D5.1: Simulation of the semi-automated PCB disassembly process

30/11/2022 (M18)

Author: Chiara Cimino, Lorenzo Francesco Gandini, Paolo Rosa (Politecnico di Milano)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

Technical References

Project Acronym	TREASURE
Project Title	leading the TRansion of the European Automotive SUpply chain towards a circulaR future
Project Coordinator	POLITECNICO DI MILANO (POLIMI)
Project Duration	36 months as of 1 June 2021

Deliverable No.	5.1
Dissemination level [1]	CO
Work Package	WP5 - Pilot plants reconfiguration/optimization
Task	5.1 - Simulation of the semi-automated PCB disassembly process
Lead beneficiary	POLIMI
Contributing beneficiary(ies)	TXT
Due date of deliverable	30/11/2022
Actual submission date	22/11/2022

Document history		
V	Date	Beneficiary partner(s)
V1.0	29.09.2022	POLIMI
VF	22.11.2022	POLIMI

DISCLAIMER OF WARRANTIES

This document has been prepared by TREASURE project partners as an account of work carried out within the framework of the EC-GA contract no 101003587. Neither Project Coordinator, nor any signatory party of TREASURE Project Consortium Agreement, nor any person acting on behalf of any of them:

a. makes any warranty or representation whatsoever, express or implied,
   i. with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or
   ii. that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or
   iii. that this document is suitable to any particular user's circumstance; or
b. assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if Project Coordinator or any representative of a signatory party of the TREASURE Project Consortium Agreement, has been advised of the

[1]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)

EXECUTIVE SUMMARY

The objective of TREASURE project is to offer an opportunity to make the automotive sector more circular. This objective is pursued with the realisation of tools that support the development of a circular supply chain within the possibility of testing different technologies. As already identified in the precursor FENIX project, the Key Enabling Technologies (KETs) can be integrated into various processes to obtain real benefits and to improve the efficient recovery of secondary resources. Among the KETs - within the Industry 4.0 context – simulation is used to replicate real-world behaviours in a digital environment. The fundamental concept behind using simulation tools for circular approaches is that the most important stages of the simulated assembly-disassembly process can be duplicated in the virtual world and optimized in real time.

Deliverable 5.1 focuses on developing a tool for the disassembly of wasted car electronics through a semi-automated (I4.0-based) process. Starting from the knowledge acquired during the H2020 FENIX project, T5.1 wants to apply the semi-automated PCB disassembly process to the automotive sector in order to automatize as much as possible the car electronics disassembly process while improving the user-friendliness of the application and offer the simulation as a service for the user.

Section 2 discusses simulation for the human-cobot interactions, the I4.0 technologies adopted and their connection with CE, by offering background on some real cases found in the literature. Section 3 introduces POLIMI's I4.0Lab, where the application has been physically carried out, by describing the disassembly process already implemented for the H2020 FENIX project (www.fenix-project.eu). Section 4 describes the requirements for the cobot interface development and the proposed structure to fulfil the TREASURE objectives. The cobot interface will have two different operative modes, Learning Behaviour and Automatic Behaviour. Both need a communication platform to be enabled. Section 5 presents the communication platform of the cobot interface that allows the WEAVR platform to communicate with the workstation, the cobot, the simulation environment and all the devices connected to the workstation. Section 6 shows the structure of the single Learning Behaviour, leaving the implementation of the Automatic Behaviour to Task 5.2. The Learning Behaviour is described together with the development of a Graphical User Interface (GUI) that allows a user-friendly procedure both for interacting with the cobot and the simulation environment. Finally, Section 7 reports the results derived from the adoption of simulation tools described in the previous section.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

TREASURE

TABLE OF CONTENTS

DISCLAIMER OF WARRANTIES 2

EXECUTIVE SUMMARY 3

1. Introduction 5

1.1. Project Overview 5

1.2. Scope of the deliverable 5

1.3. Contributions to other WPs 5

2. State of the art on Human-Robot Collaboration (HRC) 5

2.1. Collaborative Robot 5

2.2. HRC for Circular Economy 6

2.3. Simulation for HRC 6

3. HRC in the Industry 4.0 Laboratory 7

3.1. The Industry 4.0 Laboratory of Politecnico di Milano 7

3.2. The Franka Emika Panda Cobot 8

3.2.1. Franka Emika Panda interfaces 8

3.2.2. Manual Guidance and other specifications 10

3.3. Semi-automated PCB disassembly process – FENIX project 10

3.3.1. The structure 10

3.3.2. The process 11

3.3.3. The simulation 12

3.3.4. The user interface 12

4. Cobot Interface requirements and structure 12

4.1. The objective 12

4.2. The Cobot Interface requirements 13

4.3. The Cobot Interface structure 14

5. Communication Platform 15

5.1. Communication Platform Tasks 15

5.2. ROS environment structure 16

5.3. Simulation 16

5.4. Integration with the WEAVR platform 17

6. Cobot Interface – the Learning Behaviour 17

6.1. Learning Behaviour Architecture 17

6.2. GUI structure 17

6.3. GUI creation 18

6.4. Additional Comments on the Learning Behaviour 18

7. Conclusions 19

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

8. References.. 19

1. Introduction

1.1. Project Overview

The project is focused on recovering the electronic systems, as microcomputers and electronic components, present in modern cars that represent from 30% to 50% of the total vehicle cost. The main problem arising in the recovery process regard mainly the End-Of-Life(EoL) of the product. Difficulties exist in the implementation of the Circular Economy(CE) in this sector: the EoL is not well connected with the Beginning-of-Life(BoL) and the data about materials embedded in cars are partially accessible from all the actors. This project wants to make use of the Industry 4.0 enablers to deal with those problems realizing an AI-based scenario assessment tool that can support the development of CE while involving all the main actors and practically demonstrating the benefits with case studies.

1.2. Scope of the deliverable

Deliverable D5.1 focuses on the simulation of a semi-automated PCBs disassembly process for the automotive sector that can be integrated into the platform structured in WP4. The task starts from the application obtained from the H2020 FENIX project (www.fenix-project.eu - reported into D3.2 of the said project) where the disassembly procedures are performed with a collaborative robot (so-called cobot). The objective of D5.1 is to make use of the simulation within a user-friendly tool during the disassembling procedures while using the TREASURE platform to enhance the human-cobot interaction, increase the productivity of the process and preserve the operator's comfort and safety.

1.3. Contributions to other WPs

The deliverable D4.1 “TREASURE technical architecture” shows the whole platform architecture that will be used by the operator for the disassembly task.

Starting from the architecture of the whole procedure, this deliverable focuses on the use of simulation for the DIS module, introduced in D4.1, regarding the disassembly process of PCBs through the use of a cobot in the module.

Then, the activities carried of Task T5.2 about the “Pilot-scale reconfiguration, testing and optimization of a semi-automated PCB disassembly process” will make use of the simulation environment here created, allowing the operator to safely interact with the cobot.

2. State of the art on Human-Robot Collaboration (HRC)

2.1. Collaborative Robot

A cobot is defined in the ISO/TS 15066:2016 (ISO/TS 15066:2016 - Robots and robotic devices – Collaborative robots. 2016. url: https://www.iso.org/standard/62996.html) as “*a robot that can be used in a collaborative operation*”, defined in turn as an operation “*where purposely designed robots work in direct cooperation with human within a defined workspace*”.

The ISO 10218 safety standard (the ISO 10218-1:2011- Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots. 2011 url: https://cutt.ly/BNuekXF) and the RIA ISO/TS 15066 technical specification define the safety functions and performance of a cobot, within four different Collaborative Robot Operations:

• *Safety-rated monitored stop*, that pauses a robot's motion while an operator is in the collaborative workspace;

• *Hand-guiding operation*, which allows an operator to move the cobot to a specific point without any particular knowledge.

• *Speed & separation monitoring*, which allows the cobot to move with a certain speed until the human and the cobot maintain a certain distance;

• *Power and force limiting*, which allows for detection of the physical contact between the robot system (including the workpiece) and the operator, that can occur either intentionally or unintentionally. Of course, those contact should be limited to the ones planned to guarantee the highest safety level possible.

The operative modes above create new opportunities for a human to work in cooperation with a robotic system, but pose different limitations to the operative possibility of the systems.

2.2. HRC for Circular Economy

Among all the solutions that can help the CE under the Industry 4.0 context (Rocca et al., 2020), the HRC is considered one of the key research trends that can support CE with the creation of remanufacturing and recycling frameworks (Daneshmand et al., 2022). The presence of both the human and the robot allows one to divide and assign the tasks differently: the robot can perform all the dangerous tasks while the human can guide properly the robot and deal with more value-added tasks, increasing job satisfaction (Álvarez-de-los-Mozos et al., 2020).

Even if many of the aspects related to HRC remain challenging for the industrial application, it is considered crucial for the development of new processes that must reduce the Waste on Electric and Electronic Equipment (WEEE) (Álvarez-de-los-Mozos et al., 2020). The flexibility provided using **cobots** – capable of working without any barrier close to the operator – allows the possibility of creating processes that are in turn flexible and can adapt to different disassembly requirements (Kerin & Pham, 2019).

Focusing on the disassembly operations to be performed in the project context it is evident that, when dealing with the disassembling of different types of PCBs, the cobot can indeed help the operator in automatizing the procedures (Cesta et al., 2016). Nevertheless, the set of possible PCBs that could be disassembled is really large, and at least at the first stage of the process development, the human is needed to guide the cobot when dealing with a new set of procedures to be executed. Hence, we focus on simulation as one of the tools that can support the operator when he/she interacts with the cobot.

2.3. Simulation for HRC

As shown above, simulation has several advantages in the Industry 4.0 context with the integrated use of sensors and advanced technologies. Also, simulation has multiple applications for the WEEE disassembly process (Kerin & Pham, 2019; Kobayashi & Kumazawa, 2005) and it is used to evaluate different choices that may affect different parts of an asset life cycle (Sassanelli et al., 2021). Since the goal of this deliverable is to use simulation in a process where interactions with humans are crucial for the process results, herein it is important to understand the state-of-the-art on the use of simulation in these types of processes.

Different types of interactions with cobots exist depending on how the activities are divided between the operator and the cobot(El Zaatari et al., 2019): Independent, Simultaneous, Sequential, and Supportive. The most commonly used interactions at the level of industrial applications tend to be Independent and Simultaneous, as these make it relatively easy to manage the safety of the operator working with the cobot. Although the cobots are built in compliance with ISO 10218-1 (the ISO 10218-1:2011- Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots. url: https://cutt.ly/BNuekXF) and ISO/TS 15066 (ISO/TS 15066:2016 -Robots and robotic devices — Collaborative robots. url: https://www.iso.org/standard/62996.html), the safety procedures depend very much on the process and the type of interaction between user and cobot. Hence, cobots still need to undergo a risk assessment before being implemented on a factory floor (Realyvásquez-vargas et al., 2019; Vicentini, 2021).

Overall, at this stage of HRC's presence in industrial applications, simulation tends to be used in terms of 3D simulations, mainly for training the operators and for safety reasons (Daneshmand et al., 2022; Sassanelli et al., 2021). It can both help to compute the risk assessment and to support the user in dealing with the interaction with the cobot, i.e. stress in dealing with interfacing with a cobot(Arai et al., 2010).

3. HRC in the Industry 4.0 Laboratory

3.1. The Industry 4.0 Laboratory of Politecnico di Milano

This section introduces the Industry 4.0 Laboratory (I4.0 Lab) owned by the Manufacturing Group of the Department of Management, Economics and Industrial Engineering of Politecnico di Milano (www.polimi.it).

(a) (b)

Figure 1 - Industry 4.0 Laboratory at the Politecnico di Milano

As well explained by (Fumagalli et al., 2013), "*I4.0 Lab is a tangible physical entity to carry out research activities in a "real-like" Industry4.0 environment. I4.0 Lab represents a central pillar for Industry 4.0 awareness and knowledge diffusion, both for industrial network and for research and academic network*". The laboratory collects different types of systems to carry out different research activities: a complete production line in Figure 1 (a), aligned with the industry 4.0 state-of-the-art technologies; an AGV for managing logistic informative system and a Franka Emika Panda Cobot in Figure 1 (b). Due to administrative problems, the Franka Emika Panda was used for the immediate realisation of task 5.1, but all the steps illustrated here – with the modification required by the vendor – will be applied to the UR5, a cobot specifically selected for the treasure application for its industrial nature. This section describes first the cobot used for the task and how it can be controlled, then the semi-automated PCB disassembly process developed for the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

FENIX project is presented as a starting point for the design of the Cobot Interface for the TREASURE project.

3.2. The Franka Emika Panda Cobot

3.2.1. Franka Emika Panda interfaces

As said above, the cobot used for task 5.1 is the Franka Emika Panda of Figure 1 (a) (Franka emika panda. url: https://www.franka.de/technology). The Panda Cobot possesses all the characteristics to enable collaborative interactions with the proper limitation described previously. The Panda Cobot – like each cobot and robot in general – can communicate with the external world and can be programmed in different ways: from the vendor app namely in this case the Desk Web interface, a user-friendly interface dedicated to educational purposes (Figure 2), and the Franka Control Interface (FCI), a low-level programming interface.

The **Desk Web vendor interface** is an interactive online application that offers an easy way to communicate with the cobot. It controls the cobot using the visual interface illustrated in Figure 2. The application enables the use of blocks that allow the organisation of the paths through easier drag-and-drop actions. Each of these blocks must then be set with the right parameters from the user.

Overall, this interface enables quick and easy robot programming for high levels of versatility, simple programming, and quick setup. However, the vendor interface does not provide complete access to all robot characteristics and is deficient in key aspects like condition-based operation and communication capabilities (Ionescu et al., 2020). Hence, the interface is ideal for educational purposes, testing and quick prototyping of some set of operations given its unique properties, while it lacks the completeness required to simulate the cobot and communicate with other possible devices for the development of complex tasks.

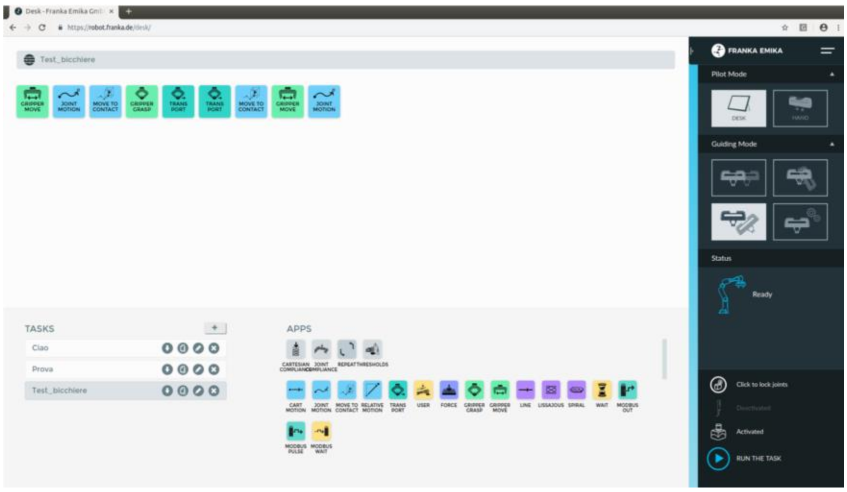

Figure 2 – The Desk Web Interface vendor application for the Franka Emika Panda Cobot

The **Franka Control Interface (FCI)** is still provided by the vendor, but it can be considered more *open*. The FCI allows communications between the cobot and a workstation within a fast and direct low-level bidirectional connection.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

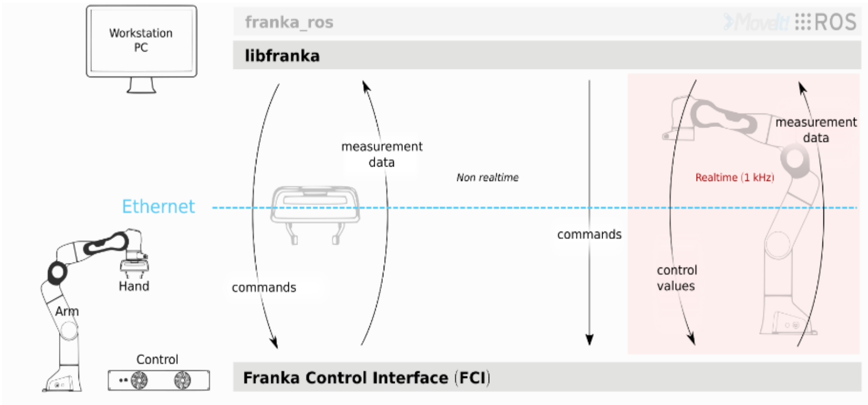

Figure 3 – The Franka Control interface (FCI) for the Franka Emika Panda

Libfranka, as shown in Figure 3, is the C++ implementation of the client side of the FCI that provides that connection. It handles the network communication with the cobot control and provides interfaces to easily read the robot state to get sensor data at 1 kHz:

- Execute real-time commands to run external control loops, accessing and computing the desired kinematic and dynamic parameters;
- Execute non-realtime commands to control the cobot and configure the arm parameters.

Libfranka is developed to communicate with the cobot through a ROS environment (https://www.ros.org/). It uses the **franka_ros** package shown in Figure 4, specifically developed to connect the Franka Emika Cobot with the entire ROS ecosystem installed in the workstation, which includes also all the URDF models, the detailed 3D meshes of the robots and the end effectors. Those models are useful to simulate and visualize in 3D through **RViz** (http://wiki.ros.org/rviz) the cobot.

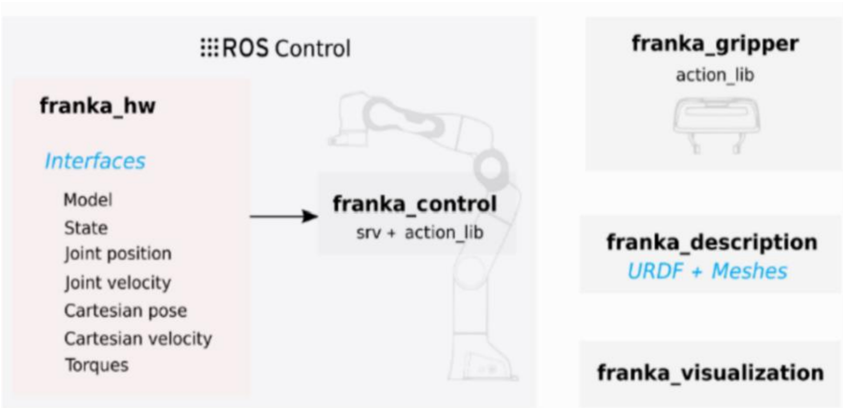

Figure 4 – The Franka ROS package to control the Franka Emika Panda

The description and data provided by franka_ros allow the user to use **MoveIt!** (https://moveit.ros.org/), an open-source library widely used in the field of robotics to compute the pose and trajectory plan and execution (Görner et al., 2019). This way to interact with the robot enables all the capabilities needed to develop an industrial-like (hence, high-level) control of the cobot.

3.2.2. Manual Guidance and other specifications

Regardless of the interface, the cobot, which by its nature can cooperate with humans, can be used in manual guidance mode by pressing a button – Figure 5 (a) – and then driven around by the user by pressing two buttons simultaneously immediately above the cobot end effector, as in Figure 5 (b). Manual guidance is only activated when the safety button is pressed, while if the

(a) *(b)*

Figure 5 – Manual Guidance for the Franka Emika Panda Cobot

user approaches the cobot before pressing the button, the safety system will stop the cobot if it is in motion.

3.3. Semi-automated PCB disassembly process – FENIX project

3.3.1. The structure

The semi-automated PCB disassembly process was structured for the disassembly of PCBs coming from telephones. As depicted in Figure 6 and Figure 7, the station is made by: i) a table supporting the full process, ii) a cobot, iii) a frame supporting PCBs during the disassembly process, iv) heating equipment needed to desolder components from the board, v) a keyboard allowing the interaction of the human operator with the cobot, vi) a desktop PC for the configuration of the disassembly process and vii) an extractor hood intercepting (eventually) fumes.

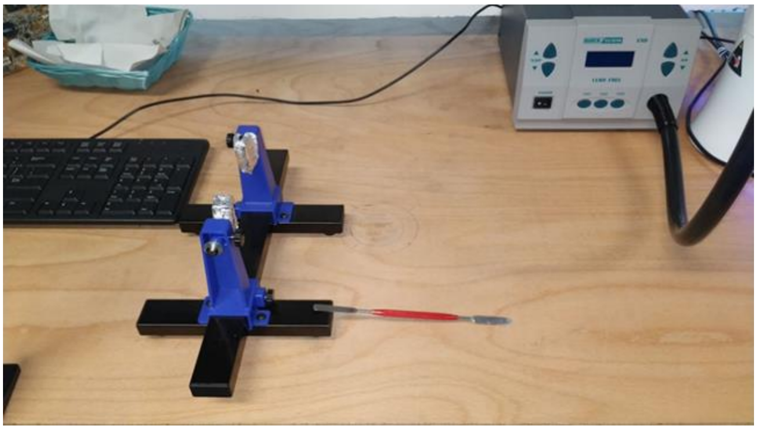

Figure 6 – Fenix Process structure in the Industry 4.0 Laboratory at the Politecnico di Milano

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

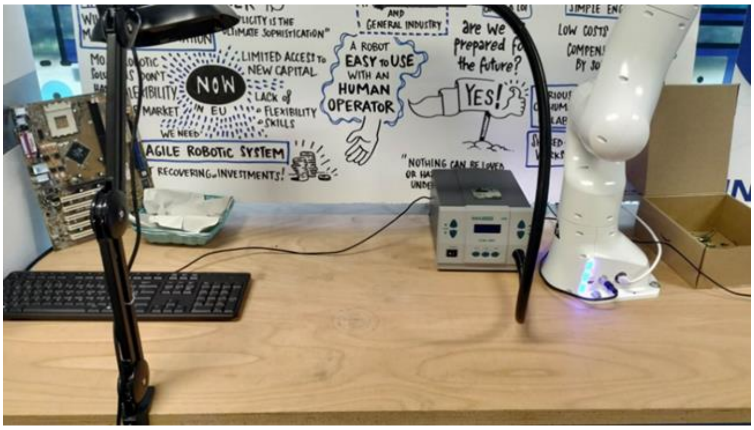

Figure 7 – Fenix Process setting in the Industry 4.0 Laboratory at the Politecnico di Milano

3.3.2. The process

The developed Fenix process starts from a clean worktop as in Figure 8, where all the tools needed for operating have been previously positioned as explained above. The PCB disassembly process is then constituted of the following steps:

i. The environment setup creation, where the table, tools and PCB holder are placed.
ii. Firstly, the front setup is set: the PCB is placed in the PCB holder by the operator and the cobot with the heating tool is placed at the starting position.
iii. The cobot, with human help, performs the front desoldering: the human from the keyboard moves the cobot to the right position (Figure XX) to desolder the PCB’s front side chipsets from the board.
iv. If necessary, the same is repeated for the back side of the PCB: the PCB is placed in the back setup in the PCB holder and the same operations are performed for the back desoldering.
v. Finally, the environment reset is performed to restore the initial environment setup: the PCB holder is removed, tools are cleaned from residues and the PCB is stored in a dedicated warehouse

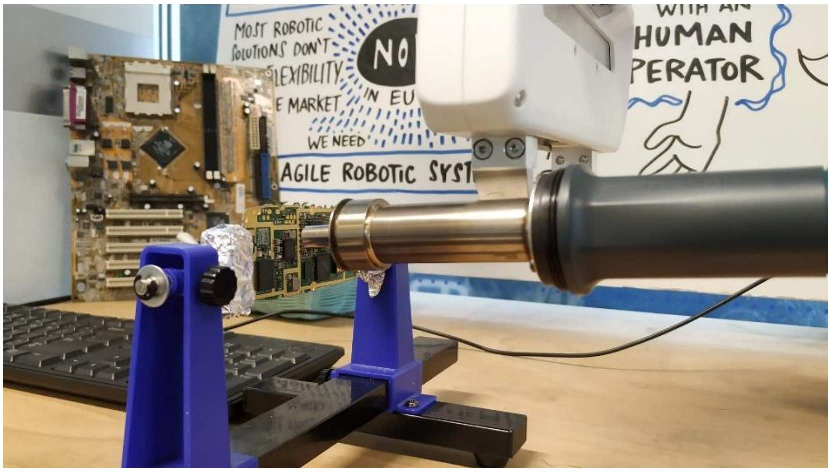

Figure 8 – Fenix Process in the Industry 4.0 Laboratory at the Politecnico di Milano

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

3.3.3. The simulation

The cobot computes the desired pose from a direct operator input from the keyboard. Fenix uses the 3D real-time robot visualization in the virtual operating space as shown in Figure 9, only to visualize the change of position in real-time in RViz, to give the operators a better understanding of the cobot state and avoid collision and injuries.

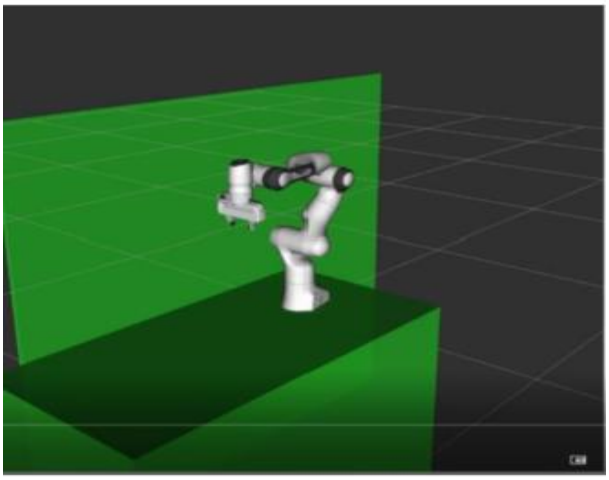

Figure 9 – Real-time visualization in Fenix Process

3.3.4. The user interface

The only enabled user interface of the Fenix Process is the keyboard, through which interaction with the cobot and real-time visualisation of the virtual environment takes place. There is no physical interaction between the operator and the cobot, and neither the user can establish the sequence of positions of the operation for the disassembly operation through the interface.

4. Cobot Interface requirements and structure

4.1. The objective

As already mentioned in the objective of the deliverable, Treasure wants to introduce new technologies to enable CE in the automotive sector. One application where those technologies must be incorporated is the DIS structure within the Treasure Platform, introduced in the deliverable D4.1.

The two main requirements for the DIS Module, already introduced in D4.1 (from Table 3.1 of the deliverable D4.1) are the ones in Table 1 and must be provided by the Cobot interface.

Requirement ID	Requirement Name	Description	Component in charge
R_14	COBOT ACTIVATION	The platform must allow disassemblers to communicate and activate pre-defined operations of the cobot	Cobot Interface
R_15	COBOT TRAINING	The platform must allow disassemblers to teach the cobot to perform unknown operations and save a reference in the platform	Cobot Interface

Table 1 – Requirements for the DIS Module from deliverable D4.1

Starting from the configuration developed for the FENIX project illustrated, it is possible to observe that:

- Simulation allows to visualize only the real-time movements of the cobot while enabling task planning requires specific user training about the ROS-RViz environment;
- The human-cobot interaction is not properly enhanced, since all the commands to the cobot are given from a keyboard (Section 3.2.2) and the collaboration provided by the cobot is not well exploited;
- The process must be repeated for each PCB, there is no way to save the operation in a user-friendly manner in case the same PCB must be disassembled again.

Overall, the FENIX process structure must be changed properly to be adapted to the Treasure project. The objective of Task 5.1 is to create a simulation environment that can allow the introduction of the HRC while making it safe and user-friendly for the operator. The solution proposed must provide all the requirements of the project in Table 1 by solving all the open points from the Fenix project and automatise as much as possible the process.

This section illustrates both the requirements needed and the proposed structure for the development of a *Cobot Interface* for the DIS Module that fulfils the R_14 and R_15 requirements of Table 1.

4.2. The Cobot Interface requirements

As shown in Table 1, R_14 refers to the use of the cobot during automatic disassembly, the automatic cobot activation, while requirement R_15 speaks of cobot training. The intention is to automatise the process as much as possible to obtain a semi-automated process enabling the operator to learn quickly and in a user-friendly manner how to interact with the cobot. In fact, given the number of different PCBs that could be disassembled, the process *must* involve human intervention for training the cobot when a new PCB enters the process to be disassembled.

Hence, the process must be composed of the cobot (the Franka Emika Panda described in Section 3 is herein considered but all the steps will be then customized to be applied to the UR5), the PCB holder and the heating tool, as already provided by the Fenix project. For the objective of this deliverable in addition to them, the process needs:

- a *learning platform* to allow the operator both to teach the cobot the set of disassembly procedures and to simulate the trajectory in a virtual environment;
- a *communication platform* to enable communications among all the devices that need to exchange information with the cobot – the Treasure platform, the cobot, the Learning platform and others if necessary, i.e. a camera if it is needed for the pilot implementation.

Table 2 lists all the requirements that must be fulfilled by the components of the process for the development of the Treasure *Cobot Interface*.

Requirement ID	Requirement Name	Description	Component in charge
S_1	Cobot Integration	The structure must enable integration with the cobot	Communication Platform
S_2	Cobot Manual Guidance	The structure must enhance a safe collaboration between the cobot and the user, allowing for the manual guidance of the cobot: the user can	Cobot

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

		move the end effector of the cobot to decide the points where the heating tool must be used	
S_3	Simulation Integration	The structure must enable integration with the simulation environment	Communication Platform
S_4	Trajectory Simulation	The structure should enable simulating the trajectory generated after the user decided the set of points in which to perform the disassembly operation	Learning Platform
S_5	Trajectory Save/Discard	The structure should enable to save or discard the set of points and the trajectory generated	Learning Platform
S_6	WEAVR Platform Integration	The structure must enable the integration with the WEAVR Platform and with the DIS described in deliverable D4.1	Communication Platform
S_7	Other devices Integration	The structure must allow integration with other devices, i.e. a camera	Communication Platform
S_8	Workstation Integration	The structure must enable communications among the cobot, the workstation and other devices	Communication Platform

Table 2 – Requirements for the Cobot Interface development

4.3. The Cobot Interface structure

All the "components in charge" from Table 2 must be connected one to the other to enable the Cobot Interface usage from the WEAVR Platform. As depicted in Figure 10, the process must be structured to have two operating modes. When the Cobot Interface is activated from the WEAVR Platform:

- If the disassembly operations are already defined for that PCB, the cobot will automatically perform them; this can be called **Automatic Behaviour** since the operations are already settled and the cobot performs them automatically. This behaviour allows the direct connection to the communication platform that extracts the right procedures for that PCB(s) from a database. This behaviour must be built to enable the HRC only if it is needed, i.e. in supporting the cobot to follow the right process steps, but avoiding any proper contact with it, i.e. manual guidance- for independent or supporting interactions (El Zaatari et al., 2019).
- If the disassembly operations are not defined for that PCB, the cobot learns them guided by the operator and stores them inside a database, together with the other information about the PCB (implementation to be structured in Task 5.2); this is called the **Learning Behaviour** since the cobot enters in setup mode and the operator must teach the right disassembly operations to the cobot through HRC with manual guidance and a proper interface.

Hence, both the two operative modes must be connected to the communication platform, but they require different procedures and efforts from the user's viewpoint.

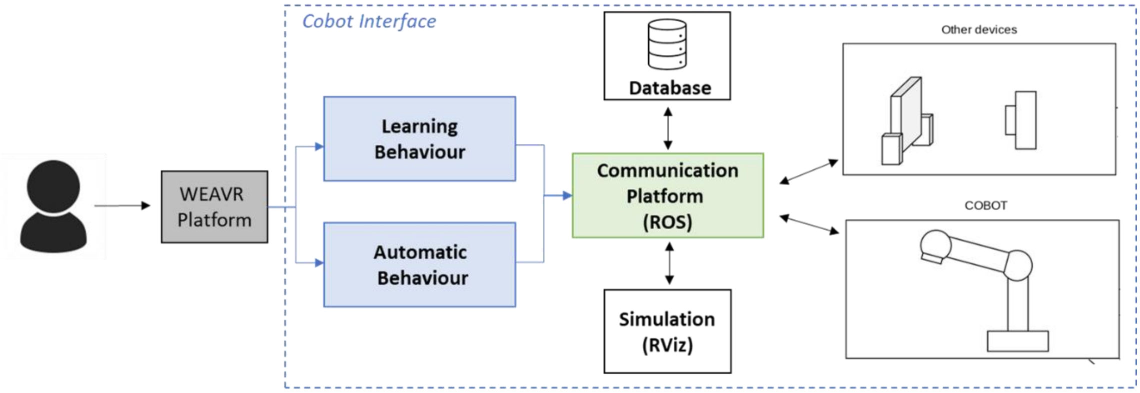

Figure 10 – Cobot Interface architecture for Treasure Project

5. Communication Platform

5.1. Communication Platform Tasks

Recalling the requirements needed for the Cobot Interface realization in Table 2, it is possible to see that the communication platform is the core of the process structure and it is needed in both the automatic and learning behaviour. The communication platform must connect the WEAVR platform with the workstation, the cobot, and the simulation environment and add the possibility to connect other devices, i.e. a camera for the development of the automatic behaviour, that will be dealt with in Task 5.2.

For the Cobot Interface realization, the chosen communication platform is ROS, since the FCI of the cobot enables the control of the cobot with the franka_ros package (better explained in Section 3.1). This type of connection can be reused for the UR5, obviously using the ad-hoc package developed by the vendor for that cobot: the Franka Emika Panda uses Libranka and Franka_ROS to take commands from ROS, the UR5 uses other libraries that will be better described and established. The same platform was also used in the Fenix Project (see Section 3.2) to link different devices, connecting in that case the workspace, the cobot, the simulation environment and the keyboard.

Starting from that choice, the interaction with the keyboard is replaced with the use of the **manual guidance** (see Section 3.1.2) rightly offered by the cobot. In this way, the human interaction with the cobot is immediate and safe: the user will have to press the button for manual guidance before starting to use the cobot and will then be able to bring it to the desired position to perform the disassembly operation.

Each time the user must add a new path for the cobot, the Communication Platforms must be already initialised to perform those operations:

1. Acquire and store or discard the set of positions of the disassembly path;
2. Simulate the cobot path to replicate that path;
3. Execute the trajectory in the real environment.

Here, we illustrate how each of these operations is enabled in the Communication Platform, and then the complete procedure for the Learning behaviour will be explained in Section 6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

5.2. ROS environment structure

To establish the connection with the cobot, the work started from the ROS environment built for the Fenix project. A *panda_robot_stack* launch file establishes the connection between the cobot and the workspace. When the communication with the cobot is established, the code will fetch from Libfranka the control part and add the gripper. After the initialisation, the functions from the MoveIt! library (Section 3.1.1) is used inside the following ROS nodes to perform the operations mentioned above.

- **Point acquisition** (point_acquisition_txt)**:** Acquires in the workstation (with the possibility of adding a proper database) each point position of a specific path decided by the operator through manual guidance.
- **Path execution in simulation** (move_from_txt_sim): Generates the trajectory in the RViz simulation environment;
- **Points storage** (save_management): Saves the last set of points acquired with a name decided by the operator if the user is satisfied by the last simulation;
- **Path execution in the real environment** (move_from_txt_real): execute the trajectory manually asking for the path name, then generates the required trajectory in the real environment with the saved positions.

These ROS nodes will be used to develop the Learning Behaviour in Section 6.

5.3. Simulation

To establish While the *panda_robot_stack* launch file, as said above, enables the connection between the cobot and the workstation, the *demo* launch file initializes the communication with the simulation environment in the workstations. The simulation environment used is the RViz tool that allows the visualisation of the cobot with the parameters provided through the ROS ecosystem. The *demo* launch file will invoke an RViz instance to open the simulation environment on the screen as in Figure 11 and show the user the path execution created with the set of points acquired in the simulation.

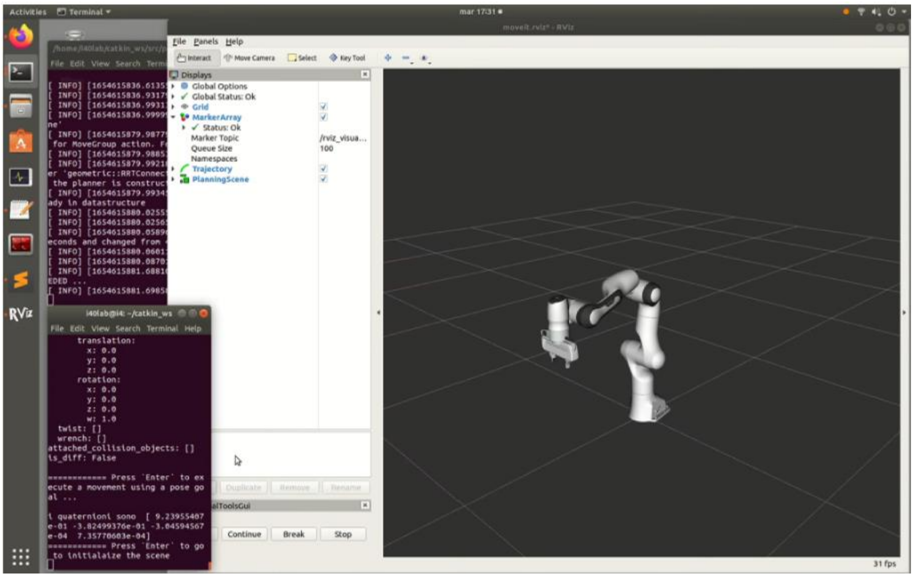

Figure 11 – RViz simulation environment with the Franka Emika Panda

The simulation is fundamental to let the user test the trajectory **safely** before saving it. As recalled from the state-of-the-art, this is the major role of simulation while supporting the HRC.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

5.4. Integration with the WEAVR platform

Once selected the ROS environment for the development of the communication platform, it will be possible to interface the WEAVR platform with the communication one of the Cobot interface in the workstation directly using ROS APIs (http://wiki.ros.org/APIs).

6. Cobot Interface – the Learning Behaviour

6.1. Learning Behaviour Architecture

As previously mentioned, the goal of this deliverable is to build a simulation environment of the semi-automated process that has already been implemented using RViz and ROS. However, the other major goal of this deliverable is to make the simulation user-friendly while the users learn to the cobot the operations to be performed in the so-called "Learning Behaviour". To this aim, the architecture of Figure 12 is proposed within the realization of a GUI, so that the users can both interact with the cobot and use the simulation to safely visualize the path execution needing much training.

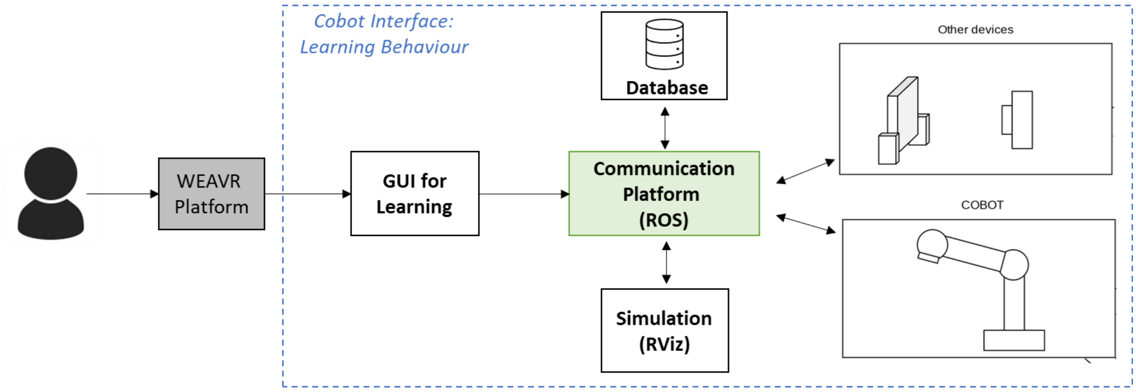

Figure 12 – Learning Behaviour architecture for Treasure Project

In other words, the communication platform allows the execution of the single ROS nodes developed in Section 5.2 from the workstation prompt. An interface is needed that enables these operations for the user without the user having to know the ROS development environment.

While the communication platform and the interfaces with both the cobot and the simulation environment remain the same, a GUI is proposed to realize a user-friendly interface that allows the user to easily run all the ROS nodes.

6.2. GUI structure

Each time cobot training is needed (as prescribed by the requirements R_15 in Table 1) the platform must allow the user to teach the cobot the right path to perform the disassembly operations: the learning behaviour should be enabled right from the WEAVR platform. Hence, the GUI must be structured to enable all the following actions from the WEAVR platform, as depicted in the UML in Figure 13:

1. Acquire a sequence of points where the operation on the PCB must be executed (the loop in Figure 13);
2. Simulate the obtained trajectory – to pass through the points acquired – to the user;
3. Save the sequence of points if the user is satisfied with the trajectory;
4. Execute the trajectory in the real environment;

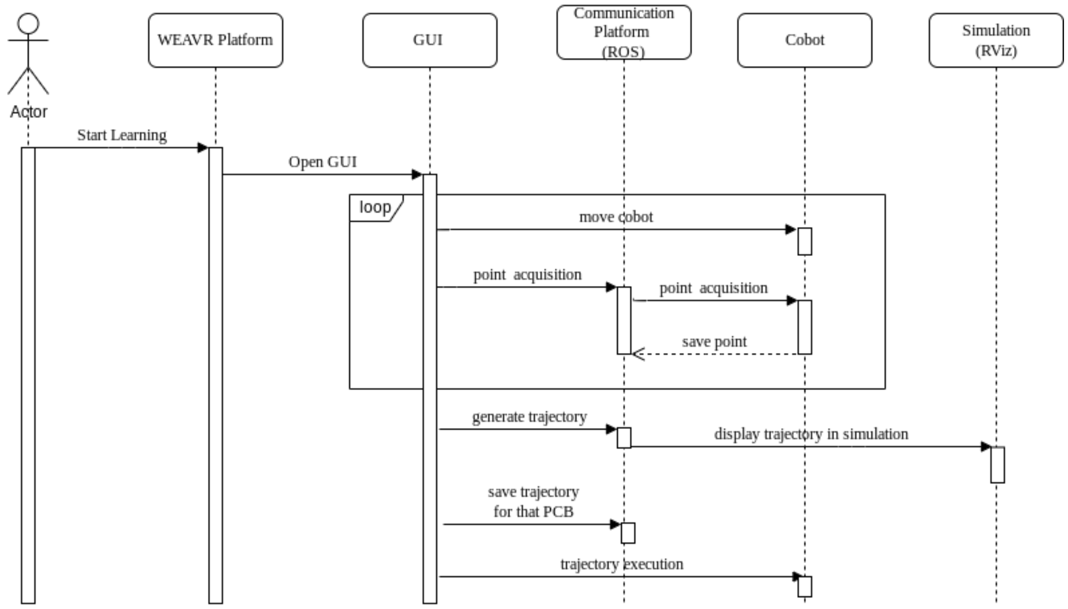

Figure 13 – UML structure of the GUI for the Learning Behaviour

6.3. GUI creation

Once realized all the ROS nodes, the GUI was created following the structure of Figure 13. The Python library Tkinter (https://docs.python.org/3/library/tkinter.html) was used and the resulting GUI is shown in Figure 14: each button allows an operator to use properly the Learning Behaviour as prescribed above.

Figure 14 – UML structure of the GUI for the Learning Behaviour

6.4. Additional Comments on the Learning Behaviour

It must be noted that the path execution in the real environment is the first attempt of reproducing the path generated by the user to disassemble a PCB, hence the first attempt of a possible "automatic behaviour" called from the GUI. When the procedure is called by the user, the cobot is capable of going autonomously from one point to another as specified by the user. The only possible interaction between the user and the cobot is that the user must manually disassemble the PCB's components with a tool while the cobot is heating the PCB. The two

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587

operations are parallel, and the ROS node mentioned above (move_from_txt_real) gives the possibility to the user to manage the time in which the cobot heats a specific point through the push of the enter button on the keyboard.

7. Conclusions

This deliverable presents the creation of a simulation environment for the semi-automated PCB disassembly process.

Starting from the process realised during the H2020 FENIX project (www.fenix-project.eu), the following objectives were realised for safe and user-friendly use of the cobot by the operator during the phases in which human and cobot have to interact:

- Understand how the use of simulation could be exploited through a study of its usage in the state-of-art applications using HRC;
- Divide the process in order to isolate the *cobot training,* which includes the physical interaction between the user and cobot from the development of the automatic process;
- Understand how to realize a user-friendly interaction between man and cobot by using simulation to make it as safe as possible for the operator.

Overall, the deliverable led to the creation of a Learning Behaviour for the user, which can be modified and recalled if necessary to manage any stage of the Automatic Behaviour process in which human-cobot collaboration (HRC) is involved.

8. References

Álvarez-de-los-Mozos, E., Rentería-Bilbao, A., & Díaz-Martín, F. (2020). WEEE recycling and circular economy assisted by collaborative robots. *Applied Sciences (Switzerland)*, *10*(14). https://doi.org/10.3390/app10144800

Arai, T., Kato, R., & Fujita, M. (2010). CIRP Annals - Manufacturing Technology Assessment of operator stress induced by robot collaboration in assembly. *CIRP Annals - Manufacturing Technology*, *59*(1), 5–8. https://doi.org/10.1016/j.cirp.2010.03.043

Cesta, A., Orlandini, A., Bernardi, G., & Umbrico, A. (2016). Towards a planning-based framework for symbiotic human-robot collaboration. *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA*, *2016-November*. https://doi.org/10.1109/ETFA.2016.7733585

Daneshmand, M., Noroozi, F., Corneanu, C., Mafakheri, F., & Fiorini, P. (2022). Industry 4.0 and prospects of circular economy: a survey of robotic assembly and disassembly. *International Journal of Advanced Manufacturing Technology*, *0123456789*. https://doi.org/10.1007/s00170-021-08389-1

El Zaatari, S., Marei, M., Li, W., & Usman, Z. (2019). Cobot programming for collaborative industrial tasks: An overview. *Robotics and Autonomous Systems*, *116*, 162–180. https://doi.org/10.1016/j.robot.2019.03.003

Fumagalli, L., Macchi, M., Pozzetti, A., Tavola, G., & Terzi, S. (2013). *New methodology for smart manufacturing research and education : the lab approach*. 42–47.

Görner, M., Haschke, R., Ritter, H., & Zhang, J. (2019). *MoveIt ! Task Constructor for Task-Level Motion Planning*.

Ionescu, T. B., Schlund, S., & Schmidbauer, C. (2020). Epistemic debt: A concept and measure of technical ignorance in smart manufacturing. *Advances in Intelligent Systems and Computing*, *959*(February), 81–93. https://doi.org/10.1007/978-3-030-20040-4_8

Kerin, M., & Pham, D. T. (2019). A review of emerging industry 4.0 technologies in remanufacturing. *Journal of Cleaner Production*, *237*, 117805. https://doi.org/10.1016/j.jclepro.2019.117805

Kobayashi, H., & Kumazawa, T. (2005). *A Simulation-based Decision Support Methodology for Reuse Business*. 598–605.

Realyvásquez-vargas, A., Arredondo-soto, K. C., García-alcaraz, J. L., Márquez-lobato, B. Y., & Cruz-garcía, J. (2019). Introduction and configuration of a collaborative robot in an assembly task as a means to decrease occupational risks and increase efficiency in a manufacturing company. *Robotics and Computer Integrated Manufacturing*, *57*(October 2018), 315–328. https://doi.org/10.1016/j.rcim.2018.12.015

Rocca, R., Rosa, P., Sassanelli, C., Fumagalli, L., & Terzi, S. (2020). Industry 4.0 solutions supporting Circular Economy. *Proceedings - 2020 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2020*. https://doi.org/10.1109/ICE/ITMC49519.2020.9198517

Sassanelli, C., Rosa, P., & Terzi, S. (2021). Supporting disassembly processes through simulation tools: A systematic literature review with a focus on printed circuit boards. *Journal of Manufacturing Systems*, *60*(July), 429–448. https://doi.org/10.1016/j.jmsy.2021.07.009

Vicentini, F. (2021). Collaborative Robotics: A Survey. *Journal of Mechanical Design, Transactions of the ASME*, *143*(4), 1–20. https://doi.org/10.1115/1.4046238

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003587