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## 3D Design Support for Rapid Virtual Prototyping of Manufacturing Systems

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### Abstract

The paper presents several 3D layout configurator software tools and a library of manufacturing system components to rapidly build up the 3D models of manufacturing systems; some analysis tools to analyze the created 3D models; and some methods to rapidly create 3D models from point cloud of scanned manufacturing facilities. Within the configurators the user can define the following data as input: production process (e.g. type and order of operations), type of production equipment, type of material handling systems (e.g. robots, conveyors), type and sub-type of layout, and some spatial constraints (e.g. distance between machines, spatial arrangement). The configurators are able to create the 3D model of the manufacturing systems based on the selection of an appropriate layout template. The layout templates are defined by the species identified with a cladistic classification system or by the sub-species where each sub-species inherits the characteristics of its species. Based on the selected layout template and the defined production process the appropriate elements of the manufacturing system can be selected by the user from a predefined component library. Such library includes the 3D models and technical data of workstations, machine tools, material handling equipment, etc. Two analysis tools have been developed to evaluate the created 3D models: a collision elimination tool and a robot programming tool. The paper also presents two solutions to rapidly create 3D models from point cloud of scanned manufacturing facilities; as well as an application to automatically create a simplified quasi-volumetric point cloud model that can be used for collision detection.

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**Keywords:** manufacturing systems; cladistic classification; layout design; layout planning; layout configurators; point cloud

## 1. Introduction

The European joint research project COPENICO was initiated with the aim of developing methodologies, tools and a cooperation environment for rapid design and prototyping of manufacturing facilities [1]. This paper presents the results of the project achieved in the development of 3D design support tools for rapid virtual prototyping of manufacturing systems. In particular, these results are configurator software tools, manufacturing system component databases, component selection tools, and techniques to rapidly create 3D models from scanned point cloud data. In the context of this paper the term ‘layout design’, as an activity, means

– similarly to the term ‘design’ used in design science [2] – the synthesis, analysis and optimization of the selection and arrangement of manufacturing system equipment mainly focusing on the layout of machine tools, workstations and material handling in 3D environments.

## 2. Cladistic classification of manufacturing systems – layout species and layout templates

A cladistics based classification of manufacturing systems has been developed within the COPENICO project. Cladistics is an evolutionary classification scheme that describes the attributes of existing entities as well as their ancestral characteristics. Cladistic

relationships are commonly understood as the evolutionary branching sequences using taxonomies. It is assumed that characters can be expressed in discrete states and arrayed in a presumed evolutionary order from primitive to derived advanced. The application of cladistics to manufacturing systems has opened up a new way to classify and link evolutionary changes to main manufacturing changes of the past and present. [3]

Using the cladistic approach, the evolutionary relationships between forty-six candidate species of manufacturing systems were hypothesized, described and presented diagrammatically (as it was in the 4<sup>th</sup> generation cladogram of the COPERINCO project). The manufacturing species were then organized in a hierarchical classification using genera, families and orders under the class of discrete manufacturing.

Some of the species and their layout patterns have been selected as layout templates for rapid systematic layout design. Then further layout sub-species (or sub-types) of each of the selected species have been identified. Configurator software tools have been developed to create the 3D models of several sub-species of the following layout species:

- Unidirectional robot line;
- Robot centered FMS;
- Rotary indexer table.

### 3. Component library

A library has been populated with manufacturing equipment components that is used by the layout design tools. The components included in the library have two sorts of data: 3D models and properties. The properties of the components contain the name of the components, the file name of the 3D models and many other technical and non-technical data. Such data are stored in a Microsoft Access database. The selection of the components (see Section 4) is based on the properties stored in the Access data tables.

The following types of components have been populated so far: press machines, milling machines, turning machines, grinding machines, wire and sinking electro discharge machines, rotary indexer tables and stations, conveyor elements, robots, bending machines, cutting machines, drilling machines, plastic injection machines, and welding workstations.

Fig. 4 below shows some instances of 3D models of press machines. The properties of the press machines are the following: name of the component, name of the 3D model, name of the manufacturer, press force, number of press heads, max. distance between bad and ram, stroke, ram length, ram width, power, speed, rapid speed, length, width, height, weight, existence of autofeeder, type of operation, MTBF, MTTR, and price.

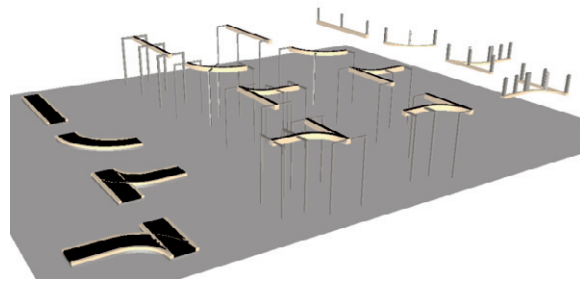


Fig. 1. 3D models of conveyor elements

Fig. 1 shows the 3D models of the elements of four conveyor types.

For the population of the component library machine configurators developed in a previous research project called NEXT [4] have been used. These machine configurators are able to create the 3D models of some manufacturing equipment [5].

Most of the populated components have fixed geometrical model but some of the components have parametric 3D model. For instance, the 3D models of the configured conveyor assemblies can be built up from parametric 3D models of the conveyor elements (Fig. 1).

### 4. Component selection

Three component selection tools have been developed that are able to filter the components populated in the library presented above: one graphical user interface (GUI) has been developed for filtering and selecting robots, another GUI for conveyors, and another general GUI for filtering and selecting workstations. These selection tools filter the components using their property data. On the GUIs as many filters can be added as the user wants using comparing rules, such as '>', '<' or '=' in AND relation. For example, the user can look for all the press machines where the length and width are smaller than the values specified on the GUI.

These filtering and selection tools can be easily used for simple problems where the user can search for and manually pick the needed components. For more sophisticated and automated selection problems, ontologies are being developed to aid the selection of suitable resources which meet specific requirements.

### 5. 3D layout configurators

Five 3D configurators have been developed to support the rapid creation of the 3D models of manufacturing facilities. These software tools have been developed under the Visual Components 3DCreate 3D modeling and simulation system using the C# programming language and COM interface.

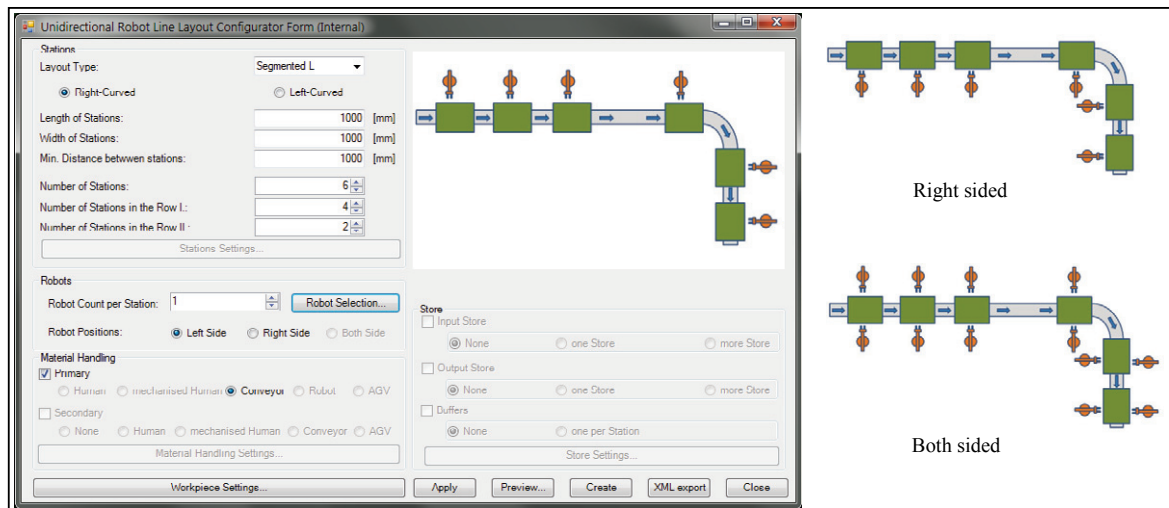


Fig. 2. GUI of unidirectional robot line layout configurator for the layout sub-type segmented L

### 5.1. Unidirectional robot line configurator

The left side of Fig. 2 presents the configurator GUI developed for the species 'Unidirectional robot line'. With the help of this configurator various layout sub-types can be selected, and then the 3D model can be created after configuring some layout parameters. With this GUI 15 unidirectional robot line layout sub-types (or templates) can be configured: straight line, left or right curved segmented L, left or right curved segmented U, where all can have left sided, right sided or both sided robot arrangements. For example, on the GUI presented in Fig. 2 the left sided segmented L layout sub-type is selected, while the right side of Fig. 2 shows the pictogram of the right sided and both sided robot arrangements as well.

On the GUI of this configurator the user can define the layout sub-type, the number of, the geometric dimensions of and the distances between the stations, and he can select robots using the selection tools presented in Section 4. Having the robots selected the 3D model of the manufacturing system can be created by pressing the 'Create' button on the GUI.

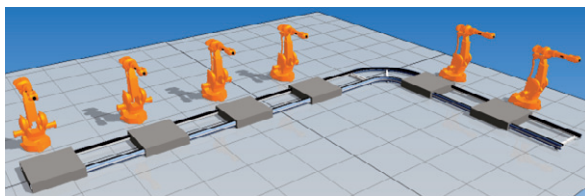


Fig. 3. Example of the 3D model of a right curved segmented L unidirectional robot line layout

Fig. 3 depicts the automatically created 3D model of the right curved segmented L unidirectional robot line layout configured with the settings of the GUI presented in Fig. 3.

### 5.2. Robot centered layout configurator

A configurator together with a special GUI has been developed for the layout species 'Robot centered FMS'. With the help of this configurator various layout sub-types can be selected, and then the 3D model can be created after configuring some layout parameters. Several layout sub-types have been defined for the type 'Robot centered FMS', such as line, double line, rectangular, circular, L-form, U-form, and matrix. The GUI of this configurator enables the selection of the robot and stations by calling the GUIs described in Section 4. Fig. 4 shows a 3D model created automatically using this configurator. The layout sub-type of this robot centered system is 'Line' and the selected robot is a general portal robot.

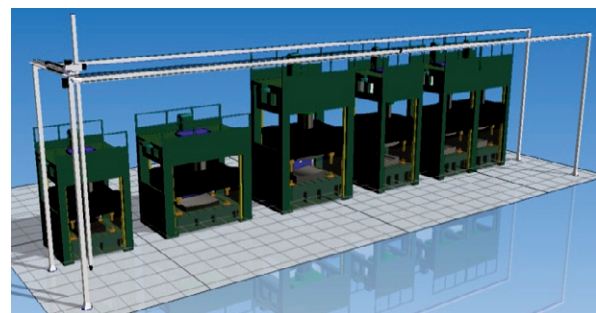


Fig. 4. Example of the 3D model of a robot centered FMS layout: layout sub-type is 'Line'; 5 press machines served by a portal robot

In the specific case presented in Fig. 4 the dimensions of the portal robot are calculated taking the dimensions of the selected stations and the distances specified on the configurator GUI into account. Then the parametric 3D model of the portal robot is adjusted to the required size. In other cases, where the components are fixed in size (i.e. not parametric), with the help of this configurator the user can quickly validate if, for example, the dimension range of the selected robot matches the dimensions of the selected stations. This is one of the strengths of the 3D configurators presented in the paper.

### 5.3. Conveyor configurator

The conveyor configurator has been developed to support the fast definition and 3D model creation of conveyor assemblies. Fig. 5 presents the GUI of this configurator. With this GUI the user can select the type of the conveyor added in the component library, define the major dimensions (width and height), and he can build his conveyor assembly from either basic units or predefined basic layouts. Currently, there are four basic units available: straight, curve, divert Y, and merging Y. Moreover, there are eight predefined basic layouts available: line, circular, rectangular, parallel paths, lateral branching, U-form, L-form, and S-form. Each basic unit and basic layout has some driving parameters to be specified. For example, Fig. 5 shows the U-form basic layout selected on the GUI, and Fig. 6 shows other two basic layouts and their driving parameters.

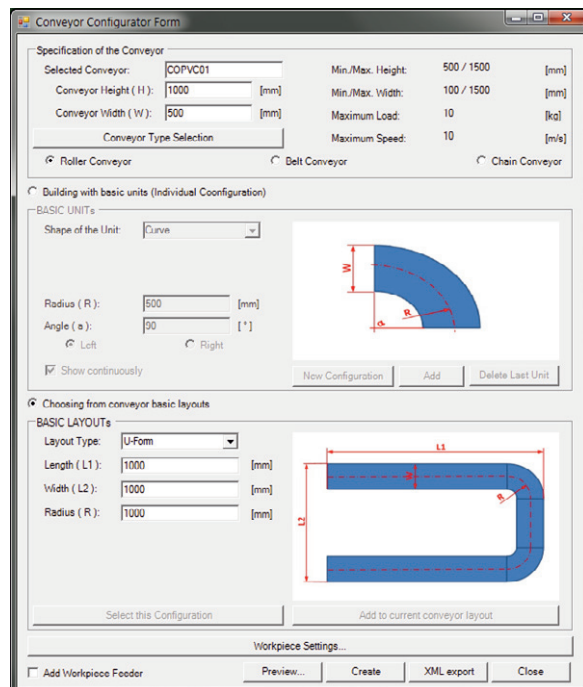


Fig. 5. GUI of the conveyor configurator

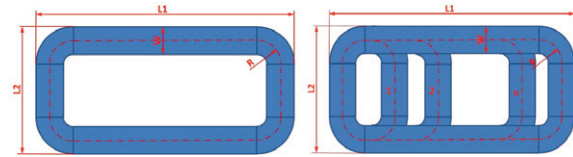


Fig. 6. Example of basic conveyors layouts: rectangular and parallel paths

### 5.4. Rotary indexer configurator

The rotary indexer configurator helps the rapid creation of rotary indexer systems. A GUI has been developed where the user can define the workpiece (mass, dimensions), the number of stations, the working directions (top, bottom, radial), and the type of the primary and secondary material handling system (human, robot, auto-feeder). Based on these configuration data the 3D model of the rotary indexer can be automatically created.

### 5.5. Factory building configurator

The factory building configurator has been developed in order to support the rapid creation of walls around a manufacturing system or within a factory. With this configurator the area to be surrounded by walls can be directly defined by the user or the configurator can automatically recognize the overall area of a manufacturing system (or subsystem) that has been created before. With the configurator the places and sizes of windows and doors can be easily specified and created as well. The configurator can also create pillars in the factory, where the user can specify the number of rows and columns and the cross-section of the pillars.

## 6. 3D analysis tools

Two analysis tools have been developed to evaluate and improve the 3D design of the layouts: a collision elimination tool and a robot programming tool.

### 6.1. Collision elimination tool

The collision elimination tool has been developed to check the geometric collisions and support their elimination. Fig. 7 presents the GUI developed for the tool. On the GUI the user can select the 3D objects to be included in the analysis and then the collisions can be identified (it is a standard feature of Visual Components). An application has been developed that attempts to eliminate the collisions by moving the selected objects along the specified directions using some embedded methods. These methods can be configured on the GUI.



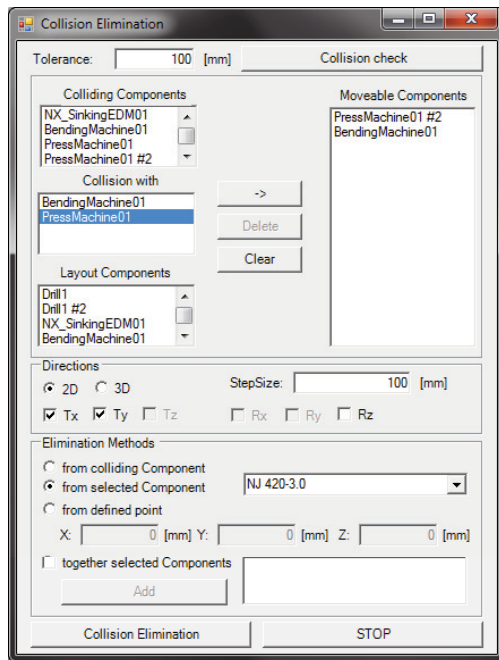


Fig. 7. GUI of collision elimination tool

## 6.2. Robot programming tool

The main function of the robot programming tool is to help the user evaluate if a selected robot reaches the selected stations to be served or how the robot moves around the stations. On the GUI developed for this tool the user can specify the stations and their order to be reached, the approaching points, the orientation methods, the insertion methods, and the interpolation modes. Then the robot program can be automatically created. For this some points have been predefined within the 3D components populated in the system library. The generated motion programs can be virtually executed by the robot within Visual Components. During the simulation the robot motions can be visually evaluated, or eventually, even collision detection can also be used. An error message appears if the robot cannot reach a particular station. In this case the layout has to be changed for which the configurators presented above may provide a valuable support.

## 7. Creating 3D models from point cloud

Within the COPENICO project several techniques have been investigated on data processing of scanned 3D factory objects. As a case study the point cloud of the workshop of Footprint Sheffield, one of the industrial partners of the project, was created by a laser scanning method. This point cloud contains more than 10 million colored points (Fig. 8) that should be further processed for efficient 3D visualization and layout design.

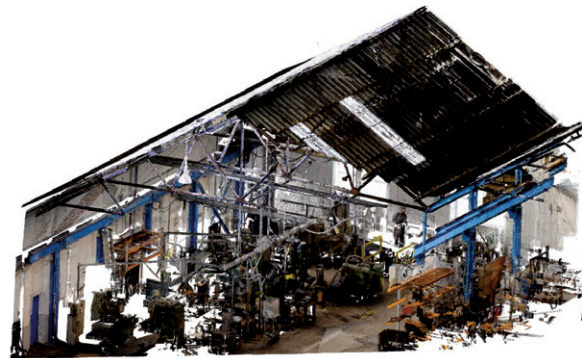


Fig. 8. Point cloud (raw data); courtesy of Footprint Sheffield, UK

### 7.1. User assisted creation of CAD models from big point cloud

Existing software technologies have been used to create CAD models from point cloud.

In the first method, the point cloud was imported into Autodesk AutoCAD Architecture as a reference. This allowed the cloud to be used as a base from which a CAD mesh could be generated. A series of slices were taken through the cloud helping to identify the location of key features. Once the key features had been generated, the cloud was removed leaving the standalone CAD mesh. The final data was exported as a .dwg and viewed in stereo through Autodesk Navisworks (Fig. 9). Navisworks was chosen because it enabled both the mesh and point cloud to be viewed in stereo simultaneously, allowing the viewer to compare the two data sets. The resulting mesh can be used for more powerful 3D visualization.

In the second method the Rapidform XOR 3 software was used which enables the recognition of some features (e.g. plane, cylinder) from point cloud. After recognizing some features the contour of surfaces can be detected by the intersection of the recognized features. Then the closed surface models can be created using the well-known solid body modeling techniques (e.g. sweeping). Fig. 10(c) shows the surface model created within Rapidform from the point cloud of a machine.

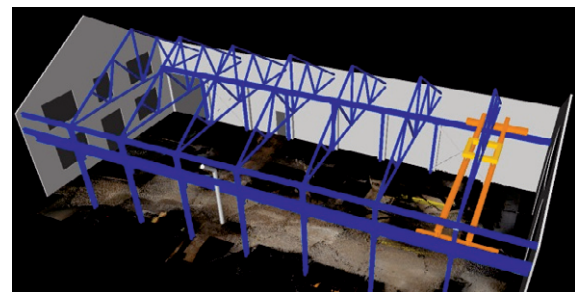


Fig. 9. CAD mesh model of the roof, building, and floor of a workshop (machines are removed)

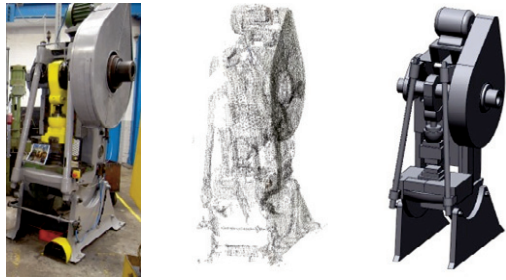


Fig. 10. (a) Photo of the original machine; (b) Point cloud of the machine; (c) Surface model of the machine created in Rapidform

The creation of the CAD models presented above needed some user interaction but the creation of the models took less time than starting the 3D modeling from scratch.

### 7.2. Automatic creation of quasi-volumetric point cloud models from big point cloud

Another aim was to automatically create quasi-volumetric CAD models from the point cloud. Therefore, an algorithm and a GUI for its configuration have been developed within Visual Components that reduces the number of points in a customized manner. With its help small spheres or cubes are created in the centers of the filtered points. In this manner a quasi-volumetric point cloud model is created which can be used for e.g. collision detection during layout design. The left side of Fig. 11(b) shows the solid body model of the machine presented in Fig. 11(a). The creation of this solid body model could take some time. The right side of Fig. 11(b) shows the quasi-volumetric point cloud model made from small spheres created automatically within a very short time.

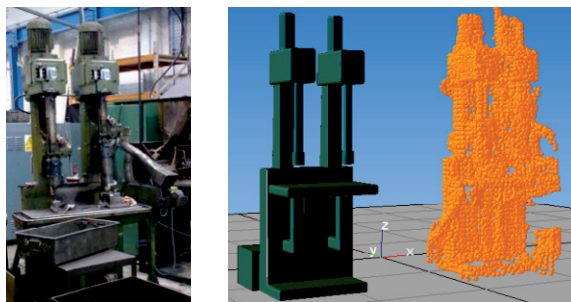


Fig. 11. (a) Photo of the original machine; (b) Solid body model (left) and quasi-volumetric point model (right) of the machine

## 8. Conclusions

Several methods, databases and software tools have been developed in the framework of the COPENICO research project which support the rapid 3D design of

manufacturing systems. The 3D modeling techniques presented in the paper offer much functionality that current factory design tools provide. The 3D configurators support the user in the fast configuration and creation of the 3D models of manufacturing systems based on well-defined layout templates that are identified and defined by a cladistics based classification system. The analysis tools support the user to evaluate and improve the 3D design of the layouts: they help detect or eliminate collisions and analyze whether the selected components match each other or fit into a system arrangement. The populated factory components library serves as a collection of essential building blocks; it can always be extended. For the extension the point cloud based modeling techniques may provide valuable support to rapidly created 3D models of existing objects.

The presented 3D modeling techniques indicate the direction in which factory design tools should advance in the future. In this way, the factory design tools may reach a similar functionality that current CAD systems provide for product design.

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