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Circular and Dynamic Manufacturing Supply Chain Orchestration and OptimiSation

D3.3 3D Digital Twin of supply chain/production/products M12			
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Table of Contents

List of Figures

List of Tables

No Tables in this document

Abbreviations

Acronym	Description
BPMN	Business Process Modeling Notation
CO2	Carbon Dioxide
DT	Digital Twin
EC	Electrical Consumption
JSON	JavaScript Object Notation
ROS	Robot Operating System
SCDT	Supply Chain Digital Twin
SCOPT	Supply Chain OPTimization
URDF	Unified Robot Description Format

Executive Summary

The document describes the demonstration deliverable **D3.3** "**3D Digital Twin of supply chain/production/products**". It is a direct output of Task T3.2. It is essentially a 3D visualization application that can represent and simulate the operation of a collection of factories. The application developed connects to a Camunda server and an Orion LD server and controls the parameters through Python and JSON scripts, as well as through user input. A ROS server is also running in the background that manages information exchange between user, representation, and visualization. The deliverable describes the first stage in the development of the application, with the second one at M24, deliverable **D3.4** "**3D Digital Twin of supply chain/production/products is the first of two stages**".

In the first stage of the digital twin development, the necessary visualization plugins/tools were developed, and the application was integrated with Camunda and Orion LD servers and tested for a collection of indicative factories.

1 Introduction

The Supply Chain Digital Twin (SCDT) is a tool that simulates a collection of factories, and the interactions between them. The complexity of the simulated operation of each factory is scalable and can be tailored to suit the needs of any particular factory. A generic abstraction is adopted that models factory operations as a generalized 3-step process, where the first step are the factory inputs the second step is the internal factory processes and the third step is the factory outputs. This generic abstraction is sufficiently expressive, allowing arbitrarily complex factory setups to be modeled. The capabilities of SCDT were then expanded with respect to factory representation and visualization. The visualization module can update SCDT's state, from either autonomous evolution of the collective, or from message inputs from users or from other applications. The aim of the first phase of the SCDT (D3.3) was to develop the necessary representation and visualization tools for the Pilot Applications to support decision making at the point of composing/synthezing new supply chains. The objectives related to this deliverable have been achieved in full and as scheduled.

The developed SCDT tool uses the Gazebo 3D environment, and a set of plugins and ROS nodes were developed for its operation. The developed ROS nodes interact with Gazebo and, through and Orion-LD server with a Camunda server to bi-directionally update the factory status.

In the context of CIRCULOOS, the SCDT tool will serve as the GUI for setting up and monitoring the factories and the circular supply chains. The SCDT tool serves the project's objective (O1) of Agile Circular Manufacturing Supply Chains Architecture and platform by providing a visualization and digital platform interaction solution.

2 Digital Twin Development

2.1 Architecture

The Supply Chain Digital Twin (SCDT) is a tool that simulates a collection of factories, and the interaction between them. The complexity of the simulated operation of each factory is scalable and can be tailored to suit the needs of any particular factory. In its simplest form, each factory is a set of inputs with a process, converting inputs into outputs.

For each factory, many inputs and outputs can be simulated. Each of them can have a type (e.g. liquid, gaseous, solid) triggering a different representation shape/texture in the simulation. Each of them has a quantity associated with it, that can be in any unit of measurement (kg, tons, liter). Several processes can be simulated for each factory. The processes in their simplest form can subtract from input quantities, convert them, and add to output quantities. The processes can be triggered and/or timed and can be in series or parallel in a model.

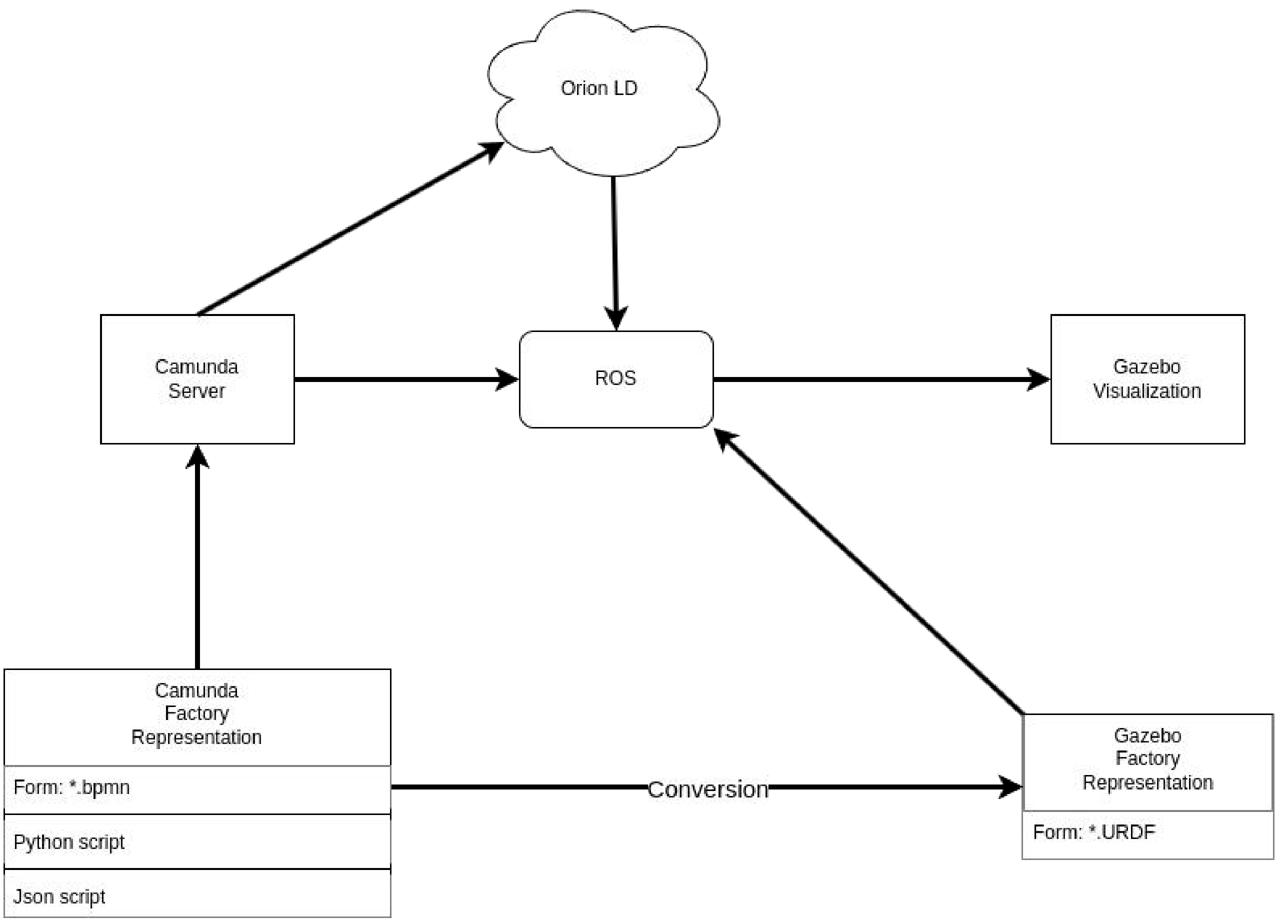

Figure 1: Information Flow of SCDT

For the development of Digital Twin tool, a series of tools was used, including Gazebo, Camunda, ROS, Python scripts, Orion LD and Jason Scripts.

Figure 1 shows the generic information/command flow of the digital twin. Factory representation is achieved through "*.bpmn" Camunda files. These run on the Camunda server, while Orion LD is used to monitor and record the representation data. The "*.bpmn" files are converted to visualization "*.urdf" files, necessary for the Gazebo visualization application software. A ROS server reads the factory states from Orion LD server, as well as from dedicated messages (user/other applications) and updates the Gazebo visualization of the SCDT.

2.2 Factory Representation

Initially, factory representations are developed using the Camunda modeler. Python scripts are written for the calculations of the quantity of materials (raw, product and scrap materials). This enables the correct subtraction of quantities from inputs, process timings (autonomous evolution), and addition of product and scrap material quantities. Files of type "*.json" (Figure 3) are uploaded on Orion LD server and set the state of initial quantity of materials in the warehouses of the factory (inputs and outputs) as well as other control parameters for each factory. Those files can further be utilized by the SCOPT tool to produce optimal arrangements of the factory layout or of the supply chain topology, which are then communicated through the Orion LD server to the SCDT. This is part of the second stage of the development of SCDT.

Figure 2 shows the development of a Factory representation being developed on the Camunda Modeler. The modeler creates a "*.bpmn" file that can be launched on the Camunda server. The Camunda server communicates with the Orion LD server. On launching the ROS server (and gazebo server), a ROS node finds all new "*.bpmn" files (one for each factory) from the designated BPMN folder and converts them into "*.urdf" files in a designated URDF folder. All factories are subsequently spawned in Gazebo. ROS messages are used to interact and update the digital twin visualization.

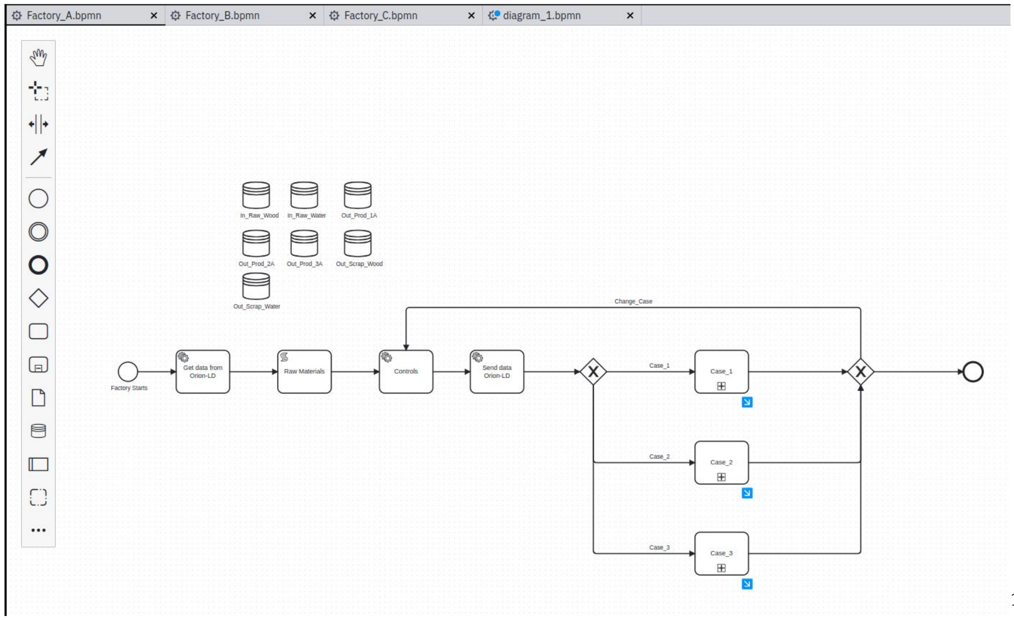

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Figure 2: Camunda Modeler

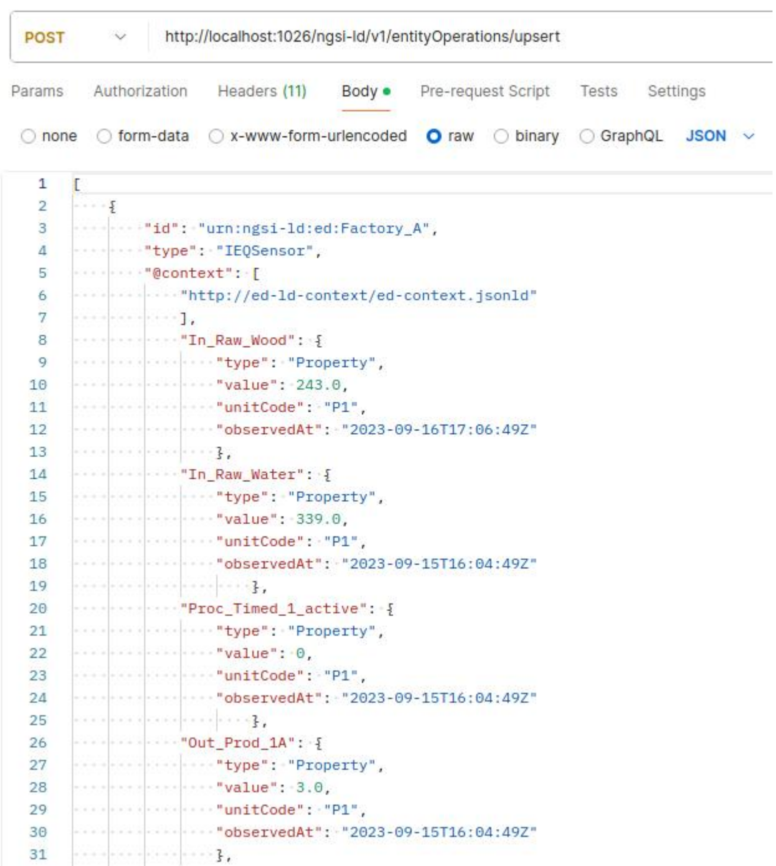

*Figure 3: Initial State quantities using *.json script*

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2.3 Factories Visualization

SCDT can provide information about every simulated entity (factories, inputs, outputs, processes). Visualization plugins were developed to display this information on screen (e.g. CO2, electric consumption) and show the status of the components of a factory. A process has four different status visualization states. Those are active or inactive, enabled or disabled, faulty state or idle state. The processes can be grouped into different cases (scenarios). The running scenario can be selected through Orion LD, and through commands that can be modified by the user in real time. Every case/scenario can test a different combination of processes.

Figure 4 shows the representation of an indicative factory, as visualized on the SCDT. The sample factory consists of four input buffers (silos bottom right), four processes (gears) and seven outputs including four product buffers (blue barns) and three scrap buffers (silos in upper figure). The various factory entities displayed on the SCDT are represented by a 3D mesh (*.stl file) and a texture image (*.png, *.jpg). These can be customized to represent different types of inputs, processes or outputs.

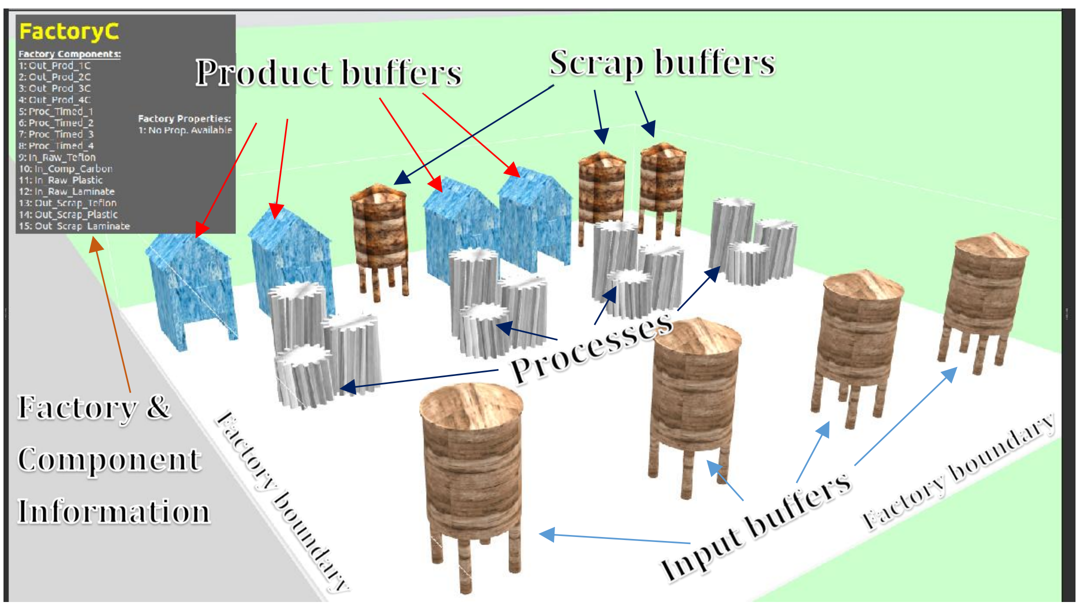

Figure 4: Factory entity representation. Shapes and textures are user customizable

For each entity, the available information can be displayed and updated in real time. Figure 5 shows a collection of factories, with a particular process of "FactoryC" selected. The CO2 and EC indicators of the selected component ("Proc_Timed_1") are displayed indicatively.

At the top left corner of Figure 5, the information displayed is divided into two columns. The left column displays all the factory components. In the right column the properties of the selected component are displayed.

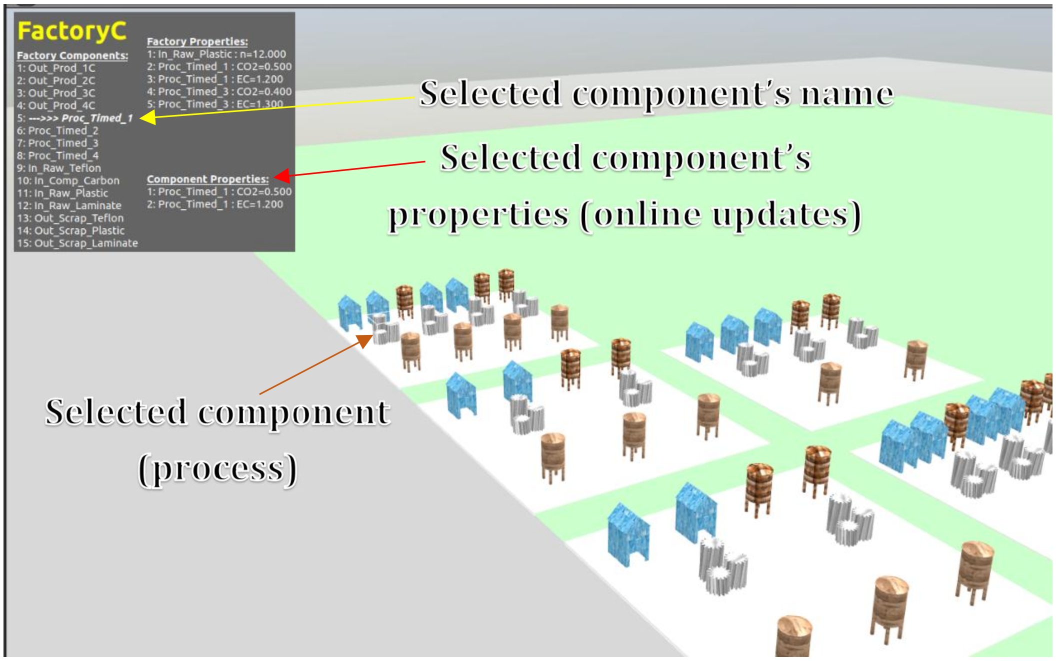

Figure 5: Component information

3 Conclusion

The Supply Chain Digital Twin application was developed to be able to represent and visualize a wide variety of factories. Visualization tools were developed to simulate various states and conditions of factories and their processes. Input and output quantities can initially be set and thereafter be updated online through timed or external process triggering. This allows for an autonomous evolution of the system (collection of factories). Other factory component data can be updated through ROS messages, either from user input or from other connected applications. Factory case scenarios were implemented, whereby for the same factory different combinations of processes are enabled. The various case scenarios can be selected in real time through messages to the Orion LD. This can accommodate future optimizations into the Supply Chain Digital Twin. The Supply Chain Optimization tool (SCOPT) can use the factory data uploaded to the Orion LD server, and its output can be fed back to the SCDT to update its representation and visualization states.

The Digital Twin was developed to be highly flexible in connectivity, representation and visualization, making it able to simulate a wide range of Pilot Applications. All information can be accessed and modified in real time through external messages. The messages could originate from user input or from other applications/tools.

Appendix A – Plastic Factory Representation

The Appendix describes how an indicative plastic factory case scenario could be represented in Camunda and visualized in the SCDT. As an example, a part of a plastic factory is used.

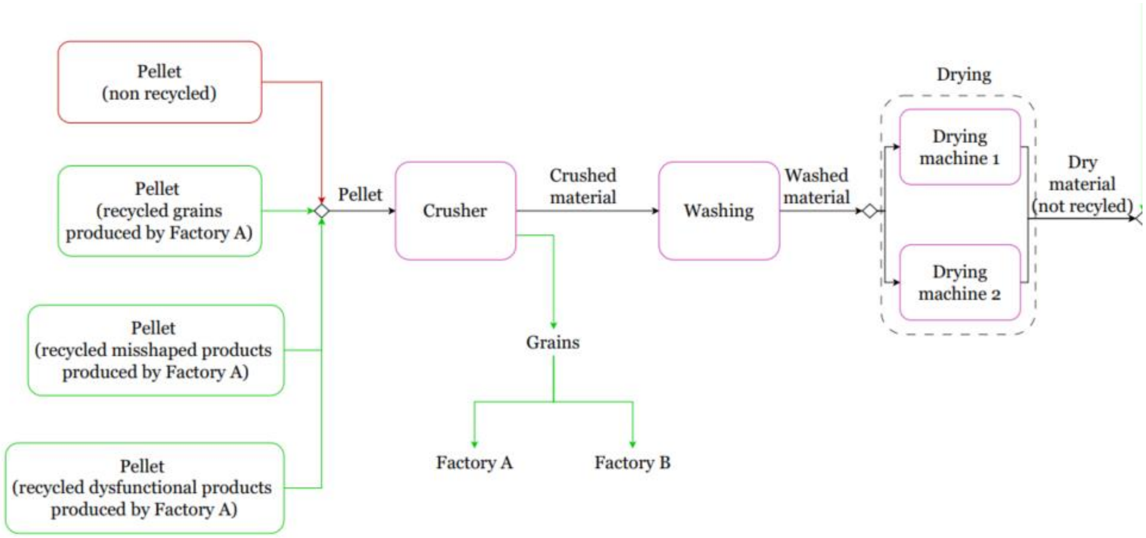

Figure 6: Plastic Factory Example

The Factory shown in Figure 6, shows 4 possible inputs (pellet types on the left) and 2 possible outputs. A "Dry Material" product and a scrap material "Grains". The manufacturing process could also use a "Drying Machine 1" or a "Drying Machine 2". Viewing the Factory from an input-output point of view, there are 8 possible case scenarios for running the Factory. Four for each Drying Machine. The Factory representation must be developed in Camunda Modeler so that the case scenarios can be controlled and monitored from Orion LD. Any developed tools/modules (e.g. SCOPT) can use the representation data from Orion LD and output various optimized solutions for any individual Factory or the supply chain. The optimized solutions from Orion LD can then be applied to the Digital Twin that modifies the visualization.

Figure 7 shows the development of the example Factory on the Camunda Modeler. It needs to reflect the 8 distinct case scenarios, the four inputs and the two outputs. The modeler produces a *.bpmn file. When Camunda server is run, representation information is transferred to the Orion LD server. A sample of the information transferred to the Orion LD is shown in Figure 7. This information is altered during the SCDT evolution and the information can be read from any other module/tool that in turn could have an output solution (e.g. SCOPT) that can select a different scenario to enable for the Factory and/or the supply chain.

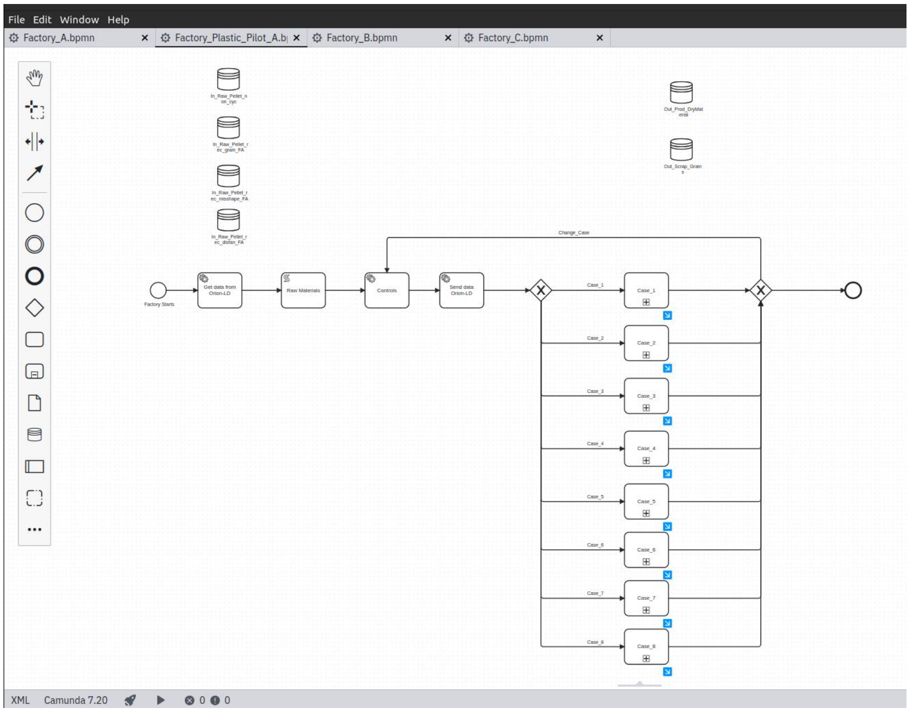

Figure 7: Camunda Modeler

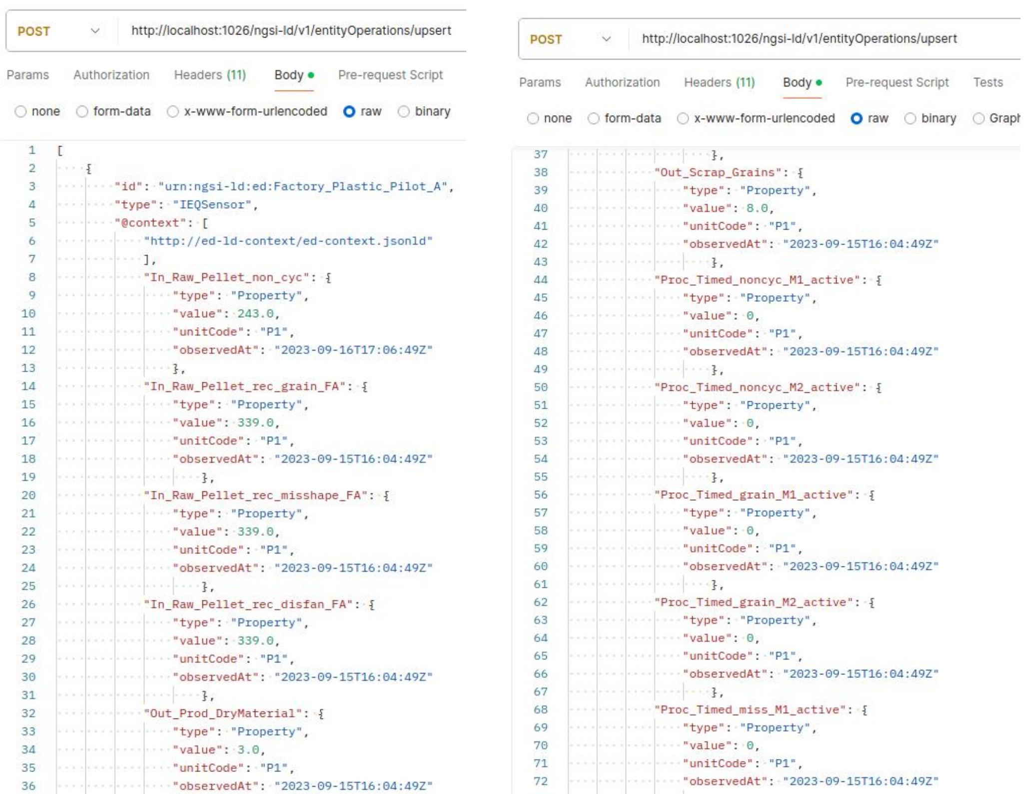

Figure 8: Orion LD sample Information

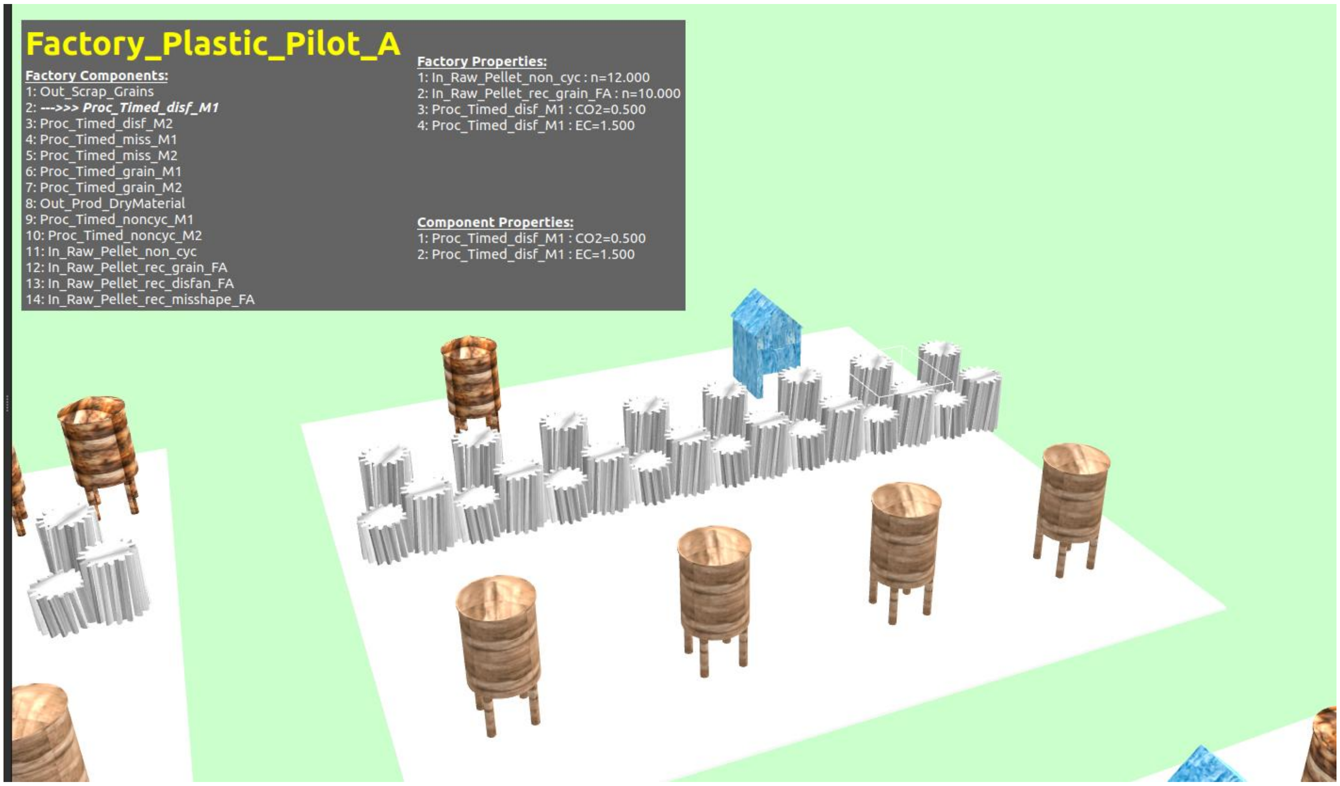

Figure 9: URDF file Visualization.

Digital Twin autonomously converts the representation file to *.urdf file for visualization. Figure 9 shows the visualization result of the conversion from *.bpmn file to *.urdf file. It shows 4 inputs, 8 processes and 2 outputs, one of which is scrap material. The shape, color and size of each entity shown on the visualization screen can be customized accordingly.

Appendix B – Video File Description

A video file was captured during a test with an overview of the operation of the SCDT. The video file is part of this deliverable and is described in this Appendix

Attached File: D3.3_DigitalTwin_VideoFile.mp4

3.1 Test Description

Before Test – Various factory representation files ("*.bpmn" files) were developed using the Camunda modeler. The BPMN files are copied to a dedicated folder.

Time 0:00 – The DT application scans the folder and autonomously converts the BPMN files to URDF format and displays them in Gazebo 3D environment. Initial conditions and parameters (e.g. enabled case scenarios and initial quantities) are loaded to the Orion LD.

The factories with automated scripts start active processes that are displayed accordingly (blinging green for activated). The quantities in inputs and outputs are updated based on the scripts and each process timing (e.g. Factory_C and Factory_A). The user can navigate in the Digital Twin space and select any Factory and its components to display available information.

Time 1:25 – Another BPMN file is moved to the folder. Digital Twing identifies the file, converts it and loads it to the Digital Twin Visualization (Factory_Plastic_Pilot_A). The example factory has no automated scripts and is used to demonstrate control from external messages (bullets below). The messages can originate from any other application/tool/module.

- Time 2:25 – Message is sent to activate process **Proc_Timed_disf_M2** in factory
- Time 3:00 – Message is sent to flag process **Proc_Timed_grain_M1** in factory as faulty
- Time 3:20 – Message is sent to disable process Proc_Timed_miss_M2 in factory
- Time 3:57 – Message is sent to update information related to factory components In_Raw_Pellet_non_cyc (quantity n=12), In_Raw_Pellet_rec_grain_FA (quantity n=10), Proc_Timed_disf_**M1** (CO2=150, EC=200), **Proc_Timed_disf_M2** (CO2=100).

Time 5:50 – Message is sent to select case scenario 2 in Factory_C. In initial conditions case 1 was selected (processes Proc_Timed_1 and Proc_Timed_2 enabled). On selecting case 2 processes Proc_Timed_2 and Proc_Timed_3 are enabled, while processes Proc_Timed_1 and Proc_Timed_4 are disabled (displayed in black). Every timed process has a duration associated for converting inputs to outputs. After a case scenario is chosen, the previous case processes need to be finalized before the new case processes are activated - flashing green (Time 6:08).

CIRCULOOS

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