Generating Simulation Models From CAD-Based Facility Layouts

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***Abstract*—The latest advances in industry have been boosted by the application of the Industrial Internet of Things (IIoT), which is being supported by the implementation of Cyber-Physical Production Systems (CPPS). In this context, simulation and optimization models have, for some time now, been used to reduce CPPS design complexity, implementation time, and operating costs throughout its life cycle. Considering the complexity and heterogeneity of CPPS components and their different application areas within the manufacturing context, simulation models may contain unreliable representation of the real system, since the behavior of the CPPS in a physical environment can be quite different from the same CPPS, specified in a simulation model, considering the same events. Thus, facing this inherent difficulty in reliably modeling a CPPS in a virtual environment, the authors propose a tool - *Layout CAD Interface*, which enables simulation modeling software with automatic generation capabilities of discrete-event simulation models. The tackled simulation software was *Simio*, and the generation of simulation models was based on Computer-Aided Design (CAD) files referring to shop-floor layouts.**

Keywords*–*Cyber-Physical Production System; Simulation; Simio; CAD.

I. INTRODUCTION

Cyber-Physical Production Systems (CPPS) are used whenever complex manufacturing systems need to communicate with the digital world, allowing their performance to be optimized and their efficiency improved. This type of system plays an increasingly important role in industrial processes and production control, leveraging the concept of intelligent factory in the context of the Industrial Internet of Things (IIoT). This are being used to build Internet-based architectures that facilitate remote control of currently isolated production systems, leading to the fusion between the physical and virtual worlds, which is the basis of IIoT applications

The complexity of production systems in the various production sectors is increasing and results from a greater need for flexibility and interoperability to produce low volumes and high variety of customized products, according to customer specifications. This is known as the *Mass Customization & Personalization* [1] production paradigm. To meet these requirements, virtual environments based on optimization and simulation models allow the real-time evaluation of the operational and safety characteristics of the real system. In this way, virtualisation acts as an interface between the real productive system and the decision makers, allowing the simulation and prediction of the future state of the system against different operating scenarios (e.g., different levels of demand) or stochastic events (e.g., a significant increase in demand).

The decision support systems, based on simulation and optimization, are particularly interesting because they allow simultaneously to predict and evaluate the functioning of the productive systems in a virtual environment. The main objective of the simulation and optimization methods is to model the individual aspects of the manufacturing equipment and the production lines with a high degree of detail, in order to minimize the costs involved. These methods have been used to anticipate the operational performance of work centers, production lines and, when considering more complex systems, the simulation and optimization models allow to create virtual environments of complete factories by detailing the dynamics of the flow of materials, the effective capacity and efficiency of the equipment, the time evolution of the Work-in-Progress (WIP) and the intermediate stocks, and the existing wastes associated with the tasks of rework, setup, or movement.

Manufacturing systems modeling and simulation is a research topic that has been addressed by the academic community and industry. Oztemel and Gursev [2] defend the importance for companies to primarily understand the features and content of the Industry 4.0 for potential transformation from machine dominant manufacturing to digital manufacturing. These digital environments are highly oriented to the data that different components/machines produce or collect. Jain [3], Jain *et al.* [4] and Sacco *et al.* [5] argue that there must be virtual models of the factory - Virtual Factory, in order to build real system behavior analysis applications. Also, these models also serve as generators of information, which can be used in evaluating the configuration and adaptation of the current real systems.

Regarding the use of simulation models, as representations of the real physical systems, developing these models imply studying the real system based on physical and/or mathematical models, in order to replicate their behavior. The execution of these models result in a deeper knowledge about the behavior of the system in different contexts, allowing to evaluate the impact of alternative strategies of operation. However, the development of reliable simulation models is not trivial and requires a high level of knowledge. If the model is not a valid representation of the system under study, the result of its execution will yield little useful information about the actual system. Building a detailed and reliable model of the production system is a task that can last from a few days to a few weeks or months depending on the complexity of the system that is being represented. Furthermore, several of the current simulation tools require knowing the simulation language being used. With this in mind, new approaches for CPPS simulation should address the challenges associated with the simulation model specification and development.

The R&D Portuguese National project PRODUTECH-SIF [6] focuses on the development of new methodologies to promote the integration of the design, engineering, commis-

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sioning, operation and maintenance phases regarding CPPS. As such, these methodologies will significantly reduce the operating costs and the implementation cycles of improvement actions, since they will allow the validation, in a virtual environment, of the key characteristics of the systems and reduce the risks of their implementation in the real scenario.

The main outcome consists in a tool, designated *CPPS Design Platform*, which contemplates a reference design model for the standardization of the design, implementation and virtual installation of CPPS. This tool, available as a service within an *IIoT Platform* for production information management and service delivery, is supported by several modules, such as: *Simulation Module*, for modeling stochastic behavior and events on the factory floor; *Optimization Module*, for the generation of optimized production plans; *Layout CAD Interface*, for semi-automatic creation of simulation models based on Computer-Aided Design (CAD) shop-floor layout files; and *Communication Interfaces*, which provide interconnection between shop-floor equipment and external information systems, such as Enterprise Resource Planning (ERP). *IIoT Platform* also supports system diagnosis and the calculation of performance indicators for further improvement, available in the *CPPS Performance & Diagnostic Platform*, and the generation and scheduling of production plans, available in the *CPPS Planning & Operations Platform*.

The work described in this paper focuses on the *Layout CAD Interface* development, which is part of the *CPPS Design Platform*, and tackles the automation of the simulation model generation, by enabling simulation software with automatic generation capabilities of simulation models, or part of them, depending on their complexity and customization. Thus, the simulation model creation and execution is based on shop-floor layout information, which is contained in CAD files [7], and process data, which is contained in ERP systems. In this work, the simulation software used was *Simio* [8] [9].

The structure of the paper is as follows: in Section II, literature review is provided. In Section III, the overall architecture of the system being developed is described and, in Section IV, the *Layout CAD Interface* tool functionalities are detailed. In Section V, a CPPS use case scenario is introduced, where the *Layout CAD Interface* is validated and, finally, in Section VI the conclusion and future work are presented.

II. RELATED WORK

Modern practice is to use CAD in the planning stage of facility layout design, which consists on organizing facilities, such as industrial equipment, in the shop-floor. The problem of organizing facilities in the most efficient way possible, currently motivates active research work, in a field known as Facility Layout Planning [10]. CAD refers to the use of computers, or more specifically, CAD software, to aid in the creation, modification, analysis, or optimization of a design. These designs often represent technical, engineering, electronic/automation, mechanical and manufacturing drawings. In the context of manufacturing, CAD specific tools are used to develop and optimize 2D and 3D factory layout solutions, by enabling the design layouts of machines, production lines or entire manufacturing facilities. The main goal is to enable factory managers to try different layout scenarios, arranging industrial equipment according to product demands or equipment functionality, in order to identify the most efficient layout scenario, regarding waste elimination in material flows, inventory handling and management.

The term CAD gained its notoriety with the work developed by Douglas T. Ross in the computer-aided design project [11] at MIT. The long-term goal of the project was to use a computer as an active partner to the designer, thus reducing the elapsed time and resources necessary in completing the design process. Regarding commercial software, *AutoCAD*, which is *Autodesk*'s flagship CAD software, has grown to become one of the most widely used CAD program for 2D non-specialized applications. Nowadays there are CAD systems for all of the major computer platforms. Some of the commercial tools most commonly used were developed by *Autodesk*, *Dassault Systems*, *Siemens PLM Software*, *PTC Creo* and *SketchUp*. Depending on the type of software tool used, the CAD drawings can be 2D or 3D.

The most popular CAD file format is the *DraWinG* (DWG), a native proprietary file format for *AutoCAD*, used for storing 2D and 3D design data and metadata. DWG is a binary file, so all types of information are stored efficiently, including 3D elements and photos. Since several CAD practitioners do not have access to licensed software, such as *AutoCAD*, *Autodesk* proposed the *Drawing Exchange Format* (DXF), which is a neutral file exchange, i.e., uses an intermediary neutral format to translate data between CAD systems, enabling data interoperability between *AutoCAD* and other CAD systems. DXF is a vector graphic file format that stores only 2D drawings. Regarding file size, DXF is a plain-text format and complicated drawings are usually slightly larger than DWG. Considering drawing content, DXF only supports 2D shapes, such as lines, polygons, circles and text. Other neutral file exchange are the *ISO 10303 – STandard for the Exchange of Product model data* (STEP) and *Initial Graphics Exchange Specification* (IGES).

Since CAD files typically define the static arrangement of facilities in a shop-floor, only structural analysis can be achieved with these tools, typically performed in the planning phase. For a proper analysis of the manufacturing system behavior and production dynamics, along with the planning, evaluation and monitoring of the relevant processes in the operational phase, simulation tools have been used for decades. Also, for further system analysis in the context of virtual commissioning as "emulation" for the real system, simulation models must use real-time process data collected from the shop-floor equipment. This can be accomplished by the integration of simulation with tools such as ERP.

Dias *et al.* [12] underline the frequently usage of CAD, process simulation and information systems software tools for production system design, and claims that they have been used with low levels of integration, resulting in duplicated work, incoherence and errors during the planning phase. Facing this, the authors propose an integrated approach for systematic system design, based on these three software classes (CAD, process simulation and information systems software tools).

Regarding the manufacturing virtual commissioning based in simulation, according to AbouRizk and Mather [13], a drawback of computer simulation is the investment required to build simulation models, such as time to learn the languages and human effort to put together the model. It is very important to model accurately the system in a simulation model, in a

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way that allows sufficiently exact predictions about the real system behavior. To tackle this challenge, the authors refer to approaches that automatically generate simulation models, specifically structural approaches, where model generation is based on data describing the structure of a system, typically in the form of factory layout data from relevant CAD-systems. These approaches are also known as "data-driven model generation", and can be distinguished into either supporting the planning phase or the operational phase of a factory.

According to Bergmann and Strassburger [14], challenges for automatic model generation may be: 1) Incomplete data or low level of detail within external systems; 2) Generation of dynamic/complex behaviour, i.e, dealing with missing information regarding the dynamic behaviour of the system; 3) Support of cyclic approaches involving multiple generation cycles, i.e., how to incrementally generate models, allowing manually added details to survive in such cyclic model generation scenarios; and 4) Support of multiple life cycle phases of the production system, i.e., how models of the planning phase can be adapted to work in the operational phase.

Considering the literature for automatic model generation, proposed solutions may be supported by CAD-based data, referring to the structure of a system, or non CAD-based. Regarding CAD-based automatic model generation, Zhai *et al.* [15] proposed an integrated simulated method, which combines CAD, virtual reality and discrete event simulation techniques, for virtual factory engineering. Regarding static simulation for factory layout assessment, the authors use input information of the factory plant that includes the shapes and sizes of the facilities, operation rooms, among other. This information may be collected from CAD files, however it is not clear how this is accomplished.

Also, Dias *et al.* [16] proposed an approach for integrating simulation and CAD. *AutoCAD* is used for the layout design and *WITNESS* is the simulation platform. *Microsoft Access* is used as the database for data exchange between *AutoCAD* and *WITNESS*, enabling the integration of both software tools.

Hoffmann *et al.* [17] described concepts for the systematic design of manufacturing system models, based on model libraries and standardized recipes for the design of component models from CAD data. The authors used *CIROS* for the plant simulation tool, which provides import filters for STEP/IGES file formats to collect geometric data from the plant. The authors claim that manual simplification of overly complex geometry data may become necessary. Also, if manual hierarchical structuring of the CAD data into objects, sections and components is not performed, the generated simulation model is not usable for the functional modelling, nor would be a simulation based on such model.

Lorenz and Schulze [18] focus only on the layout based model problem generation, considering every type of layout, such as barber shops, job shop, road traffic or copper smelter. Their approach can be used for any simulator with a language oriented model description interface, and uses the DXF file format as the layout basis for the model generation. The DXF file is inputted into a modeling filter, which eliminates unneeded layers of the file and transforms the DXF into a Proof Layout file, for a native animation layout. Later, domain specific information regarding simulation and animation specifics is appended to the native animation layout, resulting in an animation layout and, after analysis, a structure file. This structure file contains all classes, objects with names and positions, messages, bars, plots and paths in a text format, which is the input for the simulation model generators.

AbouRizk and Mather [13] propose an approach for simplifying the process of building and experimenting with computer simulation models of heavy earth-moving construction operations, where simulation models are automatically generated from high-level descriptions in CAD. In this approach, a commercial CAD tool (*MicroStation*) is extended for specify construction information, such as facility/components to be constructed, construction methods and resources, and sharing these information with the simulation tool (*Visual Slam*). The authors propose an add-on tool referred to as the "Intelligent Data Manager", to exchange data between the two systems. Other *MicroStation* add-ons, specifically developed for this type of application, are used to relate CAD objects to the construction objects and extract all construction objects from the CAD model and translate them into simulation information.

Moorthy [19] proposed an automated method for generating simulation models and 3D model animations directly from CAD drawings. First, facility layout drawings are developed using the *FactoryCAD* (run from within *AutoCAD* application). Then, from the *FactoryCAD*, a Simulation Data Exchange (SDX) is generated, which is an ASCII text file, containing a compilation of physical data, manufacturing and production data, and simulation data. Finally, the SDX file is used as an input to generate discrete event simulation models in several tools. The simulation model generates animation data that is subsequently available for dynamic viewing and analysis in the *FactoryTalk VIEW* environment.

In this work, the authors want to achieve CAD-based automatic simulation model generation in *Simio*, since this is one of the most popular simulation tools among CPPS scenarios. Also, the capability of representation of dynamic information and components in the simulation model is highly desirable, since layout planning is a task performed several times during the entire manufacturing system lifecycle, according to ever changing product demand (both variety and quantity). Considering the literature review, the authors believe that there are still gaps in current solutions, considering the product described.

III. Overall System Architecture

Part of the work developed within the PRODUTECH-SIF [6] project addresses, in an integrated way, the design, evaluation, operationalization and optimization of CPPSs. These bring several benefits, from a dynamic response in terms of production to the variable demand for new products, as well as real-time optimization of production and operation processes (particularly value chains). Thus, the scenario where the product diversity is high and its life cycle is tendentiously shorter, the tools and methodology being developed allow for the optimized design, evaluation and operation of CPPSs for each reality. More specifically, the work focus is on the development of an integrated tool, enabling factory simulation and monitoring, planning and scheduling of operations, and production diagnosis for performance improvement.

In the case of the PRODUTECH-SIF project, it was developed a solution, designated *CPPS Design Platform*, for flexible high performance CPPS design, used for the integration of

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the design, implementation and installation phases of CPPS, with the objective of reducing implementation time and risks, and operating costs throughout their life cycle. This solution contemplates the simulation of the manufacturing environment and processes of the factory floor, as well as the optimization of production plans, taking into consideration real time information of the factory shop-floor, such as operating status of the equipment, production orders, and WIP. Also, the *CPPS Design Platform* integrates a CAD-based automatic simulation model generation solution, designated *Layout CAD Interface*.

The *CPPS Design Platform* provides a service available within the *IIoT Platform*, used for micro-services management, which consist in modules involved in the design and management of the CPPS. The *IIoT Platform* also provides other services for the planning and scheduling of lot sizing, capacity assessment, collaborative process management, and real-time scheduling, which ensure efficient, integrated and adaptive management of the CPPS and the diagnosis of the productive system in an agile and automatic manner, classification of the improvement needs and consequent identification of the resolution method to be implemented. Services regarding planning and scheduling are provided by the *CPPS Planning & Operations Platform* and services regarding methodologies for diagnosis are provided by the *CPPS Performance & Diagnostic Platform*. Figure 1 represents the overall architecture of the system being developed within the PRODUTECH-SIF project, regarding to solutions dedicated to the life cycle management of CPPSs, from their design and development, to their operational management and improvement.

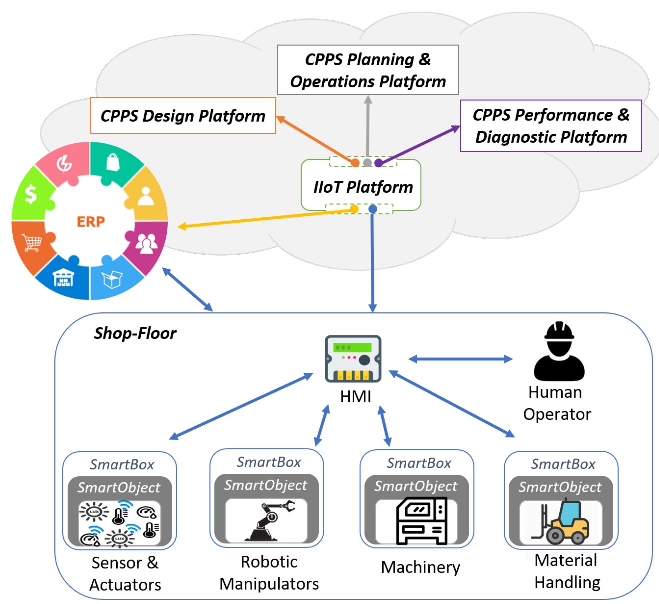

Figure 1. System Architecture Within the PRODUTECH-SIF [6] Project.

In this context, the *IIoT Platform* serves to interconnect productive equipment, information systems, sensors, devices, people and products that are part of a production system, allowing the collection and sharing of information among all stakeholders providing services. The integration and virtualization of shop-floor entities into the *IIoT Platform*, such as sensor & actuators, robotic manipulators, machines and material handling equipment, is achieved by the encapsulation of such entities, using the *SmartObject* and *SmartBox* concepts [20], also developed within the scope of this project.

The *CPPS Design Platform* is expected to run simulation and optimization models, which can use relevant information of the factory shop-floor in real time during their operation time. These models will include information from ERP systems, such as product process orders, available materials and routes between the different shop-floor entities, as well as real time information from the *SmartObjects*/*SmartBoxes*, such as equipment state, failure events and WIP. In addition, these simulation and optimization models may be integrated with information from the *CPPS Planning & Operations Platform*, aiming at solving the problem of integration of different decision levels, from design, planning and scheduling. Finally, the results of the simulation execution will be used as input to the *CPPS Performance & Diagnostic Platform*, in order to run diagnostic and performance improvement models based on the calculation of several Key Performance Indicators (KPIs).

A. *CPPS Design Platform*

The *CPPS Design Platform* is supported by a simulation modeling software, integrated with various modules, namely the *Simulation Module*, *Optimization Module*, *Layout CAD Interface*, and *Communication Interfaces*. The most relevant communication interface of the *CPPS Design Platform* provides interconnection with the *IIoT Platform*, which manages the overall interactions with ERPs, *SmartObjects* and *SmartBox* within the shop-floor, the *CPPS Planning & Operations Platform* and the *CPPS Performance & Diagnostic Platform*. Figure 2 represents the architecture of the *CPPS Design Platform*.

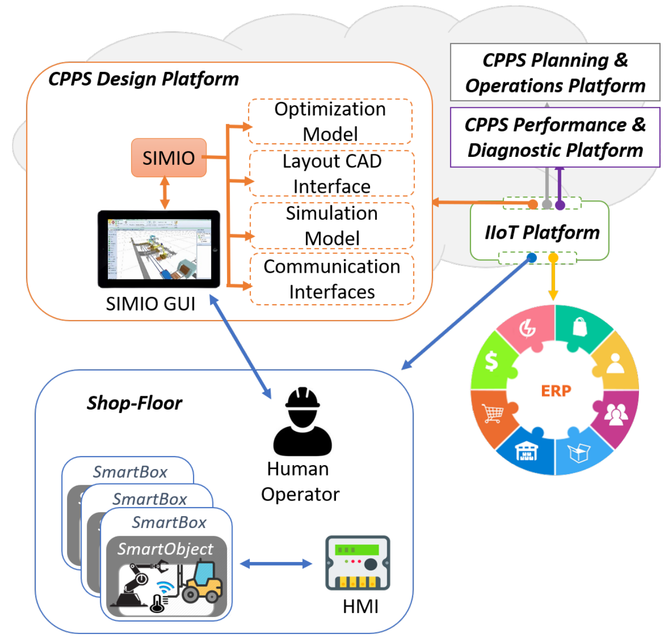

Figure 2. *CPPS Design Platform* Architecture.

The simulation modeling software is the main component of this platform, which, through the use of simulation models representing the dynamics between all shop floor equipment, operators, conveyors, as well as the various operations and processes between them, allows the study of the behavior of

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the system. For this, *Simio* is used. *Simio* is a simulation, production planning and scheduling software to support the object modeling paradigm. This approach is suitable to model a CPPS, where complex stochastic simulation models are constructed by combining different objects representing different components of the system under consideration. By using the *Simio* GUI, the human operator can build and run 3D animated models from a variety of systems.

In *Simio*, the concept of *Process* exists, which represents a custom logic that can be included in the model objects, so that they behave and react to events in a certain way. This custom logic can be used to capture / free resources, assign values to different variables, change the network connections used, evaluate alternatives, etc. Every *Simio* process consist of several interconnected *Steps*, which can already exist, predefined, in *Simio* or be added to the *Simio* by the user, in order to extend the base framework functionality. These *User Defined Steps* can be developed by the user using the *Simio* API.

The *Optimization Module* will implement a new methodology related to operational planning and scheduling, to support the simulation module. The *Optimization Module* will permit to introduce variation in the generation of production plans, contemplating the associated risks. Thus, a production plan can be evaluated not only for its viability at the time the plan was generated, but also for its robustness over time, considering the associated risk in the order of execution of the various operations (critical operations, which depend of factors such as demand, existence of stocks and maintenance of equipment).

Before executing the simulation, the *Optimization Module* obtains an estimate of the quantities of the manufacturing orders, i.e., the optimization model will determine the products, the quantity and the planning period in which the production should take place. Taking into account this new dimension, the *Optimization Module* aims to optimize production plans, which will later make available to *Simio*, as a starting point to execute a new simulation. In this case, the *Optimization Module* will be based in the *IBM-CPLEX* tool [21].

Finally, the *Layout CAD Interface*, detailed next, provides to *Simio* automatic generation capabilities of simulation models, or part of them, depending on their complexity and customization, based in facility layout CAD files.

IV. LAYOUT CAD INTERFACE

The *Layout CAD Interface* is a software application developed within the context of the PRODUTECH-SIF project, and it is one of the modules of the *CPPS Design Platform*, which enables simulation modeling software to automatically generate simulation models based on shop-floor layout CAD files. The main goal of the *Layout CAD Interface* is to provide to a human operator means for simplifying CPPS simulation modeling. When using the *Layout CAD Interface*, the human operator is capable of extracting facility layout and other information from a CAD file. Also, this tool is an Java software application, independent from CAD and simulation modeling specific software. Currently being developed, this tool is, so far, capable of interpret DXF format CAD files. For this, it uses the *Kabeja* open Java library [22]. *Kabeja* is a library for parsing, processing, and converting *Autodesk*'s DXF file format to other output formats, such as SVG, JPEG, PNG, TIFF, PDF and XML.

Due to the nature of the DXF file type, extracting information of industrial equipment and facility layout is not trivial. As seen before, the DXF file is a vector graphic file format that only supports simple 2D shapes, such as lines, polygons, circles, and text [23] and [24], other more complex designs are supported in, e.g., the DWG file format. In this first version, the *Layout CAD Interface* only supports the DXF file type, since it is the most popular open-source format among every licensed or unlicensed CAD-based software.

As for the integration with simulation modeling tools, the *Layout CAD Interface* only outputs simulation data in a specific format interpretable by *Simio*, since it is the simulation modeling tool used among the partners involved in the project. Figure 3 represents an UML Use Case Diagram of the *Layout CAD Interface* tool.

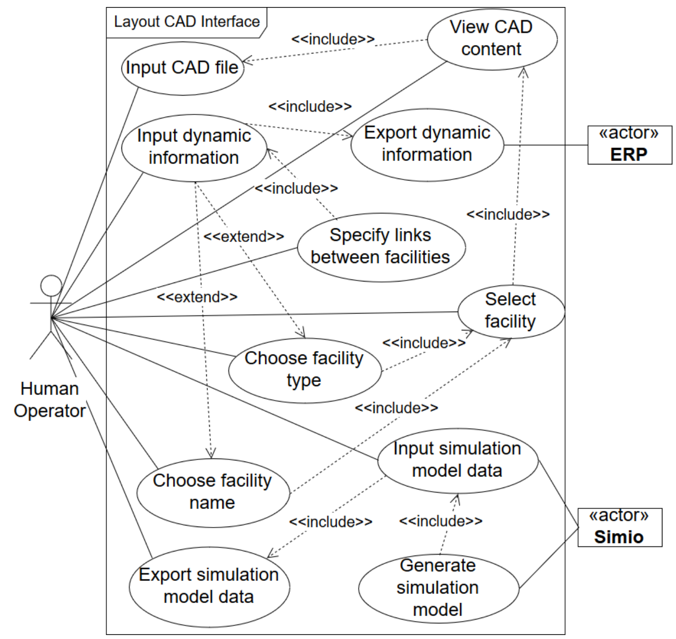

Figure 3. UML Use Case Diagram of the *Layout CAD Interface*.

Considering the UML Use Case diagram of the *Layout CAD Interface*, the system actors represented are every entity that plays a role in the system. In this case, the represented actors are the *Human Operator*, the *ERP* and the *Simio*. The *Human Operator* represents the person responsible for the CPPS design and simulation modeling, and which will in fact use the *Layout CAD Interface* for simplifying the model generation. The *ERP* and the *Simio* actors represent external systems that will interact with the *Layout CAD Interface*. Regarding the use cases, which represent the features interactions or the actions that an actor can do in the system, and the relations among use cases and actors:

- *Input CAD file* - The *Human Operator* can import to the *Layout CAD Interface* a CAD file, which contains a static information of the shop-floor layout. Currently, the *Layout CAD Interface* is limited to DXF file formats.
- *View CAD content* - Since, currently, the *Layout CAD Interface* is limited to DXF formats, the shop-floor layout representations considered are in 2D. This use

case represents the *Human Operator* capability of viewing, within a canvas, a 2D graphical representation the information contained in the CAD file.

- *Input dynamic information* - While static information of the shop-floor layout can be collected from the CAD file, dynamic information, such as equipment characteristics and links between facilities in a given process, are collected from ERP systems. If the *Layout CAD Interface* is integrated with an ERP, the *Human Operator* can import dynamic information to include in the simulation model. Currently, the *Layout CAD Interface* is prepared to import a CSV file, containing exported dynamic information from a ERP.
- *Export dynamic information* - The *ERP*, representing ERP systems integrated with the *Layout CAD Interface*, are capable of exporting CSV files, containing dynamic information regarding facilities, such as equipment characteristics and links between facilities in a given process.
- *Select facility* - Since the 2D shop-floor layout is represented within a canvas, the *Human Operator* can select facilities, by drawing a rectangle around the desired facility. This selection allows the *Layout CAD Interface* to collect from the CAD file information about the size and position of the facility selected.
- *Choose facility name* - The *Human Operator*, after selecting a facility, must choose a proper name. For this, the *Human Operator* has the possibility of manually writing the facility name, or, if dynamic information is available from an ERP system, the *Human Operator* can choose a name from a predefined list of names regarding every existing facility.
- *Choose facility type* - The *Human Operator*, after selecting a facility, can choose a facility type to be included in the simulation model. Considering *Simio*'s models, typical facility types are: server, workstation, source, sink, and vehicle.
- *Specify links between facilities* - If dynamic information is available from an ERP system, the *Human Operator* is capable of define links between facilities, i.e., connections between different facilities, regarding material and product flow in a given process.
- *Export simulation model data* - After defining all static and dynamic information to be included in the simulation model, the *Human Operator* can export the simulation model data, which will be used as input to generate the respective simulation model. The information considered contains the definition of all facilities names, types, location on the shop-floor (x and y coordinates), dimensions (length and width) and the links between facilities. Since the simulation modeling tool used is *Simio*, the simulation data output is in a CSV file, with the format of the content interpretable by *Simio*.
- *Input simulation model data* - The CSV file generated by the *Layout CAD Interface* tool is formatted to be imported into *Simio*. This is achieved by the use of a *Simio User Add-in*. In this case, the *Simio User Add-in*, built in C#, using the *Simio* API, is capable of importing the CSV file exported by the *Layout CAD Interface* and generate the simulation model.
- *Generate simulation model* - By executing the *Simio User Add-in*, *Simio* imports the CSV file containing simulation data outputted by the *Layout CAD Interface*, to generate the simulation model.

V. Layout CAD Interface Validation

With the purpose of validating the developed *Layout CAD Interface*, two test case scenarios were defined, which will be described next.

A. Test Case 1

Test Case 1 represents a process layout situation, where the design of the shop-floor facilities aims to arrange facilities according to their function. In this case, several equipments within a given department are represented. Also, it is assumed that only access to static data is available. Figure 4 represents the *Layout CAD Interface* and the respective simulation model layout in *Simio*, regarding Test Case 1.

In order to validate the *Layout CAD Interface* in Test Case 1, the *Human Operator* inputs the CAD file, already containing the respective facility layout, which is then available in the canvas. For this, button number 1 can be used - *Open CAD File* in Figure 4 and view the CAD content in the canvas (number 6 in Figure 4). Then, to select a given facility in the canvas, the *Human Operator* can click and hold in one of the facility corners and drag until the opposite corner, so that the equipment is inside a red square. To save the facility, pop-ups will appear, in order to manually input the name and choose a type. In this test case, there are five workstations (*mvc1*, *mvc2*, *mvc3*, *mvc4*, and *mvc5*) and two servers (*mbj1* and *mbj2*). For this, it can be used the button number 3 - *Save Facility* in Figure 4.

Finally, after all the facilities have been saved, the output file is produced in a standardized format, to be used in *Simio*, interpreted by the *Simio User Add-in* used. For this, it can be used the button number 5 - *Save File* in Figure 4. One limitation, regarding the placement of facilities within a simulation model, is the orientation of the facility. In this case, all facilities are placed with a 90^{o} orientation, since *Simio* API doesn't currently allow adjusting this parameter.

B. Test Case 2

Test Case 2 represents a product layout situation, where there is a production line and the facilities are arranged according to a particular production sequence. In this case, it is represented a simple wine bottling process, consisting of four equipments with different functions: fill the bottles with the wine; seal the bottle with the cork; labeling the bottle; bottle packaging. At the end of the process, a vehicle transports the wine bottles to a warehouse. Also, it is assumed that access to both static and dynamic data is available. Figure 5 represents the *Layout CAD Interface* and the respective simulation model layout in *Simio*, regarding Test Case 2.

Regarding the *Layout CAD Interface* in this test case, besides inputting the CAD file, the *Human Operator* also loads dynamic information exported from an ERP system, by the input of the CSV file, containing the list of the available facilities. For this, it can be used the button number 2 - *Open*

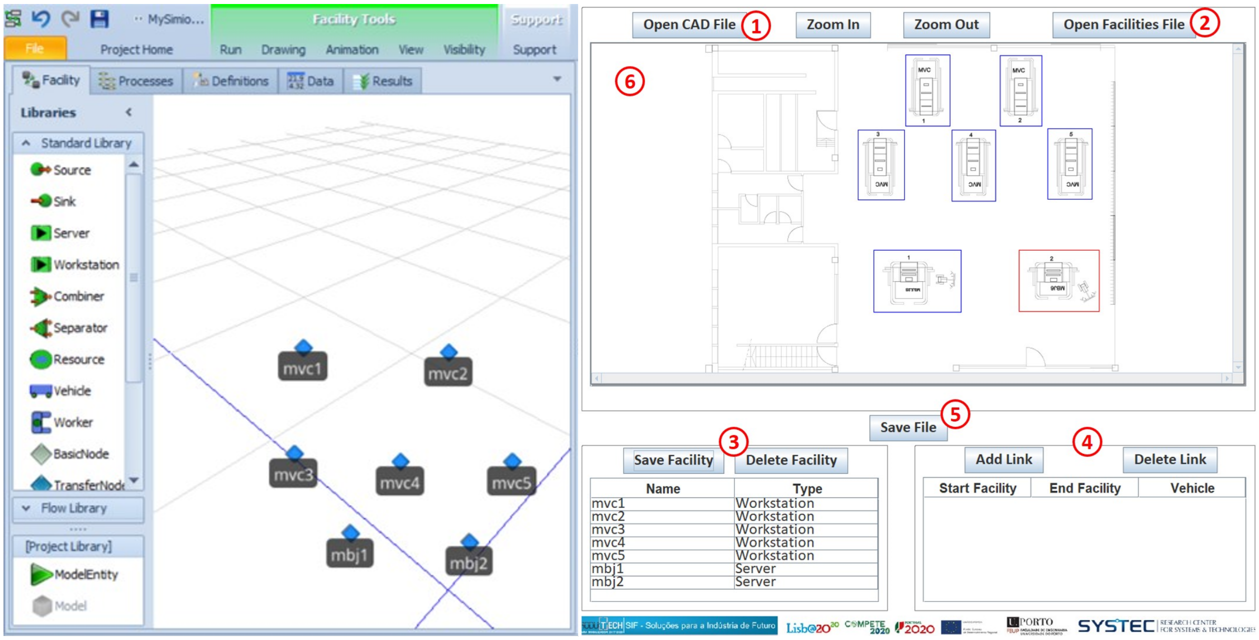

Figure 4. *Layout CAD Interface* and simulation model layout in *Simio*, regarding Test Case 1.

Facilities File in Figure 5. In this case, there is one source (*source1*), four workstations (*Filler*, *Cork_crew*, *Labelling*, and *Packing*), one sink (*warehouse*), and one vehicle (*Transport1*). When selecting a facility in the canvas, a pop-up appear, which allows to choose a name and type from a drop-down list.

Finally, the *Human Operator* can specify links between facilities in order to provide information regarding the production process flow. He can choose, from the predefined list of facilities, the facility that marks the process start and end points, and the transport type facilities used. The option ”none”, will always be available and should be the choice if no vehicles are used to transport the pieces between the start and end point of the link. For this, it can be used the button number 4 - *Add Link* in Figure 5. In this case, five links are defined, where only the link between the *Packing* and *Warehouse* facilities have material transport. The other links use conveyor belts for transportation. As in Test Case 1, the output file can be produced and used in *Simio* (Figure 5). Regarding the links between facilities, the tool limits the type of facilities linked to each other, according to the *Simio* capabilities. In this case, it is only possible to link source or server with Workstation/Vehicles and again with a sink. Also, moving facilities, such as vehicles, may be difficult to generate automatically, since these components usually are not represented in static CAD files.

VI. Conclusion and Future Work

The current document refers to the development of a tool, designated as *Layout CAD Interface*, focused in enabling the simulation software *Simio*, with the capability of semi-automatic generation of discrete-event simulation models regarding CPPS. This tool was part of the development of the *CPPS Design Platform*, within the PRODUTECH-SIF project, which supported the design and maintenance of CPPS. Regarding the simulation model generation, while the *Layout CAD Interface* contributed to the static information of the model (shop-floor layout), the dynamic information (system behavior and production) was collected from the ERP systems and directly from the shop-floor equipment.

The *Layout CAD Interface* validation results showed that the tool proposed is suitable for automatic generation of simulation models, considering both process (Test Case 1) and product (Test Case 2) layouts. While production layouts are suitable for mass production with less job variety, process layout are suitable for moderate production with more job variety. According to the different levels of product demand during the whole lifecycle of a manufacturing system, both scenarios will greatly benefit from the usage of such a tool, since flexible layout reconfiguration and earlier planning for cost reduction are frequent needs.

Regarding future work, the *Layout CAD Interface* may be extended to support 3D designs, which will permit the replacement of the *Simio* default simulation objects for the real design models of the facility to be included in the simulation. This may be achieved by adding the support of CAD file formats that support 3D designs. Also, further definition with the input of the dynamic components of the simulation model are needed, in order to enable the fully automatic generation of modules, such as: WIP, production plan within a given time, facility scheduling, production capacity and down-times, alternative process flow and bill of materials.

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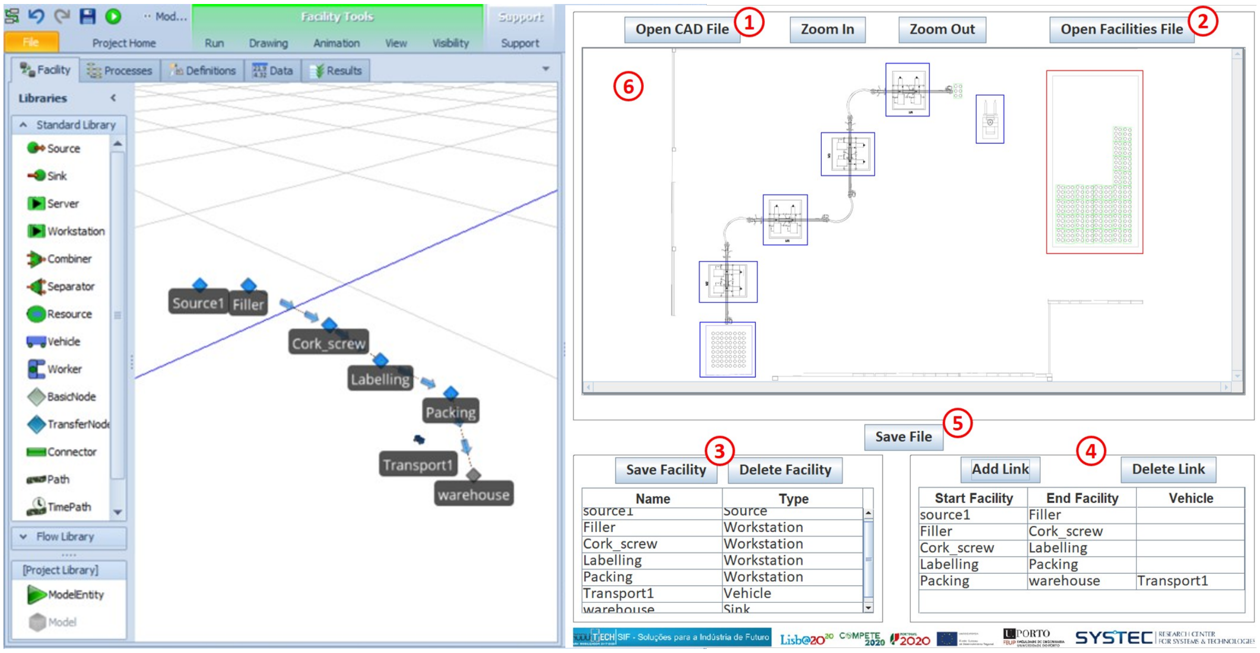

Figure 5. *Layout CAD Interface* and simulation model layout in *Simio*, regarding Test Case 2.

REFERENCES

[1] S. J. Hu, "Evolving paradigms of manufacturing: From mass production to mass customization and personalization," Procedia CIRP, vol. 7, 2013, pp. 3 – 8, forty Sixth CIRP Conference on Manufacturing Systems 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2212827113002096

[2] E. Oztemel and S. Gursev, "Literature review of industry 4.0 and related technologies," Journal of Intelligent Manufacturing, vol. 31, no. 1, 2020, pp. 127–182.

[3] S. Jain and G. Shao, "Virtual factory revisited for manufacturing data analytics," in Proceedings of the 2014 Winter Simulation Conference. IEEE Press, 2014, pp. 887–898.

[4] S. Jain, N. Fong Choong, K. Maung Aye, and M. Luo, "Virtual factory: an integrated approach to manufacturing systems modeling," International Journal of Operations & Production Management, vol. 21, no. 5/6, 2001, pp. 594–608.

[5] M. Sacco, G. Dal Maso, F. Milella, P. Pedrazzoli, D. Rovere, and W. Terkaj, "Virtual factory manager," in International Conference on Virtual and Mixed Reality. Springer, 2011, pp. 397–406.

[6] "PRODUTECH-SIF," URL: http://mobilizadores.produtech.org/en/produtech-sif?set_language=en [accessed: 2020-09-14].

[7] T.-C. Chang and R. A. Wysk, Computer-aided manufacturing. Prentice Hall PTR, 1997.

[8] C. D. Pegden, "Simio: a new simulation system based on intelligent objects," in Proceedings of the 39th conference on Winter simulation: 40 years! The best is yet to come. IEEE Press, 2007, pp. 2293–2300.

[9] D. T. Sturrock and C. D. Pegden, "Recent innovations in simio," in Proceedings of the 2011 Winter Simulation Conference (WSC). IEEE, 2011, pp. 52–62.

[10] R. Pinto, J. Gonçalves, H. L. Cardoso, E. Oliveira, G. Gonçalves, and B. Carvalho, "A facility layout planner tool based on genetic algorithms," in 2016 IEEE Symposium Series on Computational Intelligence (SSCI), Dec 2016, pp. 1–8.

[11] S. A. Coons and R. W. Mann, Computer-aided design related to the engineering design process. MIT Electronic Systems Laboratory, 1960.

[12] L. Dias, G. Pereira, P. Vik, and J. A. Oliveira, "Layout and process optimisation: using computer-aided design (cad) and simulation through an integrated systems design tool," International Journal of Simulation and Process Modelling, vol. 9, no. 1/2, 2014, pp. 46–62.

[13] S. AbouRizk and K. Mather, "Simplifying simulation modeling through integration with 3d cad," Journal of construction engineering and management, vol. 126, no. 6, 2000, pp. 475–483.

[14] S. Bergmann and S. Strassburger, "Challenges for the automatic generation of simulation models for production systems," in Proceedings of the 2010 Summer Computer Simulation Conference. Society for Computer Simulation International, 2010, pp. 545–549.

[15] W. Zhai, X. Fan, J. Yan, and P. Zhu, "An integrated simulation method to support virtual factory engineering," International Journal of CAD/CAM, vol. 2, no. 1, 2002, pp. 39–44.

[16] L. Dias, G. Pereira, P. Vik, and J. A. Oliveira, "Integrated systems design in an automotive industry-using cad and simulation in layout and process optimization," in 11th International Conference on Modeling and Applied Simulation, MAS 2012. Caltek Srl, 2012, pp. 326–334.

[17] P. Hoffmann, R. Schumann, T. M. Maksoud, and G. C. Premier, "Virtual commissioning of manufacturing systems a review and new approaches for simplification." in ECMS. Kuala Lumpur, Malaysia, 2010, pp. 175–181.

[18] P. Lorenz and T. Schulze, "Layout based model generation," in Proceedings of the 27th conference on Winter simulation. IEEE Computer Society, 1995, pp. 728–735.

[19] S. Moorthy, "Integrating the cad model with dynamic simulation: simulation data exchange," in WSC'99. 1999 Winter Simulation Conference Proceedings.'Simulation-A Bridge to the Future'(Cat. No. 99CH37038), vol. 1. IEEE, 1999, pp. 276–280.

[20] L. Neto, G. Gonçalves, P. Torres, R. Dionísio, and S. Malhão, "An industry 4.0 self description information model for software components contained in the administration shell," in The Eighth International Conference on Intelligent Systems and Applications. International Academy, Research, and Industry Association, 2019.

[21] C. Bliek1ú, P. Bonami, and A. Lodi, "Solving mixed-integer quadratic programming problems with ibm-cplex: a progress report," in Proceedings of the twenty-sixth RAMP symposium, 2014, pp. 16–17.

[22] "Kabeja," URL: http://kabeja.sourceforge.net/ [accessed: 2019-06-12].

[23] "Dxf specification - autodesk," URL: https://images.autodesk.com/adsk/files/autocad_2012_pdf_dxf-reference_enu.pdf [accessed: 2020-09-14].

[24] I. Kumari and A. M. Magar, "Dxf file extraction and feature recognition," International Journal of Engineering and Technology, vol. 4, no. 2, 2012, pp. 93–96.