ACROBA

connect & produce through agile production

D6.4 Final Demonstration Tests in Medical Device Setting

WP6. Evaluation of Performance and Sustainability of the ACROBA Framework

Lead Beneficiary Partner Name: STERIPACK

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The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.

Approval Status

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Version	Date	Description of Changes	By
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1.0	27/11/2024	Final Version	Franck Petit-Renaud

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Disclaimer: // This title and paragraph should be kept in every report

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Table of Contents

The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.

List of Tables

List of Figures

The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.

Executive Summary

This document is a summary of the results of tests conducted on the Steripack lights out Medical Device 3D printing manufacturing cell. Incorporating a robotic system supported by the ACROBA platform, the line operates from start (a 3D CAD file of the part to be printed) to finish (Final inspection of the produced component). The main objective is to reduce human intervention and the ACROBA system offers a solution where most tasks can be carried out by the robot, using generic skills and commercially available hardware components.

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1 Introduction of the Use Case

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). It also involves intricate and delicate manual operations, such as parts removal and supports removal, adding risks (Personal health and safety and quality output) and time to the process.

The aim is: by automating most of the steps, focusing on the most critical ones (part cleaning, part removal and supports removal), the process will subsequently be more efficient, more reliable and safer, not requiring the near-constant intervention from an operator.

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1.1 The Manual Process

The following flow chart illustrates the step-by-step process as it is traditionally carried out by an engineer or a trained operator:

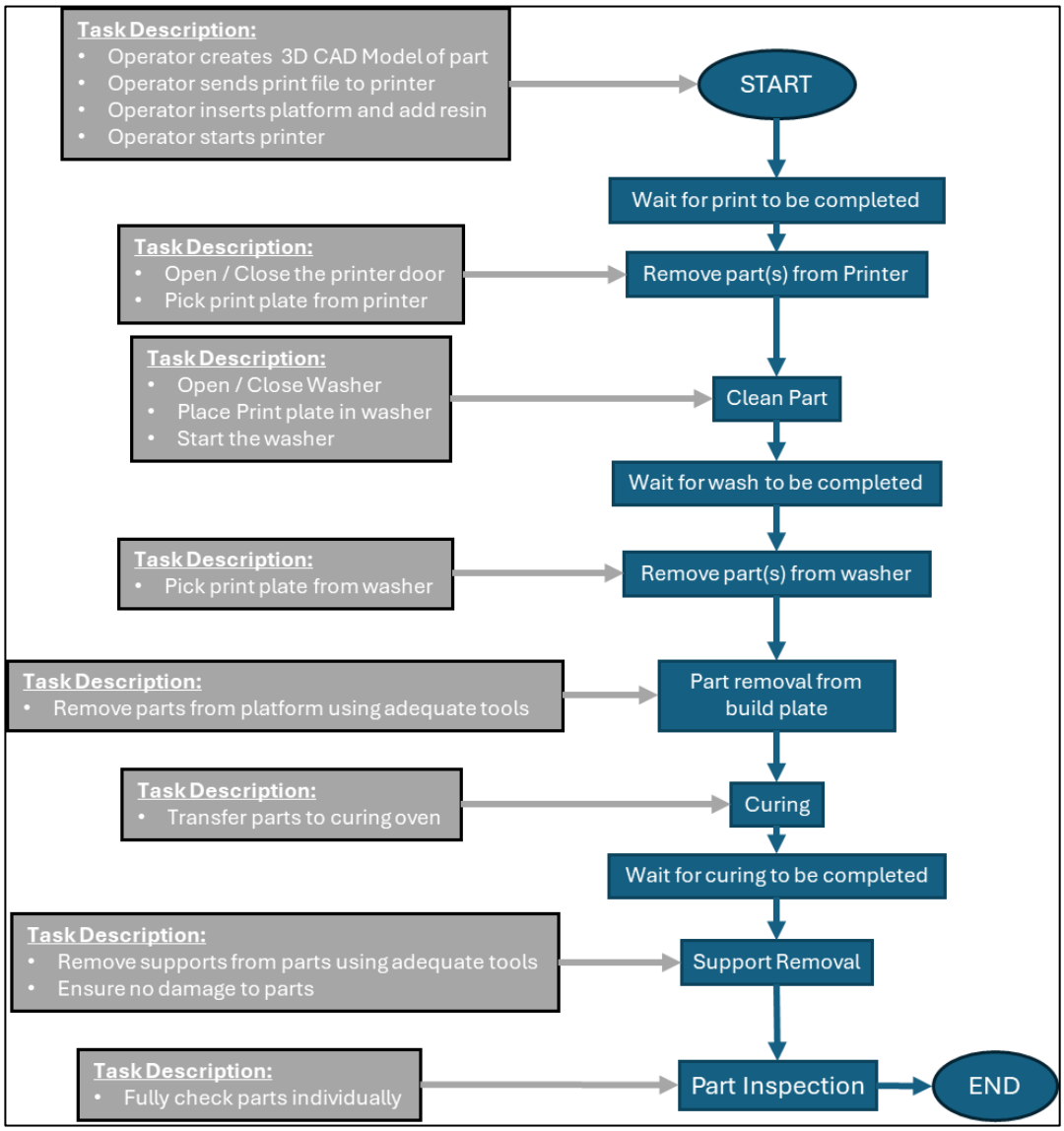

Figure 1 Flow Chart for the Manual process

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As shown, the process involves human intervention at every step as well as significant waiting times whilst ongoing operations are taking place.

Critically, small mistakes (i.e. at the time of generating the print files) and health and safety hazards due to exposure to solvents and printing liquid resins (i.e. setting up and loading the printer, washing process, part removal) contribute to a lower line performance.

1.2 The New Process

The new automated process involves a robotic system that uses the ACROBA platform.

The steps for the new process follow the structure outlined previously, shown in figure 1. The emphasis here being that the new process reduces human intervention to a minimum. In this instance, the process is managed by ACROBA, using the robot to carry out the various tasks and operations as shown in the next figure:

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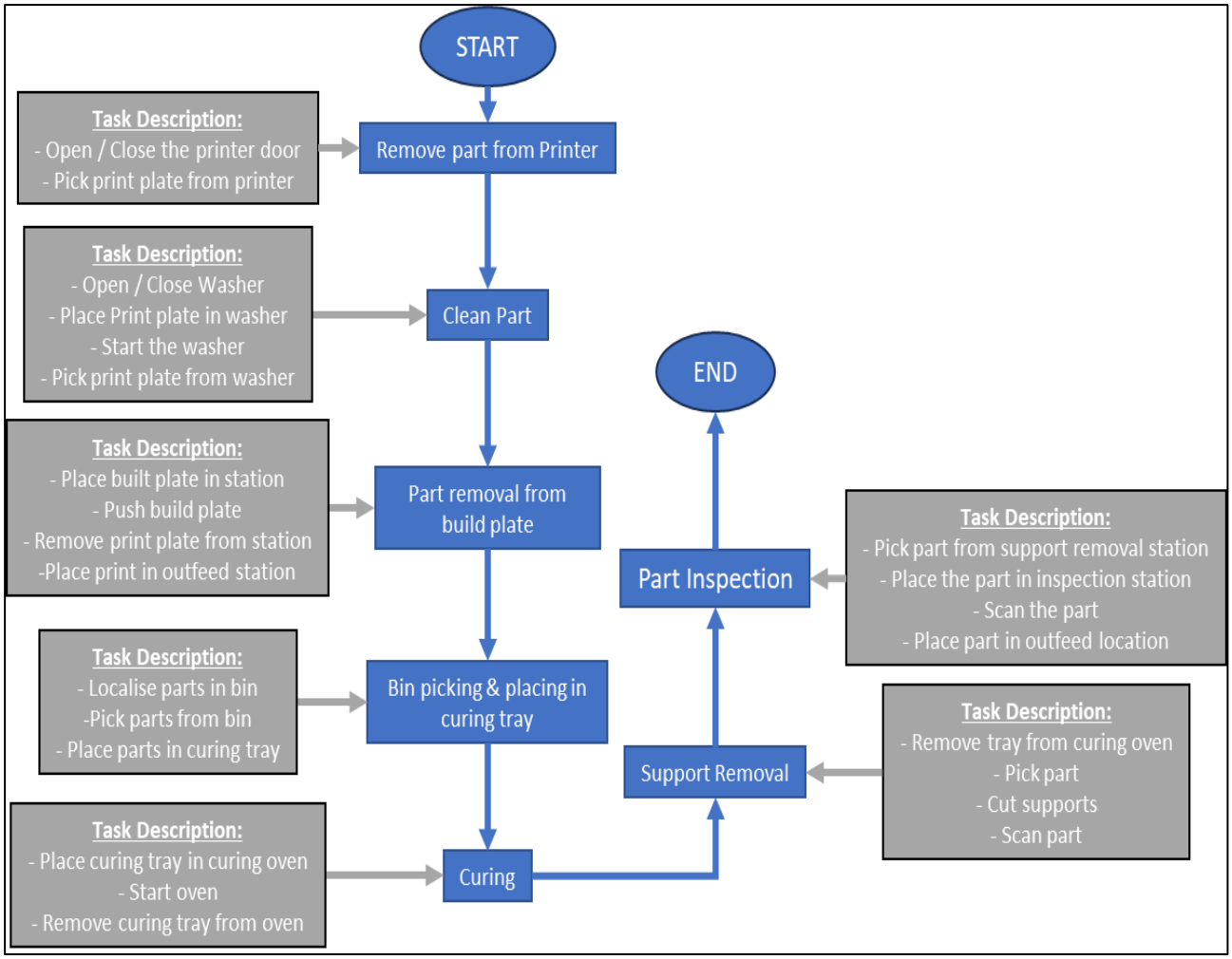

Figure 2 New Process Flow

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2 Integration

All aspects of the integration are fully outlined in the deliverable D4.4 “Report on integration of the ACROBA platform to specific use case” and the following section compiles a summary of the hardware and software integrations of the cell.

2.1 The Hardware Integration

The Steripack 3D printing line layout is shown in the following figures. Each element is clearly identified, and their individual functions detailed in a separate table.

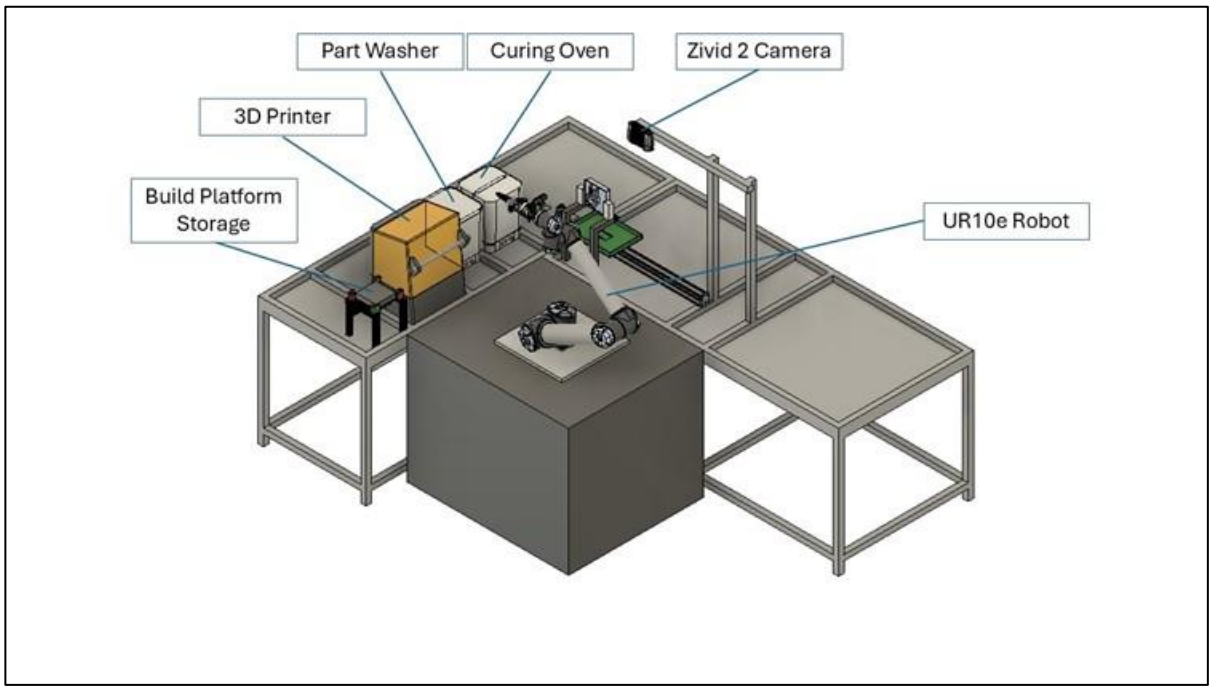

Figure 3 Steripack Cell – CAD View 1

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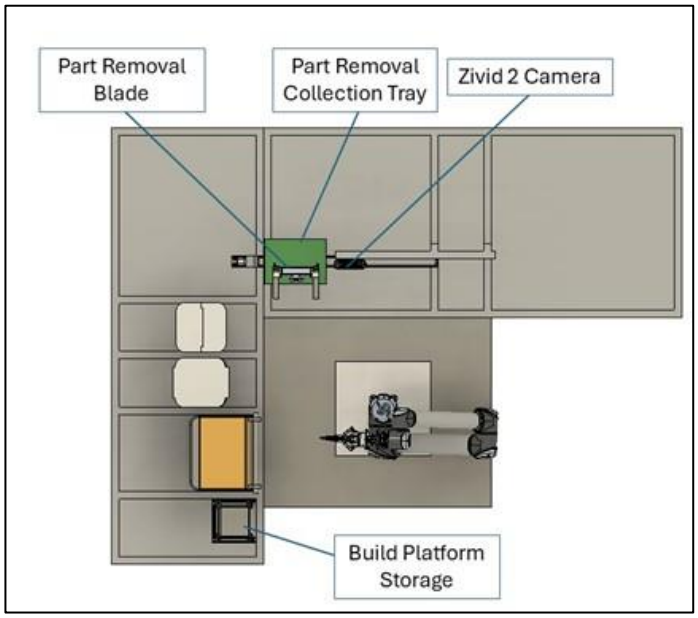

Figure 4 Steripack Cell – CAD View 2

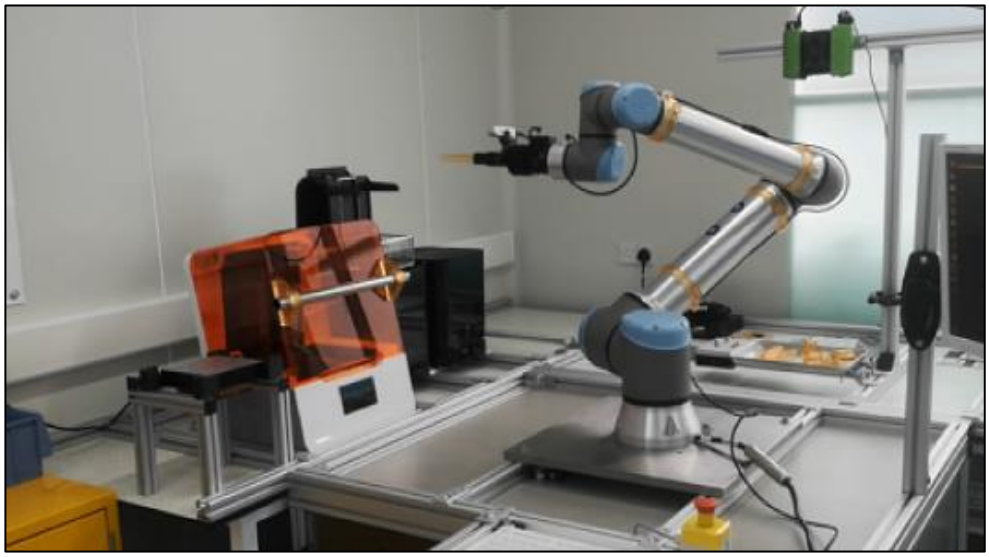

Figure 5 Steripack Cell – General View

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All the mechanical and electrical hardware components for the cell are listed in the table below:

Equipment Name	Function Description
Keyence safety laser scanner, SZ-01S	Safety sensor with different zones set up to ensure safety of the cell during processing
Zivid 2 Camera	Camera for the bin picking operations
PC with Ubuntu Operating System	Used to run the ACROBA platform
Ethernet switch	Used to enable and manage communications between each device
Intel® RealSense™ Depth Camera D435i	Planned for inspection and location
UR10e	Robot configured to run the 3D printing process
UR10e Robot controller	Robot controller
3D Printer	Formlab 3B+ Printer used to process 3D printing projects
Part UV curing oven	Formlab "Form Cure" UV oven to cure 3D printed parts

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Equipment Name	Function Description
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.

Table 1 Integrated Hardware List

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2.2 The Software (ACROBA) Integration

The software integration involves the creation of the “cell config” GitHub repository, which includes all the information required to integrate the complete cell within the ACROBA platform. The following figure describe the cell visualised in Rviz, used for interactive visualisation to develop and test process sequences:

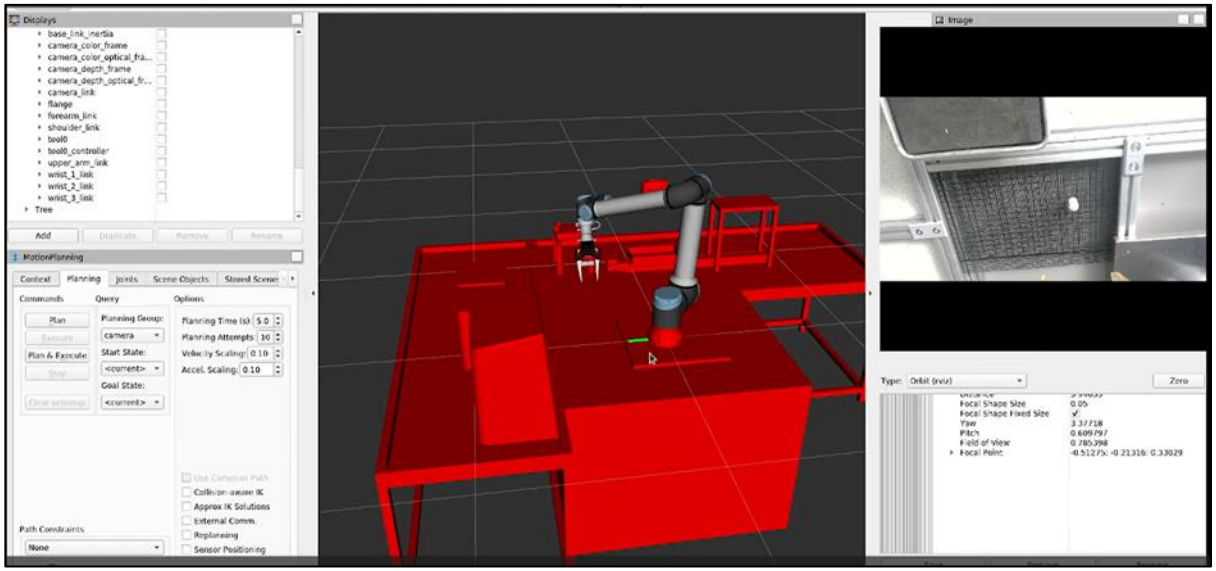

Figure 6 3D Printing Cell in Rviz

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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 11, 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.

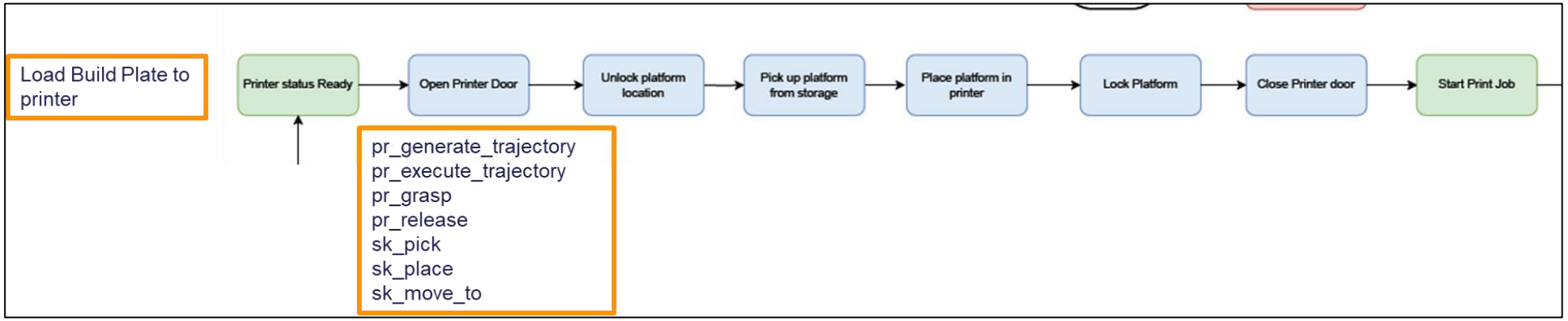

Figure 7 Setting up and Start up

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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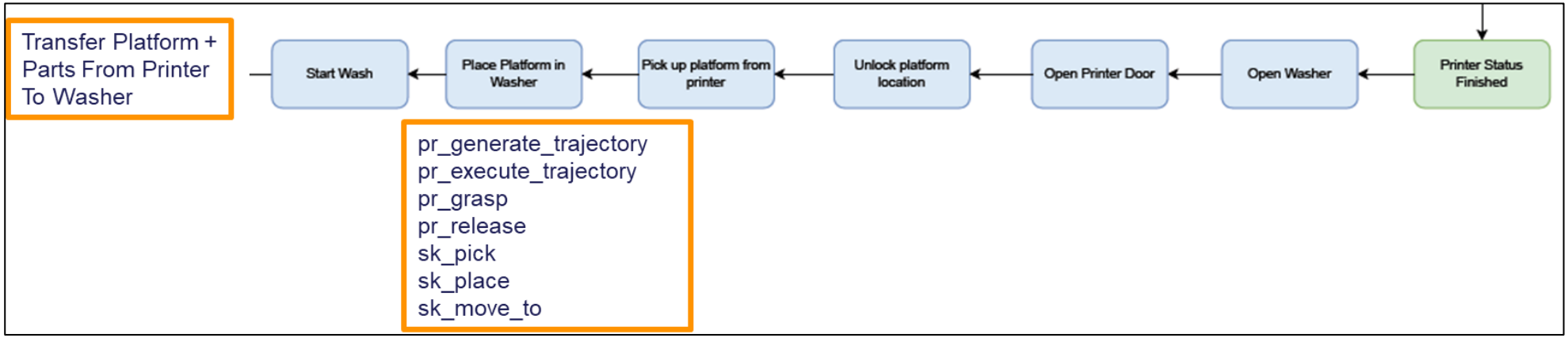

Figure 8 End of Printing and Transfer to Washing

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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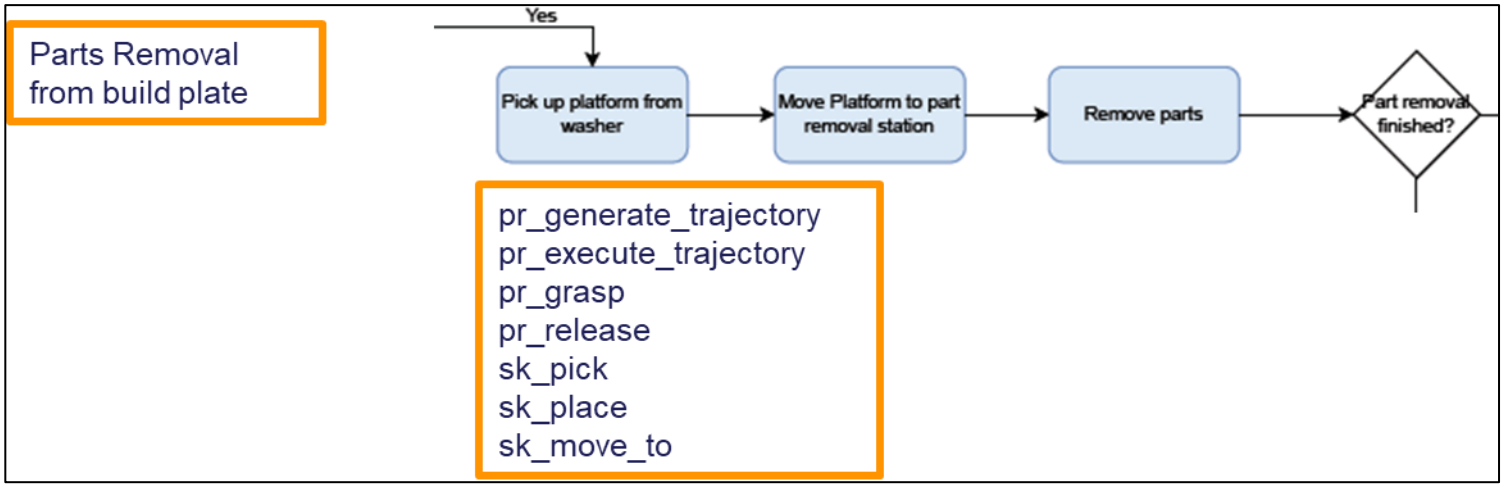

Figure 9 Part Removal Sequence

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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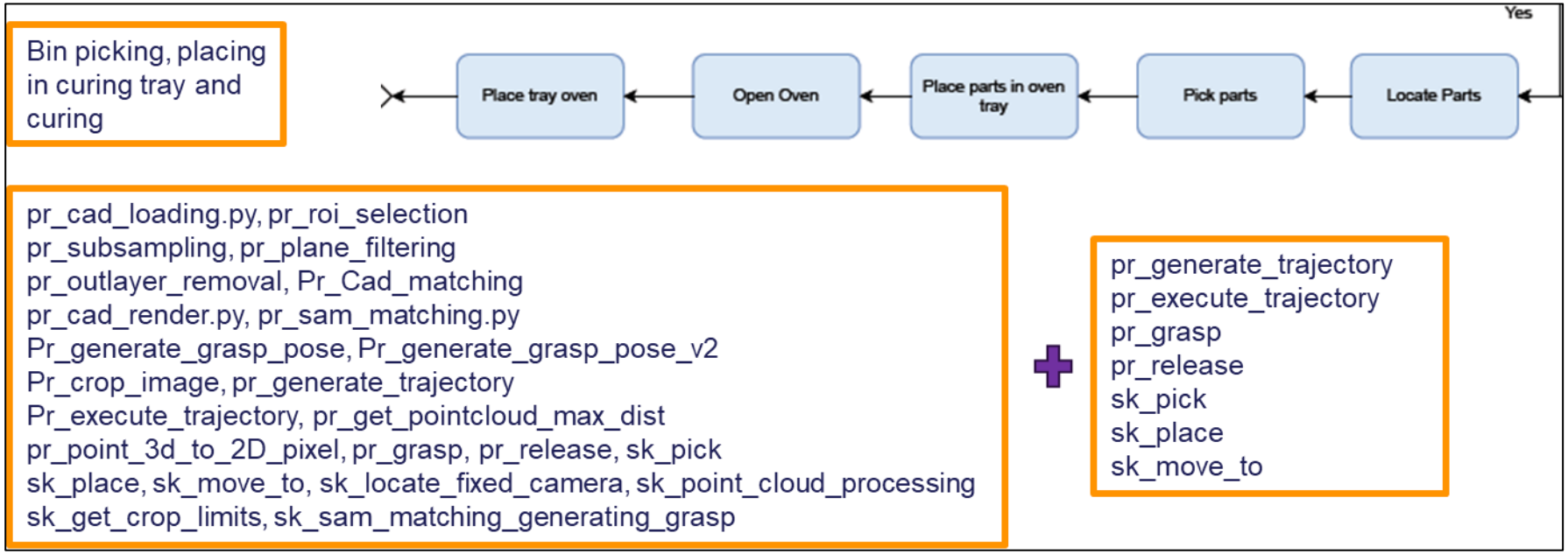

Figure 10 Bin Picking and Curing Setup

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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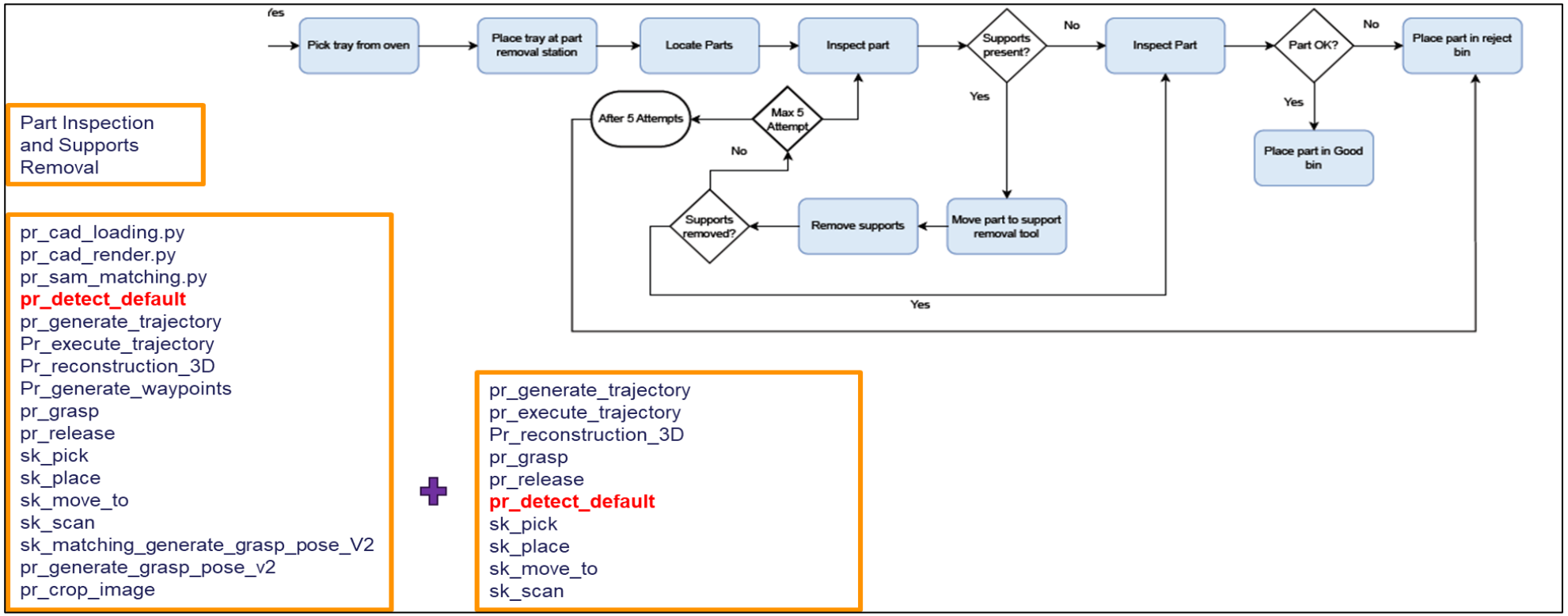

Figure 11 Inspection, Support Removal and Final Inspection

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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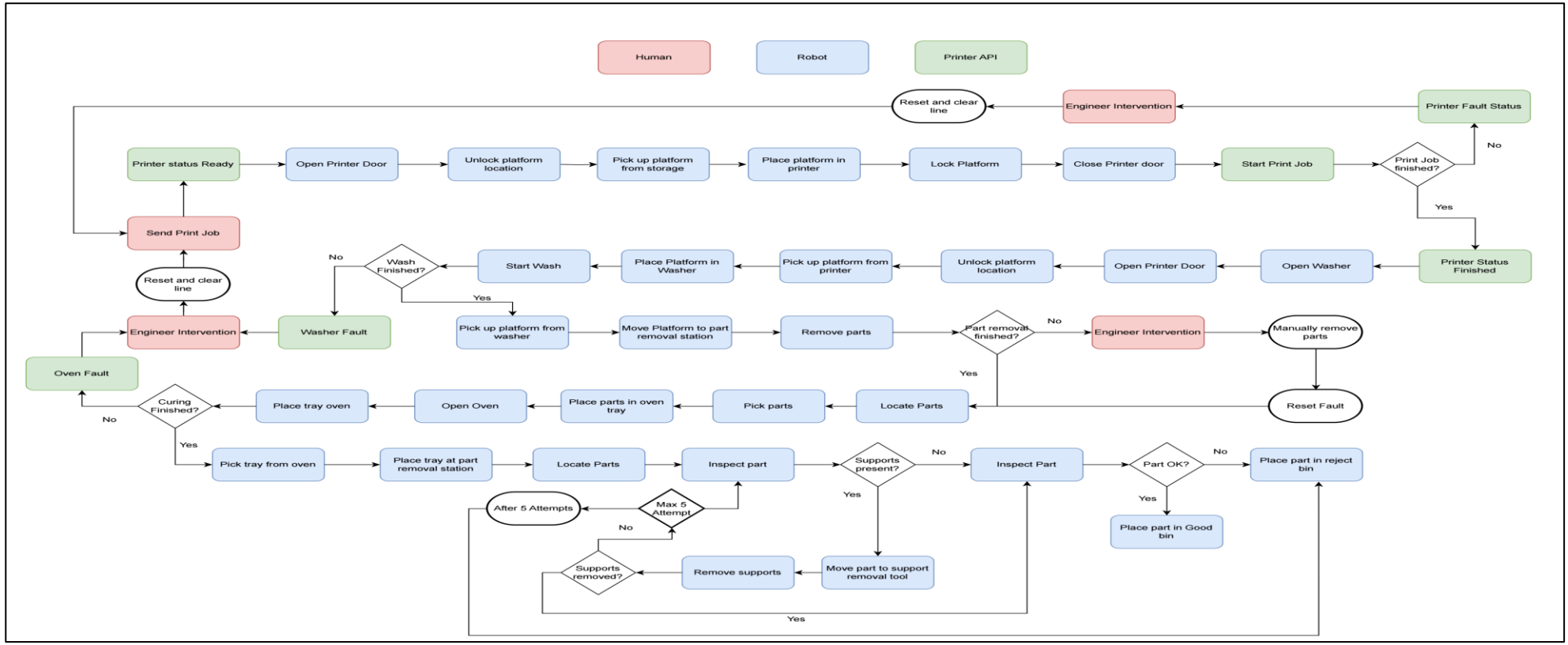

Figure 12 Overall ACROBA Process Flow

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The following figure illustrates some of the sequences described previously:

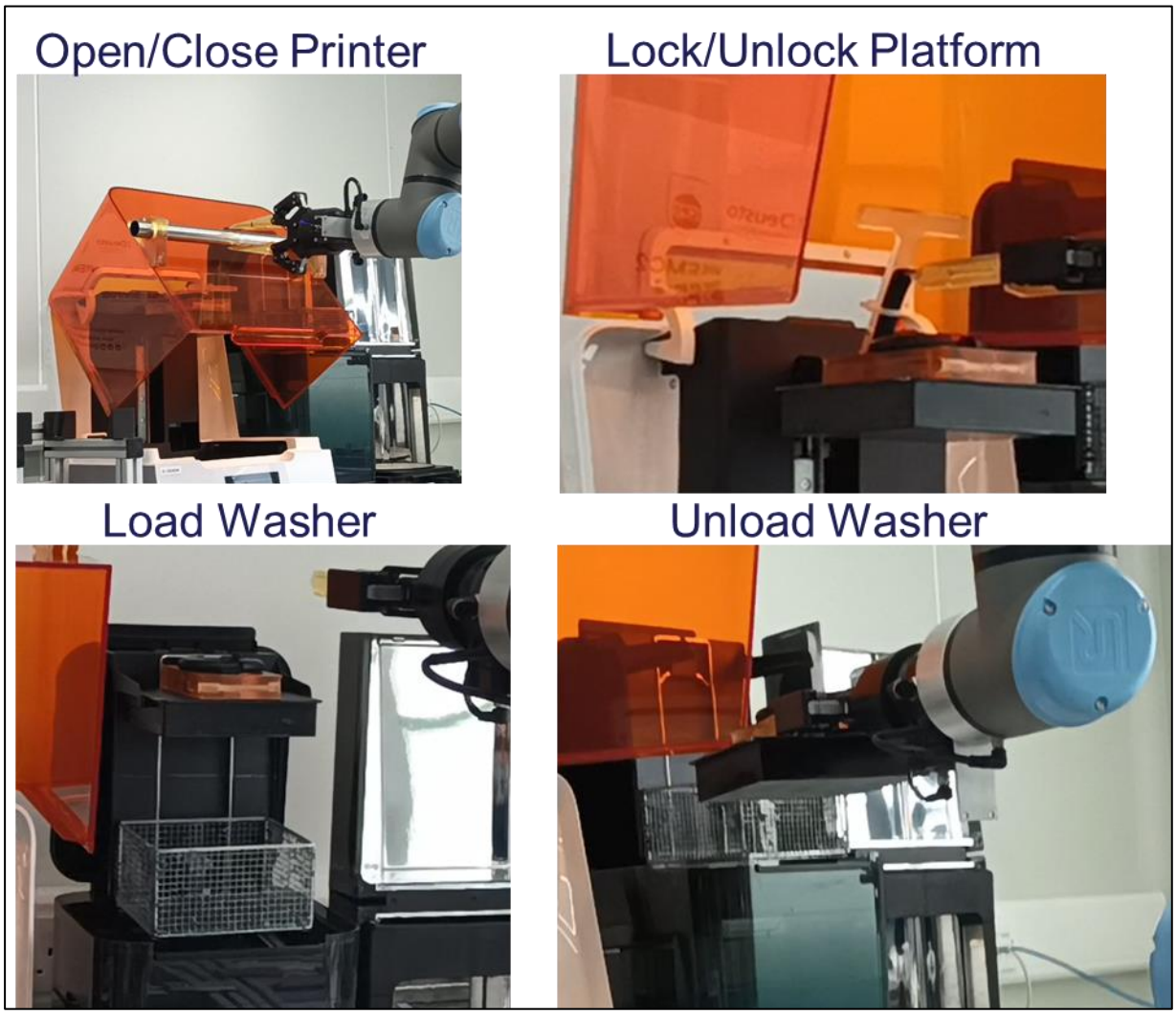

Figure 13 Examples of Sequences

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The consolidated list of all the skills/primitives in use on the cell is compiled in the table below:

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 pr_crop_image pr_Cad_matching	sk_locate_fixed_camera sk_move_to sk_point_cloud_processing sk_get_crop_limits sk_pick	G

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Process Step / Sequence	Primitive(s) name	Skill(s) Name	General / Specific
	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_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 pr_release pr_generate_waypoints pr_detect_default	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
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 2 Skills and Primitives for the Steripack Use Case

3 The Description of the Video Demonstrating for Testing

This section is a synopsis of the video created to demonstrate the functionality of the Steripack cell and the 3D printing process running with the ACROBA platform.

3.1 Print file sent to 3D printer (0:00-0:04)

This is the step during which the engineer supervising the line sets up and sends the 3D model file to printer.

3.2 Printer API initiates start (0:04 – 01:53)

Open printer (00:04-00:42)

Robot moves to grasp the 3D printer access door and open it. The robot then unlocks the build platform location.

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Robot Picks up build plate from storage (00:43 – 01:22)

The robot picks up the build plate from storage using the gripper, loads it into the 3D printer and locks in position.

Robot closes 3D printer door (01:22 - 01:53)

The robot grasps the 3D printer door and closes it.

3.3 Printer API initiates print (Simulated Print time – Normal print time would be 5hrs approximately) (01:53 – 03:33)

Printer executes printing process. On completion, API confirms print is finished and parts are ready for pick up.

Open printer (01:53 – 02:37)

Robot moves to grasp the 3D printer access door and open it. The robot then unlocks the build platform location.

Robot Unlock and Picks up build plate from 3D printer (02:37 – 03:33)

The robot unlocks and picks up the build plate from the 3D printer using the gripper and prepares to move the platform to the washing station.

3.4 Washing Process (03:33 – 04:36)

The robot transfers the build platform to the washer.

Robot locates washer and load build plate (03:33 – 03:42)

Build plate loaded in washer.

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Robot initiates wash sequence (03:42 – 03:50)

The robot starts the washing sequence by pressing the activation button located on the washer. Washing process starts (For the purpose of the video the wash cycle has been reduced to 1 minute. The normal process would take 10 to 20 minutes depending on the type of printed components.).

Wash process ends and robot unloads washer (03:50 – 04:36)

The robot grasps the build platform once the wash cycle is completed and readies to transfer parts to the removal station.

3.5 Part Removal (04:36 – 06:00)

The robot transfers the build platform to the part removal station.

Robot locates part removal station (04:36 – 04:55)

Part removal station located and build plate positioned in designated holder.

Robot executes part removal sequence (04:55 – 05:06)

The robot guides the build plate through the part removal fixture. Parts are collected in tray located below the station.

Robot exits part removal fixture (05:06 – 05:23)

The robot moves to starts location and prepares to transfer empty build plate back to storage, ready for the next print job.

Build plate moved to storage (05:23 – 06:00)

The robot transfers empty build plate back to storage, ready for the next print job. Bin picking is initiated.

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3.6 Bin Picking (06:00 – 07:05)

This sequence identifies single components for the robot to grasp and transfer to a new fixture for the next process step.

Tray with parts transfer to Zivid 2 camera (06:00 – 06:11)

The tray containing the parts moves under the Zivid 2 camera and the robot awaits the next set of instructions.

Camera locates single parts and instruct the robot to pick up (06:11 – 07:05)

The robot grasps single components and transfer each of them to the tray for curing.

3.7 Curing (07:05 – 07:33)

Once the robot has picked and transferred all the parts from the printed batch, the loaded tray is moved to the curing oven.

Robot grasps the fixture and executes transfer to curing oven (07:05 – 07:33)

Parts in fixture transferred to oven. Curing process initiated. On curing process completion, parts are moved out of the oven for the inspection prior to supports removal.

3.8 Inspection to identify supports (07:33 – 09:00)

Parts are inspected as a single unit. They are transferred from the curing oven tray to a secondary location for easier access to execute the inspection sequence using the Intel® RealSense™ Depth Camera D435i mounted at the end of the robot arm.

Robot executes inspection (07:33 – 09:00)

Sequence execution involves the robot moving around the part for the camera to acquire pictures for comparison with original CAD model of component.

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This sequence is also used to do the final inspection of the parts.

4 Conclusion

This document and supporting video are a summary of the setting up, implementation and testing of the ACROBA platform on the 3D printing cell at Steripack.

The main objective for the use of ACROBA in such setting is to reduce human intervention to a minimum to improve health and safety aspects as well as an improved performance of the line in terms of output and quality.

The testing primarily focussed on the good execution of each sequence to ensure the process steps were carried out accurately. The system can generally perform the required tasks. Some development to enhance the robustness, operability and accuracy performance will be needed to further enhance the running of the cell with ACROBA. The full performance will be fully assessed and documented in the final WP6 deliverable.

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