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ACROBA

connect & produce through agile production

D4.5 Lights Out Manufacturing Use Cases

WP4

STERIPACK

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Approval Status

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1 Executive Summary

The objective of this document it is to describe the final demonstration of the ACROBA platform for the lights out manufacturing use cases.

Each use case will be described, starting with the final cell design through to the implementation of each case following on the implementation of the ACROBA platform and the execution of the different tasks using the specific skills and hardware within each cell.

2 Final Designs of Use Cases Cells

2.1 MOSES Use Case Final Cell Design

The main activity of MOSES is the production of customised plastic parts. For the production of the parts, MOSES uses various plastic transformation processes, such as plastic injection, rotational moulding etc. Generally, these types of parts require direct customisation to meet the customer's needs.

At MOSES, customisation tasks are carried out by means of robotic processes, generally using motorised cutting tools. In the case of ACROBA project, MOSES has worked on the container lids customization (

), considered several types (rubbish type, size, colour, etc.) Until now, the programming of the robots was done manually using CAM software, investing long times in the generation and post-processing of the trajectories. Regarding the tooling, positioning was done manually, making positioning errors and having to do trial and error tests until the exact position was achieved, and different tooling was required depending on the type of path to be made.

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Figure 1: Customized container lids of MOSES production.

After the integration of the ACROBA platform, it has been possible to act in the entire value chain of the plastic parts customisation process, from the creation of the trajectories, through

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the calibration of the robot, tools and cell, to the execution of the robotic process, always considering the safety of the workers.

Thanks to ACROBA, MOSES has a flexible robotic cell, capable of making the appropriate cuts or drills and generating the robotic trajectories quickly and accurately.


(a) (b)

Figure 2: Main view of MOSES Plastic cells with ACROBA platform. (a) Robot and tooling. (b) Robot and tracking camera.

As a quick overview, the MOSES cell (Figure 2) consists of an anthropomorphic robot, which has an electro-spindle on its flange to perform the cutting operations. On the other hand, the cell is composed of three high-resolution RGB cameras that oversee the visualisation of the calibration elements and the tracking elements. The operation of the new MOSES process with the ACROBA platform will be explained in later sections.

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2.1.1 Sequence of Operation

As mentioned above, the working process of the MOSES cell where the ACROBA platform has been installed is intended for the customisation of the moulding caps. As for the current process of customising container lids, the ACROBA developments have been installed on a robotic system, which, broadly speaking, consists of a robot with a cutting tool. In addition, it is equipped with the artificial vision system developed in the ACROBA project for the recording of the trajectories for the cutting and drilling of the container lid openings.

The process flow that has been implemented for the MOSES use case is as follows. Firstly, the calibration of the cell, the robot and the tooling is carried out using the positioning system developed by AITIIP and based on AruKo markers. Once the cell has been calibrated, the operator places the container lid on the tooling, then the operator uses the dummy tool to record the drilling and cutting trajectories. Once recorded, the operator exits the cell (enables motors and executes the movement), at this point, the robot starts working. After cutting and drilling, the operator performs a visual inspection of the cut, usually using patterns to check for deviations. At this point, if the part is OK, the operator takes the part to the validated parts area, if not, the operator has two options. If the part is bad, it is transferred to the discard area, if not, the robotic process is executed again.

For a better understanding of the process, the 6 steps that make up the MOSES process flow (Figure 3) are described below:

1. **Calibration step.** This stage is intended for the calibration of all the cell systems (user world, robot and tooling). The various calibrations are carried out using calibration primitives. These calibration primitives use the data provided by the RGB cameras to establish the position of the bifrustum (composition of ArUkO markers). After the recognition of the ArUkO markers, the spatial position of each of the systems is established. It should be noted, however, that it is up to the user to decide whether or not to perform the calibrations. Through the calibration of the user world, the origin of the whole cell, i.e. the absolute zero for all systems, is established. With the calibration

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of the robot, its positioning is validated and finally, with the calibration of the tooling, the part is positioned in the scene.

2. **The operator places the container lid on the workstation.** This step is carried out by the operator, who must position the container lid on the tooling, following the references for each of the lid types.
3. **Trajectory recording with dummy tools.** Once the systems have been calibrated and the container lid has been positioned on the tooling, the next step focuses on the recording of trajectories. As with the calibration steps, this is where ACROBA comes into its own. In this case, using the dummy tool skills, the operator uses the dummy tool to execute the movement along the area to be cut, as well as the holes to be drilled. With the use of the cameras, the recording primitives and the AruKo markers present in the dummy tool, the ACROBA system, records, filters and saves the trajectory made by the operator.
4. **Robot movements.** Once the necessary trajectories have been recorded, the operator uses the system screen to verify that it has been saved, validating the number of drill points and the shape of the cut. Then, the operator leaves the robotic area, closes the door, and thanks to a system of buttons, enables the robot motors and then, executes the robotic process. In this step, the operator is provided with a light system that informs him about the status of the robot. The operator is only allowed to enter the cell when the green light appears, i.e. the robot has finished the process. In this step, the ACROBA system is continuously checking the safety of the cell to prevent human accidents and even collisions between the robot and the rest of the systems. For the control tasks, the system has three control cameras, through which the work being carried out by the robot can be seen.
5. **Visual inspection.** After the robotic operation, the operator is given the green light to enter the work area for visual inspection of the process. The operator has patterns, depending on the type of nozzle, to verify the cut. Depending on the quality of the cut, the operator can decide between three options: validated part, part to rework, part to rework and part to rework.

6. **Remove the container lid from the workstation.** After inspection, the operator takes the part to the destination area**.**

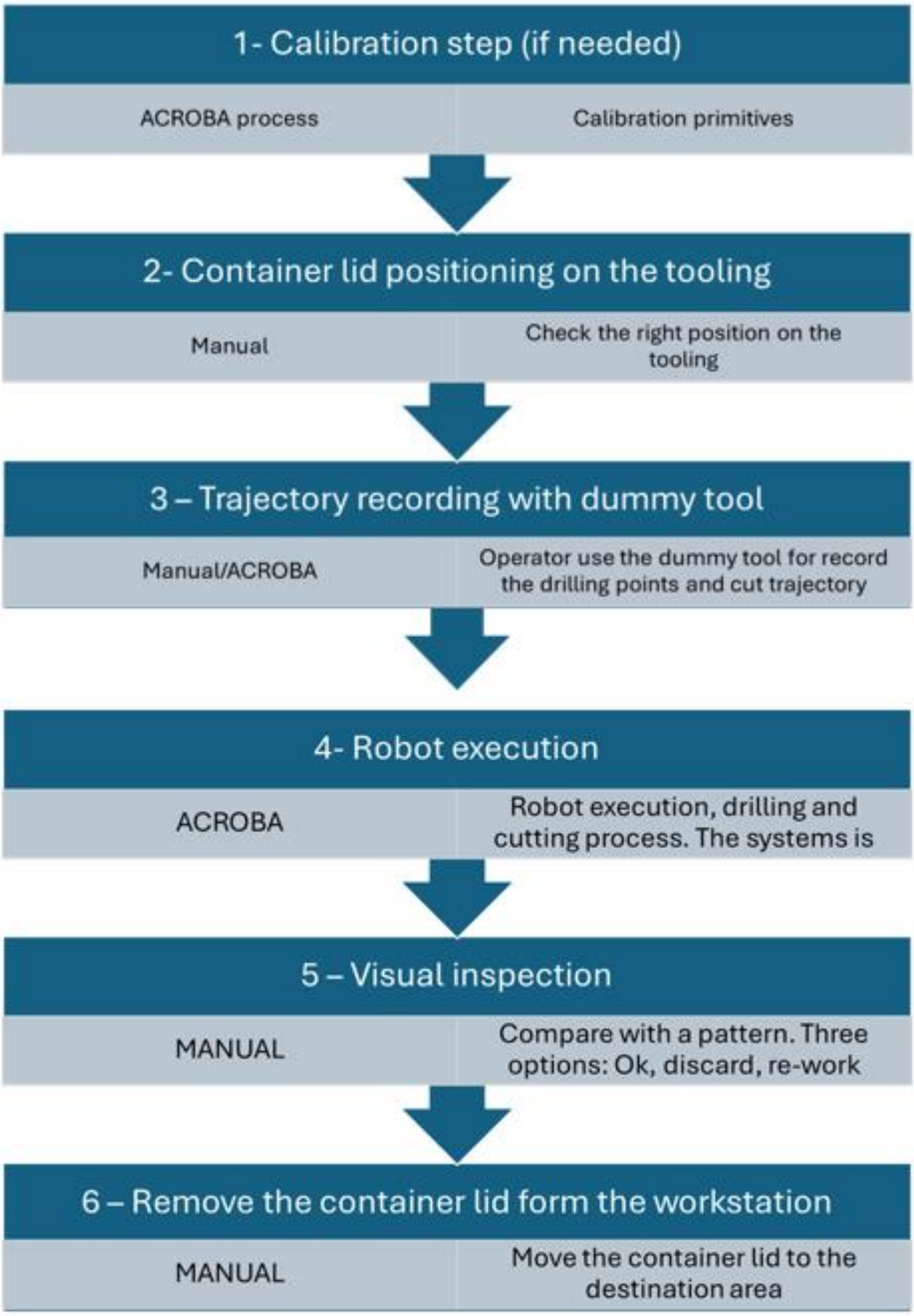

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Figure 3: Sequence diagram for MOSES use case.

2.1.2 Mechanical Overview

The MOSES robotic cell is mainly composed of a YASKAWA GP180/120 (Figure 4.1) anthropomorphic robot, which has an electro-spindle (Figure 4.3) anchored to the flange. This electro spindle oversees the cutting process. To join both systems, a metal flange (Figure 4.2) was designed and manufactured using F-114 steel. Also, the robot has two bifrustums for the calibration process. In addition, for the calibration and trajectory recording tasks, the cell has three BASLERACE asA5472-5gm monochrome RGB (Figure 4.4) cameras. These cameras are positioned at a height of 3.5 metres and focused on the centre of the work area. To anchor them, several systems were designed and 3D printed. In the same installation area, the cell is equipped with LED spotlights (Figure 4.4) to brighten up the cameras and to obtain a better detection of the Arukos. On the other hand, the cell has 3 monitoring and control cameras (Figure 5), which have magnetised bases to place them in the different places of interest.

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Figure 4: 1 - Robot YASKAWA GP180/120. 2 – Steel flange. 3 – Electro spindle. 4 – BASLER camera and LED light.

Figure 5: Monitoring cameras.

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Regarding the container lid positioning tool (Figure 6), it should be noted that it is a flexible tooling intended for various types of container lids. For the manufacture of this tooling, laser cutting technologies, welding technologies and subtractive manufacturing technologies have been combined. All components are made of F-114 steel. In addition, a bifrustum (composition of several arukos) has been included in the central part of the tooling (Figure 6c), to perform the calibration tasks.

(a) (b) (c)

Figure 6: Tooling for container lid positioning on the working area. (a and b) Tooling with the container lids. (c) Tooling and bifrustum for the calibration process.

Another mechanical aspect addressed in the MOSES use case is the design and manufacture of the dummy tool required for the recording of the trajectories. This tool has been designed considering functional and ergonomic aspects. A 3D printer, specifically an HP MJF, has been used for its manufacture. The tool is printed in PA (polyamide), whose main advantage lies in its mechanical resistance. Once manufactured, the localisation bifrustum and a radiofrequency device were installed to make the system differentiate between the drilling points and the cutting trajectory. It should be noted that all installed systems are shown in Table 1.

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(a) (b) (c)

Figure 7: Dummy tool for trajectory recording. a) Latera view. b) Top view. c) Detail of the selection buttons. A for cutting B for drilling.

Table 1: Devices included on the MOSES Cell.

Device	Quantity	Name	Specifications	Type	Description
Robot	1	Yaskawa GP180	GP180+YRC1000 Controller +AI card +DOI cards	Purchased	120 kg payload to support the cutting head and to limit vibrations and inertias produced during cutting
Spindle	1	VEVOR JST-JGF-4KW-ER25	220V, 4Kw, Aircooled, 18000rpm	Purchased	up to a maximum of 18000 rpm it allows the use of tools from 6mm to 12mm in diameter.
Flange	1	Steel flange for electro-spindle anchoring	Steel F114	Milled	Robotic flange made ad hoc in high-performance steel to withstand the vibrations caused during the cutting process
Tolling	1	Steel table for tooling placement	Steel F114	Milled, laser cut and welded	Multipurpose worktable, T-slots for anchoring any type of tooling. Manufactured with high performance steel.

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Camera	3	BASLER ACE acA5472-5gm	20MPx + BASLER lens C11-1620 -12M-P 90º horizontal field	Purchased	Cameras for tracking processes in which dummy tools are used. Also for robot, cell and tooling calibration
Led lights for cell illumination	3	LEDVANCE	Led lights. 150W	Purchased	Cell illumination
Light towers	2	Schneider Electric Harmony XVC6	24V Ac/dc, three LED red/ green/orange	Purchased	Visual and audible signalling of machine status. Machine status information at all cell access doors.
Inductive safety sensors	2	SICK RE13-SA05	24V DC	Purchased	Active safety of open/closed door control. Access detection and process pause.
Monitoring cameras	3	HIKVISION 4MPX AcuSense Fixed Dome DS-2CD2146G2-IF2.8	4MPX, omnidirectional camera	Purchased	Security camera for cell control, as well as process monitoring.
Comunication/safety boards	2	HHC-N-8I8O	9-24V IN, 8 relay OUT, 8 DIN	Purchased	security cards for door control, security light towers...
Dummy tools	1	Printed parts	A y B button for cutting and drilling	Designed and 3D printed	Trajectory recording

2.1.3 Electrical and Electronic and Safety Overview

The electrical installation was made simpler, and the installed devices are shown in Table 1. First, the robot and the controller were connected to the power socket. In addition, the input and output cards, both analogue and digital, were installed. The spindle was connected, considering the signals required for its operation from the robot control.

In parallel, the distribution of the ethernet rosettes throughout the work area was carried out, to provide communication to all the cameras. To do this, a plan was drawn up (Figure 8), considering that due to the performance of the cameras, fibre optics had to be installed to

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achieve fast and stable communication. Also an electric cabinet has been installed for control the power supply of the systems (Figure 9)

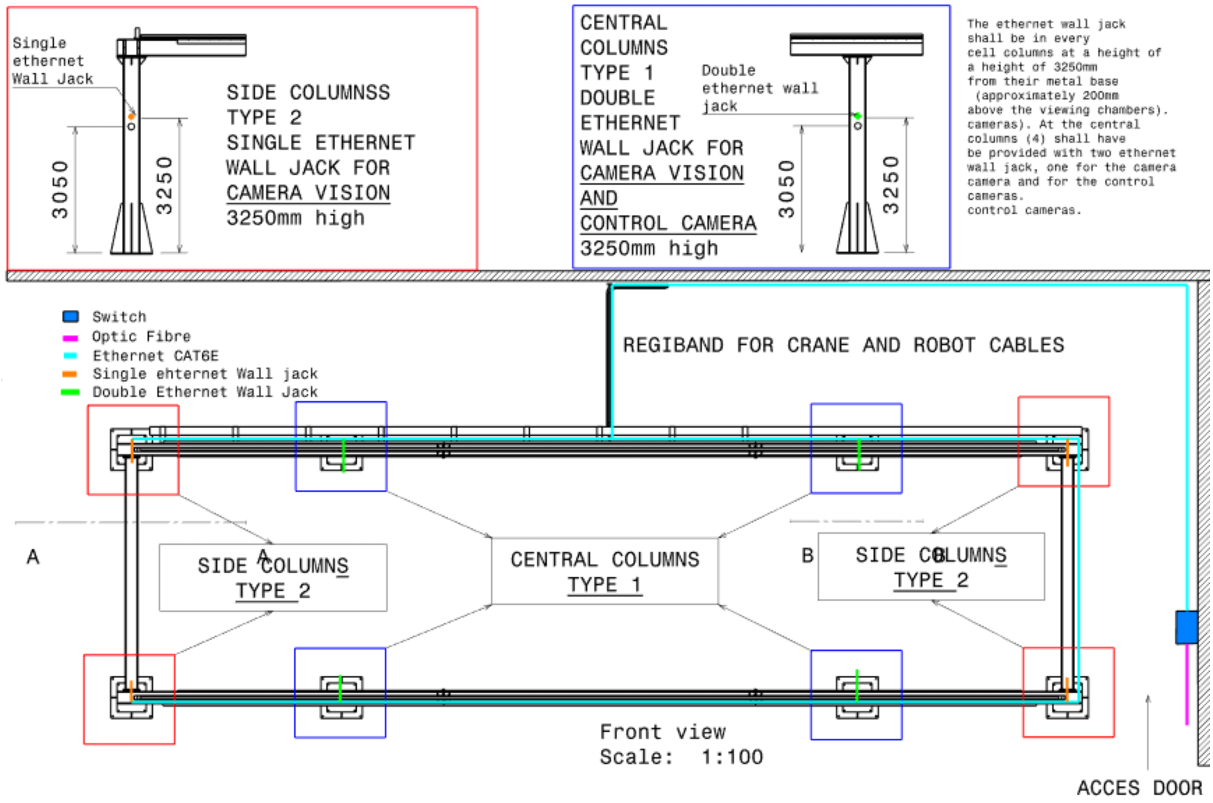

Figure 8: Drawing for the ethernet wall jack distribution.

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Figure 9: Fibre optic cabinet. Electric cabinet.

The cabling of all the systems was also carried out, to have everything under control in a single cabinet.

On the other hand, security cards (Figure 10) were purchased and installed for the control of the industrial traffic lights and the opening of the door. These cards are responsible for managing all the information around the robot, preventing personal injury.

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Figure 10: TCP/IP board.

To avoid personal damage, a magnetic system was installed in the doors to detect the opening of the doors, in addition, in both entrances, luminous signals were installed to inform about the status of the robot. On the other hand, for the execution of the robotic programs, the operator has a button panel, through which he can enable the motors and start the cutting process. If, during the cutting operation, someone opens the door or presses the emergency button, the robot stops instantly. Also the monitoring cameras are used for safety control (Figure 5)

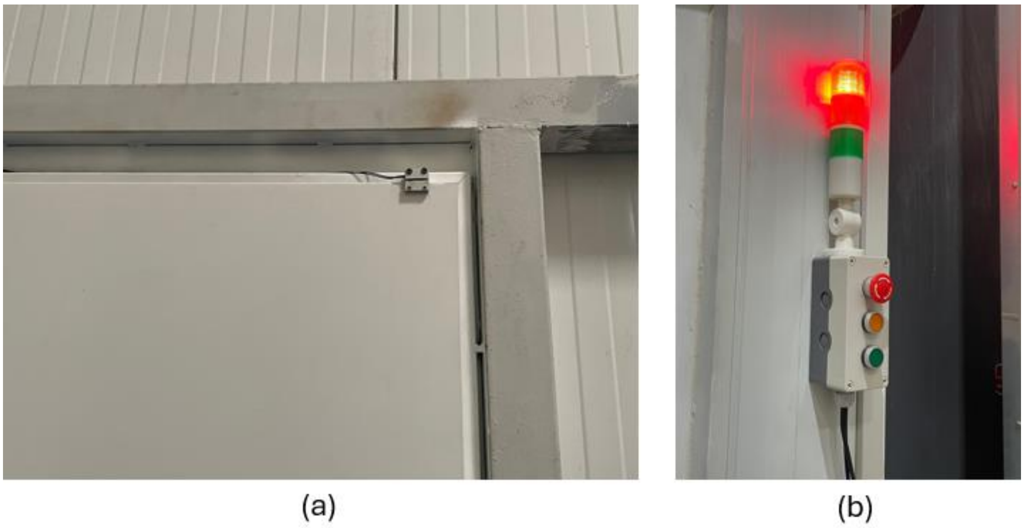

Figure 11: a) Magnetic system for opened door detection. b) Industrial light tower and button panel with emergency stop.

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2.1.4 Skills and Associated Tasks Overview

As mentioned above, the Figure 3 shows the summary of the execution steps of the MOSES use case, in that figure, the steps performed by the operator, the steps performed by ACROBA and the steps performed by both have been shown. The skills and primitives considered for each of the steps are described below. The steps in which skills and primitives developed within the ACROBA project have been used are the calibration step (1), the trajectory recording step (3) and finally, the execution of the robot movements (4).

Calibration step. This step is divided into three sub-steps. Cell calibration, tooling calibration and robot calibration. The calibration for each of the devices is based on the same concept, namely the use of bifrustum and aRuKoS for object localisation. However, each of them uses a different primitive, as the calibration process is slightly different.

- Cell calibration:
    - Pr_aitiip_dummy_tool_calibration.py: This primitive is the responsible to use BASLER cameras to identify the position of the bifrustum. For this step 5 bifrustum have been used. The primitive measure the position of each bifrustum, then it calculates the centre of the cell.
    - Pr_aitiip_dummy_tool_calibration_witre.py: Once the centre of the cell is calculated, the system uses this primitive for publish the position. This publication is used by the whole system (Rviz).

- Tooling calibration:
    - Pr_aitiip_dummy_tool_calibration_object.py: This primitive works with the same concept as the previous one, but instead of using 5 bifrustums, it uses only 1. In addition, this primitive is used to perform instant calibrations in case the operator detects that the tool has moved.
    - Pr_aitiip_dummy_tool_calibration_object_write.py: This primitive is responsible for publishing the position of the tooling so that other systems can see where it is. It simply acts as a publisher.

- Robot calibration
    - Pr_aitiip_dummy_tool_calibration_object.py: This primitive works with the same concept as the previous one, but instead of using 5 bifrustums, it uses only 1. In addition, this primitive is used to perform instant calibrations to check the position of the robot, avoiding problems with dealignments between joints.
    - Pr_aitiip_dummy_tool_calibration_object_write.py: This primitive is responsible for publishing the position of the robot so that other systems can see where it is. It simply acts as a publisher.

Trajectory recording with dummy. This step is dedicated to the recording of the trajectories using dummy tool. Therefore, it requires more primitives running at the same time. Although the basic operation is the same as the calibration process, it has different points, as it requires the instantaneous synchronisation of all cameras. Its operation requires the following primitives:

- Pr_aitiip_dummy_tool_traking.py: Once this primitive is launched, it resets the camera to its maximum ROI, after detecting the bifrustum, it resets the ROI, adapting it to the new position. This primitive is used for each camera, so it is necessary to raise N primitives depending on the number of cameras. It performs these operations continuously; it works in a cyclic way.
- Pr_aitiip_position_publisher_table_hole.py: This primitive receives the information from the previous primitives. It is responsible for the triangularisation of the position of the bifrustum received by the three chambers. Once received and collated in the same time frame; after pressing button B of the Dummy tool, it stores drill points. On the contrary, if A is pressed, it stores points for the cutting operation. Once the operator has finished recording, this primitive publishes the points for drilling and the points for cutting.
- Pr_aitiip_save_poses_table.py: Once the drilling points and cutting paths have been created, this primitive oversees creating the final file to be executed by

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the robot. This primitive oversees creating all the added paths that the robot needs to move from the homing position to the position of the first drill. On the other hand, this primitive also creates the necessary points from when the robot finishes the cut to the rest position. This primitive leaves the files required by the next primitive to execute the robot movement.

Robot execution. This is the main step in the MOSES work process. It is the robotic movement, following the trajectories generated by the operator using the dummy tool. In this step, the robotic movements and the control of all the tracking are interminable, to avoid personal injuries. In addition, the system performs a closed loop control of the actual position of the robot.

- Pr_file_reader.py: Basically, this primitive is to read the points generated during the recording stage. It outputs a list of points.
- sk_move_to.py: This skill is in charge of establishing the communication between the following two primitives, in order for the system to work, both primitives have to be running
    - Pr_generate_trajectory.cpp: This primitive has as input the points read by the previous primitive; it oversees creating the path planning.
    - Pr_execute_trajectory.cpp: The path created with the previous primitive has input. This primitive oversees sending the movements directly to the robot. It also validates the trajectories so that the robot knows which joint to move and avoids singularities.
- pr_operate_spindle.py: This is a primitive governed directly by the execute trajectory primitive. In it you can control the switching off, switching on and the rotation speed of the electro-spindle.

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2.1.5 Executed Process Overview

The following figure shows the sequence of actions during the execution of the MOSES process. This figure contains numbered boxes indicating which step is being executed. For a better understanding of this process, please refer to deliverable D6.3.

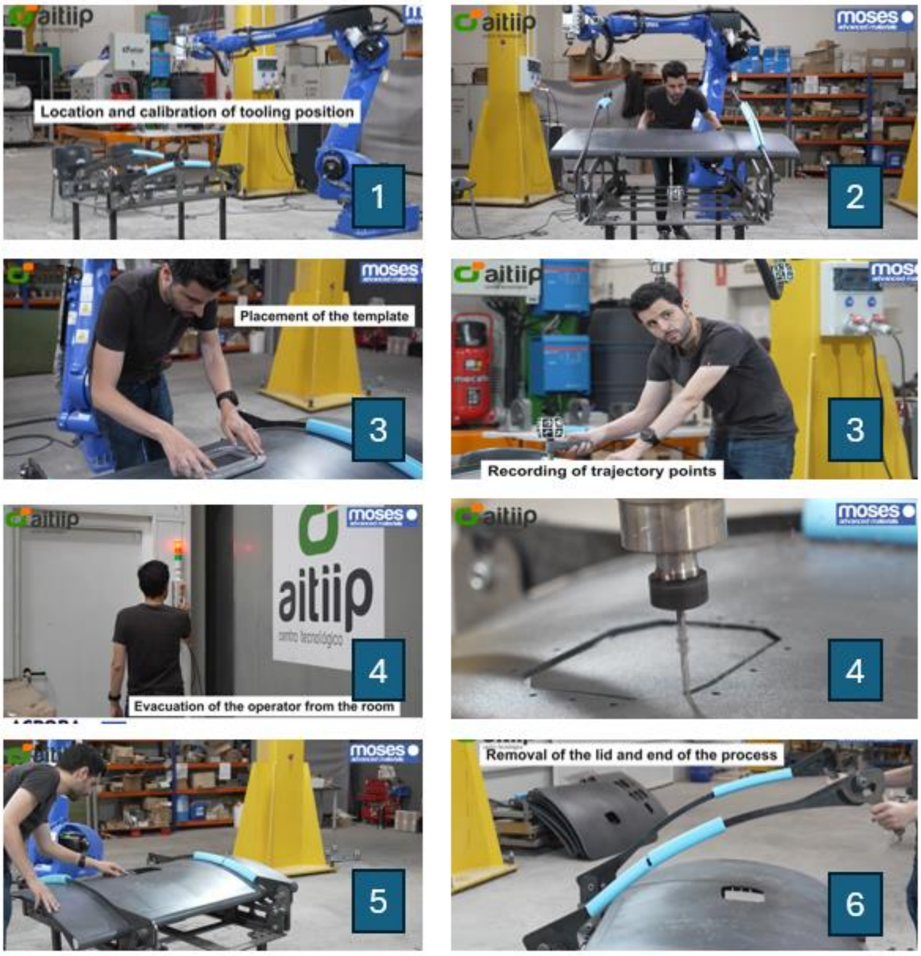

Figure 12: Steps performed in a real scenario. The numbered box indicates the process step it represents.

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2.2 CABKA Use Case Final Cell Design

The final layout of the CABKA operation cell includes several key components. At the heart of the setup is a Yaskawa robot, which performs the primary tasks. The workbench is specifically designed to accommodate the Nest I1.1 pallet (Figure 13), ensuring stability and efficiency. Three Blesser cameras are strategically positioned to provide comprehensive visual coverage and quality control. Additionally, a computer is integrated into the system to manage operations, process data, and ensure seamless communication between all components. This configuration optimizes workflow, enhances precision, and supports the overall efficiency of the operation.

Figure 13 : CABKA Nest I 1.1

2.2.1 Sequence of Operation

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The process flow for the operation cell involves several key steps:

1-Loading the Pallet: The operator loads the plastic pallet onto the workbench.

2-Hole Selection: Using the Dummytool, the operator selects the holes on the pallet to be deburred by the robot. At this stage, the cameras detect the Araucos symbols on the tool to identify its position relative to the pallet reference.

3-Simulation and Path Creation: The computer simulates the selected holes and creates the robot's movements in a virtual environment.

4-Safety Confirmation: The operator exits the work cell and confirms safety. This step is crucial to enable the robot's motors and start the deburring process.

5- Deburring Process: The robot begins deburring the pallet's burrs. Thanks to the milling tool at the end of the robot arm, the final result is successful. The milling tool holder is balanced by four compensators, allowing it to adapt to the shape of the hole. These pneumatic compensators provide a wide working range for the milling tool and help the robot perform the deburring at a higher speed than with a static milling tool.

The advantage of the ACROBA system lies in its ability to quickly adapt the new reference of the workbench to the ongoing program. Due to the presence of Araucos symbols on the workbench, if the table changes position mid-operation, the cameras swiftly capture images to determine the new location. This allows the system to reposition the workbench accurately. Consequently, all the robot's preprogrammed movements in the virtual environment are adjusted to the new position. This rapid adaptation ensures minimal downtime and maintains the efficiency and precision of the deburring process, making the ACROBA system highly effective in dynamic work environments.

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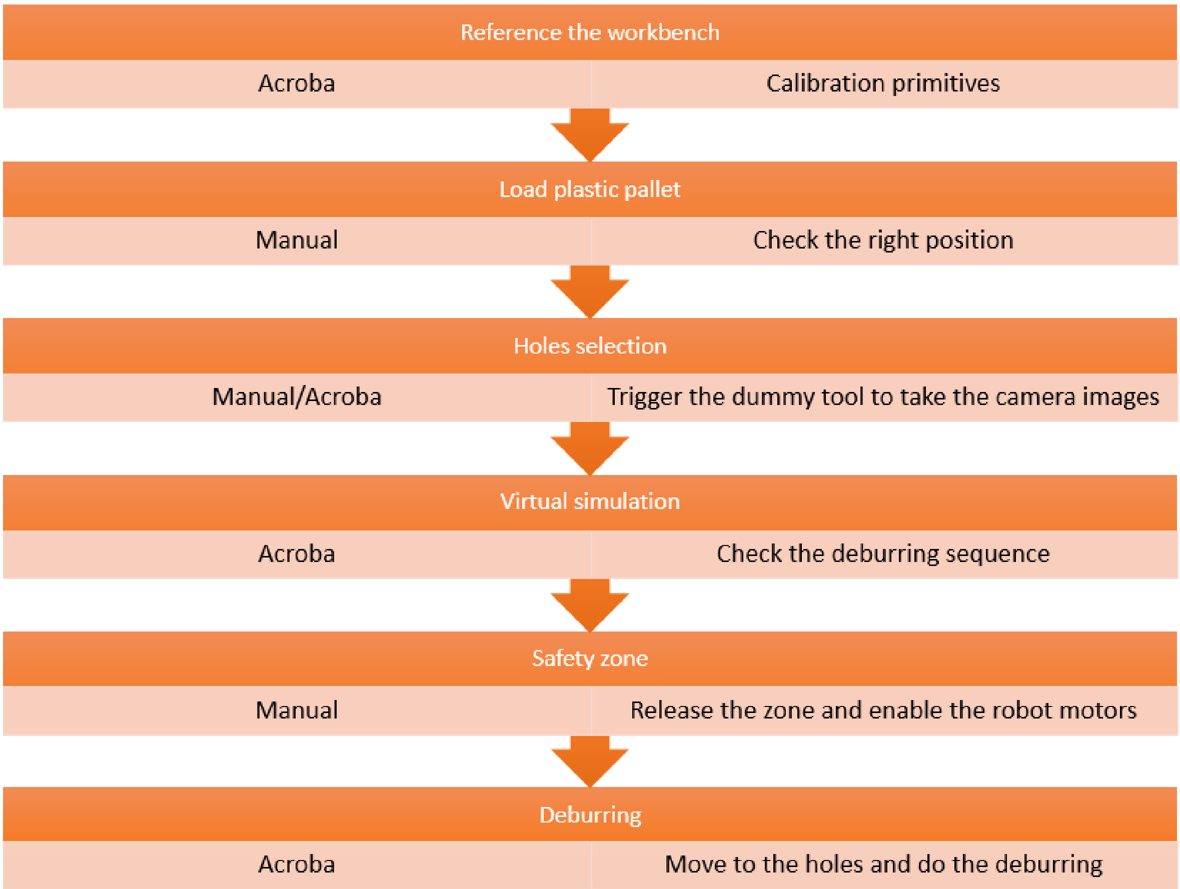

Figure 14 : Sequence diagram for CABKA use case.

2.2.2 Mechanical Overview

The only difference compared to the MOSES line is the workbench (Figure 14) and milling toon on the robot (Figure 15). The workbench is designed so that the Nest I1.1 pallet remains fixed on the table and can't move throughout the entire deburring cycle. The milling tool have 4 cylinder to create a windows work zone for the milling. Then the robots execute a hole shape

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but bigger size to be sure that the milling is touching the wall of the hole and the deburring is well done.

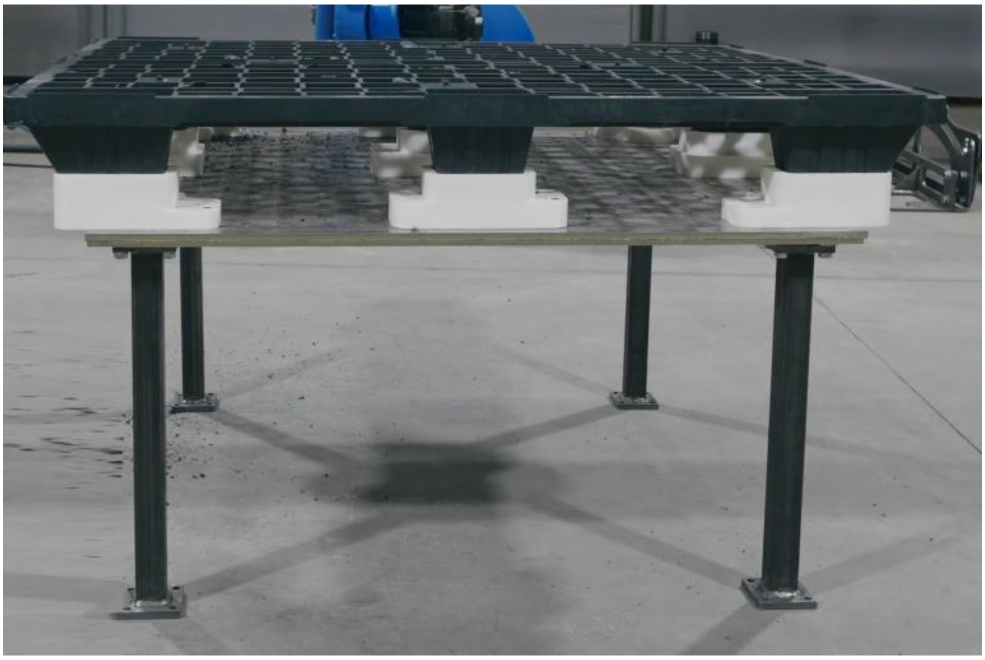

Figure 15 : Workbench for the deburring

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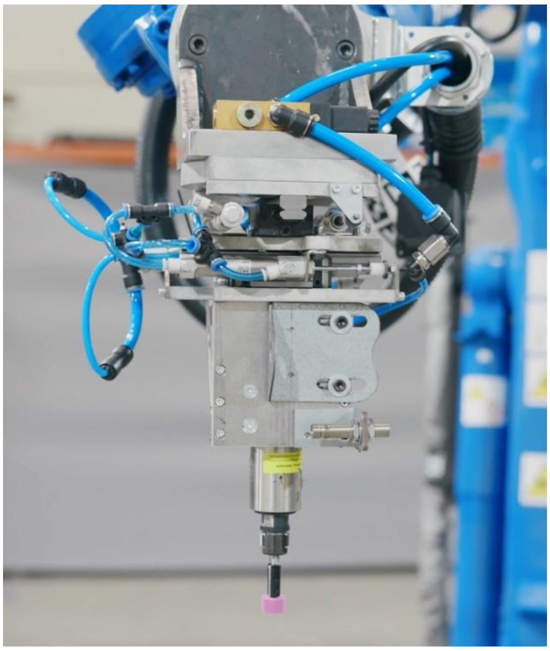

Figure 16 : Milling tool for the deburring

2.2.3 Electrical Overview

The electrical installation was streamlined. Initially, the robot and the controller were connected to the power socket. Additionally, both analogue and digital input and output cards were installed.

Simultaneously, the distribution of ethernet rosettes throughout the work area was completed to ensure communication with all the cameras. A plan was devised (Figure 8), considering that due to the cameras' performance, fibre optics needed to be installed to achieve fast and stable communication. An electric cabinet was also installed to manage the power supply of the systems (Figure 9).

The cabling of all the systems was also carried out, to have everything under control in a single cabinet.

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To avoid personal damage, a magnetic system was installed in the doors to detect the opening of the doors, in addition, in both entrances, luminous signals were installed to inform about the status of the robot. On the other hand, for the execution of the robotic programs, the operator has a button panel, through which he can enable the motors and start the cutting process. If, during the cutting operation, someone opens the door or presses the emergency button, the robot stops instantly. Also, the monitoring cameras are used for safety control (Figure 5)

On the other hand, security cards (Figure 10) were purchased and installed for the control of the industrial traffic lights and the opening of the door. These cards are responsible for managing all the information around the robot, preventing personal injury.

2.2.4 Skills and Associated Tasks Overview

The skills and primitives for each step are outlined below. The steps where skills and primitives developed within the ACROBA project have been utilized include the calibration, the trajectory recording, and finally, the execution of the robot movements.

Calibration step. This step is divided into three sub-steps. Cell calibration, tooling calibration and robot calibration. The calibration for each of the devices is based on the same concept,

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- Pr_aitiip_dummy_tool_calibration_object_write.py: This primitive is responsible for publishing the position of the robot so that other systems can see where it is. It simply acts as a publisher.

Trajectory recording with dummy. This step is dedicated to the recording of the trajectories using dummy tool. Therefore, it requires more primitives running at the same time. Although the basic operation is the same as the calibration process, it has different points, as it requires the instantaneous synchronisation of all cameras. Its operation requires the following primitives:

- Pr_aitiip_dummy_tool_traking.py: Once this primitive is launched, it resets the camera to its maximum ROI, after detecting the bifrustum, it resets the ROI, adapting it to the new position. This primitive is used for each camera, so it is necessary to raise N primitives depending on the number of cameras. It performs these operations continuously; it works in a cyclic way.
- Pr_aitiip_position_publisher_table_hole.py: This primitive receives the information from the previous primitives. It is responsible for the triangularisation of the position of the bifrustum received by the three chambers. Once received and collated in the same time frame; after pressing button B of the Dummy tool, it stores drill points. On the contrary, if A is pressed, it stores points for the cutting operation. Once the operator has finished recording, this primitive publishes the points for drilling and the points for cutting.
- Pr_aitiip_save_poses_table.py: Once the drilling points and cutting paths have been created, this primitive oversees creating the final file to be executed by the robot. This primitive oversees creating all the added paths that the robot needs to move from the homing position to the position of the first drill. On the other hand, this primitive also creates the necessary points from when the robot

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finishes the cut to the rest position. This primitive leaves the files required by the next primitive to execute the robot movement.

Robot execution. It is the robotic movement, following the trajectories generated by the operator using the dummy tool. In this step, the robotic movements and the control of all the tracking are interminable, to avoid personal injuries. In addition, the system performs a closed loop control of the actual position of the robot.

- Pr_file_reader.py: Basically, this primitive is to read the points generated during the recording stage. It outputs a list of points.
- sk_move_to.py: This skill is in charge of establishing the communication between the following two primitives, in order for the system to work, both primitives have to be running
  - Pr_generate_trajectory.cpp: This primitive has as input the points read by the previous primitive; it oversees creating the path planning.
  - Pr_execute_trajectory.cpp: The path created with the previous primitive has input. This primitive oversees sending the movements directly to the robot. It also validates the trajectories so that the robot knows which joint to move and avoids singularities.

2.2.5 Executed Process Overview

The automated pallet deburring process, as implemented by CABKA, involves several detailed steps to ensure precision and efficiency. Initially, the workbench is referenced, which involves setting up the workbench where the pallet to be reworked is placed. This step is crucial as it ensures that the pallet is correctly positioned for the subsequent operations. The holes that need to be deburred are then marked, and the robot is programmed to remove the excess plastic produced by over-injection.

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Figure 17 : Selecting holes with burrs.

The next step involves positioning the pallet accurately on the workbench and beginning the marking of the burr holes. To facilitate this, the Dummy tool, which is designed with two buttons, is used. One button powers the tool, while the other instructs the cameras to capture images. These images are essential as they identify the tool and, through advanced image processing techniques, determine the tool's exact location. With this precise information, the hole where the tool is inserted is identified and marked on the computer as a selected hole (Figure 17).

Following this, the computer calculates the optimal trajectories for the robot to perform the deburring on all the selected holes. These trajectories are visualized in a virtual environment (Figure 18), allowing for adjustments and ensuring accuracy before actual execution. The process then continues with the operator exiting the work cell. This step is critical for safety, as it ensures that the robot's work area is clear and secure. Once the operator confirms the safety conditions, the robot's motors are enabled, and the robot begins executing the programmed movements.

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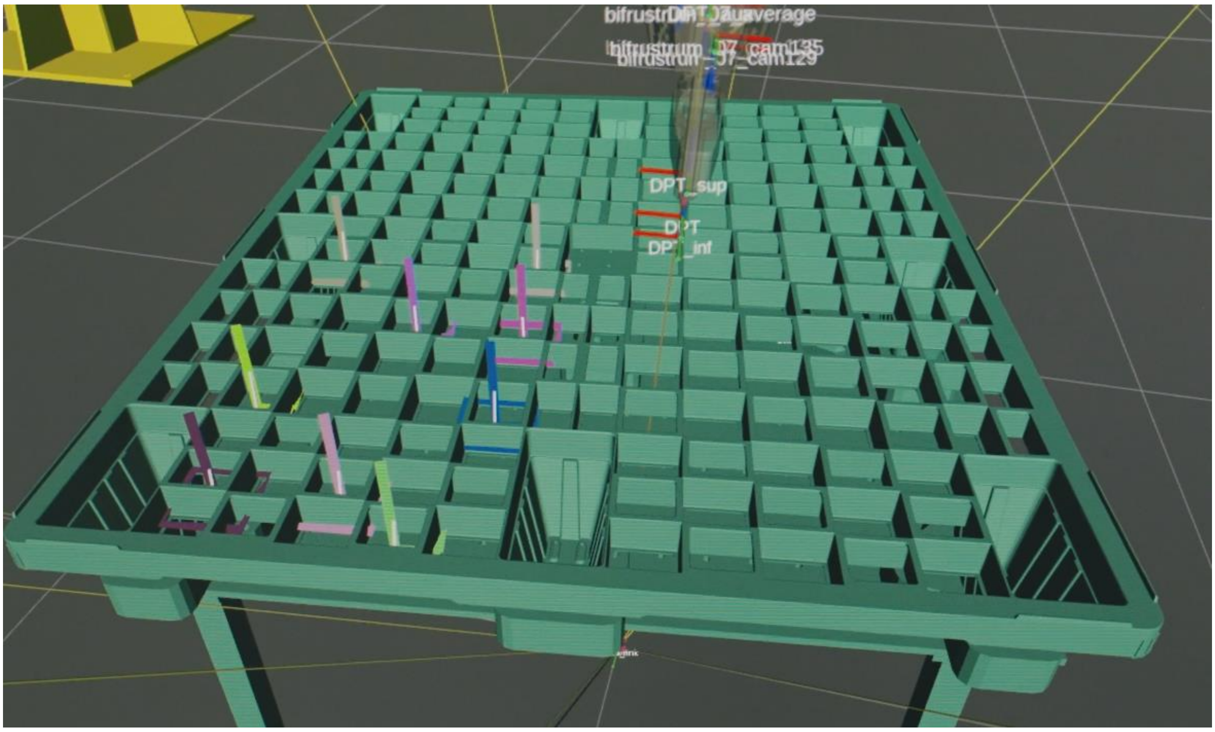

Figure 18 : Virtual environment simulating the deburring process.

A notable feature of this process is its adaptability. If the workbench position changes mid-process, the system can pause the operation to re-reference the workbench’s new location. This involves capturing new images to determine the updated position of the workbench. The system then adjusts all the robot’s virtual environment trajectories to align with the new position. Once the operator exits the cell and confirms the safety conditions again, the process resumes from where it left off, but with the updated positions. This flexibility ensures that the process can continue smoothly without significant downtime, maintaining efficiency and precision throughout the deburring operation (Figure 19).

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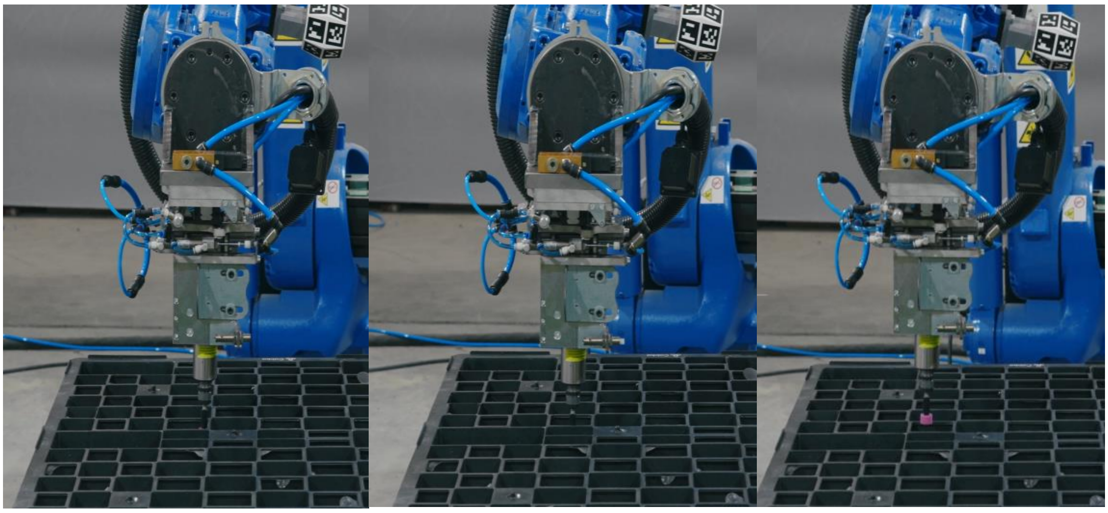

Figure 19 : Deburring process.

2.3 STERIPACK Use Case Final Cell Design

The current additive manufacturing process (3D Printing) is labour intensive, with an operator required to intervene at every step. Each step of the process exposes the operator to several chemicals (3D Printing resins and solvents) and involves intricate and delicate manual operations, such as parts removal and supports removal, adding risks and time to the process.

The Steripack 3D printing line final layout is shown in the following figures, with each element identified their individual functions detailed in separate tables, in the following sections.

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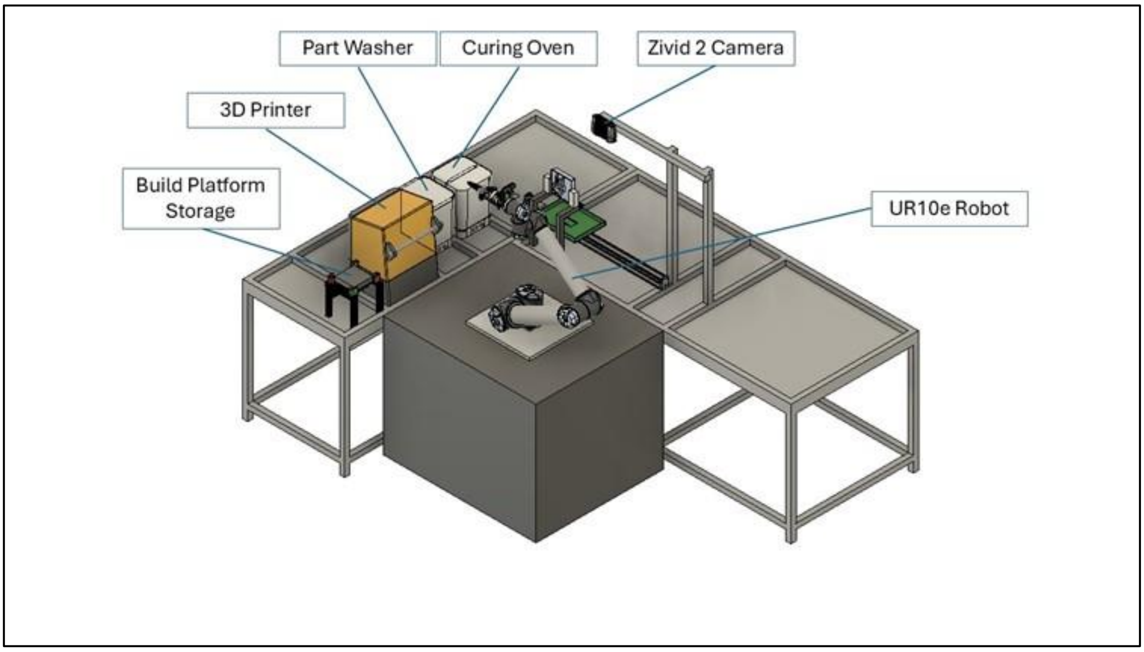

Figure 20 : Steripack Cell – CAD View 1

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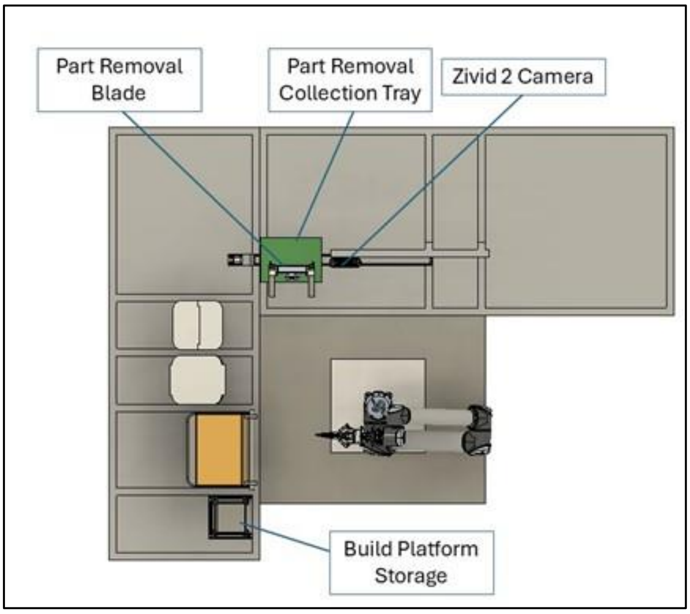

Figure 21 : Steripack Cell – CAD View 2

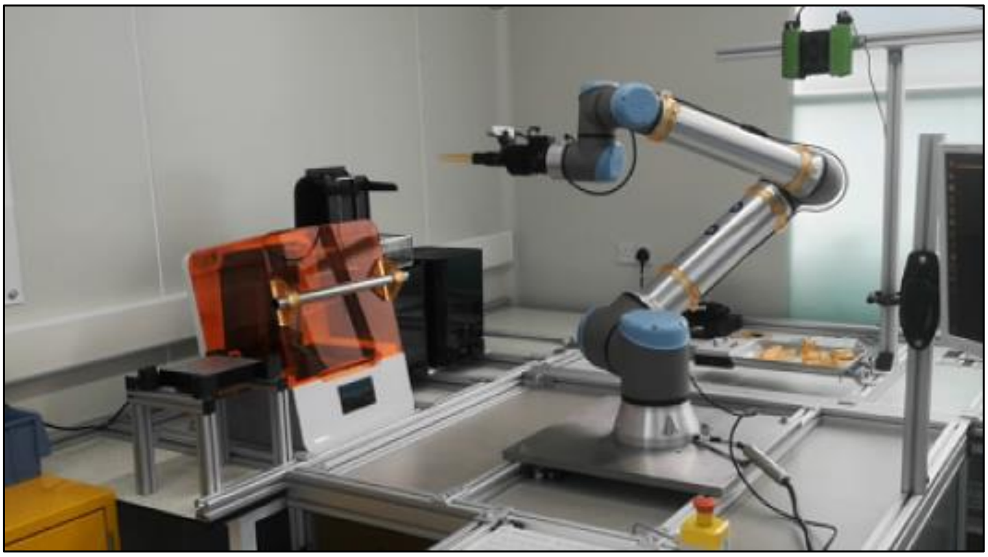

Figure 22 : Steripack Cell – General Overview

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2.3.1 Sequence of operation

The process flow for the Steripack 3D printing line involves the following steps:

1. **Create a 3D CAD model file** of the medical device or component to be print. This is usually an STL of STEP file and acts as a setup file for the printer to replicate. An example is show in the following figure:

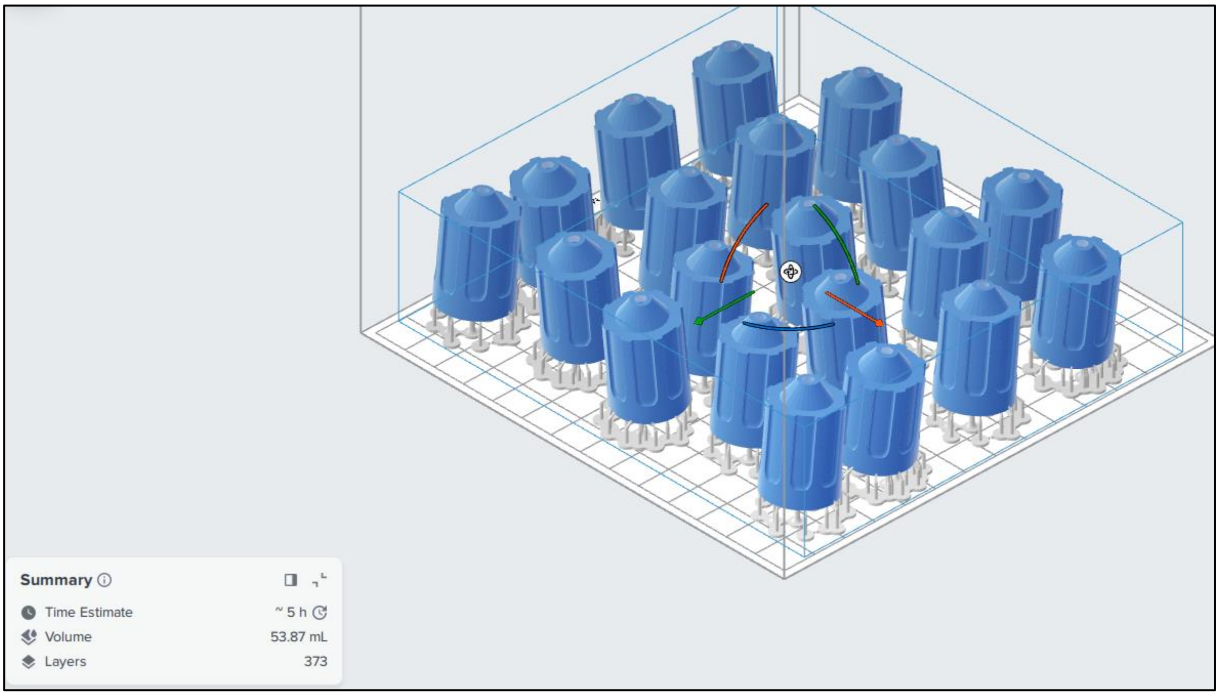

Figure 23 : Example of a 3D set up file for the £D printer

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2. **Send the created file to the 3D printer.** This is a step carried out by the engineer or operator running the line and is done locally or remotely.
3. **Printer communicates ready status via its API connected to ACROBA.** Once the printer has acquired the print file, it communicates a "Status Ready" and the automated process is initiated. From this point, the robot and ACROBA take over the process.
4. The robot, supported by ACROBA, executes the following tasks:
    a. Open and close the 3D printer
    b. Loads and unloads the build plate.
    c. Transfers the build plate from the 3D printer to the washing station.
    d. Loads and unloads the washing station.
    e. Starts the washing cycle.
    f. Transfers the cleaned build late with the parts to the part removal station.
    g. Loads and unloads the part removal station.
    h. Identifies and picks single component with its gripper.
    i. Transfers each 3D printed component to the curing tray.
    j. Transfers the curing tray with the components to the curing oven.
    k. Removes cured parts from oven.
    l. Individually inspects each part for support removal.
    m. Carries out final part inspection.

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The overall process is outlined in the following figure:

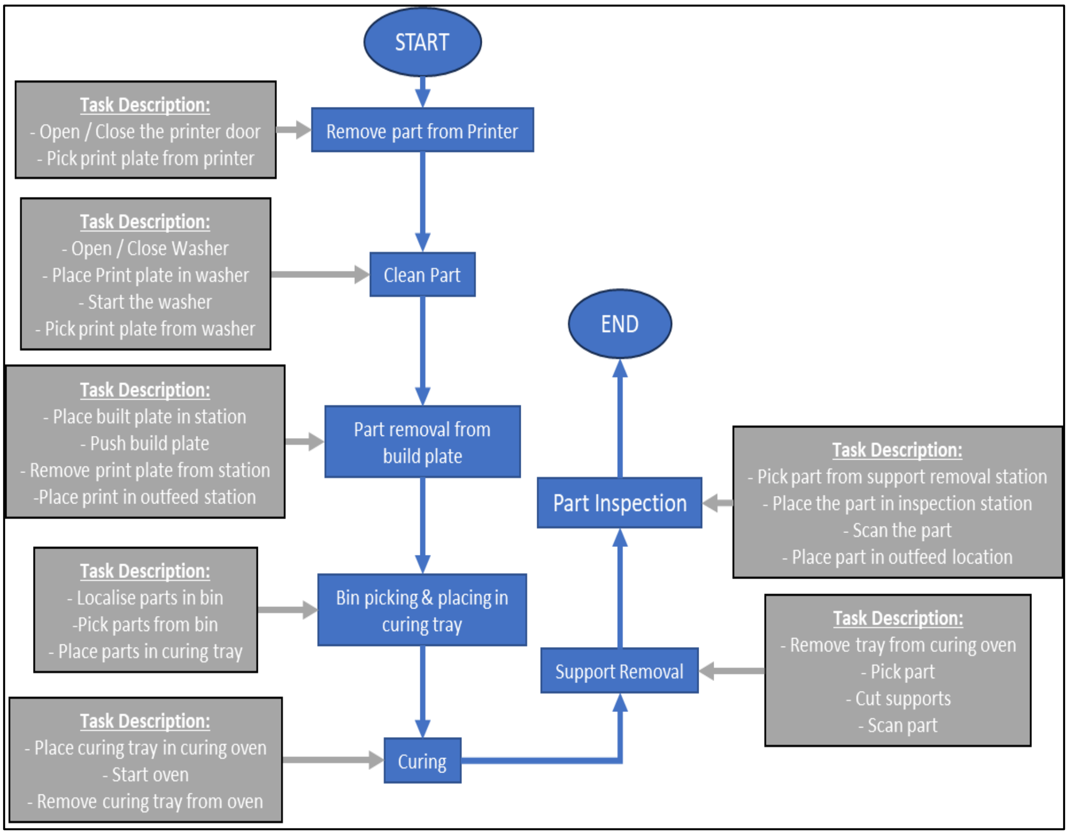

Figure 24 : Sequence diagram for the Steripack use case

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The following figure illustrates some of the steps and operations described above:

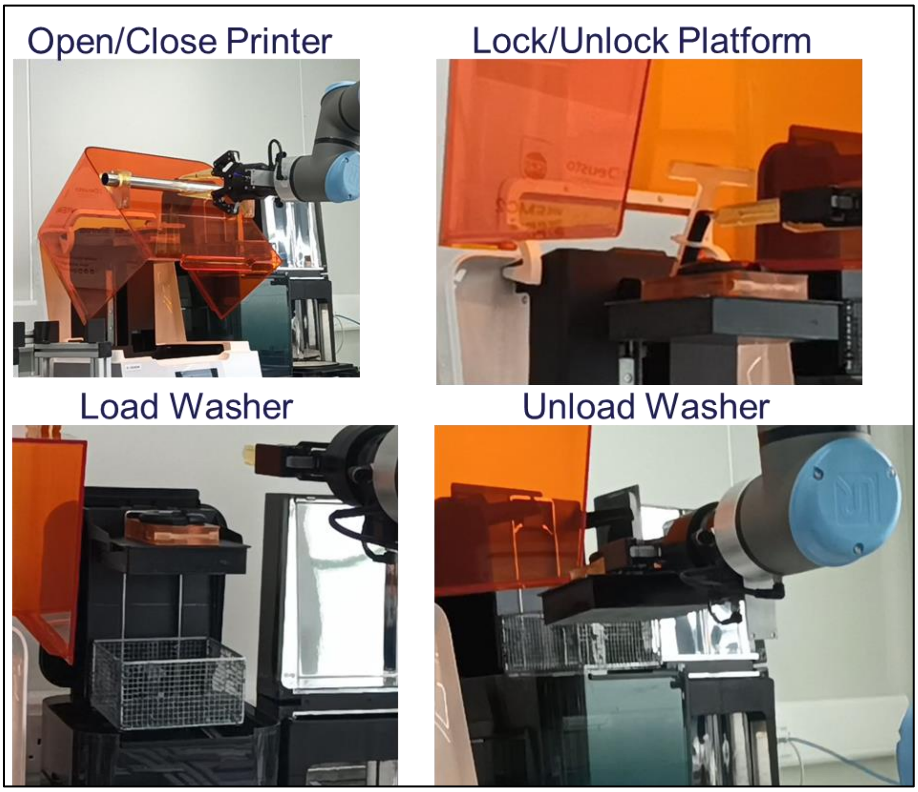


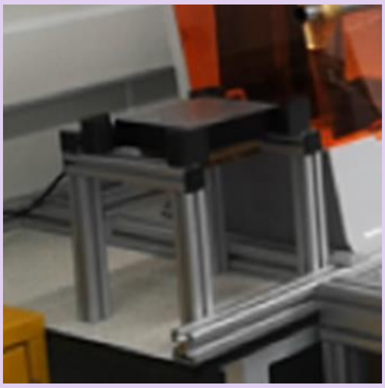
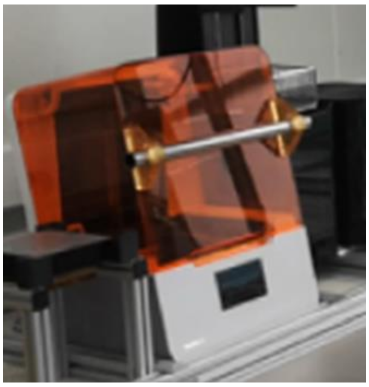
Figure 25 : Examples of process steps carried out by the robot with the ACROBA platform

2.3.2 Mechanical Overview

As outlined in the previous section, the 3D printing cell is comprised of the following elements:

- Build platform holder / storage
- 3D printer
- Part washer
- Part UV curing oven
- Part removal fixture
- Support removal fixture

The following table lists each section / element of the line and their function:

Equipment Name	Function Description	Device
Build platform holder / storage	Fixture used to hold / store build platform ready to be picked up for queued print project	
3D Printer	Formlab 3B+ Printer used to process 3D printing projects	

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Equipment Name	Function Description	Device
Part UV curing oven	Formlab “Form Cure” UV oven to cure 3D printed parts	
Part Washer	Formlab “Form Wash” cleaning station to automatically clean 3D printed parts after the printing process is complete. This washer currently used IPA as the cleaning agent.	

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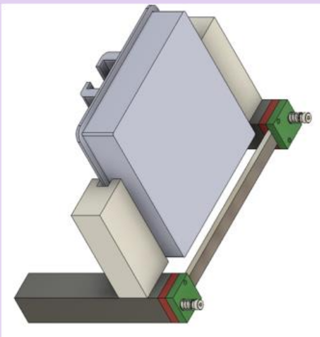
Equipment Name	Function Description	Device
Part removal fixture	Station used to hold the build plate with the printed parts and carry out the part removal step 	
Support removal fixture (In design)	Station used to carry out the support removal process and final inspection of the 3D printed parts	At concept and development phase.

Table 2 Hardware elements for the Steripack cell

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In addition, a bin picking station is set up with a frame mounted camera, located at the part removal fixture and an Intel RealSense D435 camera is mounted on the robot, as shown in the following figure:

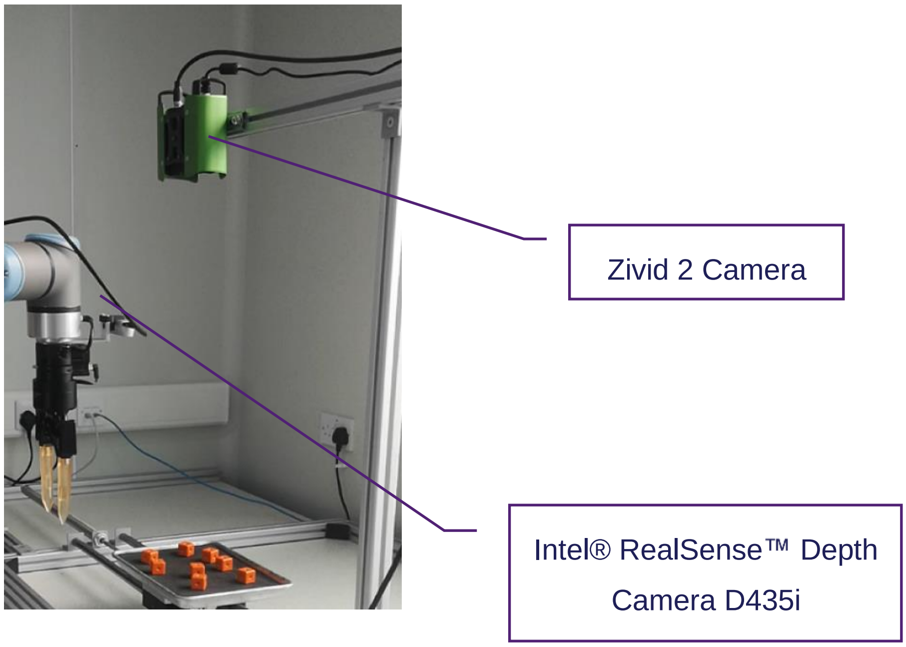

Figure 26 : Bin picking station with Zivid 2 camera

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The different elements of the cell are connected and / or communicate as per the high-level descriptive figure below, with the following table identifying each device:

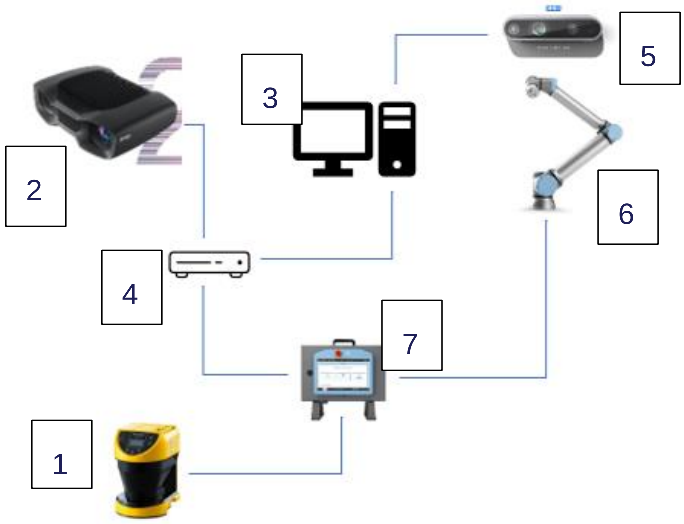

Figure 27 : SteriPack Cell – Connection / Communication architecture Overview

Device ID #	Equipment Name	Function Description
1	Keyence safety laser scanner, SZ-01S	Safety sensor with different zones set up to ensure safety of the cell during processing
2	Zivid 2 Camera	Camera for the bin picking operations
3	PC with Ubuntu Operating System	Used to run the ACROBA platform

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Device ID #	Equipment Name	Function Description
4	Ethernet switch	Used to enable and manage communications between each device
5	Intel® RealSense™ Depth Camera D435i	Planned for inspection and location
6	UR10e	Robot configured to run the 3D printing process
7	UR10e Robot controller	Robot controller

Table 3 Steripack cell connected components

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2.3.3 Electrical Overview

As fully outlined in the D4.4 deliverable, the overall electrical aspects of the Steripack line are as follows:

Equipment Name	Function Description	Power / Electrical Requirements
3D Printer	Formlab 3B+ Printer used to process 3D printing projects	100–240VAC, 2.5A, 50/60Hz, 220W
Part UV curing oven	Formlab "Form Cure" UV oven to cure 3D printed parts	90–240V, 6.0A, 50/60Hz, 144W
Part Washer	Formlab "Form Wash" cleaning station to automatically clean 3D printed parts after the printing process is complete. This washer currently used IPA as the cleaning agent.	90–240V, 2.0A, 50/60Hz, 50W
Keyence safety laser scanner, SZ-01S	Safety sensor with different zones set up to ensure safety of the cell during processing	Power through I/O board of UR10e Robot controller, 24 VDC ±10 %, Ripple (P-P) 10 % or less
Zivid 2 Camera	Camera for the bin picking operations	240VAC, with 24 V 5A power adapter

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Equipment Name	Function Description	Power / Electrical Requirements
PC with Ubuntu Operating System	Used to run the ACROBA platform	240VAC
Ethernet switch	Used to enable and manage communications between each device	240VAC
Intel® RealSense™ Depth Camera D435i	Planned for inspection and location	Power through Ubuntu PC via compatible USB 2.0 / USB 3.1 port
UR10e Robot + controller	Robot configured to run the 3D printing process	100-240 VAC, 47-440 Hz

Table 4 Electrical components for the Steripack cell

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2.3.4 Skills and Associated Tasks Overview

For the execution of the process steps as described in section 3.3.1, the necessary skills and primitives needed are listed in the next table. Each process step is listed with the relevant skills and primitives.

Process Step / Sequence	Primitive(s) name	Skill(s) Name	General / Specific
Remove Parts From 3D Printer	pr_generate_trajectory pr_execute_trajectory pr_grasp pr_release	sk_move_to sk_pick sk_place	G
Clean Parts	pr_generate_trajectory pr_execute_trajectory pr_grasp pr_release	sk_move_to sk_pick sk_place	G
Part Removal from build plate	pr_generate_trajectory pr_execute_trajectory pr_grasp pr_release	sk_move_to sk_pick sk_place	G
Bin Picking and placing parts to curing tray	pr_generate_trajectory pr_execute_trajectory pr_generate_grasp_pose	sk_locate_fixed_camera sk_move_to sk_point_cloud_processing	G

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Process Step / Sequence	Primitive(s) name	Skill(s) Name	General / Specific
	pr_crop_image pr_Cad_matching pr_cad_loading pr_get_pointcloud_max_dist pr_point_3d_to_2D_pixel pr_grasp pr_release pr_roi_selection pr_subsampling pr_plane_filtering pr_outlayer_removal	sk_get_crop_limits sk_pick sk_place	
Curing	pr_generate_trajectory pr_execute_trajectory pr_grasp pr_release	sk_move_to sk_pick sk_place	G
Support removal	pr_generate_trajectory pr_execute_trajectory pr_reconstruction_3D pr_grasp	sk_move_to sk_scan sk_pick sk_place	G

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Process Step / Sequence	Primitive(s) name	Skill(s) Name	General / Specific
	pr_release pr_generate_waypoints pr_detect_default		
Part Inspection	pr_generate_trajectory pr_execute_trajectory pr_reconstruction_3D pr_generate_waypoints pr_detect_default pr_grasp pr_release	sk_move_to sk_scan sk_pick sk_place	G

Table 5 Skills and primitives for the Steripack 3D printing cell

All skills and primitives used on the 3D printing cell are generic.

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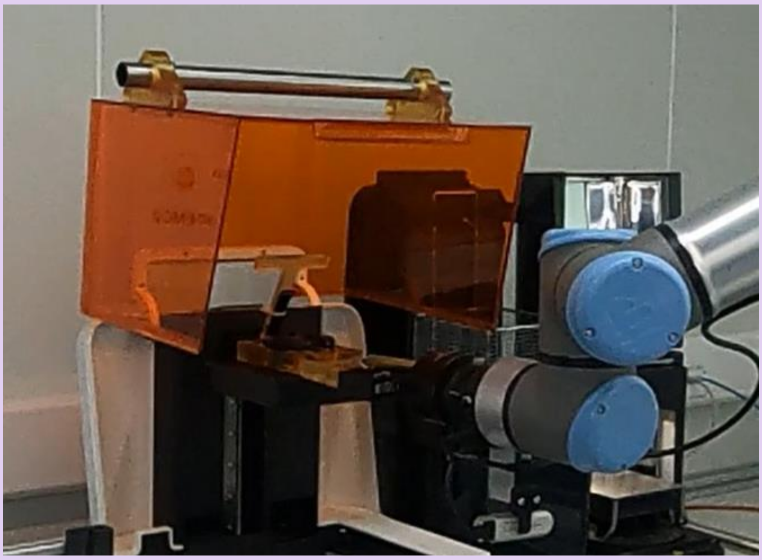
2.3.5 Executed Process Overview

The following figures illustrate the main steps executed during the process. Fo a full description and a visualisation of the running cell with ACROBA, refer to the D6.4 deliverable and the supporting video.

Process Step / Sequence	Visual
Remove Parts From 3D Printer	

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Process Step / Sequence	Visual
Clean Parts	
Part Removal from build plate	

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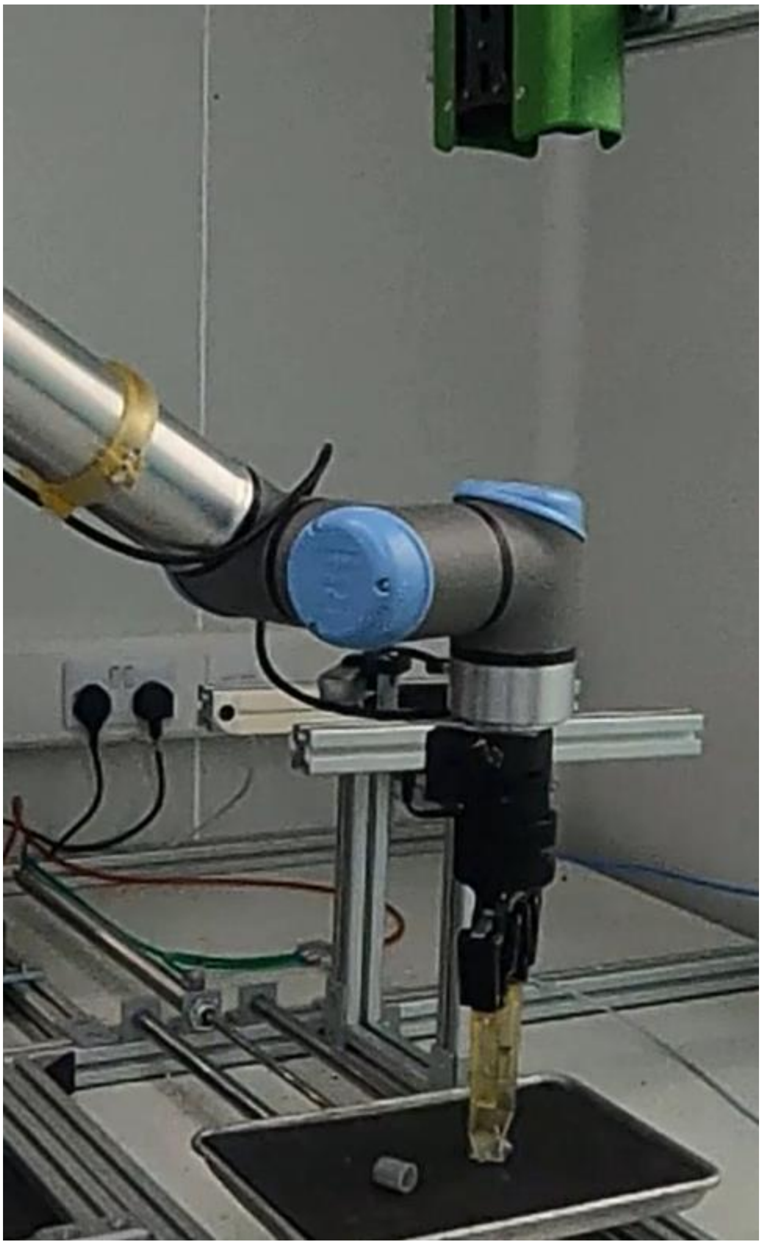
Process Step / Sequence	Visual
Bin Picking and placing parts to curing tray	

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Process Step / Sequence	Visual
Curing	

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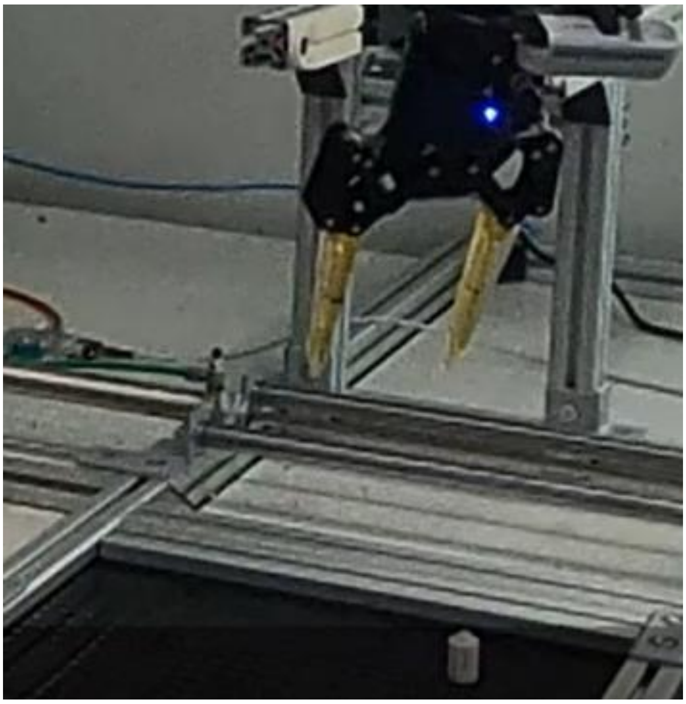
Process Step / Sequence	Visual
Part Inspection and Support removal	

Table 6 Process steps overview

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3 ACROBA – Skills Integration and Process Execution

3.1 Process and Flow Charts

3.1.1 MOSES Use Case

Figure Figure 28 shows the flowchart of the MOSES cell with the integration of the ACROBA platform. This flowchart represents the sequence to follow to execute the cut recording process for a lid, however, once the cut path is recorded, this flowchart will only have step 2, 4, 5 and 6.

The recording of paths using dummy tools has a direct influence on the robot's programming times, largely reducing them, as no CAM software is required. On the other hand, the automatic calibration of the cell, tooling and robot reduces positioning times, facilitating the task of tool assembly.

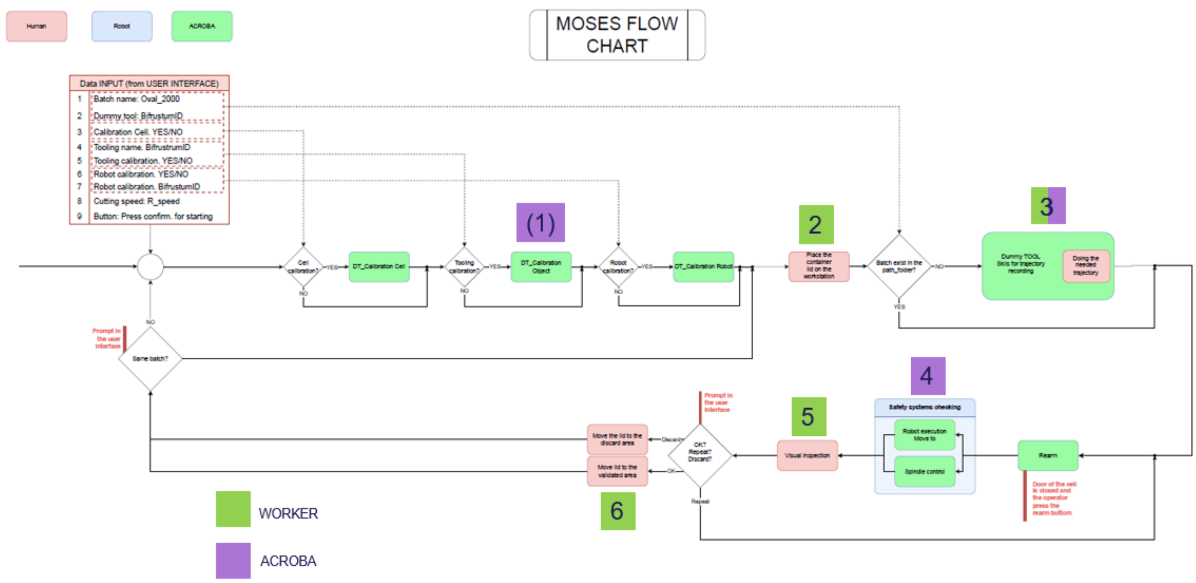

Figure 28: General overview of the MOSES flow chart.

For a better understanding, the workflow has been divided into different figures. Firstly, Figure Figure 29 shows the information that the ACROBA system requests from the user before

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starting with a new batch of container lids. The user must enter the batch name as well as the ID of the bifrustum to be used for the recording tasks. In addition, before the execution, the operator must decide whether to calibrate the cell, the tooling and the robot, taking into account the IDs of the bifrustum used for this purpose. Finally, depending on the specifications of the container lids, the operator must set the cutting speed. Based on this calibration, the system sets the rotational speed of the spindle.

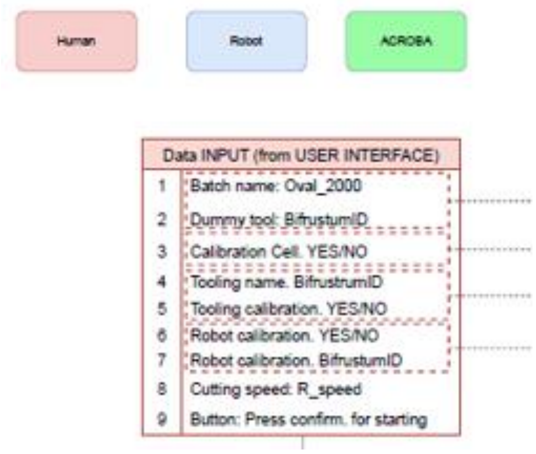

Figure 29: MOSES flow chart. Data input form the operator.

Once the system has entered the parameters described above, the work sequence starts, in this case, if the operator has requested any of the calibrations, the system indicates on the screen the action to be carried out, as well as the necessary bifrustum. Figure Figure 30 shows the process followed for each of the calibrations.

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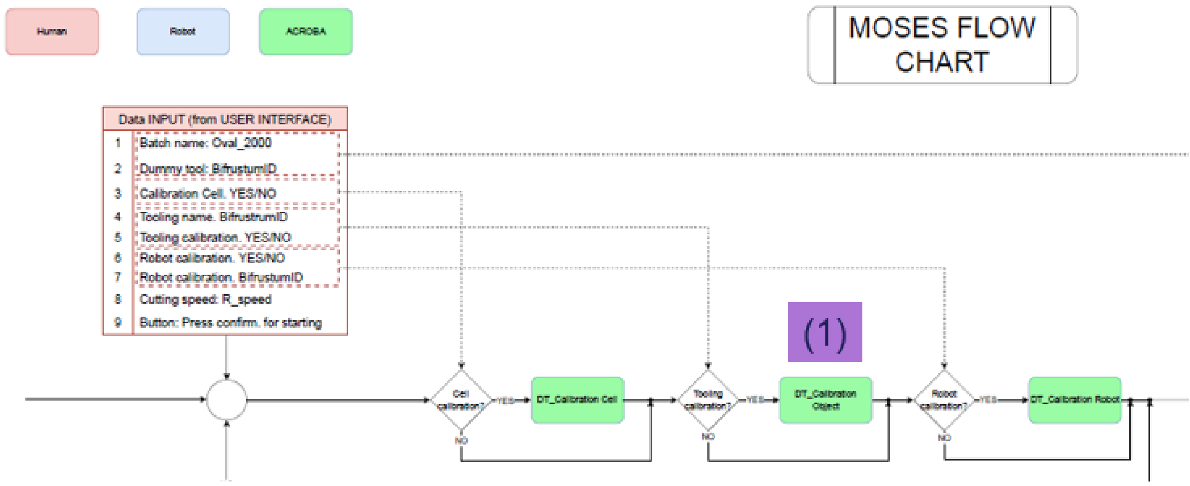

Figure 30: MOSES flow chart. Calibration steps, if needed.

After the calibration stage, the system is ready for recording and cutting execution. Figure Figure 31 numerically illustrates each of the steps previously described. Once the operator places the lid, if it is the first piece of the batch, the system prompts the operator to use the dummy tool to record the trajectory. On the other hand, if the batch already exists, the system will skip this step and proceed directly to robotic execution.

After creating the trajectory, the operator can visualize the recorded trajectory on the system screen. If the trajectory is satisfactory, the process continues; otherwise, it must be repeated. Once the trajectory is finalized, whether for drilling or cutting, the next step is robotic execution. For this, the operator must exit the cell, close the door, and press the request button. At this point, the robot's motors are enabled, and it awaits the operator to press the execution button. Once the execution button is pressed, the robotic process begins. At this stage, all the cell's safety systems are active. Any action that breaches the cell's perimeter will automatically stop the robot. Additionally, during this process, the spindle's rotational speed is controlled based on the speed specified by the operator to the robot. When the robotic process is completed, an industrial light tower signals green, indicating the operator can enter the cell and visually inspect the lid.

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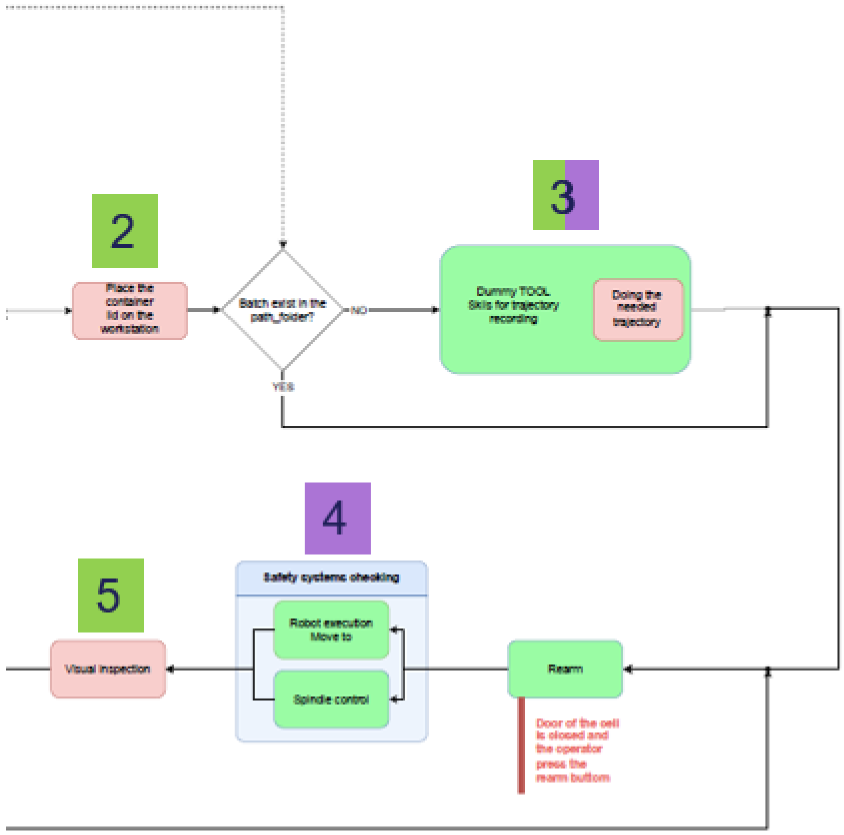

Figure 31: MOSES flow chart. Main process of MOSES use case using ACROBA platform.

During the visual inspection, the operator must determine whether the piece is acceptable (OK), requires rework, or needs to be discarded. Based on this decision, the operator will transfer the piece to the designated area.

Additionally, if the operator decides to repeat the process, they only need to exit the cell and initiate the request/execution sequence again. Once the piece is removed from the fixture, the cycle begins anew.

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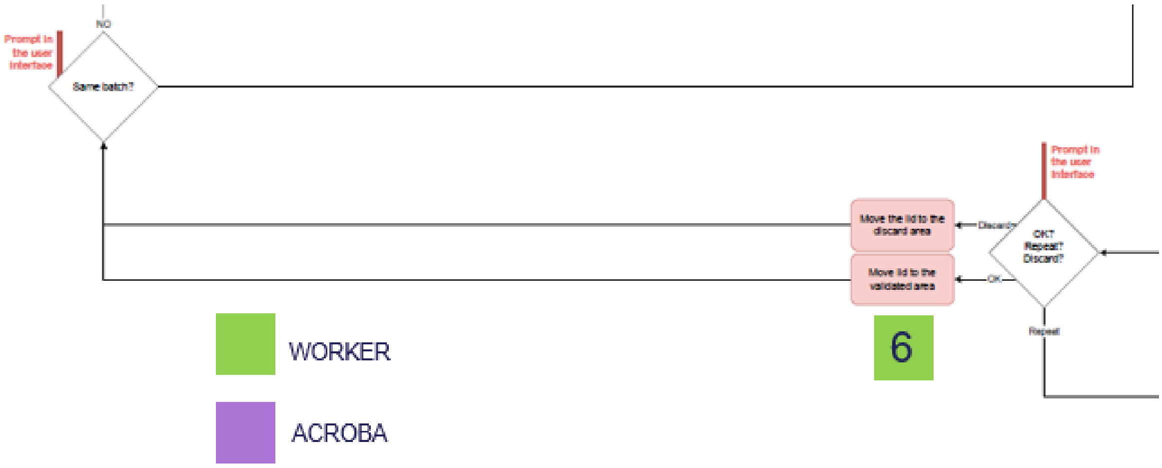

Figure 32: MOSES flow chart. Final step. The operator removes the container lid from the workstation.

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3.1.2 CABKA Use Case

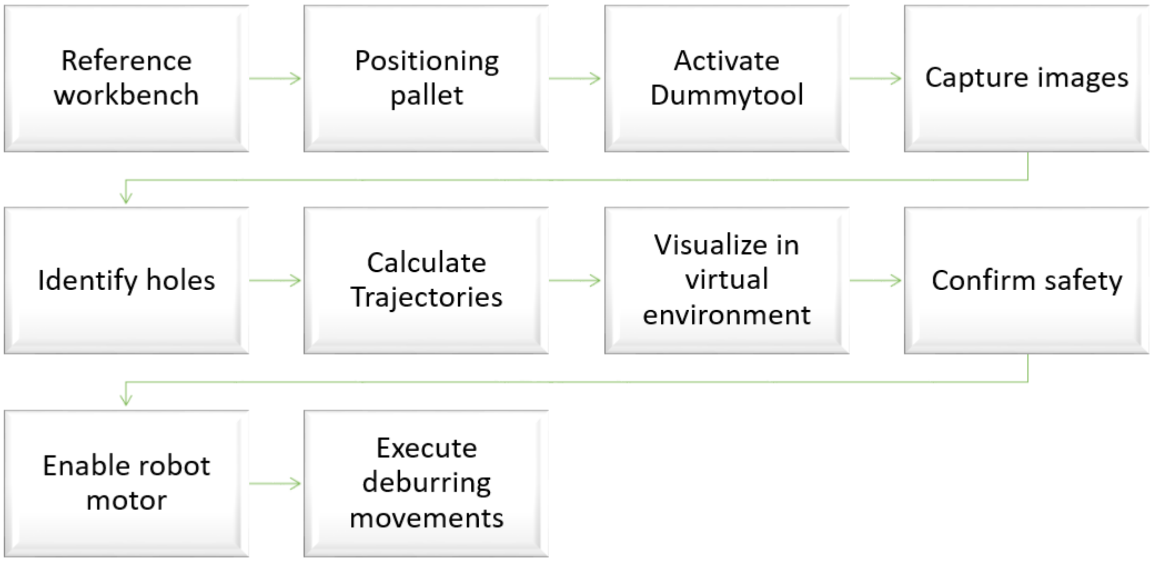

Figure 33 : CABKA Flowchart

From the operator’s perspective, they must ensure that access to the area is enabled for them. Once inside the work zone, they position a pallet on the table and turn on the Dummytool selection tool. They select the holes with burrs by pressing the button on the tool. Once the selection task is completed, they place the tool back where they took it from and exit the work area. Outside, next to the door, they press the button that checks the safety measures. If everything is correct, the red light on the control panel will activate, indicating that the robot is now executing the trajectories commanded by the ACROBA system.

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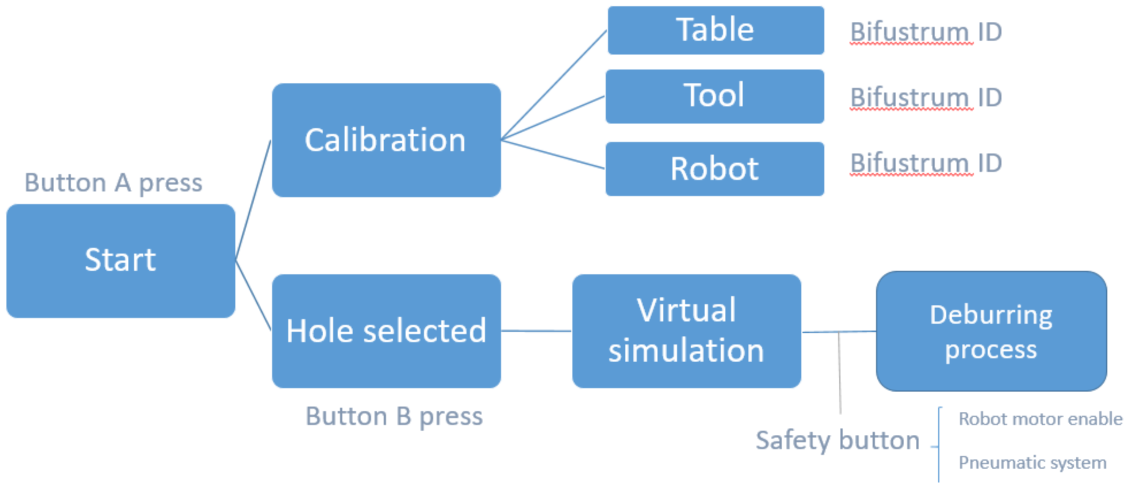

Figure 34 : CABKA Flowchart. Using ACROBA platform.

3.1.3 STERIPACK Use Case

To run the cell within the ACROBA platform, it is possible to execute the full sequence by using the set of instructions (at the time of writing this report) found at the following location on the Github space of the ACROBA project:

> [ACROBA-Project/steripack_demo_steps (github.com)]

This repository contains the specific configuration files to the Steripack 3D printing cell as well as a full set of steps to ucn and execute the copmplete process sequence.

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The following figures are a step-by-step breakdown of the process, with the associated skills. The process flow was broken down for clarity and the complete process flow is shown in figure 40, at the end of this section. A summary table of the skills and primitives used throughout the process can be found at the end of this section as well.

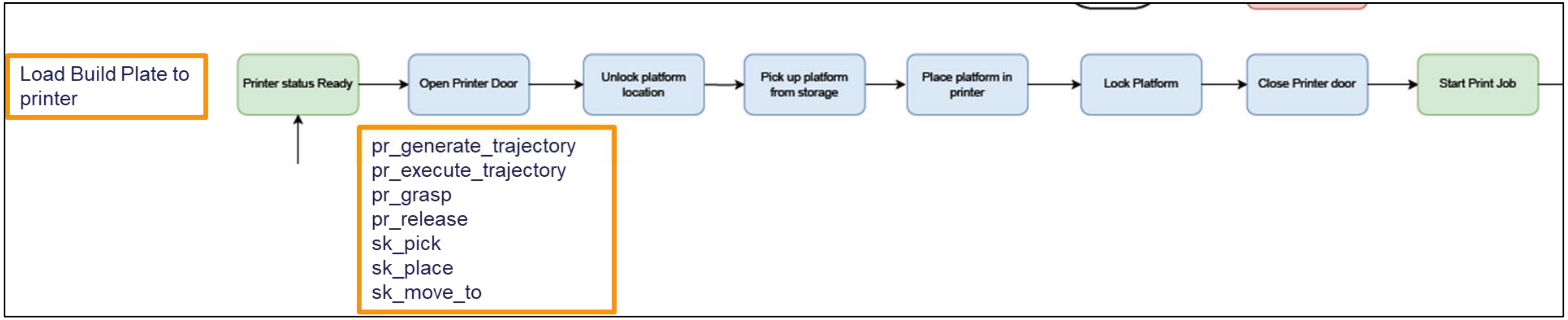

Figure 35 : Setting up and start up

Once the printer acquires the print file (3D CAD Model of components to print), the robot, supported by the ACROBA platform, takes over the process and initiates the sequence shown above.

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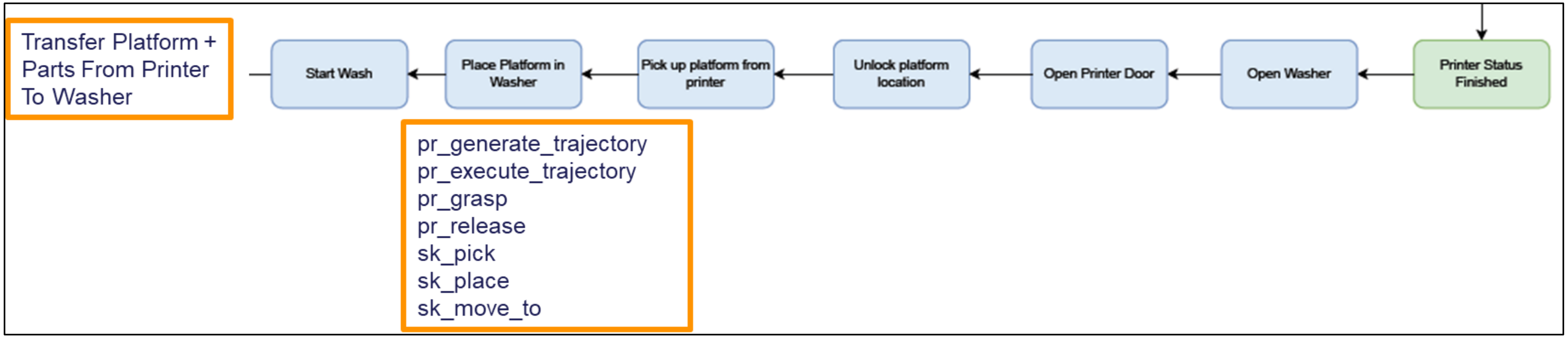

Figure 366 : End of printing and transfer to washing

Once the print process is completed, the printer informs ACROBA that it is ready and idle. The robot initiates the sequence as outlined in figure 3 above.

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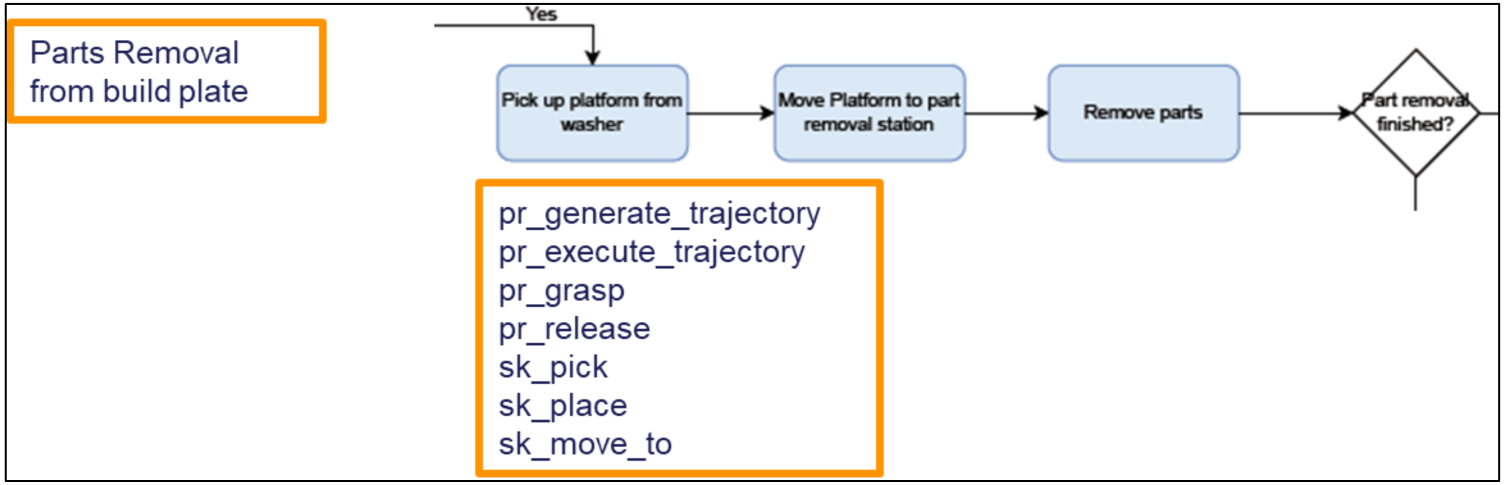

Figure 37 : Part removal sequence

On completion of the washing process, the parts are picked up by the robot to be physically removed from the build platform as per the above sequence.

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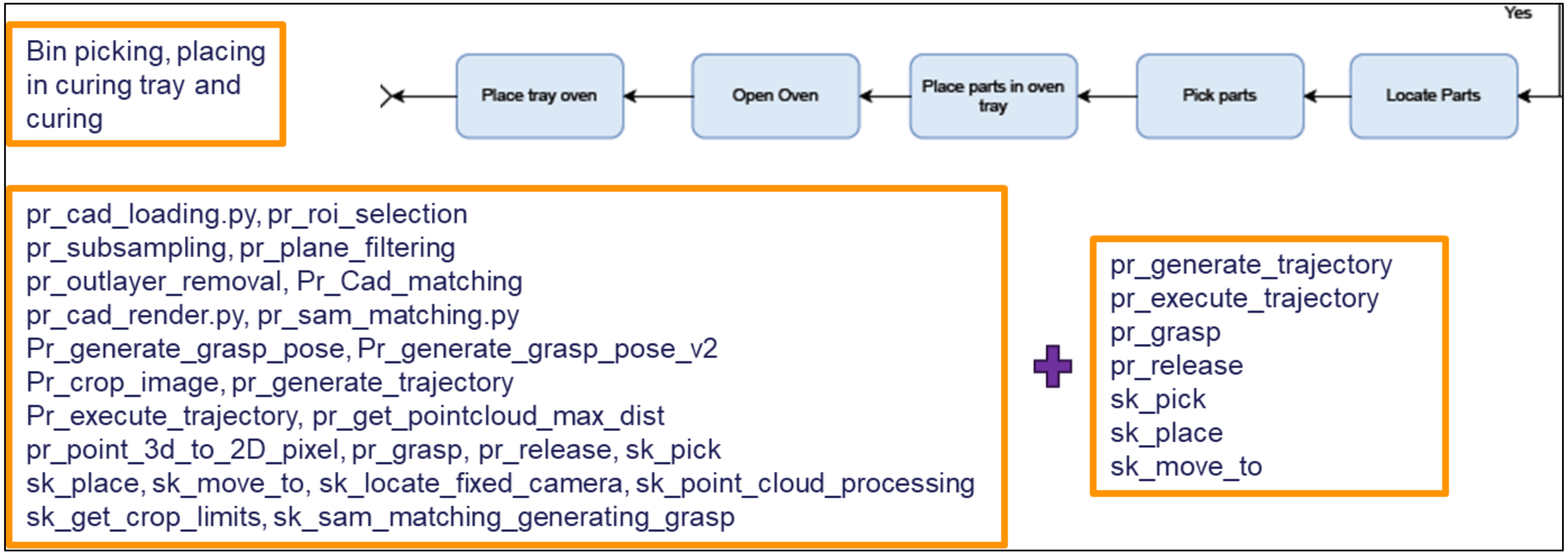

Figure 38 : Bin picking and curing setup

Once parts have been removed from the build platform and collected in a tray positioned underneath, each part is individually picked by the robot using its gripper and place in the fixture for the next process step, which is curing.

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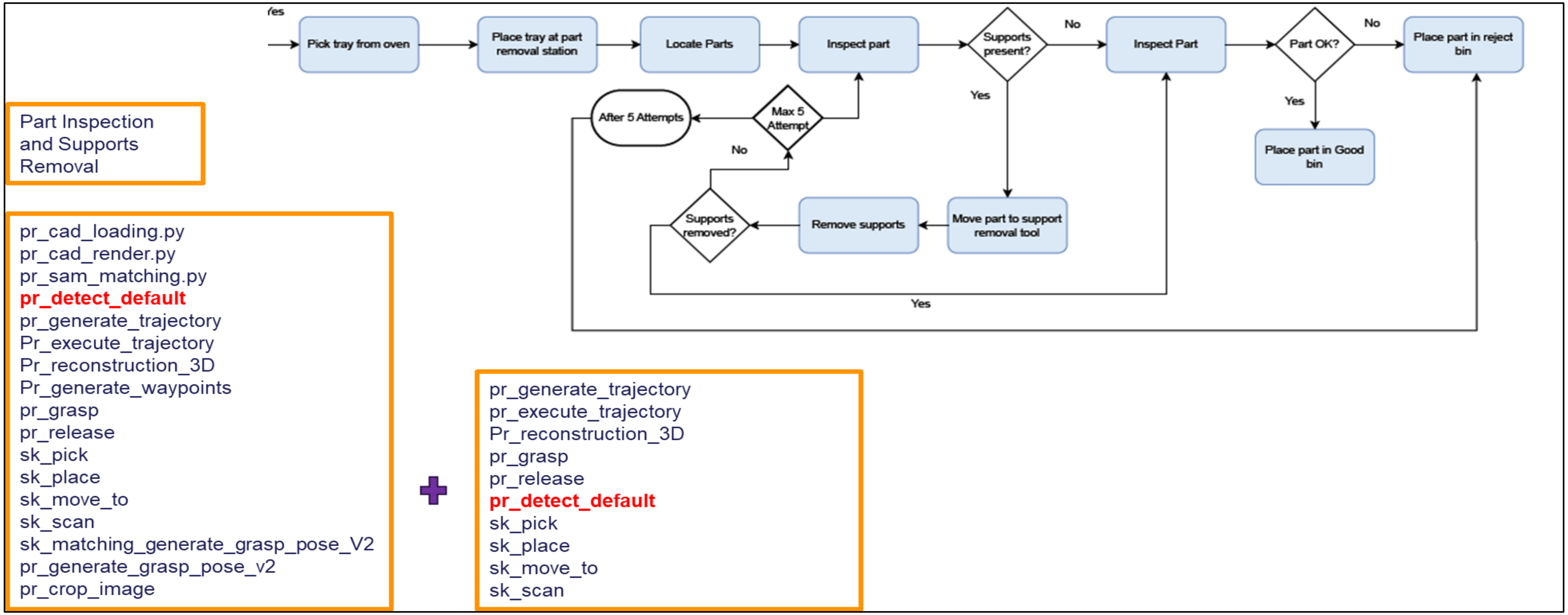

Figure 39 : Inspection, support removal and final inspection

Post curing, the parts must be inspected to identify the supports and initiate the support removal sequence. Once supports are removed, a final inspection is carried out and parts can be "Passed" or "Rejected" depending on defects detected.

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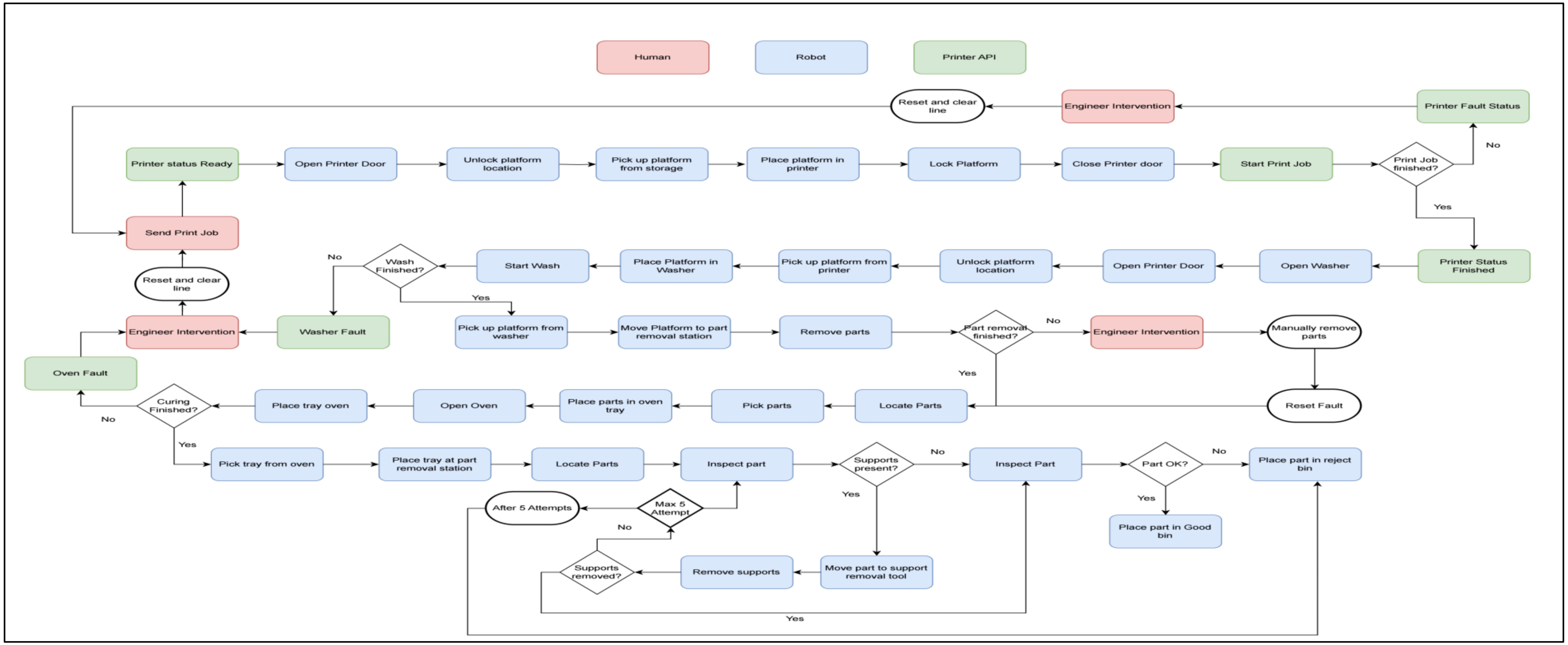

Figure 40 : Overall ACROBA process flow

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4 Conclusion

This deliverable is demonstrating the final implementation of the ACROBA platform for the lights out use cases, highlighting the use of generic and customised skills to execute a series of tasks and operations associated with the processes of each cell.

Functionnality and performance of the cells are described in the associated deliverables from WP6.

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