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# Circular and Dynamic Manufacturing Supply Chain Orchestration and OptimiSation

| D3.4 3D Digital Twin of supply chain/production/products M24 | | | |
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# 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 **D3.4** "**3D Digital Twin of supply chain/production/products**". The Supply Chain Digital Twin (SCDT) is a direct output of Task T3.2 and comprises a 3D visualization application that provides a visual representation of the factory operation as well as a simulation of the operation of a collection of factories in the supply chain. SCDT, upon user request, receives input from the Data Platform and generates a visual representation of the supply chain(s), including the factories with their components, as well as logistic processes that transfer materials and products between factories. A simulation is developed for each request, and the application returns a link via which the user can see and interact with the SCDT through their web browser. The deliverable describes the second phase in the development of the application, with the first one having been delivered at M12, deliverable **D3.3** "**3D Digital Twin of supply chain/production/products M12**".

In the second phase of the SCDT development, the necessary visualization plugins/tools were further developed, and the application was upgraded to work directly from data provided by an Orion LD Server. SCDT now reads data from the server and develops the required 3D representation and visualization. The simulation is based on user requirements, and updates the visualized data either through real time inputs from the factories that are available on the Data Platform, or through simulated data based on factory definition (according to user inputs). The additions to SCDT for the second development phase are summarized as follows:

- ✓ Near real-time correspondence capability between the SCDT and the data platform
- ✓ Remote web viewing capability of SCDT
- ✓ Material flow visualisation
- ✓ Upgraded simulation, visualisation and interaction with production and supply chain operations, including near real-time monitoring visualisation.
- ✓ Automatic simulation creation and execution based on appropriate factory and supply chain descriptions, triggered by data platform requests.
- ✓ Development of a tailored data collection template to create the supply chain and factory digital twins.
- ✓ Development of training material to enable the mentors to gather the required data from the open call experiments.
- ✓ Supply chain modelling framework utilizing the concept of "Logistics Factory"

# 1 Introduction

The Supply Chain Digital Twin (SCDT) can simulate a single factory, a supply chain or a number of supply chains. During the second phase, SCDT was further developed in order to cover the needs of the three CIRCULOOS pilots and the new experiments of the open calls. A data collection template was developed and revised through feedback from the three pilots. The template was utilized in collecting the necessary data for the realization of the corresponding SCDT implementations. The collected data includes the input materials, processes, quantities for the processes, duration of the processes, outputs from processes, products and scraps. The data collection is described in detail in Section 2.

The revised architecture of the SCDT removes the dependency on Camunda server and BPMN files (as described in D3.3) as this requirement was deprecated. This enables faster deployment of multiple simulations, to satisfy the needs of multiple users. The SCDT deployment procedure was further streamlined, since the limits of BPMN definitions were removed. The revised SCDT architecture is described in Section 3.

The SCDT tool now accepts requests from the data platform that describe the required simulation. A sample request is described in JSON form in Appendix A. The SCDT tool develops a dedicated simulation and outputs a link and password pair. The users can use them to view and interact with the simulation on their browser.

# 2 Factory Data Collection

In order to develop and test the SCDT tool based on the complexity of the three pilots, factory data was required to be obtained. For this reason, a data collection template was developed, along with examples on how to fill the template. The template was developed to describe a wide range of processes and factory setups. A series of meetings was subsequently organized with pilot partners in order to explain the template, receive feedback from the pilots to refine the template, and eventually collect the necessary information.

The SCDT implementation has a variable level of simulation granularity, reflecting the level of detail of information provided by the pilots. This allows each factory to provide information at the level of abstraction and/or granularity that is considered necessary, to appropriately reflect their role in the circular supply chain within the SCDT implementation. The information collected captures the complexity and variation of the pilot setups. Using the information, the SCDT tool was then fine-tuned and further developed to expand its capabilities and cover the needs of more complex setups.

A video detailing the use of the template for data collection was developed and distributed among partners. The video will be used to train the mentors of the open call experiments, in order to collect the necessary data from the participating factories. Information of the corresponding video attachment is provided in Appendix B.

# 3 Digital Twin Development

## 3.1 Architecture

The SCDT is provided as a service by CUT utilizing a local server. The SCDT module has a monitoring node. This node is responsible for monitoring and capturing user requests from the Data Platform. The request includes data that describes the simulation requested. The simulation can be of a single factory in a supply chain, multiple factories in the same supply chain or multiple factories in multiple supply chains. The simulation can utilize real-time data supplied from the CIRCULOOS Data Platform, or generate model driven data based on internal simulations of models created from the information obtained from factories. The monitoring node sends an update to the data platform, setting the request status as “Received”, and proceeds to developing a dedicated simulation.

Every dedicated simulation is developed in its own docker container. The factory and supply chain information of the request is loaded to an Orion LD server in the container. A ROS2 node inside the container then scans the information on the local Orion LD server and develops the gazebo URDF files required for the visualization and starts a gazebo server. A second ROS2 node converts information from the Orion LD server to gazebo visualization. In the case of real time monitoring, the information on the local container is updated by a node that links information on the Data Platform to values inside the container. In the case of simulated visualization, a ROS2 node inside the container reads the properties of the processes and material buffer quantities and updates the local Orion LD with simulated data based on the information given.

When the simulation is ready, the monitoring node updates the request on the data platform. It provides a link and password for the user and sets status to ready. The user can view and interact with the simulation using their browser.

When the user logs out of the simulation in their browser, the dedicated simulation container is destroyed. The request is set to status closed and is disabled (isEnabled=0). The request can now be deleted.

**Error! Reference source not found.** shows an Overview of the architecture adopted for the SCDT.

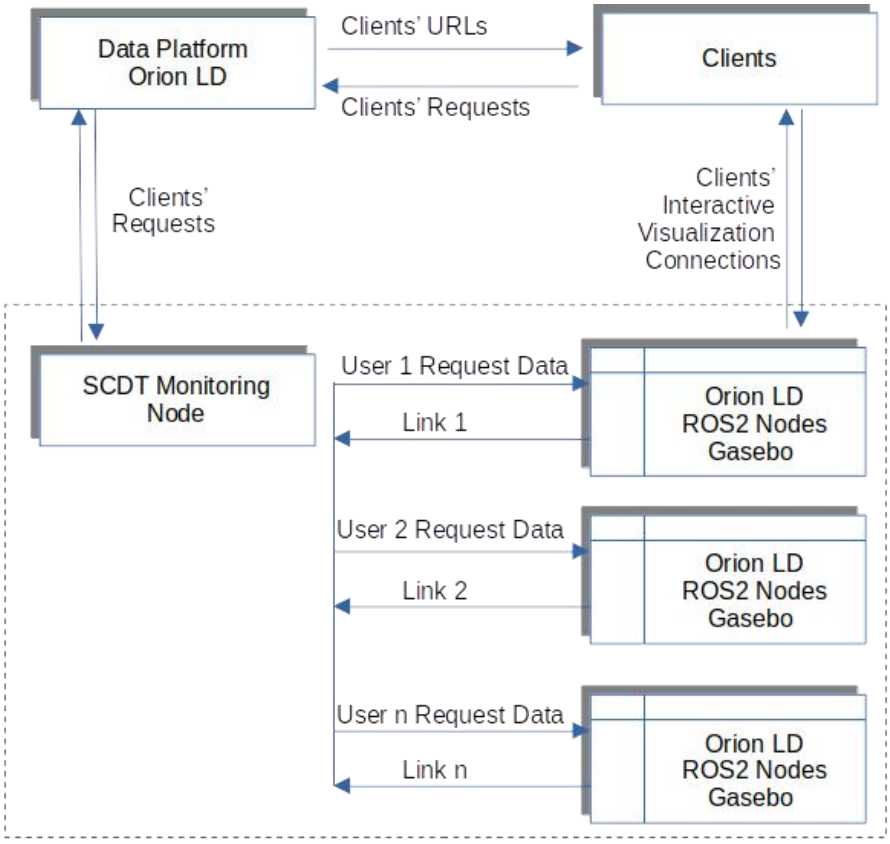


*Figure 1: Architecture Overview of SCDT*

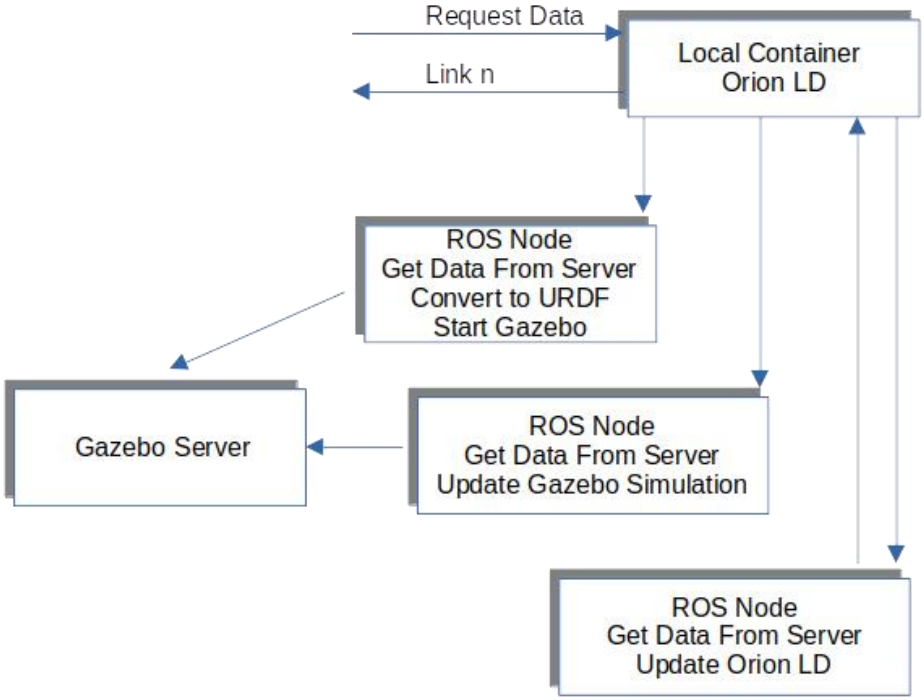


*Figure 2: SCDT Local Container Architecture*

Figure 2 shows the information/command flow of the local containers of the SCDT. Each container represents a dedicated simulation.

Cybersecurity aspects are taken into account at two levels. On the first level the Data Platform provides access to resources to authorized users according to the Data Platform's security policy. On the second level, an authorized user is provided with a one-time password to access SCDTs of supply chain arrangements that are available to the specific user. Each SCDT instance is available only for the time that the user is logged in the SCDT remote visualization system, and is destroyed when the user logs out (or closes the tab/browser).

## 3.2 Factory Representation

The data obtained from the SCDT data collection template is transferred to a *.json (JSON) file. The JSON file is a representation of a factory and can be loaded directly to the Orion LD server. The JSON file contains various entities that in their totality describe the factory and its components. A "Factory" entity describes general factory parameters including, type of factory, supply chain name to which the factory belongs to, and list of factory components that the factory includes. The factory components are divided into two main categories. Processes and material buffers. Each "FactoryComponent" is described in the JSON file as a separate entity. Each component has status settings that can be updated to Idle, Faulty, Active and Disabled.


```
277         "Inputs": {
278             "type": "Property",
279             "value": [
280                 "N4th_prod",
281                 "Glue",
282                 "Energy",
283                 "Lubricant"
284             ],
285             "observedAt": "2000-01-01T10:05:08Z"
286         },
287         "InputsQ": {
288             "type": "Property",
289             "value": [
290                 1.0,
291                 0.5,
292                 1.85,
293                 1.5
294             ],
295             "observedAt": "2000-01-01T10:05:08Z"
296         },
297         "InputsU": {
298             "type": "Property",
299             "value": [
300                 "u",
301                 "kg",
302                 "kWh/m2",
303                 "kg/year"
304             ],
305             "observedAt": "2000-01-01T10:05:08Z"
306         },
307         "Outputs": {
308             "type": "Property",
309             "value": [
310                 "Final_prod",
311                 "Waste_Glue",
312                 "Waste_Saw_Dust"
313             ],
314             "observedAt": "2000-01-01T10:05:08Z"
315         },
316         "OutputsQ": {
317             "type": "Property",
318             "value": [
319                 1.0,
320                 0.4,
321                 0.4
322             ],
323             "observedAt": "2000-01-01T10:05:08Z"
324         },
325         "OutputsU": {
```


*Figure 3: Partial Process definition in *.json script*

Each process has a timing setting that is associated with the time required for the process to convert inputs to outputs. The inputs and outputs are listed in the process representation, along with their units and quantities required to produce the quantity output. Emissions of the process are also listed and defined based on information provided. Figure 3 shows the definition of the inputs and outputs of a factory process.

Each material buffer is either an input to a process, an output of a process or both. Depending on this, they are classified as inputs to a factory, products of a factory or intermediate components. Through the data collection template described in section 2, the users can declare if intermediate components are available to market or not.


```
2350        "quantity": {
2351            "type": "Property",
2352            "value": 135.0,
2353            "unitCode": "kg",
2354            "observedAt": "2000-01-01T10:05:08Z"
2355        },
2356        "isActive": {
2357            "type": "Property",
2358            "value": 1,
2359            "observedAt": "2000-01-01T10:05:08Z"
2360        },
2361        "isEnabled": {
2362            "type": "Property",
2363            "value": 1,
2364            "observedAt": "2000-01-01T10:05:08Z"
2365        },
2366        "isFaulty": {
2367            "type": "Property",
2368            "value": 0,
2369            "observedAt": "2000-01-01T10:05:08Z"
2370        },
2371        "Status": {
2372            "type": "Property",
2373            "value": 0,
2374            "observedAt": "2000-01-01T10:05:08Z"
2375        },
2376        "Inputs": {
2377            "type": "Property",
2378            "value": [],
2379            "observedAt": "2000-01-01T10:05:08Z"
2380        },
2381        "Outputs": {
2382            "type": "Property",
2383            "value": [
2384                "N1st_proc"
2385            ],
2386            "observedAt": "2000-01-01T10:05:08Z"
2387        },
2388        "Suppliers": {
2389            "type": "Property",
2390            "value": [
2391                "Plennid",
2392                "Supplier_V"
2393            ],
```


Figure 4: Partial Material Buffer Definition in *.json script

Figure 4 shows the partial definition of a material buffer. The inputs and outputs of a material buffer are the processes that produce the material and use the material respectively. The shown material buffer is an input to the factory. It is not produced by a factory process (empty “Inputs” list). It is supplied to the factory as can be seen from the “Suppliers” list.

In order to transfer quantities between material buffers of different factories, a “Logistics Factory” type was defined to model supply-chain level logistics processes. A “Logistics Factory” does not have its own materials buffers. It only has processes. These processes have inputs and outputs from material buffers of a different factory that could be in the same or different supply chain.


```
372         "Inputs": {
373             "type": "Property",
374             "value": [
375                 "SC_Wood->Plennid->Rough_sawn_planks"
376             ],
377             "observedAt": "2000-01-01T10:05:08Z"
378         },
379         "InputsQ": {
380             "type": "Property",
381             "value": [
382                 1.0
383             ],
384             "observedAt": "2000-01-01T10:05:08Z"
385         },
386         "InputsU": {
387             "type": "Property",
388             "value": [
389                 "m2"
390             ],
391             "observedAt": "2000-01-01T10:05:08Z"
392         },
393         "Outputs": {
394             "type": "Property",
395             "value": [
396                 "SC_Wood->Herso->Raw_Material"
397             ],
398             "observedAt": "2000-01-01T10:05:08Z"
399         },
400         "OutputsQ": {
401             "type": "Property",
402             "value": [
403                 1.0
404             ],
405             "observedAt": "2000-01-01T10:05:08Z"
406         },
407         "OutputsU": {
408             "type": "Property",
409             "value": [
410                 "kg"
411             ],
412             "observedAt": "2000-01-01T10:05:08Z"
413         },
```


Figure 5: Partial Process Definition of a “Logistics Factory”

Figure 5 shows the partial definition of a process of a “Logistics Factory”. The process removes material from a material buffer in supply chain SC_Wood factory “Factory_A” and adds the material to a material buffer in supply chain SC_Wood factory “Factory_B”.

## 3.3 Factories Visualization

The factory representations are scanned and implemented by ROS2 Nodes as explained in Section 3.1. The visualization of the factories was modified to accommodate upgraded factory representation according to user data that was collected using the SCDT data collection template (Section 2). More

particularly, the material buffers are not all inputs and outputs of a factory. Some are waste by-products that are not available to the market, since some are intermediate components produced by a factory process to be used by other processes for product manufacturing. Nevertheless, these intermediate components could be available to market or not. In order to reflect this, each factory now has four rows of components as shown in Figure 6.

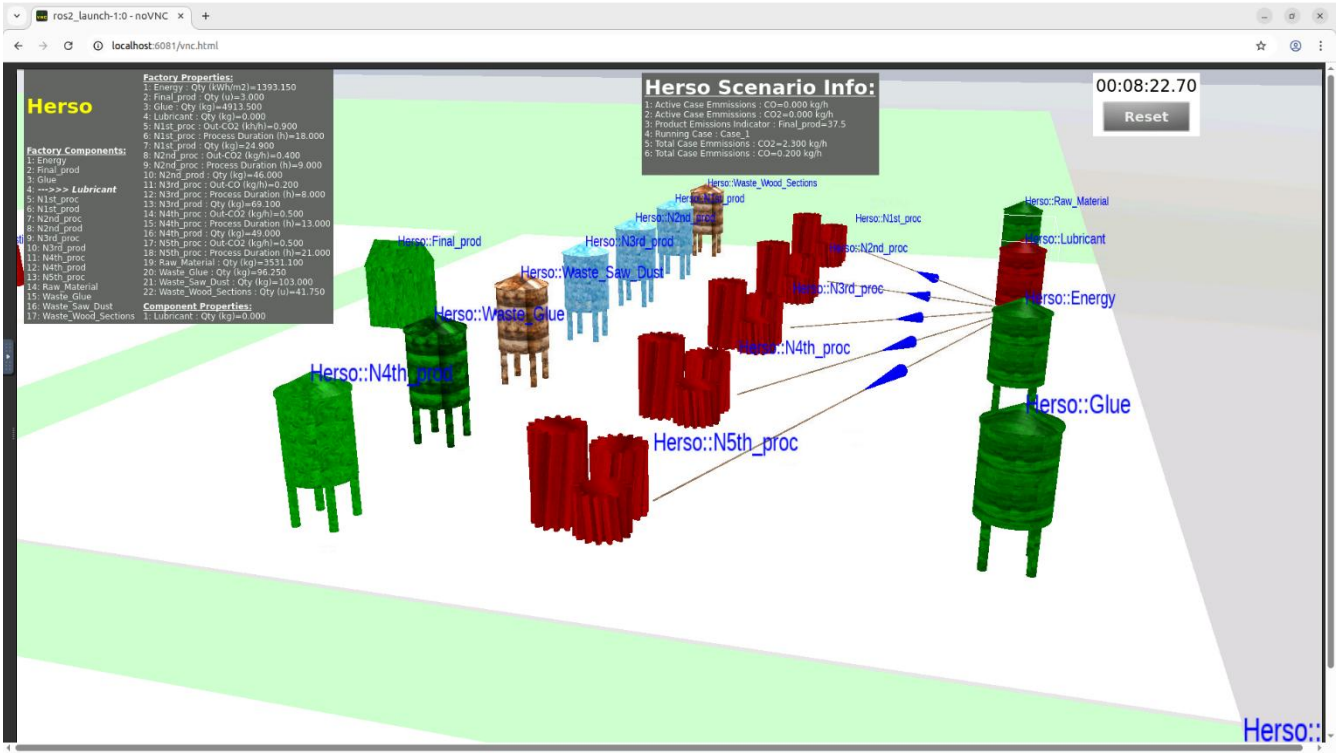


*Figure 6: Indicative Factory Visualization.*

Figure 6 shows the visualization of a factory. Four rows of components are shown. From right to left, those are

- Row 1: the input materials buffers coming from suppliers to the factory
- Row 2: the processes of the factory,
- Row 3: the material buffers that are produced by processes,
- Row 4: the final products of the factory

The material buffers in Row 3 are divided into two categories. The ones that are available to market shown in blue texture to indicate market availability and blinking[1] green to indicate activity, and the ones that are not available to market shown in brown texture to indicate no availability to market and blinking[2] green to also indicate activity. The ones that are available to market could be scrap/byproducts that could be used by another factory as material, or material that is used by an internal process but can be used by another factory as is.

[1] Please refer to video attachments to see the blinking behavior
[2] Please refer to video attachments to see the blinking behavior

In simulation mode, the processes convert quantities from material buffers to output material buffers according to the process definition of quantities and timing. In SCTD, simulation time to actual execution time mapping is as follows: 1 second in simulation time maps to 1 hour (3600 seconds) in actual execution time. So, if a process converts a quantity of input materials in 5 hours, in the simulation it will convert them in 5 secs. Figure 6 shows a particular instance during a simulation of a scenario named "Case_1". The scenario information is shown in the top-middle information panel. The panel also shows the total emissions (all processes involved in the scenario) and active emissions (from active processes). For the example, two types of emissions were defined (through data collection template) and displayed on the panel. Those are CO2 and CO emissions. The panel also displays a "Product Emissions Indicator" for every product of the factory. During this example simulation, after approximately 502 hours of operation, the factory runs out of a particular input material (second buffer from top in Row 1). The buffer is updated to color red in the simulation, indicating a problem with the buffer. This particular buffer is required by all processes and they are shown also in red. The "Active Case Emissions" show zero values, since no process is running. The user can reset the simulation time and quantities to the initial values using the "Reset" button on the top right.

Figure 7 shows a "Logistics Factory" (top left) with 3 processes. Each process represents one material transfer of a specific quantity from one factory to another. The source factory could also be any supplier not shown in the visualization. The example shows that the product's quantity availability is not enough to proceed with the defined transfer. The transfer details are shown on the top left information panel. The logistics process transfers 10 units from one factory to another factory every 8 hours. The process turned red to indicate inability to process, since there are not sufficient units available to complete the scheduled transfer. However, the factory is still producing. When the quantity of the product of the factory reaches the required amount, as defined by the logistics process, it will return to active status, and the transfer will be performed.

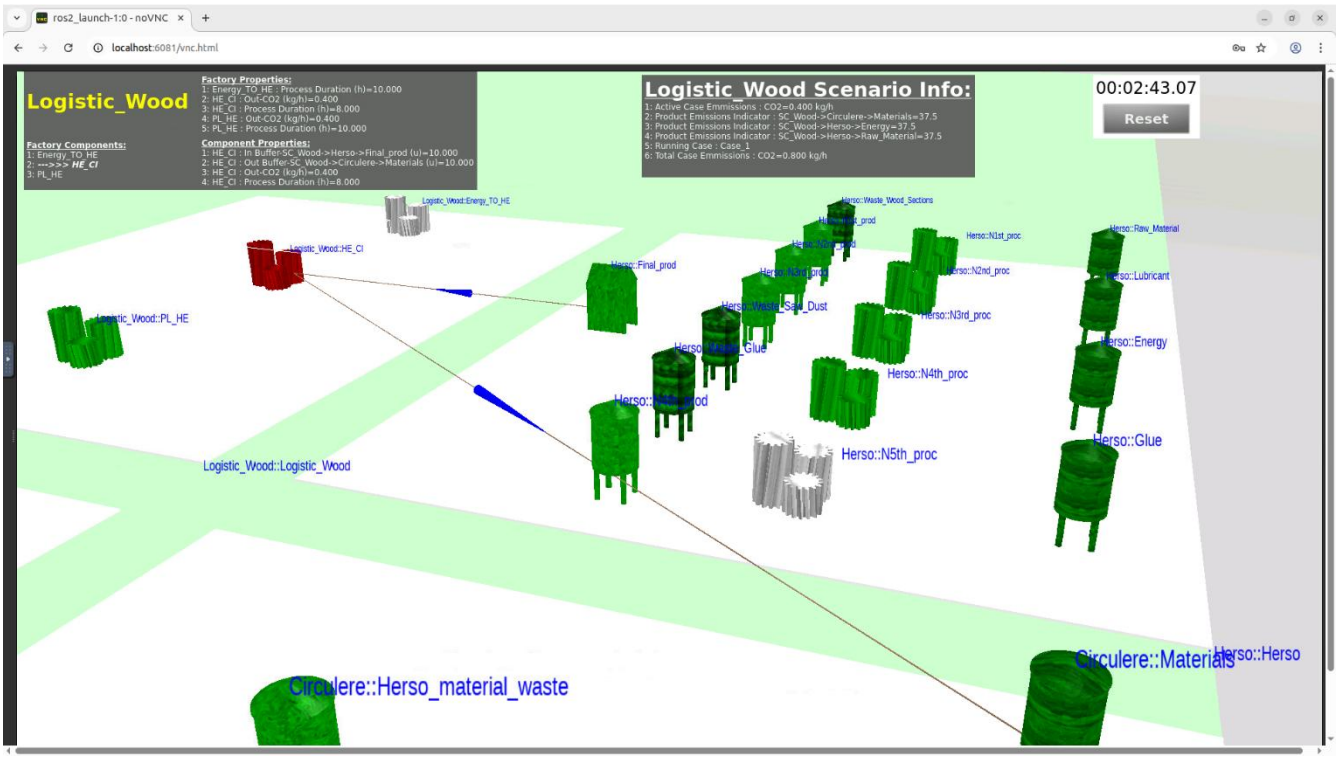


*Figure 7: Indicative "Logistics Factory" Visualization*

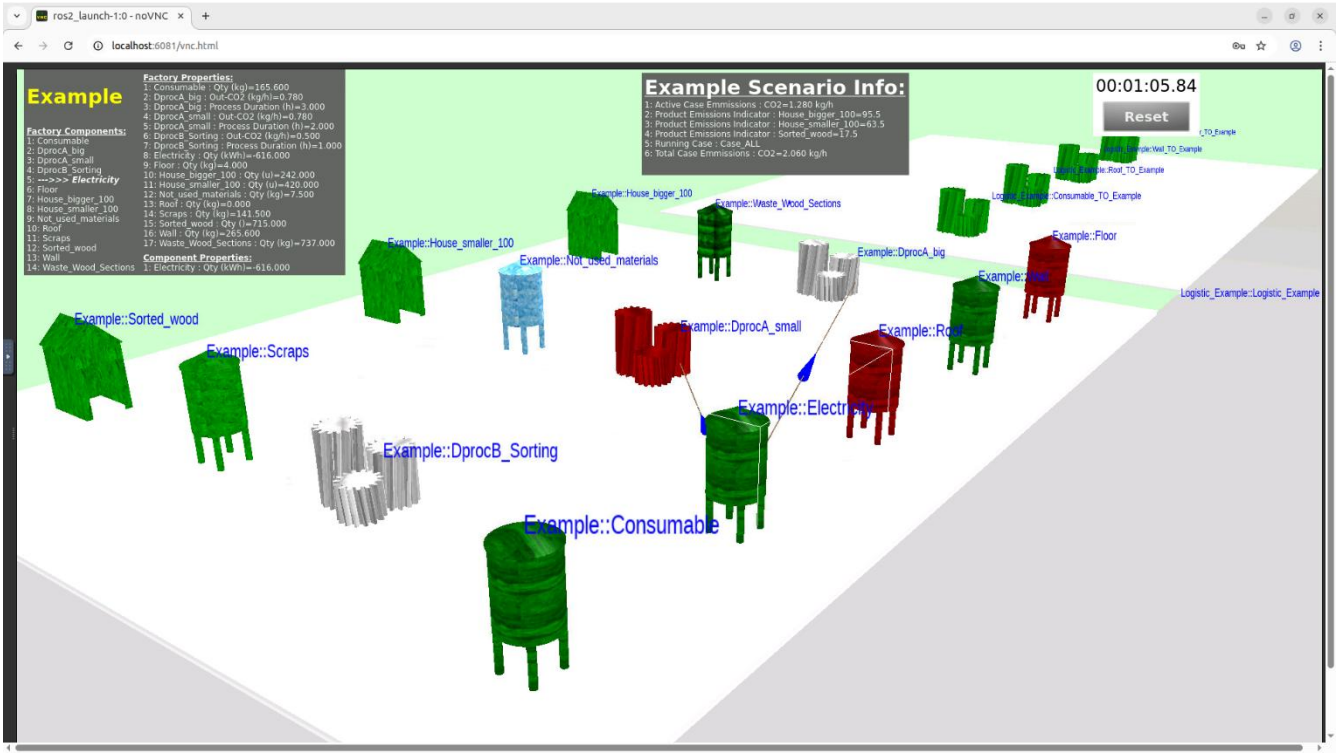


*Figure 8: Indicative Networked Supplier Visualization*

Any of the inputs of the factory can be defined as a networked supplier. In this case, the simulation allows for negative values. In Figure 8, Electricity Input Buffer (second from bottom) is defined as a networked supplier. The factory now does not run out of electricity in the simulation, and the quantity on the top left information panel is shown as negative. In this scenario, the negative energy quantity (KWh) captures the total consumption since the beginning of the simulation (or from the last "Reset" time).

To determine the validity of the results produced by SCDT, a large number of test cases variations were implemented to identify and fix operational issues and feedback from the partners was taken into account in improving the SCDT visualization e.g. by adding directional indicators to clarify the material flows and the components' names.

# 4 SCDT Simulation Type Requests

As outlined in section 3.1, the SCDT accepts requests from users who place the requests through the data platform. For this an entity of type "SCDT_Request" was developed (Appendix A, Attached File 1). When an entity is submitted to the Data Platform, the SCDT develops a simulation and gives back the password and URL link. Using those, the user can view and interact with the simulation using their browser. Some of the key settings, as well as the request operation sequence are described in Appendix A.

As described, a simulation of "SimType"= 0 triggers a real-time monitoring visualization. For this, real time data is required from the factory to be supplied to the data platform, given from sensors, or from plc systems connected to the internet. These need not be from every component of the factory. If a factory does not provide real time data, the "SimType"= 0 setting will not be available for them. A real time visualization file is described in Appendix C.

A simulation of "SimType"= 1 is available to all users who have provided data through the data collection template, as described in Section 2. The visualization simulates values according to the information supplied. If the user has provided alternative running scenarios for their factory, these can be viewed by choosing "SimType"= 2,3...n. The user can also access the visualization of optimized scenarios, as provided by the SCOPT tool. Appendix C describes factory simulations based on different scenarios.

For the operation described above, an entity of type "SCDT_Valid_Fields" was developed (Appendix A, Attached File 2). The entity describes the available simulation options of the various factories. The entity is uploaded to the data platform and is updated as soon as a new simulation type is available for a factory. A simulation of different scenarios and the corresponding video attachment is described in Appendix D.

Using the keyword "All" in the factory list of a request, then all factories that are part of the listed (in Request) supply chains are visualized. Appendix E describes the simulation of a complete supply chain while Appendix D describes the visualization of three supply chains in the same simulation.

# 5 Conclusion

The data collection template captured the complexity of the pilot factories and the supply chains associated with them. This enabled the development of the SCDT module to be highly flexible in connectivity, representation and visualization, making it able to simulate a wide range of Pilot Applications, so that it reflects that complexity. It can provide real time monitoring and scenario simulations of single factories, or a collection of factories in a supply chain or collection of factories from multiple supply chains. “Logistics Factories” can simulate the transfer of materials between factories of the same or different supply chains. Besides the three pilots and their factories, the SCDT module was also tested with hypothetical factories from multiple supply chains, anticipating the factories to be introduced with the open calls.

# Appendix A – Request for SCDT

**Attached File 1:** D3.4_APPNDX_A_SCDT_Request_Example.json
**Attached File 2:** D3.4_APPNDX_A_SCDT_Valid_Fields.json

Fields that need to be provided for a valid request to the SCDT.

- "id": Each request needs to have a unique id. It should start with "urn:ngsi-ld:circuloos:SCDT:SCDT_Request:"
- "type": "SCDT_Request"
- "Status": 0  This means that the DT has not started yet. We will update back the status accordingly so that the progress can be monitored
- "SupplyChains": [Supply Chains list ...]  e.g. [SC_Wood, SC_Plastic]. These are the supply chains to be displayed
- "Factories": [Factories List …]  e.g [Factory_A, Factory_B]. These are the factories to be displayed. The "All" keyword can be used to visualize all factories in the supply chains list
- "SimType": 0 for real time monitoring, 1 for simulation based of process values and the data the factories have provided. If a factory provides alternative scenarios, these can be accessed via "SimType": 2,3,...n
- "isEnabled": 1  (i.e request is active)
- "UserName": Optional
- The other fields can be left empty

The SCDT updates the following Fields

- "Link":  a URL link that the users can use to view the simulation from their browser
- "Password": The password the user can use to log on to the link site from browser
- "description": Status description
- "dateStarted": When the DT simulation started
- "Status":
    - Status_Requested = 0  :Initial Request Status
    - Status_Recieved = 1 : The Request was received by the SCDT
    - Status_Processing = 2 : The Request is being processed by the SCDT
    - Status_Ready = 3 : The SCDT simulation is ready. Link and Password are available (above)
    - Status_Closed = 4: The user has left the SCDT simulation.

When the user disconnects from the URL link the SCDT simulation is destroyed. The Status on the request is updated to 4 (Status_Closed) and the user can see a new DT with a new Request. The "isEnabled" field is set to 0.

# Appendix B – SCDT Data Collection Template Video File

**Attached File:** D3.4_APPNDX_B_SCDT_DataCollectionTemplate_VideoFile .mp4

The video file describes how the SCDT data collection template should be filled. It is meant to train mentors to help the factories to fill the mentioned template.

# Appendix C – SCDT Real Time Visualization

**Attached File:** D3.4_APPNDX_C_SCDT_ReaTimeVizualization_VideoFile.mp4

The video file was captured during a test with real time data on the Data platform updating the visualization. The video file is part of this deliverable and is described in this Appendix

Pre-Test Requirements:

1. The user has provided data (to the Data Platform) from 2 sensors on two factory components. Namely those are the process named “N4th_proc” and the material buffer named “Glue” giving status and quantity available respectively
2. The user has issued a request with the supply chain their factory is in (provided by Valid_Fields.json Appendix A), the name of their factory and a simulation type "SimType"=0

Key Points in the Video File:

1. The user logs in to the link using the password provided
2. The process is active, and quantities are removed from the material buffer
3. A fault in the process is indicated by the process changing from flashing green to red
4. No more material is subtracted from the material buffer
5. The process is disabled (offline) and changes from red to black

# Appendix D – SCDT Scenario Simulation

**Attached File:** D3.4_APPNDX_D_SCDT_ScenarioSimulation_VideoFile.mp4

The video file was captured during various tests of a factory with simulation of different scenarios. The scenarios could describe the factory with different processes being enabled, different products being produced with different emissions indices, and/or using different suppliers. The video file is part of this deliverable and is described in this Appendix

Pre-Test Requirements:

1. The user has provided data for 3 alternative scenarios (main + 3). These are named “Case_2”, “Case_3” and “Case_4”.
2. The user has issued requests with the supply chain their factory is in, the name of their factory and a simulation type "SimType"=1,2,3,4 (4 requests)

Key Points in the Video File:

1. The user logs in to the link using the password provided to Scenario 1.
2. All Processes are active, and 3 products are being produced.
3. The information panel in the middle shows the scenario name being run and an emission index for every one of the products (provided a priori).
4. The user logs in into different scenarios (after associated requests) and views the simulation of different scenarios.

# Appendix E – SCDT Supply Chain Simulation

**Attached File:** D3.4_APPNDX_E_SCDT__Sypply_Chain_Visualisation.mp4

The video file was captured during the testing of a supply chain including 3 factories and a “Logistics Factory” transferring goods between factories. The video file is part of this deliverable and is described in this Appendix

Pre-Test Requirements:

1. All supply chain factories have provided data for their factories
2. The user has issued a request with the supply chain they want to simulate. In the "Factories" field of the request, the keyword “All” was used. The simulation type "SimType"=1 was also used.

Key Points in the Video File:

1. The user logs in to the link using the password provided.
2. The user selects various processes and material buffers.
3. For every selected component, arrows show the flow of materials.
4. The same applies to logistics processes that transfer materials between factories.
5. The user can reset the timer and quantities of the simulation by clicking the Reset button on the top right

# Appendix F – SCDT Multiple Supply Chain Simulation

**Attached File:** D3.4_APPNDX_F_SCDT_Multiple_Supply_Chains.mp4

The video file was captured during the simulation testing of three supply chains including 7 factories and three logistics factories transferring goods between factories. The video file is part of this deliverable and is described in this Appendix

Pre-Test Requirements:

1. All supply chain factories have provided data for their factories
2. The user has issued a request with the supply chains they want to simulate. In the "Factories" field of the request, the keyword “All” was used. The simulation type "SimType"=1 was also used.

Key Points in the Video File:

1. The user logs in to the link using the password provided.
2. The user can see the factories of the three supply chains clustered in three areas.
3. The user investigates the flow of materials using the arrows displayed upon selecting a component.
4. The user resets the simulation several times and checks depletion of quantities and where they arise from

CIRCULOOS

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