatically compute and adjust tool paths (for sanding, cleaning, or coating) based on the unique geometry of the damage detected in the diagnostic phase.
- *AI-Driven Decision Support for Repair:* Reasoning engines that analyze inspection data to propose the most efficient repair strategy (e.g., "patch vs. replace") based on cost, material savings, and energy footprint.

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- *Robotized Automation of Interventions: Flexible* robotic cells capable of performing complex corrective actions, such as the high-precision replacement of sub-components or delicate material removal.
- *Additive and Hybrid Manufacturing Tools:* Use of robotic additive manufacturing (3D printing) or laser cladding to restore material loss or rebuild worn-out features directly on the original component.
- *Intelligent Operator Support & HMIs:* Advanced Human-Machine Interfaces (HMIs) or Augmented Reality (AR) tools that guide operators through collaborative repair tasks, allowing the system to benefit from human dexterity while the robot handles precision and force.
- *Autonomous Interventional Logic:* Development of "skills-based" robotic behaviors where the system understands the *goal* of the repair (e.g., "close this crack") and autonomously selects the appropriate tools and movements.

Challenge #2: AI, Data and Robotics for Value Retention

Positioning & Strategic Context: Within the hierarchy of circular economy strategies (the "Butterfly Diagram"), Value Retention through Refurbishing and Remanufacturing represents a critical bridge between first-life usage and high-value second-life cycles. Unlike simple repair, this strategy involves industrial-scale processes aimed at capturing the maximum residual value of a product by updating its state or restoring it to a condition that meets or exceeds its original performance specifications. This product will attract new customers from the same or alternative sectors (repurposing). The strategic goal is to decouple economic growth from the consumption of virgin raw materials by transforming "cores" (used products) into high-quality assets that can be reintroduced to the market with full functional warranties.

Under this challenge, there are two priority areas for development which represent the functional requirements needed to bridge the current gap between manual labor and automated circularity:

a. **R5 - Refurbishing:** This area focuses on improving or updating a product, often involving aesthetic restoration and minor technical upgrades to align with current market standards or user expectations.
b. **R6 – Remanufacturing & R7 Repurposing:** This represents a high-level industrial process where a used product is systematically restored to an "as-new" condition. This involves standardized industrial steps, disassembly, cleaning, testing, and reassembly, to ensure the final product is functionally indistinguishable from a new one. A subset of activites corresponds to the repurposing of products where the product emerges with enhanced specifications (e.g., facelift, upgrading of sensors or electronics) or different ones (e.g., automotive battery pack repurposing for civil energy storage).

The proposed solutions should **enable flexible, AI-driven robotic automation** that can handle the high variability of incoming used products while maintaining industrial-grade quality and safety. Applicants must propose solutions for:

i. at least two (x2) of the following "Refurbishing and Remanufacturing Management" areas:

- *DPP-Enabled Lifecycle Tracking:* Integration of Digital Product Passports (DPP) and Asset Administration Shells (AAS) to access historical maintenance data and track remanufacturing steps, ensuring full traceability of the "second-life" asset.
- *Autonomous Multi-Criteria Sorting:* AI-driven systems that evaluate used products based on age, residual lifetime, and condition to automatically decide the optimal value-retention route (e.g., refurbish vs. remanufacture vs. recycle).
- *Standardized Quality Verification AI:* Development of automated testing protocols and AI reasoning that can certify that a remanufactured part meets original safety and performance standards.

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- *Reconfigurable Process Planning:* AI engines capable of generating dynamic assembly/disassembly sequences based on the specific version and state of the product "core" being processed.

ii. at least two (x2) of the following "robotized re-X processing" areas:

- *Flexible Robotic Cleaning and Stripping:* Autonomous robotic systems (e.g., using dry ice, lasers, or chemicals) that can adapt to different product geometries to remove contaminants without damaging the base material.
- *Skill-Based Robotic Reassembly:* Collaborative robots equipped with flexible grippers and force-feedback that can perform precision assembly tasks, accommodating for minor variations or wear in reused components.
- *Automated Aesthetic Restoration:* AI-controlled finishing systems (e.g., painting, polishing, or coating) that detect surface imperfections and apply tailored treatments via robot(s) to restore a product's "as-new" appearance.
- *Human-Robot Collaborative Refurbishing:* HMIs and AR-assisted workstations where robots handle heavy lifting or repetitive tasks, while operators perform high-dexterity updates.
- *Automated Functional Upgrading:* Robotic cells designed to swap out obsolete electronic modules (e.g., sensors or controllers) with modern equivalents to increase the technical value of the product.

Challenge #3: AI, Data and Robotics for Parts Harvesting

Positioning & Strategic Context: Within the hierarchy of circular economy strategies, Parts Harvesting serves as a vital recovery mechanism for high-value components and rare materials. This challenge addresses products that have reached the end of their functional life but still possess valuable sub-systems (e.g., electronic control units, specialized sensors, or subassemblies). Unlike bulk recycling, parts harvesting preserves the "embedded intelligence" and functional value of individual components, allowing them to be reused as spare parts for R4 Repair, R5 Refurbish, R6 Remanufacturing, R7 Repurposing or be integrated into completely new products. The strategic goal is to maximize resource recovery by selectively dismantling complex assemblies. This process reduces the need for primary material extraction and lowers the energy footprint associated with manufacturing new parts from scratch. Under this challenge, there are two priority areas for development:

a. **Inspection and Condition Checking:** The "Diagnostic" phase focused on identifying internal components and assessing their quality and reuse potential without damaging the host product.
b. **Dismantling and Sorting:** The "Extraction" phase, where robotic systems perform high-dexterity tasks to selectively remove and categorize parts based on their subsequent circular path.

Proposed solutions must address the high complexity and variability of heterogeneous waste streams while ensuring the integrity of the recovered parts. Applicants must propose **robotic solutions** for:

i. at least two (x2) of the following "Inspection and Condition Checking" areas:

- *Cognitive Multi-Sensor Identification:* AI systems utilizing RGBD, Near-Infrared (NIR), or other vision methods to recognize and locate specific components within a complex assembly (e.g., Identifying parts on a PCB).
- *Non-Destructive Reuse Assessment:* Integration of NDT tools (e.g., X-ray, ultrasound) to verify the functional integrity of internal parts before extraction, ensuring only viable components are harvested.

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- *Automated Value-Assessment Reasoning:* AI models that combine inspection data with market demand and "Digital Product Passport" (DPP) information to determine the economic and environmental benefit of harvesting a specific part.
- *Digital Twin-Guided Localization:* Using a product's Digital Twin to guide robotic end-effectors to precise fastening points, even when the physical product is deformed or dirty.

ii. at least two (x2) of the following "Dismantling and Sorting" areas:

- *Dexterous Robotic Disassembly:* Use of robots and advanced modular grippers capable of performing delicate unbolting, unscrewing, de-soldering, or detaching tasks without damaging the target part.
- *Adaptive Path Planning for Dismantling:* Robotic systems that autonomously compute extraction trajectories based on the real-time condition and orientation of the product.
- *Intelligent Sorting and Binning:* AI-driven robotic cells that categorize harvested parts into specific circular streams (e.g., direct reuse vs. secondary market) with a target accuracy of >90%.
- *Human-Robot Collaborative Harvesting:* Collaborative workstations where robots handle hazardous or repetitive disassembly steps (e.g., heavy casing removal), while humans focus on high-dexterity part retrieval.
- *Autonomous Skill-Based Manipulation:* Development of robotic "skills" (e.g., "gentle pull," "rotate and lift") that allow the system to adapt to different component joining methods autonomously.

Challenge #4: AI, Data and Robotics for Decommissioning and Recycling

Positioning & Strategic Context: Within the hierarchy of circular economy strategies, Decommissioning and R8 Recycling represent the fundamental layers for closing the material loop. This challenge is directed at large-scale assets and products that have exhausted their functional utility (e.g., wind turbine blades, heavy industrial infrastructure, or structural composite parts). Unlike previous challenges focused on reuse, the strategic goal here is to safely dismantle these assets and recover raw materials with high purity to prevent downcycling and minimize landfilling. In line with the European Green Deal, ROB4GREEN is heavily focused and prioritizes material recovery and reuse instead of energy recovery (i.e., incineration).

Innovative automation is necessary to transform recycling from a hazardous, manual task into a high-throughput industrial process. By utilizing robotics and AI, the project aims to demonstrate that even challenging materials (e.g., those found in composites), can be processed profitably and sustainably, directly contributing to the European Green Deal's carbon neutrality goals. Therefore, under this challenge, there are two priority areas for development:

a. **On-site De-commissioning Solutions:** Focused on mobile, aerial, or flexible robotic systems that can operate in non-standardized environments (e.g., wind farms, construction sites, etc.) to perform initial cutting, dismantling, or pre-processing.
b. **Material Recycling:** The "Processing" phase where AI and robotics ensure the accurate separation and sorting of raw materials into high-purity streams for secondary manufacturing.

The proposed solutions must improve safety by removing operators from hazardous or repetitive environments while increasing the efficiency of raw material recovery. Applicants must propose **robotic solutions** for:

i. at least two (x2) of the following "Decommissioning" areas:

- *Mobile, aerial or naval Robotics for on-site processing:* Development of adaptive robotic systems capable of maneuvering around and processing components on-site. Typical

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examples include wind turbine blades, building infrastructure, photovoltaic parks, trash collection, etc. among others.

- *Autonomous Cutting and Pre-processing:* AI-driven robotic tools that can autonomously identify optimal cutting paths and perform material separation on-site, adapting to the geometry and orientation of the decommissioned asset.
- *Environmental & Hazard Monitoring AI:* Integration of sensors and AI to monitor the surroundings during dismantling, ensuring the containment of dust or hazardous substances and protecting the local ecosystem.
- *Augmented Reality for Site Planning:* AR/VR tools to support human-robot collaboration in complex decommissioning environments, allowing operators to remotely supervise and guide robotic interventions.

ii. at least two (x2) of the following "Material Recovery" areas:

- *AI-Driven Material Characterization:* Real-time identification of material compositions (e.g., distinguishing between different types of composites or alloys) using advanced vision or spectroscopy before the sorting process begins.
- *High-Purity Sorting and Binning:* Robotic cells capable of high-speed, accurate sorting of shredded or dismantled materials into secondary raw material streams with a target accuracy of >90%.
- *Automated Cleaning for Recycling Purity:* Systems designed to remove contaminants (coatings, adhesives, or surface dirt) to ensure that the recovered material meets the technical requirements for high-quality secondary usage.
- *Process Optimization for Pyrolysis/Chemical Recycling:* AI reasoning engines that optimize the pre-processing of materials (e.g., cutting size and purity) to increase the yield and efficiency of subsequent chemical recycling or pyrolysis processes.
- *Circular Logistics Integration:* Software solutions that link recycling data with the value chain, providing "Verified Condition Profile" regarding the origin and quality of recycled materials for secondary markets.

<u>Note:</u> In line with the European Green Deal, ROB4GREEN is heavily focused and prioritizes material recovery and reuse instead of energy recovery (i.e., incineration). Therefore, external pilots under this prism are considered out of scope for this open call.

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4 ROB4GREEN FRAMEWORK AND SUPPORT PROVIDED

4.1 ROB4GREEN technologies at a glance

The ROB4GREEN framework is engineered to transform highly variable, manual "Re-X" tasks into scalable, automated industrial processes. To achieve its objective, the ROB4GREEN consortium has analyzed industry requirements and designed a software architecture that effectively supports the project's goals. This architecture defines how ROB4GREEN modules exchange data and interoperate using different forms of communication and dedicated APIs. ROB4GREEN utilizes a service-oriented, distributed architecture that can fit into the centralized control requirements of a re-X system. Rather than providing isolated tools, the project offers an integrated ecosystem aiming sustainability, innovation & openness, adaptation, perception, reasoning, collaboration, scalability, modularity & interoperability and reusability.

The project's enabling technologies can be described by four main layers:

- **Perception and cognitive mechatronics layer:** Consists of robotic manipulators, sensors and perception modules. The physical and cognitive foundation of the ROB4GREEN solution is provided by the technologies that belong to this layer.
- **AI-based programming and continuous learning layer:** Modules for task planning, continuous learning, collision-free motion planning and human-robot interaction. Adaptability, autonomy, social interaction and personalization are some of the most important benefits that stem from this layer's outcomes.
- **Information exchange and multi-level optimization layer:** Digital twin, AI-based decision-making components and open communication architecture. Optimization of Re-X processes, data integration of the system with external platforms, and updates of digital representations based on shopfloor data are handled under this layer.
- **Integration and pilot deployment layer:** Performance, sustainability, and adaptability validation through integration of the complete ROB4GREEN system within industrial demonstrators. This layer ensures that the developed technologies interact coherently in realistic production conditions.

The start of the funding programme is timed for ROB4GREEN's eighteenth month (M18) since its kickoff that was celebrated in January 2025. By that timing, the ROB4GREEN consortium will be able to deliver the first working prototypes of the project's technology blocks that will support core functionalities. The following subsection elaborates further.

4.2 What ROB4GREEN tools are available for 3rd party integration?

The ROB4GREEN's first prototypes that can be available for 3rd parties are showcased in Figure 3. A summary of the technologies along with their formatting and used interfaces is provided in Table 1.

It is mandatory, that the applicants select one (x1) or two (x2) ROB4GREEN tools to be integrated in their solutions.

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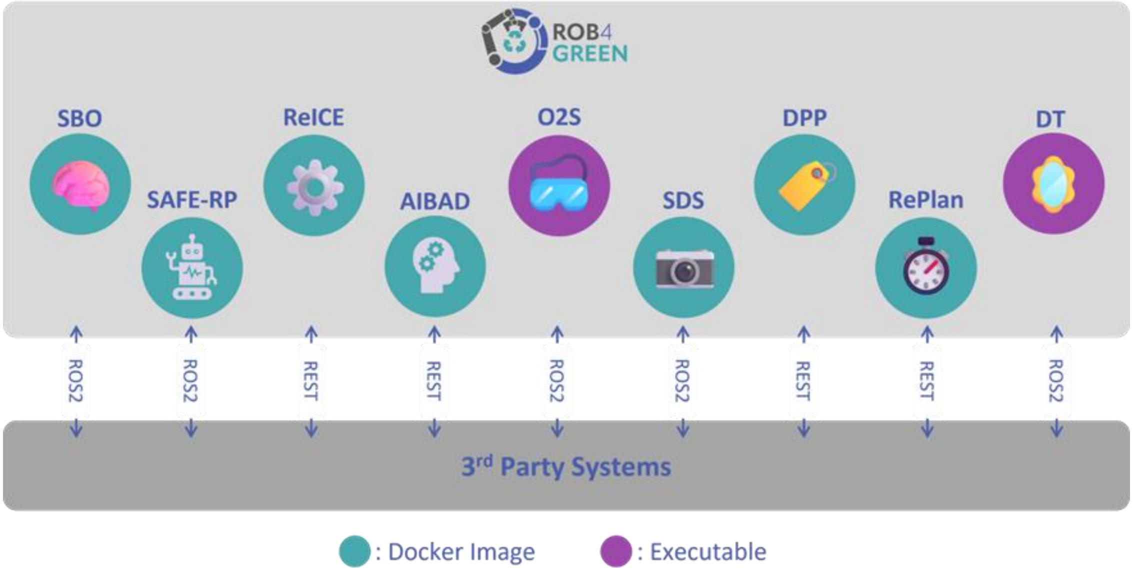

Figure 3. ROB4GREEN Tools available to 3rd Parties

Table 1. ROB4GREEN tools format and supported interfaces

Tool name	Tool acronym	Format	Interface
Shopfloor Perception & Digitalization Suite	SDS	Docker	ROS2
AI-based scheduling engine for robotized Re-X	RePlan	Docker	REST
Skill based dynamic orchestrator with behaviour trees	SBO	Docker/Executable	Behaviortree.cpp / ROS2
Collision-free robot motion planning	SAFE-RP	Docker	ROS2
Multi-modal Operator-System Interaction Suite	O2S	Executable	ROS2
Digital Product Passport	DPP	JSON-LD	REST
Digital Twin Platform for sustainable optimization of circularity operations	DT	Docker/Executable	ROS2
AI based Decision Making	AIBAD	Docker	REST
Re-X Integration & Coordination Engine	ReICE	Docker	REST

More technical details per software tool can be found in the following sub-sections.

4.2.1 Shopfloor Perception & Digitalization Suite (SDS)

Perception and interaction module for collaborative shopfloor environments. Provides real time human tracking based on skeleton detection and exposes the skeleton data via a standardized API. Supports contactless operator interaction through spatially defined virtual buttons, with button placement information received via a structured message type. Enables safe and flexible human robot collaboration and can be integrated seamlessly across different processes and industrial setups.

4.2.2 AI-based scheduling engine for robotized Re-X (RePlan)

AI-based scheduling engine that considers process constraints, priorities, and operational objectives to sequence Re-X actions and assign them to shopfloor resources. To optimize schedules and resource

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assignments, factors such as resource availability, estimated execution time, and system state are also considered. Execution progress gets continuously evaluated and schedules can be adapted and updated dynamically in response to unexpected events in the execution environment. The outputs of replan include schedules and scheduling metadata. The functionalities of RePlan are accessible through an intuitive graphical user interface.

4.2.3 Skill based dynamic orchestrator with behavior trees (SBO)

The SBO skill-based programming framework will provide a visual programming framework for building adaptable robot applications easily. Skills will be implemented with behavior trees and context models that will standardize parameters and state. The core architecture will remain reusable so other ROS2 implementations would be able to build on it. Robotics engineers would be able to build applications for ABB, Fairino, and UR, with runtime support and external configuration.

The framework will integrate camera and vision stacks like Daheng, IDS, and Pickit. Computer vision researchers would be able to plug-in their vision skills with support for YOLOv8, SAM models and python plug-ins. Users would also be able to plug-in MoveIt task planning as skills so that motion planning and execution can be reused across robot brands. Users would be able to drag and drop skills to build more complex orchestration behaviors and would be able to change configuration to swap vision models. Robots and camera drivers without rewriting the behavior tree logic.

4.2.4 Collision-free robot motion planning (SAFE-RP)

SAFE-RP will leverage the use of Skills and AI for automatic programming of robots. This block focuses on the development of collision-free motion planning algorithms and automated program generation for flexible robotic systems. The primary objective is to generate safe and efficient trajectories for two key operations: scanning and processing of parts. The processing involves linearly movements of robot Tool Center Point (TCP) at constant speed for cutting, sealing, welding, deburring etc. The planning process will leverage both static environmental data and if available, other real-time sensor inputs, ensuring adaptability to dynamic conditions. Different planning algorithms will be developed, with a focus on: a) Implementing Cartesian trajectory constraints, and b) Optimizing computational efficiency for real-time execution.

It is noted that the deployment of the tool prerequires an available robot URDF and ROS drivers. The third parties need to provide product's geometrical information (e.g. 3D cad) and support the parameterization process).

4.2.5 Multi-modal Operator-System Interaction Suite (O2S)

O2S is a Unity-based operator interface that works on a tablet, PC, or projector. It shows human tasks along with Task ID, Task name, Task description, and an image instruction panel. It also includes buttons or features for "Task Completed" and "Cancel" feedback. Task data come through ROS2 (topic/service). Instructional images are provided by a third party and stored in a specific folder using a set naming pattern (for example, per task and step) to allow for automatic loading. For projection, the overlaying, positioning and calibration of elements depend on accurate digitalization of the scene by the third party that needs to directly support such activities.

4.2.6 Digital Product Passport (DPP)

DPP captures and structures information about the product lifecycle including critical for repair and reuse decisions. It enables storing and tracking structured product data including historical repairs and modifications, component-level metadata and lifecycle events. It enables access to product information by other systems via its JSON-LD API (e.g., AIBAD, RePlan). It supports decision-making during Re-X by providing crucial information about the lifecycle and product specifications. It comes in the form of an JSON-LD schema and can be linked to other tools (such as AIBAD) via a dedicated DPP Service Tool. The DPP can also be used to reflect any Re-X processes that have been performed on the product.

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4.2.7 Digital Twin Platform for sustainable optimization of circularity operations (DT)

A docker- or executable -based Digital Twin platform that provides robot visualization based on accurate URDF models, 3D assets and ROS2 robot drivers. The DT enables the visualization of robot kinematics, execution states and workspace layout, and can be integrated with the SDS module for the visualization of human position in the virtual environment.

Additional functionalities, such as custom analytics, could be provided only if the third party leads their integration and supports the R4G consortium in that direction. ROS2 drivers, hardware interfaces, etc. need to be available by the third party for supporting related functionalities.

4.2.8 AI based Decision Making (AIBAD)

AIBAD implements a symbolic AI model in Python+RDF using PyReason that provides recommendations regarding the next steps in the remanufacturing process. Based on incoming product information (BOM, DPP, visual inspection information) and predefined logic rules, it determines if a product is fit for remanufacturing and, if so, prescribes the next steps. RDF-based ontologies are used to describe product components, parameters, and metadata.

4.2.9 Re-X Integration & Coordination Engine (ReICE)

Integration and coordination backbone for Re-X processes. Facilitates interaction between heterogeneous software modules, robotic systems, and human interfacing components. ReICE facilitates monitoring and control of Re-X workflows, coordinates task execution, and manages execution dependencies and synchronization. It also enables interoperability and allows seamless integration and testing of new technologies.

4.3 Support provided within ROB4GREEN Assistance Programme

In addition to the financial support of up to €300,000 per project, participants will benefit from tailored mentoring for the overall solution deployment, as well as expert guidance to integrate and deploy ROB4GREEN digital tools that will complement the existing solutions in real-world scenarios.

Each selected project will be supported by a dedicated ROB4GREEN Mentoring Team, ensuring that External Pilots maximize the potential of ROB4GREEN digital tools while effectively implementing their solutions. The mentoring team includes:

- **Innovation Mentor (IME):** Main contact point between the External Pilot and the ROB4GREEN project. The IME may provide inputs on innovation and technical aspects, and involve other resources from ROB4GREEN, if necessary.
- **SSH Mentor (SSM):** Ensures that your solution is fit for market, user-centric, and aligned with societal and regulatory considerations, leveraging insights from social sciences and humanities (SSH).
- **Industry Mentor (IND):** Contribute with inputs from the overall sector of which the External Pilot operators. Whether or not to include an IND will be evaluated on a Pilot-to-Pilot basis, based on, e.g., the composition of the team in the External Pilot and the choice of Innovation Mentor.

To ensure fair and objective assessment, an Internal Evaluator Board (IEB) will independently evaluate project progress, offering valuable feedback while remaining uninvolved in day-to-day activities.

The Innovation Mentor (IME) will provide the External Pilot with a template, which will serve as a roadmap for monitoring milestones and results. Each External Pilot will undergo a minimum of three evaluation meetings, corresponding to key project sprints, ensuring continuous improvement and impact assessment (Section 5.3).

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5 Activities During the Work Programme

5.1 Programme Phases

The ROB4GREEN Programme includes three sprint phases summarized in Table 2.

Table 2. Programme phases

Phase number	Name	Duration
Sprint 1	Requirements	M01 – M02
Sprint 2	Deployment & development	M03 – M08
Sprint 3	Validation	M09 – M10

The corresponding deliverables (reports, dissemination summaries, videos, etc.), upon delivery and acceptance, mark the successful conclusion of the phases/ sprints and are mandatory.

During the activities, the beneficiaries will have the support of a mentoring team. Information for Mentoring team can be found in the "Guide for Applicants".

5.1.1 Sprint 1: Requirements [M01 – M02]

Sprint 1 is the starting point the project and will last up to 2 months.

Within this phase, beneficiaries must finalize the implementation plan, including key requirements and roadmap for the development and deployment of the funded pilot. The implementation plan should account for the integration of ROB4GREEN tools with the rest of the envisioned technologies and the fulfilment of the project's objectives.

At the end of Sprint1, beneficiaries should deliver:

1. **One (x1) technical report** presenting:
    a. The full set of functional requirements, quality attributes, technical and business constraints. This includes technical specifications of the solution, description of the baseline technologies/prototypes and roadmap to the final demonstrator together with the finalization of the case specific KPIs.
    b. Detailed development and implementation plan including, detailed description of the tasks to be performed, milestones and means of verification.
    c. Detailed resource planning.
    d. Risk management process and risk identification.
    e. When required, evidence that a research protocol was submitted to an ethical committee
2. **One (x1) dissemination 1-pager**: this includes a publishable summary of the results obtained at this stage. It is accompanied by high-resolution figures and graphical material for social media usage.

<u>Relevant Notes:</u>

- The **plan must be agreed with the mentors** of ROB4GREEN project.
- The projects are required to deliver the two deliverables **two (x2) weeks before the end of the phase**.

5.1.2 Sprint 2: Development & Deployment phase [M03 – M08]

Sprint 2 lasts 6 months and is dedicated to the core development and deployment stage of the projects, following the specifications provided in the technical annex of the proposal, the detailed plan

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submitted in Report #1 and eventual updates required by the ROB4GREEN consortium. More specifically activities involve:

- development of the required functionalities as identified in "Sprint 1"
- deployment of a demonstrator of the system prototype in relevant environment, including the ROB4GREEN tool(s) that the beneficiaries have selected from the list in Table 1.
- collection of relevant data to support to describe the operation of the initially deployed solution.

At the end of Sprint 2, beneficiaries must deliver:

1) **one (x1) technical video demonstration** of the system prototype in relevant environment (internal use)
2) **one (x1) technical report** (Report #2) including:
    a. technical activities performed
    b. compliance with the plan approved, including milestones and means of verification.
    c. usage of resources
    d. detailed risk management information
    e. updated plan for the validation phase.
    f. When required, evidence that a research protocol approved by an ethical committee was followed and is considered in the updated plan for the validation phase.
3) **one (x1) publishable dissemination summary**: this includes a publishable summary of the results obtained until this stage. It is accompanied by high-resolution figures and graphical material for social media usage.
4) **one (x1) publishable video**: video showcasing project outcomes that will be shared through social media for raising awareness.

Relevant notes:

- When required, evidence that a research protocol was approved by an ethical committee, and the implementation plan is updated according to their recommendations. If the requirements and/or recommendations of the Ethical Committee significantly update the scope of the project or the workplan, the consortium must promptly inform the ROB4GREEN consortium. Significant updates will be evaluated case by case and may lead to project termination if the updated goals as work to be performed cannot meet the goals of the proposal.
- The projects are required to **deliver the "technical video demonstration" and the "Report #2" two (x2) weeks before the end of the phase**, and the **dissemination material one (x1) week before the end of the phase**.

5.1.3 Sprint 3: Validation Phase [M09 – M10]

Sprint 3 marks the final stage of the project and its goal is to validate the pilot, following the specifications provided in the technical annex of the proposal, the detailed plan submitted in Report #2 and eventual updates required by the ROB4GREEN consortium. In addition, through exploitation activities, the consortium will be outlining the potential for future exploitation and impact. More specifically activities involve:

- system prototype demonstration in an operational environment (TRL7).
- exploitation roadmap, outlining potential commercialization pathways, and next steps for scaling up.
- user validation study to assess the use case, engaging at least 5 individuals if human intervention is maintained in the process (users of the proposed solution e.g. operators, engineers, workers). Participants should agree to provide structured feedback on usability and

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technology acceptance, including the validation of the ROB4GREEN tool(s) with an option to share insights in relevant industry events or publications.

At the end of Sprint 3, beneficiaries must submit:

1) **one (x1) technical video demonstration** of the integrated system in relevant environment (internal use)
2) **one (x1) technical report** (Report #3) including:
    a. technical activities performed
    b. Pilot Validation
    c. Future exploitation and market potential
    d. compliance with the plan approved, including milestones and means of verification.
    e. usage of resources
    f. Detailed risk management information
    g. When required, evidence that a research protocol approved by an ethical committee was followed.
3) **one (x1) publishable dissemination summary**: this includes a publishable summary of the results obtained by the end of the project. It is accompanied by high-resolution figures and graphical material for social media usage.
4) **one (x1) publishable video**: video showcasing project outcomes that will be shared through social media for raising awareness.

Relevant Notes:

- The **plan must be agreed with the mentors** of ROB4GREEN project.
- The projects are required to **deliver the "technical video demonstration" and the "Report #3" two (x2) weeks before the end of the phase**, and the **dissemination material one (x1) week before the end of the phase**.

5.2 Participation in public Events

During any of the Phases previously described, the sub-projects can be requested to:

1) attend at physical events (≤3) two-day events in Europe, either organized by ROB4GREEN or in which the ROB4GREEN Project is participating.
2) audio calls, video calls, webinars, online training, virtual conferences, etc. organized or suggested by the ROB4GREEN Consortium.

The scope of the events is to disseminate the projects' activities and results. **Applicants will need to plan the attendance on these events as part of the budget requested.**

5.3 Evaluation during the programme

The milestones, KPIs and deliverables will be evaluated at the end of each Sprint. **A remote review meeting will take place after each phase** (via teleconference platform) to evaluate the progress of the beneficiaries.

The reviewing process will take in consideration the achievement of the Key performance Indications presented in Table 4 through the deliverable reports that are enlisted in Section 5.1. A summary of a summary of the three reviews along with their expected requirements and outcomes are summarized in Table 3.

The beneficiaries will present the work completed, outline the progress achieved, and answer questions from the ROB4GREEN experts.

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After the review, the beneficiaries will receive a review report, including short comments and potential recommendations. The report will indicate whether the deliverables are accepted, require revision, or are rejected.

Therefore, the following scenarios emerge:

- **Acceptance of all deliverables:** This validates the successful completion of the corresponding phase; therefore, the lump sum payment tranche will be approved. Payments will be processed within forty (x40) working days following the positive review outcome.
- **Rejection of at least one deliverable:** In the event of a rejected deliverable or an unsatisfactory review, beneficiaries will be requested to re-submit improved deliverables. The ROB4GREEN experts will then determine whether the project may proceed to the next Sprint or if the risk of failure is too high. If rejection or an unsatisfactory review occurs in the final Sprint (Sprint 3), the ROB4GREEN Consortium may allow a short extension for the beneficiary to revise and resubmit the deliverables. If the deliverables are approved within the extension period, the final lump sum payment will be released accordingly.

Table 3. Summary of project reviews: requirements, result and timeline

Phase	Item	Description
Requirements	**Requirement**	Submission of ✓ **One (x1) technical report** (Report #1) ✓ **One (x1) dissemination 1-pager**
	Result	Approval of the Updated plan for Development & Deployment Phase and compliance with funding conditions.
	Timeline	End of month M02.
Development & Deployment	**Requirement**	Submission of ✓ **One (x1) technical report** (Report #2) ✓ **One (x1) publishable dissemination summary** ✓ **One (x1) technical video demonstration** ✓ **One (x1) publishable video**
	Result	Approval of the Updated plan for Validation Phase and compliance with funding conditions.
	Timeline	End of month M08
Validation	**Requirement**	Submission of ✓ **One (x1) technical report** (Report #3) ✓ **One (x1) publishable dissemination summary** ✓ **One (x1) technical video demonstration** ✓ **One (x1) publishable video**
	Result	Approval of the deployment and validation activities and compliance with funding conditions. Payment of up of the remaining 50% of the grant and successful completion of the project
	Timeline	End of month 10

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Table 4. Relevant KPIs and expected outcomes considered in the reviewing process

Main KPI categories	List of relevant KPIs
ROB4GREEN overall KPIs for external Pilots	Universal indicators: ○ KPI 1: Successful demonstration of the use case in the selected challenge at TRL7. ○ KPI 2: Number of ROB4GREEN tools utilized (1 or 2). ○ KPI 3: Energy/material savings thanks to AI & robotics by 50%. Select x2 of the following: ○ KPI-O1: Reduction of Greenhouse Gas (GHG) emissions by 10%. ○ KPI-O2: Ratio of tasks performed by AI enhanced robotic solutions over tasks by human by more than 5%[1]. ○ KPI-O3: Reduction of energy during the pretreatment process by 20%. ○ KPI-O4: For composites, reduction of energy during the pretreatment process by 20% and time for the segregation/preprocessing by 30%. Extra KPI for challenge #2: ○ KPI-Ch1: materials savings increase by 15%. Extra KPI for challenge #3: ○ KPI-Ch2: accurate detection of components more than 90%. Extra KPI for challenge #4: ○ KPI-Ch4: Reduction of unwanted materials around 5% to 6%.
Dissemination KPIs	○ KPI 1: 1 Minimum 1 public announcement of the scope of the project (e.g., via Social Media (SM) (Sprint 1). ○ KPI 2: Minimum 1 prototype video demonstration at TRL 6 or above (Sprint 2). ○ KPI 3: Minimum 1 solution video demonstration at TRL7 (Sprint 3). ○ KPI 4: Minimum 3 social media posts per each Sprint ○ KPI 5: Minimum 200 interactions (likes, shares, comments) across all posts during the programme. ○ KPI 6: One blog post for ROB4GREEN website per Sprint.
Expected final outcome	The expected outcome at the end of the 10-month project execution includes: ○ the demonstration of the solution including the ROB4GREEN selected functionalities at a relevant environment with the selected use case (onsite or testbed). ○ a report presenting the testing of the solution. When applicable, it must involve testing with actual users (individuals such as workers, operators, engineers) in the selected industry. This should be supported by a user satisfaction study and documented in a report. In addition the report must be presenting their go to market strategy.

Relevant notes:

- It is important that **reports and technical demonstration videos must be submitted at least two weeks in advance**, so that the reviewers will have enough time to prepare. Similarly, **dissemination material (summaries, videos, etc.) needs to be submitted at least one week in advance**.

[1] e.g., 53% robotised- vs 47% manual- tasks, or better

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- During the remote review meeting, the participation of **at least one (1x) representative per beneficiary is mandatory**.
- Failure to (re-)submit rejected or delayed deliverables within the specified (or extended) deadlines, insufficient quality of outputs, or the inability to achieve agreed Key Performance Indicators (KPIs) may lead to the **rejection of deliverables and, consequently, the rejection of associated costs**. Such instances **may also result in project termination**. To mitigate these risks, ROB4GREEN provides dedicated mentoring support to assist beneficiaries throughout the implementation phase.

6 Conclusions

This document summarizes the challenges of the Open Call along with the tools that will be accessible to the selected applicants of the 1st ROB4GREEN Open Call. The applicants should consider the presented functionalities and involve at least one of the ROB4GREEN tools in their proposals. The ROB4GREEN consortium will guide and support the integration and deployment of the selected toolset in their use case. The feedback collected after the end of the projects' execution will drive further enhancements of the functionalities of the ROB4GREEN modules.

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