FACTORY LAYOUT PLANNER:
HOW TO SPEED UP THE FACTORY DESIGN PROCESS IN A NATURAL AND COMFORTABLE WAY

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ABSTRACT

This paper describes a new tool, named *Factory Layout Planner (FLP)*. The FLP is meant to speed up the factory design process and to facilitate the cooperation of heterogeneous actors usually involved in the design, simulation and analysis of future or existing layouts. The idea is to provide an innovative *environment* where people can perform the aforementioned activities in a natural, comfortable and creative way, without any constraints. In the vision of the authors, this requirement points to the massive use of 3D technology supported by a new human-computer interaction solution based on the multi-touch paradigm. The FLP provides both 3D and discrete event simulation capabilities, that are key enabling technologies in speeding up the layout planning process and in finding out the desired solution. A simple test case is reported to demonstrate the industrial applicability of the FLP.

Keywords: layout planning, multi-touch system, 3D and discrete event simulation.

1. INTRODUCTION

Manufacturing facilities are one of the most important strategic elements of a business enterprise. They are expensive and their lifespan is some decades. A properly designed plant layout is an important source of competitive advantage (Quartermann et al, 1996).

Planning a factory layout involves deciding where to put all the facilities, machines, equipment and staff in the manufacturing operation and the way in which materials and other inputs (like people and information) flow through the operations.

Traditionally, factory design processes are prone to error (Ding et al, 2010). Relatively, small changes in the position of a machine in a factory layout can affect considerably the flow of materials. This, in turn, impacts on the costs and effectiveness of the overall manufacturing operation. Therefore, any mistake can lead to inefficiency, inflexibility, large volumes of inventory and work in progress, high costs and unhappy customers. Changing a layout can be expensive and difficult, so it is best to get it right the first time (Meyers and Stephens, 2000).

Thus a need for a new factory planning tool, easy to use and understand for all the involved actors, is becoming more and more pressing. 3D technology is mandatory for such a tool because 3D models look realistic, provide a better understanding of space requirements and can be animated to show the physical flow of materials. Users can have a 360 degrees view of the new factory layout and they can easily see how factory objects interact, to detect the weakness of the layout and to reduce the interpretation errors.

Another key feature is represented by the simulation technology, both 3D and discrete event, that promotes more informed decisions, before any equipment is installed (Boër et al., 1993).

Last but not less important, the way to interact with this tool should be very intuitive, quick and natural because several actors, with different skills, are involved in this strategic process.

Keeping in mind this context, the Factory Layout Planner (FLP) was developed with the main aims:

1. To accelerate and simplify the factory layout process by creating accurate factory 3D models.
2. To foster the effective collaboration between teams.
3. To facilitate the human computer interaction.
4. To reduce the time to production of new layouts.

This paper describes the main modules and technologies used in developing the FLP. It is organized as follows: section 2 presents a state of the art about factory layout planning tools; section 3 describes, in details, the architecture and the applications composing the FLP; section 4 provides a real test case and conclusions follow.

2. STATE OF THE ART

The state of the art in 3D factory layout planning and simulation for discrete manufacturing is represented by some big software solutions, generally, classified as PLM (*Product Lifecycle Management*) that provide a support from the product to the process design and management.

The major references are: *Dassault Systemes – Delmia* and *Siemens - Tecnomatix*, which support both layout design and simulation and integrate modules for task programming and production process management. These suites require technical capabilities, training courses, changes in the mindset of the involved people, changes in the processes and, sometimes, in the company organization that can discourage small or medium enterprises. Another popular suite is *Autodesk – Factory design suite,* that allows integrating 2D layout data with 3D models, but here the simulation feature is still missing and it requires people with some CAD skills. Finally, *Visual Components* supports 3D components programming and assembly for an easy layout design, while simulation requires some specific programming competences.

On the market, there are other small solutions more oriented to discrete event simulation but with some features meant to support 3D animation. A first example is *Flexsim simulation,* that allows to drag and drop 3D objects, but requires consistent programming capabilities. Another example is *Arena,* where a "look-like 3D" layout creation is supported by an additional module. Last we mention *Simio,* that allows to generate 2D and again "look-like 3D" layouts. For those tools, simulation is focused only on the 2D objects. And again all these tools require skill and know-how in simulation modelling and programming.

Several research works have been proposed over the last decades addressing the benefits of using simulation during the design of new layouts for discrete manufacturing (Avai et al., 2011, Kyle et al., 2008, Voorhorst et al., 2008). Some of them describe the development of specific applications to facilitate the use of such models or the results' interpretations (Fagent et al., 2005). While Mert (Mert, 2005) investigated how simulation helps in finding out the most performing new layout when different techniques and principles are applied.

Additionally, the factory layout planning is considered in several European projects. "*EuroShoe*" project studied "ad hoc" solution for mass customized production plants; "*Difac*" (Digital Factory for Human Oriented Production) was focused on the planning of generic manufacturing factories and "*Eupass"* (Evolvable Ultra-Precision Assembly Systems) dealt with the layout configuration of a work cell.

FLP should inspire the creativity of the team as well, because, according to Harron (Harron et al., 2008) the design of a new layout requires both art and technology. It's not only an application of technology, but it's also a creative process.

The main features of the FLP can be described as follows:

- To allow planning all the components in a comfortable, intuitive and creative way.
- To provide 3D and discrete event simulation in a smart way.
- To guarantee a natural interaction.
- To allow the collaboration between different actors also remotely placed.
- To interface with other CAD systems.
- To provide some basic drawing functions.

The next paragraph will describe in details the innovative aspects of the FLP.

3. FLP OVERVIEW

The FLP is not a single program but a suite of applications built on top of a set of common libraries. These applications are targeted at different users and contexts and can speak with each other, share documents and data thanks to the client/server architecture. The main common libraries are:

1. The collaborative engine, that allows multiple users to act at the same time on the same layout in a local or distributed environment.
2. The 3D visual engine, that provides the user interface to edit the layout.
3. The simulation engine, that enables to perform discrete event simulation (DES) on the layout that the user is composing.

The FLP suite and its main technologies are described in the following subsections.

3.1. FLP architecture

The FLP is based on a two-level architecture with a fat client: the server is mainly a synchronization manager and a repository. The documents are required data (e.g. catalogue of available components, results of simulations) and are stored on the server. The client applications can connect to the server to get all the needed data and to edit the layout. The used protocol was optimized to minimize network traffic and to be tolerant of network delay, allowing a seamless remote editing experience. The FLP server is targeted at IT staff and should run on server computers.

Thanks to client/server architecture, the collaboration on the layout planning can be both remote and local. While the first allows users, distributed all over the world, to cooperate in the layout creation, the latter allows users to act on the same device at the same time on a common model.

3.2. FLP Desktop

This is the main application targeted at the users who design, refine layouts or perform 3D and discrete event simulation. It is mostly composed by a catalogue browser and a 3D editing window. Clearly, the 3D components' models can be imported from a CAD system and saved in the catalogue. Each company can create its own catalogue. With very simple operations, such as drag-and-drop or copy-and-paste, users can place layout elements, features and equipment in the 3D editing window on a user-defined grid, dragging them from the catalogue. They can also add columns, doors, windows, fences, etc., in order to recreate the actual available space and to organize it in the best way. The "snap to 3D grid" allows users to place equipments easily. All the components in the catalogue are parametric, enabling re-shaping at the time of placement. The 3D editing window provides advanced capabilities, such as: direct manipulations, move, alignment, mirroring, offset from object and snap in order to speed up the process of creating a first layout and rapidly change the space organization when the factory layout evolves.

Moreover, users can define the material flows and dependencies between the resources.

3.3. FLP Multi-touch

The multi-touch application is a customized interface of the Desktop application tailored to work with touch devices.

According to Wikipedia, "*multi-touch refers to the ability to simultaneously detect and fully resolve 3 or more distinct positions of input touches*". In fact, this application can manage up to 32 simultaneously touches. This means that, in a very natural way, multiple users can interact on the same layout at the same time to organize better the space, to move components, to plan a new factory layout. Furthermore, the multi-touch application allows technicians, managers, salesmen and stakeholders to interact with the FLP with a very intuitive touch interface without using any traditional input device such as keyboard or mouse.

This touch interface exploits new paradigms of human-computer interaction: while single or double touch devices are becoming common nowadays, multi-user interaction managed by a multi-touch interaction is genuinely innovative and can dramatically improve the touch experience (Ramanahally et al., 2009). The main challenges to build such a user interface are:

1. Multi-user aware widgets (i.e. buttons, input boxes, check boxes, menus), because traditional GUI has a single focused component, while in the FLP, many users can play with different widgets at the same time.
2. Adjustable widgets, all the people around a table can interact from their position, so the widgets have to be represented with the right orientation. In the traditional GUI, they have only one orientation.

3.4. FLP Layout editing

The layout editing was designed to address the following main needs:

1. The generation of executive 2D layout drawings.
2. The smart creation of simulation models.
3. The preparation of commercial presentations.

The layout editing in the traditional CAD systems is generally targeted towards the needs of technicians to prepare the executive drawings. The FLP is meant to be used by a wider range of end users with different aims. For instance, when a user places a component on the grid, it should connect itself with the nearest components if needed, and it should communicate with the others. In this way, the material flow is generated in an automatic way: the components are animated in order to visualize their paths as well as their machining. This gives a visual cue of how the layout will work, both for technical analysis and commercial presentations.

These requirements were addressed combining several resources describing each component:

- A geometrical 3D representation of the component composed of coloured meshes and a kinematic description.
- A DXF drawing is used for the executive 2D layout, and it also provides the clutter of the foundation.
- A logical description of the component in terms of ports (inputs/outputs) and parameters.
- A program (written in JavaScript or in custom DSL under development) implementing the behaviour.

Each application can access only the required resources of a component. For example, the visualization engine can display the 3D meshes; the simulation engine can execute the behaviour program. Nevertheless, changes to one aspect of a component are reflected to the other aspects. For instance, if a component is linked to another in the 3D window, this affects DES, creating a connection between the respective input and output ports.

3.5. FLP Simulation

The simulation is another core application of the FLP: the basic idea is to combine 3D simulation with DES. These technologies are fundamental in planning a layout, because, at macro level, manufacturing can be represented as "material in – process – material out". Understanding the processes and the production sequences helps to ensure efficient manufacturing and control costs. DES allows to analyze the material flow and the resources' allocation at plant level (Voorhost et al., 2008), while 3D simulation allows to optimize the layout and the relative process at workcell level (Schenk et al., 2005).

From a technological point of view, each component has a set of input and output ports that are connected to each other to define the material flow and resource dependencies. Along these ports, the components can send and receive signals that can be primitive types such as integer or double values but also complex structures. Every time a new signal is published to the output port, it is propagated to all the connected input ports. In this way, the components can react to changes in the status. Moreover, the components' logic can schedule a task to be executed after a predetermined time delay or when a certain condition is met.

The logic that defines the behaviour of a component is handled by a program executed inside an interpreter. It gives virtual access to the complete layout and its associated resources. It is possible, for example, to change the colour of the geometry of a downtime machine, to move a beam on the roller conveyor, etc..

The program controlling the behaviour of the component can be written in JavaScript, using an API to access and define the required interfaces, or a DSL (Domain Specific Language) that is currently under development. The DSL will be similar to a state chart diagram and it will allow creating and editing the program visually. A set of predefine behaviour will be provided for common components such as sources, sinks, buffers, conveyor transports and so on.

4. REAL TEST CASE

This paragraph describes a simple real test case. It is meant to test some features of the FLP prototype and to demonstrate its industrial applicability.

This test case deals with an existing woodworking plant making panel doors for the furniture industry. It is composed by two identical and parallel processing lines as shown in Figure 1.

Each line is equipped with:

- A CNC drilling and routing work centre (see Figure 2).
- A brushing machine.
- A reversing device.
- A CNC drilling and routing work centre of panel side.
- A control station.

Looking at Figure 1, the material flows in the bottom-up direction.

At the beginning and at the end of these two lines there are two Cartesian robots in charge of loading and unloading the wooden boards. Identical panel doors, requiring the same processes, are stacked up on the infeed roller conveyors. A single panel is picked by a robot and put on the processing line. Each panel is machined at the routing work centre and then it's brushed by the brushing machine. When needed, it is turned upside down and comes back to the first centre, otherwise, it goes on through the drilling and routing work centre, where the panel sides are worked. Eventually, each panel is checked at the control station and then it is unloaded by the robot and put on the outfeed roller conveyor.

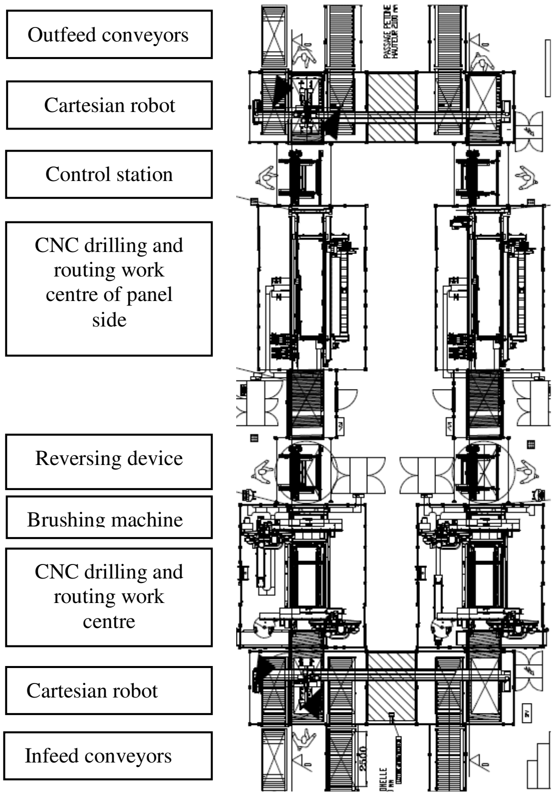

Figure 1**:** The layout of the plant

All the 3D models of the layout components were imported from a CAD system but their level of detail was even too high for this scope. Thus there was the need to simplify the 3D models trimming minor details such as screws, bolts, electric wires, and, sometimes, reducing the number of triangles of holes, cylinders, etc. Figure 2 shows the result of this simplification applied to the routing work centre. Unfortunately, this step cannot be completely automatized (some automated procedures are in place, but human intervention is still required) and it is very time consuming. However, it has to be done once, and then the model can be used as many times as needed in several different layouts. Eventually, the kinematics has been added to the machines and work centres whose movements have to be represented. These 3D models were saved in a proprietary XML format along with the other required information, and then imported in the catalogue of the FLP.

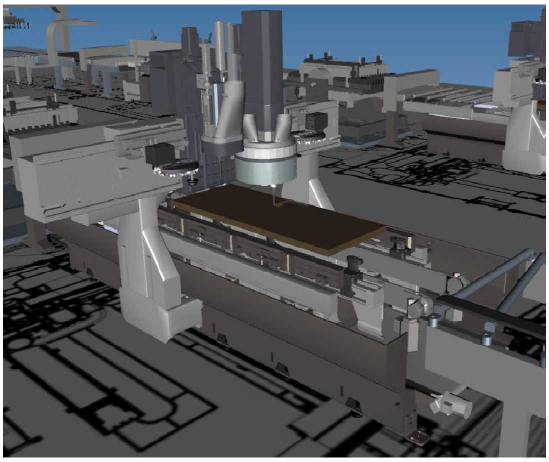

Figure 2**:** CNC drilling and routing work centre

The FLP, with a filled catalogue, is now ready to be tested by the plant designer along with the process manager working for the same company. Their goal is to re-create the existing woodworking plant, starting from scratch using the FLP provided with the multi touch feature. A very short training was made before starting the test case. The touch interface makes the layout creation very easy and intuitive and the team is more concentrated on the component placement than on understanding how to use the new tool.

Figure 3 shows the result of the planning of the woodworking plant.

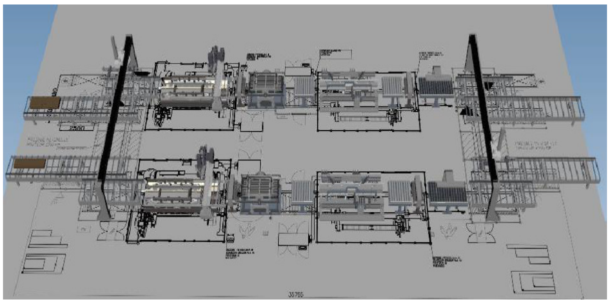

Figure 3**:** The final layout

The feedbacks gathered were positive in relation to the interface and the simplicity in creating a new layout and they appreciated the FLP speed during the walk-through. This test ran on a standard desktop PC, even though the total number of triangles of this plant was about 2,5 millions. Traditionally, CAD models are challenging to be visualized at interactive frame rates (~30 fps) on a normal hardware. Mesh simplification is a common used technique to reduce the number of triangles but to keep an acceptable level of constructive details only topology-preserving simplification algorithms can be applied (Luebke et al., 2002). Research specific for CAD models have highlighted that at least 2K triangles are needed to display a single mechanical component (Tang et al., 2010). Table 1 shows the number of triangles needed to visualize each component of the layout with an acceptable level of detail.

Table 1: Number of triangles for all the components of the final layout

Component	**Triangles**	**#**	**Total triangles**
Cartesian robot	174.624	2	349.248
Drilling and routing work centre	616.481	2	1.232.962
Brushing machine	4.732	4	18.928
Reversing device	313.744	2	627.488
Drilling and routing work centre of panel side	23.624	2	47.248
Roller conveyor_1500	6.576	4	26.304
Roller conveyor _4000	8.644	10	86.440
Roller conveyor _4000	9.272	2	18.544
Control station	9.552	2	19.104
Total			**2.426.266**

As far as it concerns the multi-touch interface, it was perceived as really immediate and comfortable in creating the layout. Only the view orientation lacked intuitiveness. Sometimes, it’s not instantaneous to understand how to move the fingers on the monitor surface in order to get the desired 3D view. This functionality has to be further investigated in order to improve its usability.

Other concerns, arisen during this testing phase, regarded the accuracy in the component positioning and sizing.

Even though the kinematic simulation application is currently under development and thus not fully accessible for inexperienced users (as it still requires a great deal of programming), an IT expert worked it out in order to reproduce the panels’ movement through the plant as well as their machining at the work centres.

The simulation of material flow and machines provides an added value, as expected, because it allows checking for bottleneck, collisions, etc., providing also some overall performances of the plant. The animation, along with the simulation results, eases the discussion about the changes to apply to the layout in order to increase its performances. An alternative solution was analyzed, as shown in Figure 4, where a new line was added just with a simple copy and paste operation.

The first impression about 3D animation was positive as well, and the company was surprised about the realistic level of the animation.

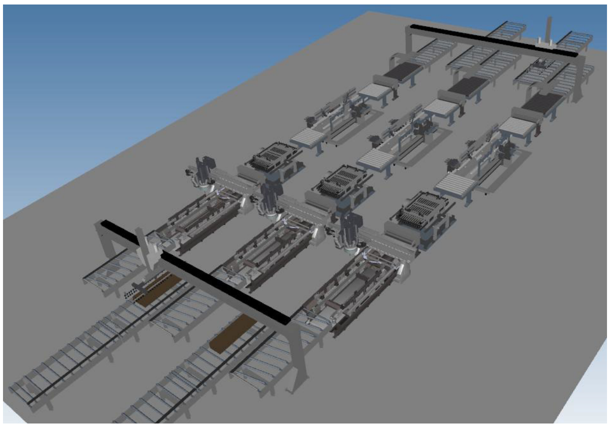

Figure 4**:** The revised layout

5. CONCLUSIONS

This paper describes the innovative Factory Layout Planner, whose main scope is to speed up and facilitate the layout planning process by combining and integrating different technologies such as 3D modelling, simulation and multi-touch interaction. Special attention was given to the interface and the processes to create and to change layouts in order to make them as easy and quick as possible. In fact, the FLP's target users are not only technicians, but also stakeholders, designer and salesmen.

The results of the simple test case were positive confirming the efficacy of the tool and its applicability in real manufacturing contexts.

Further activities will be concentrated on the development of:

- The simulation application
- A tool to drive the user in creating new components to add to the catalogue.
- Some supporting features such as: the measurement, photo realistic screenshots, etc..
- Generation of 2D plan and sections views with quotes.

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