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# Simulation of Manufacturing Processes via Virtual Reality

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## ABSTRACT

*In a world in continuous evolution, the different industrial actors need to be reactive to remain competitive and to conquer new market trends. To achieve this, they are constrained to improve their way of industrial management, both at the strategic level, to adapt to technological advances and follow market trends. In this chapter, we introduce a new simulation method that makes it easy to understand the results of a given simulation. This is of crucial importance because the design stage of a manufacturing system usually implies not specialist actors. The objective of the chapter is to present the main advantages of using the virtual reality (VR) to the manufacturing processes simulation. To this end, a state of the art will compose the first part of the chapter. In the second part, we address the issue of the contribution of the VR to the industrial simulation.*

## 1. INTRODUCTION

To remain competitive in the increasingly unstable markets, the industrial actors often have to seek innovative solutions to improve their production, assist in the decision, update and adapt their means of production management, etc. This requires software tools to allow controlling and simulating various flows of production system. There are several tools to design and simulate various industrial processes and even the decision aid. We are particularly interested in the discrete event simulator of flow. These

tools are generally used by industrial engineers specialized in management and production engineering process simulation. This prevents the simple industrial actors to understand the simulation's results which present complex and specific data.

The objective of the reactivity in production is to regularly update production systems. Since the 1990s the increasing diversity and complexity of products has gradually led manufacturers to use computer software in various stages of production, so that the industry can control management systems, as well as to simulate different processes of production systems. With the extensive development of computer technology, these software packages are now available in all stages of an industrial system life cycle. This revolution opens the door to new technologies and to their integration into the creation process and in the simulation of industrial methods. Today, several researchers are working on projects for the integration of VR into design tools and simulation of industrial systems. VR is a technology that combines software tools and other equipment to set up an immersive interactive experience that simulates a real-world scenario in virtual mode, this technology is used in various fields such as: medical, nuclear, mechanical simulation, and computer industry etc.

The simulation field is a very large one, in fact, it is applicable to all industrial flows and even services, at all levels and in all phases of the life cycle of a production system (Berchet, 2000). Often, the software packages are used for modeling of industrial systems, improving workshops to control stocks capacity, simulating the different processes of production, validating the operational rules, etc. Flow simulation can also be used at the operating stage, in addition to planning tools to estimate or schedule delays for example. It also allows determining the optimal configuration of logistics system production values (Fontanili, 1999). In this chapter, we will focus mainly on the simulation of flow of production in manufacturing-type systems using a discrete event flow simulator in which the state variables change only at events such as the start or the end of a transaction, release of a workstation, the occurrence of a failure, the standby in a queue of parts, etc... (Bel & Kieffer, 2002). The simulation allows us to project ourselves into the future to quickly measure the consequences of an event coming from appearing. It also allows the decision support by simulating several correction scenarios in a rapid way, to limit the consequences of a critical event. The modeling and the flow simulation of industrial systems is a specialty of industrial engineering, it must therefore have sufficient knowledge to be able to establish a flow simulation for a production system. Therefore, modeling and simulation is not accessible to the public industrial users, this problem represents a disability for many industrial actors.

## **2. APPROACH COMPARISON**

The typical problem with the representation of a simulation of a manufacturing system is to understand the simulation results. These results are generally understood only by experts. Although there are tools to represent them with 2D data visualization, to understand these results remains a lot of works of industry expertise, and the research works conducted by Dangelmaier *et al.* (2005) allow the implementation of a virtual reality system for 3D visualization of the complex results. The VR also allows simulating the configuration of machine installation, and the studies conducted by (Lindskog, Berglund, Vallhagen, & Johansson, 2013) show that industrial model VR can be used as a visual system when modeling and reconstruction of production systems and even testing the various setup configurations of the virtual model before the real installation of the system. Today, the 3D imaging methods and tools, i.e. the interactive virtual reality simulations appear in industrial activities, especially in project design or implementing

CAD models “Computer Aided Design” in industrial production (Sreng, Lécuyer, Mégard, & Andriot, 2006) (Jayaram, 2007), which is also the case for different industrial activities related to automotive and aerospace, etc...

The originality of this research is based on the design of a VR system that includes a flow simulator discrete event, which is generally a tool for the design and control of the production processes, and the optimization of production systems. This approach of VR allows us to develop an abstraction layer between the techniques of simulation flow and the actors concerned with the exploitation of complex data resulting from this simulation. The advantage of this layer is to have certain invisibility on different methods and techniques for the flows simulation that requires expertises in this industrial area. Indeed, this layer allows mastering of flow simulations through the VR tools, as well as to immerse the user in a scene integrating process upstream and downstream of workstation. It also allows us to have an experience feedback on the decision from the exploitation of the design. In conclusion, the simulation assisted by VR seems to us to be one of the most interesting approaches to simulate and model the production systems.

The objective of this chapter is to establish the general context of simulation of virtual manufacturing, to present a state of the art of the discrete event systems (DES), the simulation of DES, and the simulation of production flow. It also aims to introduce the different existing simulation tools, as well as a presentation of the VR, the existing projects of research in VR that treat the different industrial problems, the contribution of this new technology in the industrial context. And in the last part we address the issue of our contribution in this area through an architecture that allows implementing a solution for interactive and immersive simulation.

### **3. DISCRETE EVENT SYSTEMS**

The discrete event systems (DES) are dynamic systems whose state evolves with the occurrence of events. Indeed, instead of focusing on continuous progress of events, we take into consideration their beginnings and their ends and their dynamic concatenations. Time in this type of system is encoded by the sequence of events, so it is discretized. Some examples of DES can be cited such as: communication networks, transportation networks and manufacturing systems. The study of discrete event systems can be conducted with tools or languages parallel programming or real-time. The finite-state machine, the dynamic algebraic models, the networks of queue and well on Petri networks, they are the basis of most of the tools of flow simulation of the discrete event systems. For example, Petri networks is a modeling tool particularly well suited to systems that incorporate parallelism and synchronization. Due to their mathematical modeling aspect, the Petri networks can be used to verify properties of the system such as blocking. Generally the modeling of an industrial system is based on mathematical and physical laws that govern its behavior. Thus, there are two main classes of models: knowledge models and representation models. Indeed, the processes described by equations involving the physical laws that govern their behaviors are called knowledge models. These models, also called white box models, have the advantage of having parameters directly related to the physical elements of the system. Thus, in the case where the model structure can be constructed with physical laws, but one or more parameters must be estimated from observations, model are called gray box model. Finally, the complex or poorly known systems are often equipped with a large number of sensors, which generate signals which can be used for the identification of a model from experimental data. The model obtained is called a representation model or black box model.

The discrete event systems are generally modeled based on events. In these systems the behavior is represented by transitions between different states of the system following the occurrence. The behaviors of these systems are usually modeled by networks of queues, Petri networks and the finite automata and their extensions and variants. The observability in such systems is treated by partitioning in advance in the model all the events into two subsets: a set of unobservable events and another with observable events include events precisely faults. Thus what are observed in a discrete event system are sequences of observable events. The diagnosability in discrete event systems is defined as follows: A system is diagnosable only if every occurrence of a fault is followed by a finite observable sequence that does not occur in the absence of fault. This definition is similar to the concept of signature defined for continuous systems. Also found in (Cordier, 2006) a study that shows the concept of signature can be formally defined for discrete event systems such as diagnosability which can be defined in the same way as in the continuous and discrete systems.

### **3.1. The Automats**

Among the many tools that allow the study of discrete event systems, there are automata. An automaton is a state machine. It is represented by a set of states connected by transitions associated with events. An automaton is a finite state if the number of states is bounded. It can be seen as a machine having discrete inputs and outputs and which adapts its outputs in accordance with the changes of its inputs. If the next state machine can be determined without equivocally using its current state and symbol input, then the automaton is called deterministic, otherwise, the automaton is non-deterministic. An equivalence relationship exists between the two, in the sense that for any non-deterministic finite machine, an equivalent deterministic automaton can be found (Motwani & Ullman, 2007) (Lafortune, 2008).

### **3.2. The Networks of Queue**

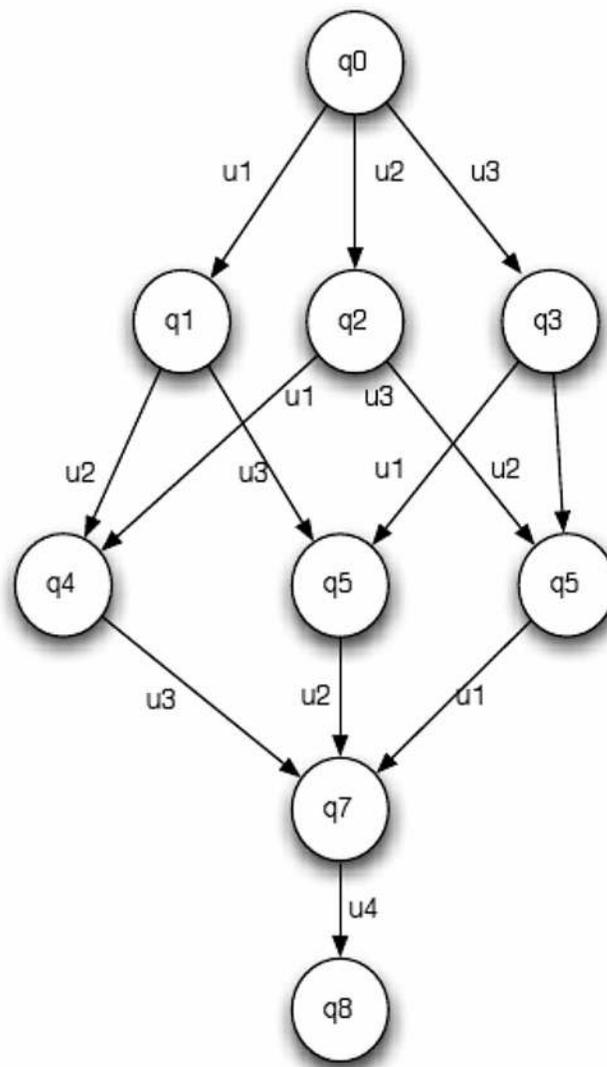
The networks of queues are parts of several formalisms for modeling discrete event systems. A queuing network is presented by the stations of several types of services (FIFO, sharing of server, etc.), and the sources of clients and the synchronization mechanisms between these stations. There are various simulation algorithms that use protocols “Chandy and Misra” optimized according to specific parameters of these parts. In such an algorithm, the process sends a null synchronization message when it enters a blocking period waiting for the messages. This has two advantages, the first is that the calculation procedures of predictions are performed during potential blocking periods, the second is that the number of messages circulating is limited.

### **3.3. The Petri Nets**

Since the appearance of Petri nets in 1962 by Carl Adam Petri (Gesellschaft, 2006), this approach represents a powerful mathematical and graphical tool for designing discrete event systems. The model for this design allows analyzing properties and validation of their specifications. The Petri nets have the advantage of being a much more general model compared to automats, and enjoying much richer structures, these networks are perfectly adapted to the description of different types of discrete event

system (Murata, 1989) (David & Alla, 1999) and (Giua & Seatzu, 2007). The Petri net is a directed graph comprising a finite set of places and a finite set of transitions, with the oriented arcs which ensure the passage of place and transition. The places (symbolized by circles) represent specific conditions for each status of system the information of type of resources number, status of a resource etc... The transitions (symbolized by lines) represent the actions that can cause the change of state of the system (discrete events). The directed arcs indicate causal relationships between states of system and events involved in its evolution. As each state change is caused by the arrival of an event, it logically follows that an arc can never link two nodes of the same type.

Figure 1. Example of a model of Petri nets



## **4. THE SIMULATION OF DISCRETE EVENT SYSTEMS**

The simulation of discrete event systems precludes a continuous simulation. In this type of simulation time is cut into equal portions without which we cannot distinguish events. At each slice or time interval, we analyze the state of the system. According to (Claver, Pitt, & Gelinier, 1996), the simulation is an activation of the model studied in time, based on the rules of evolution or assumptions that we want to validate. The simulation is a technical description of the model over time, in order to know the dynamic behavior of the real system and even to predict the effect of different parameters or scenarios on the model. Gogg & Mott (1993) defines simulation as the art and science of creating a representation of a process or system in order to test and evaluate. Pegden *et al.* (1995) specifies that the modeling and simulation of flow presents a process of creating a model for a real system and conduct experiments on this model in order to evaluate different control strategies and to understand the operation. The flow simulation allows to reproduce the dynamic behavior of a real process of a software tool, without any risk of loss and saving time with the speed execution of the simulation, and answer type questions “What happens if ...? “.

### **4.1. The Production Systems**

The first production systems were made by “Newell” and “Simon” in the 1950s. A set of generalities are obtained using all manner of industrial problems for the purpose of reinforcing the area of research, with changing to the specific production. The production systems have evolved rapidly due to the proliferation of expert systems. A production system is a computer program commonly used to provide a form of artificial intelligence, which consists primarily of a set of rules of behavior. These production rules are useful basic representations in automated planning. A production system provides the necessary mechanism for the implementation of production to achieve the objective of the system. A production system also contains a database, sometimes called working memory, which retains data on the current state of the system, and an interpreter of the rule.

### **4.2. The Evolution of Production Systems**

A production system is an organization whose function is to provide engineered products or services. The economic context and market evolution have led the industrials to adapt their production systems to improve their industrial performance. The concept of industrial evolution refers to the ability of a factory which ensures the results of his organization and thus ensures the continuing evolution of the process. The establishment of the evolution of production systems was initiated by the automotive industry (Womack, Jones, & Ross, 1990). After the period of the traditional production, for several centuries, mass production developed from the late nineteenth century in major U.S. industries. After World War II, the Japanese launched a revolution in mass production by developing the principles of Toyota production system. The Toyota production system has meanwhile demonstrated its flexibility to respond to market fluctuations. These mutations have radically improved our fundamental ideas about how to produce some products or services. The term of « Lean production » was first named by Krafcik (1988) to describe the Toyota Production System (TPS). The Lean production is a management approach to enhance performance by eliminating waste. At the moment, the Lean approach seems to be an ideal solution. Its spectacular results in terms of increased productivity and reduced cost have created great interest in many companies

(Kilpatrick, 2003), (Shah & Ward, 2003), and (Demeter & Matyusz, 2010). Over the last ten years, Lean principles have been applied intensively in many sectors of activity, such as aerospace, electronics, mechanical subcontracting (Crute *et al.*, 2003), (Abdulmalek & Rajgopal, 2007), and (Baglin & Capraro, 1999). Furthermore, note that its implementation has been done in small and medium-sized companies (Achanga, 2006) as well as in large companies (Womack & Jones, 2005). In continuous improvement of the reactivity, the virtual reality and computer stimulations open interesting perspectives for optimization of current production systems. Optimization of material flow is a current issue of the organization of production systems. A simulation tool for visualizing flows, detecting inventory shortages and queues, should lead to a better system design and a better anticipation of technical and technological decisions. As suggested by the Lean principle of just in time, flexibility and reactivity of flows are crucial. Virtual reality would enable to take action upstream, if possible at the very start of the design phase. Thus the production systems would be more adapted to the different constraints of companies.

### 4.3. The Simulation of Production Flows

The flow simulation is a process that involves matching a system to a model that represents its characteristics. In this way, it studies the impact of change on the model and not on the system, by the ticket of programming of different rules and simulation parameters, and experiments provided by the progress of model and interpretation of results for the purpose of making decisions related to the system (Ait Hssain & Dunod, 2000). We can thus validate the changes before proceeding to their implementation. Various techniques are used for the simulation of the models, such as networks of queues, discrete event simulation, operational analysis or the Petri nets. Today, Petri nets (Gesellschaft, 2006) are supported by software tools which allow the system architect to proceed himself in the study of the behavior of the system as in the design phase and during its execution and during the life cycle of the system. Since the 1990s the increasing of diversity and complexity of products has gradually led companies to use the computer software in the production process. With the considerable development of computer science, these tools are now available in all stages of the life cycle of production systems. We often find that the computer software of design and operating are used separately and therefore there is no experience of feedback from the operating to the design. Our main objective is to establish a link between a tool of flow simulation and a virtual reality system while gradually refining the performance of the simulation model through dynamic exchange of data using the techniques of virtual reality.

The flow simulation allows:

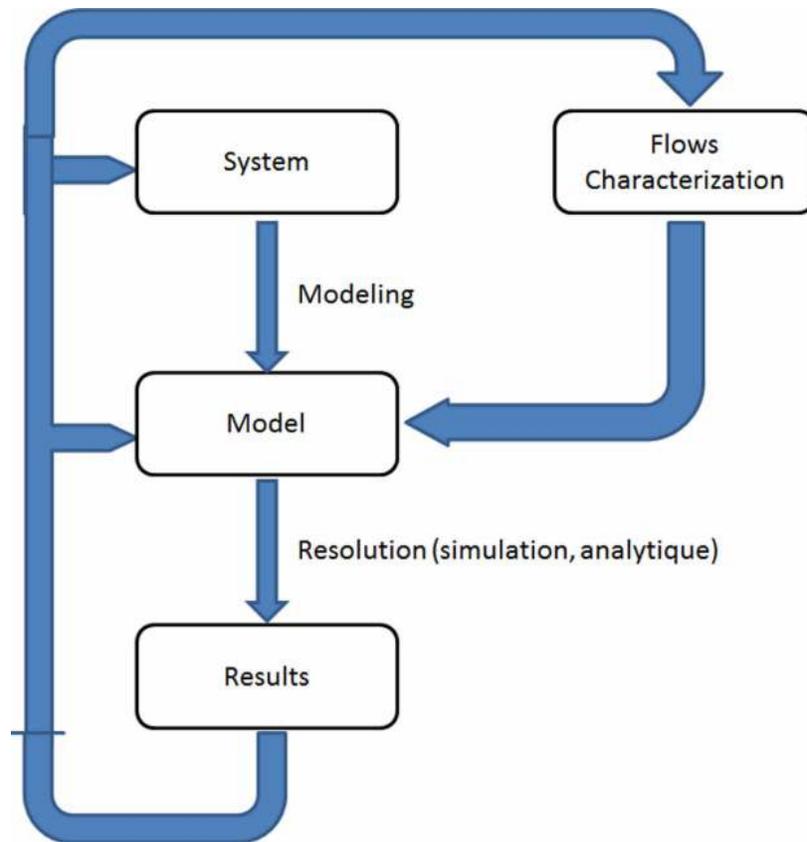
- To observe the dynamic behavior of a system: simulate to understand.
- To experience the solutions of change: simulate to improve.
- Utilize the model to predict the behavior of system: simulate to anticipate.

In production and logistics, the simulation is mainly used for:

- Analyzing the physical and information flows.
- Analyzing resource states.

Synthetically, we can say that the simulation of discrete event flow:

Figure 2. Scenario of simulation of a production system.



- Is a tool adapted for complex systems.
- Does not require mathematical modeling.
- Allows a level of detail that can be high.
- Presents a shape close to the real system.
- Provides arguments of communication and builds trust, through visualization.
- Offers the possibility to test different organizations.
- Helps to make better decisions.
- Generally production systems are based on the discrete event.

## 5. EXISTING TOOLS FOR THE SIMULATION OF INDUSTRIAL PROCESSES

To be reactive, must be competitive, is why manufacturers today have a vision to high production technologies. They compete simultaneously to achieve a common goal, which is the automation of manufacturing facilities and computerization of various functions of production, such as: design, workflow management of production and logistics. In this state of the art we focus on specialized software in workflow management and design of workshops. We start with the tools supporting the modeling functions of production systems and we detail the flow simulation software used most often in the design

phase of workshops, the analysis tools, and the techniques used to exploit the results of the simulation. The simulation of a production system is the fact of playing with the various system parameters such as the size of the storage areas, priority rule etc., to arrive at a better configuration.

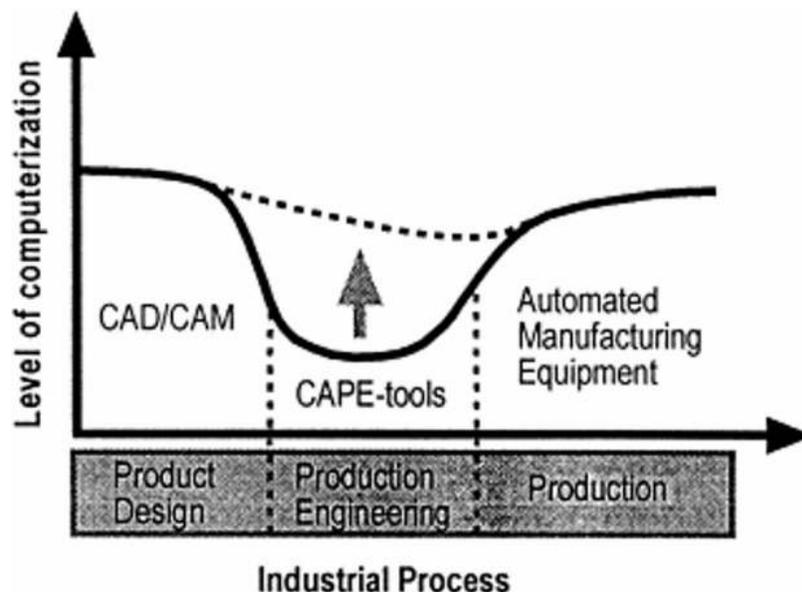
Our approach is to develop a virtual reality system that allows interfacing with a flow simulation via a tool of simulation. In the next chapter, we will show the architecture of our approach in a more detailed manner and an academic example that explains the interest of this approach. In this chapter, we show the architecture of our approach in a more detailed manner and an academic example that explains the interest of this approach.

Since the 1990s, the increasing demand for improving the efficiency and quality of production has gradually led industrials to seek solutions of computer software to master the various processes of production. With the considerable development of computer science, these tools are now available to control the different stages of the life cycle of a production system.

For the design stage, there are several tools of computer aided design (CAD) softwares, such as Catia, AutoCad, SolidWorks and ProEngineer etc. As well tools of CAPE (Computer Aided Production Engineering) are more specific to production systems such as Delmia, Tecnomatix etc, or the simulation tools flow, such as Witness, Arena, Promodel, Automod, eM-Plant, Quest etc. In industry, we used these simulation tools flows mainly in the design phase, for the design of a new production line or a new workshop. And by Klingstam, the virtual reality tools will do part of future of the production systems simulation (Klingstam & Gullander, 1999).

For the stage of data operating, there are several tools tailored to different levels of decision making such as APS and ERP used for medium and long term strategic decisions well as other operational tools of workshop for short-term scheduling. Before about ten years, tools of MES (Manufacturing Execution System) appeared, which have several functions and services more advanced compared to the simple supervision of model (the ISA 95 standard).

Figure 3. CAPE Tools: bridging the gap between product design and production (Klingstam & Gullander, 1999)



The main objective of our research is to develop a system of interfacing that allows us to connect a flow simulation tool with a virtual reality system to be able to master the simulation models hiding all the technical aspects of the simulation through a data exchange protocol in real time and also the tools and techniques of virtual reality, and also for happen to implement a flow simulation tool interactive and immersive. In the remainder of this part we will describe the different tools and technologies of simulation, and in the second part of this chapter, we present various researches in virtual reality which treats industrial problems that will be discussed.

## **5.1. Tools of modeling and simulation « ARENA© »**

Among the software tools most used in the modeling and simulation of industrial processes, we find that ARENA tool does not cease to evolve since the late 1990s. The ARENA modeling system is a flexible and powerful tool for industry analysts to create a simulation models for representing an industrial system. ARENA was published by (Takus *et al*, 1997); it is based on an object-oriented design to build a graphical model. The operation of this tool is simple; just we placed the graphic object called module in the ARENA scene to define the system components such as machines, operators and conveyors etc. ARENA uses the SIMAN simulation language to compile and run the models. After preparation of the simulation model, ARENA automatically generates the underlying model SIMAN to run in order to have the final result of the simulation. Graphical components used by analysts to create models are provided by the software. These components can also be tailored by the analyst to produce a modeling environment which is adapted to a specific field of application, the resulting collection of modules created by the user are contained within a model of application solution that can be shared by any users of ARENA.

### **5.1.1. Human machine interface of ARENA**

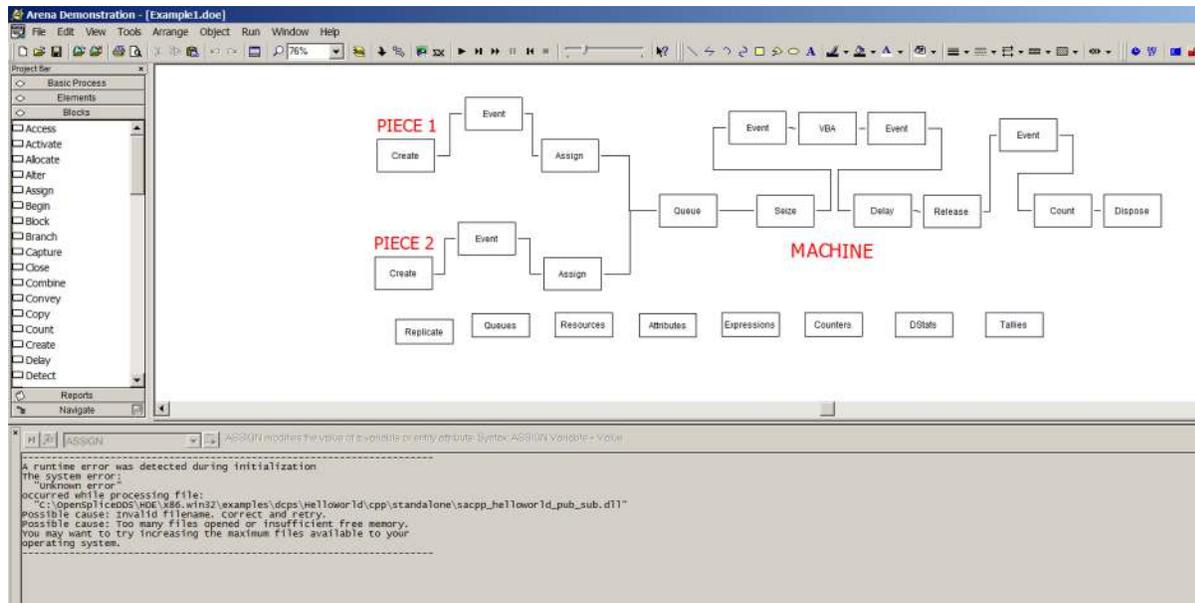
ARENA contains a base collection of over 60 graphical components in the general context of the system. It was designed to provide modeling capabilities for all types of applications. ARENA offers modules specifically focused on aspects of manufacturing and industrial management, etc. For the manufacturing process, the tool provides specific components such as machine downtime, calendars of events, etc. ARENA interface consists of three panel modules: a common panel containing modules representing the fundamental process simulation such as departures, arrivals and service; support panel containing additional modules for actions and decisions; and the transfer panel, which is a panel of components that are used to model the transfers (or flows) of different entities throughout the system.

The animated 2D of simulation model is automatically included in the ARENA modules to allow a simplified representation of these models. To apply animations to a model, we can use the graphical symbols that are automatically provided when you manipulate an ARENA model and we can edit with the integrated module of the graphic tool. We can use also the icons in the graphics library of Arena or other external applications (e.g. clip art) to set up an animation of a simulation model.

### **5.1.2. Animation 2D with ARENA**

The animation in ARENA can be launched simultaneously with the execution of the simulation or in post-processing mode. We create animations using the drawing tools of Arena, or from an AutoCAD

Figure 4. Human machine interface of ARENA



file or these animations can be created in other tools and imported into ARENA via Active X (Takus *et al*, 1997). Drawing tools of Arena include all standard objects such as rectangles, ellipse, arc, text, etc. and also provide a virtual unlimited palette of colors. The Arena interface was developed to allow direct import of CAD drawings and association of an animation and dynamic icons for the model. Once the drawings are imported into Arena, the user can enjoy the drawing tool integrated in ARENA for the implementation of the animation of model.

### 5.1.3. Custom development of AST'S with ARENA Professional Edition

The user can create his custom collection of graphical components using the features of the professional version of Arena. For example, an analyst in the automotive industry could develop an AST (Application Solution Template) personalized which allows simulating the welding lines.

### 5.1.4. The core of ARENA « SIMAN »

The technology which bases on ARENA is the SIMAN simulation language. The different modules of ARENA were created using blocks of modeling and components of the SIMAN technology. The modeling blocks of SIMAN are accessible to all users of ARENA. SIMAN offers to the user some flexibility and control of system logic. There are users who are used to program « with SIMAN » simulations directly in a text editor, they can still do that into ARENA. This tool offers a module allowing direct compile of the code which is an external file to the environment of the graphical modeling.

### 5.1.5. The Interactivity of ARENA with other tools

ARENA is a software complied with Microsoft Windows 95 and Windows NT. Arena was developed using the computer practices of Microsoft “MFC”, ARENA is based on the object-oriented approach and is developed in C++. The open architecture of Microsoft allows us to integrate external data and even other applications with arena, via communication protocols such as TCP/IP, dynamic link libraries “DLL” or a data module Real-Time.

## 5.2. Tool of modeling and simulation « WITNESS »

WITNESS is a computer tool for modeling and simulation of production systems, among several other tools that are essential for industry. Following the flexibility and openness of simulation tools available today, we can now control all aspects of the organization of industrial engineering and manufacturing (Markt & Mayer, 1997). The WITNESS as well as several other software allow to simulate a factory from the initial design process to a fully functional factory. Witness is composed of several modules such as: MATFLOW (a system of flow planning) Witness Simulation Software, WITNESS OPTIMIZER. In the rest of this section, we will detail the different modules of Witness.

### 5.2.1. System of flow planning: MATFLOW

In the case where an industry is embarking on a conception of new installation of production system or redesigning an existing site, MATFLOW is a flow optimization system for production systems which allows us to manage the different logistic flows. This MATFLOW module (Markt & Mayer, 1997) is also integrated into AutoCAD, which allows us to save time and money on dealing with models of AutoCAD and then to export them directly to WITNESS. MATFLOW allows optimizing the configuration of the components by calculating the total debit of pieces. MATFLOW uses several techniques to manage the flow such as the calculation of pieces numbers with calculating their distance traveled, other characteristics of materials can be taken into consideration such as volume, weight or cost. So to summarize, MATFLOW allows to generate a simulation model, which can then be used to simulate the real production process and provided the necessary information of the operation of the system. MATFLOW uses “CAD layout” files, which are standard formats for the exchange of data between different tools in the field. This format provides a description of the different parts of the factory: calculation of production time, the size of batches for each machine and the calculation of the buffer size of the machines. AutoCAD allows us to prepare the factory model on a CAD layout plan, in the figure below the flows are represented graphically by arrows to indicate traffic of products. The optimization of CAD layout can be done manually or automatically. The manual method is to swap the positions of the machines or buffers; MATFLOW comprises an automatic optimization function that allows testing different scenarios.

In the case where an industry is embarking on a conception of new installation of production, the various parameters of the model are also transferable to WITNESS; they allow us to determine the capacity of the buffer lines and the machine capacity. Other features of MATFLOW allow the user to:

- Define groups of machines, or cells and units of productions or services.
- Represent the various inputs and outputs of machines.

### 5.2.2. Simulation study in WITNESS

Once the significant results of the optimization of the layout of MATFLOW are available, the simulation study process can be started using Witness, a real tool for modeling and simulation. The module MATFLOW supposes that there is a capacity for all flow-optimized. The next step is to evaluate the interaction between the different product lines that can share a resource. The optimization of manufacturing flow is provided by MATFLOW. WITNESS is used to simulate complete production systems. This allows industrial actors to design an installation to get a glimpse of how the production lines could work in reality. This is a good way to predict and solve any problems and inefficiencies that may be present on the production lines.

The Witness modeling module is able to model a variety of continuous and discrete events. The most basic elements of discrete modeling are: pieces, storage buffers, machines and conveyors. The pieces are simply objects that move from one machine to another on the production line. The buffers are areas of passive storage, where pieces must pass within a minimum delay and they cannot remain in the buffer longer. A piece can possibly be ejected from a buffer if it violates any of these conditions.

### 5.2.3. Graphical interface of WITNESS

The human machine interface of Witness is compatible with Windows. The main interface of the software consists of drop-down menus and toolbar. The operation of the simulation is controlled by a button bar below the screen (start the simulation; stop the simulation, etc...). The most activities of the simulation take place in the main window where we can find different elements of the simulation using the drag-and-drop mode, these widgets are predefined elements that can be used to formulate a simulation.

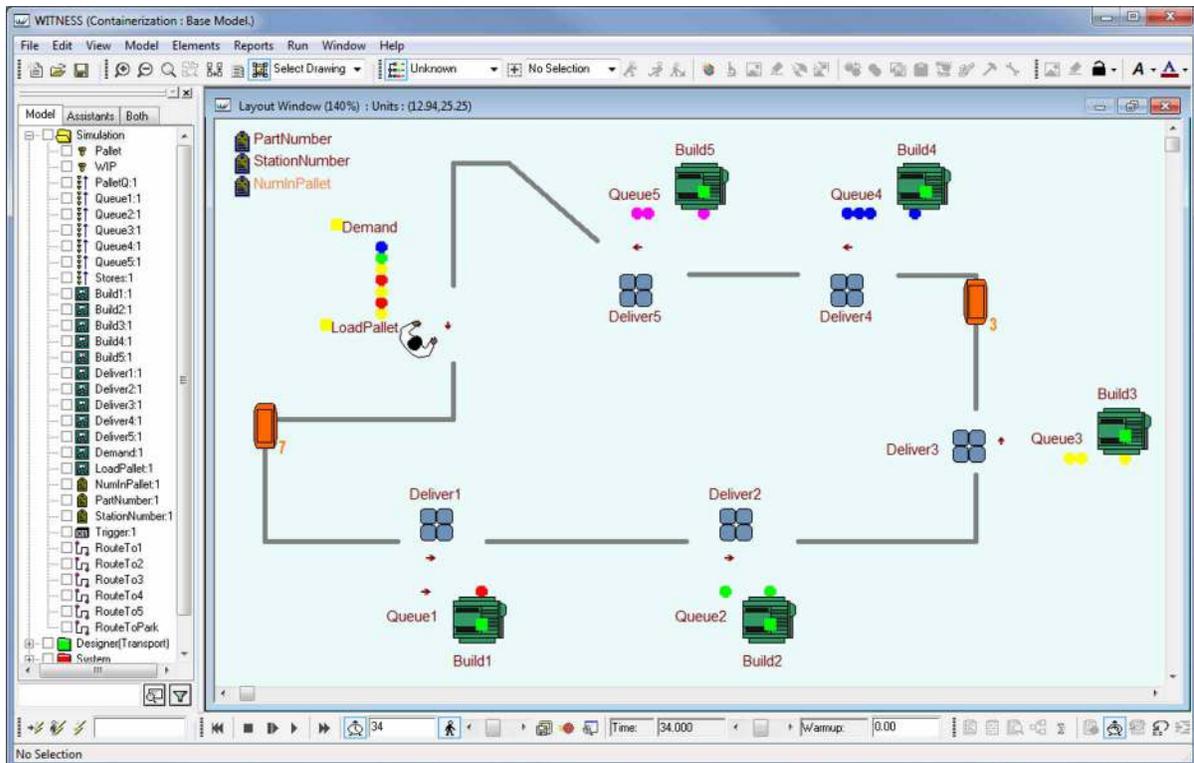
## 5.3. Tool of modeling and simulation « QUEST »

Today, all actors in the digital industry direct their research to the design and creation of tools that allows us to digitizing and simulate the industrial world. These montage technologies and virtual simulations allow to avoid or reduce the production of physical model thus to improve the quality and efficiency of montage and also to shorten the cycle of product development and to reduce the cost of production. There are several digitizing tools and industrial simulations such as « QUEST » by “Dassault Systems”. In this part of chapter we present the particularity of this tool and some examples of work that uses it. QUEST is always proposed with DELMIA. The combination of tools DELMIA / QUEST is used to help the aerospace, automotive and other areas such as teaching in universities and to strengthen the culture of competitiveness in the aerospace industry (Bzymek *et al.*, 2008). QUEST offers a unique collaborative environment for industrial and manufacturing engineers, QUEST / DELMIA provides the best management practices workflow throughout the industrial process. QUEST / Delmia, we can create virtual factories and represented in 2D and 3D formats.

QUEST offers modeling tools (models predefined of machines, pieces models and other elements) that allows users to create a model of efficient simulation. Figure Below shows the human-machine interface of QUEST.

Using QUEST enables users to develop models for simulation and industrial installations, simulate process flows on these models and incorporate ergonomic constraint. The results of the simulation can be exploited in various graphics representation tools, so the data simulation can be extracted and exported

Figure 5. Human-Machine interface of WITNESS.



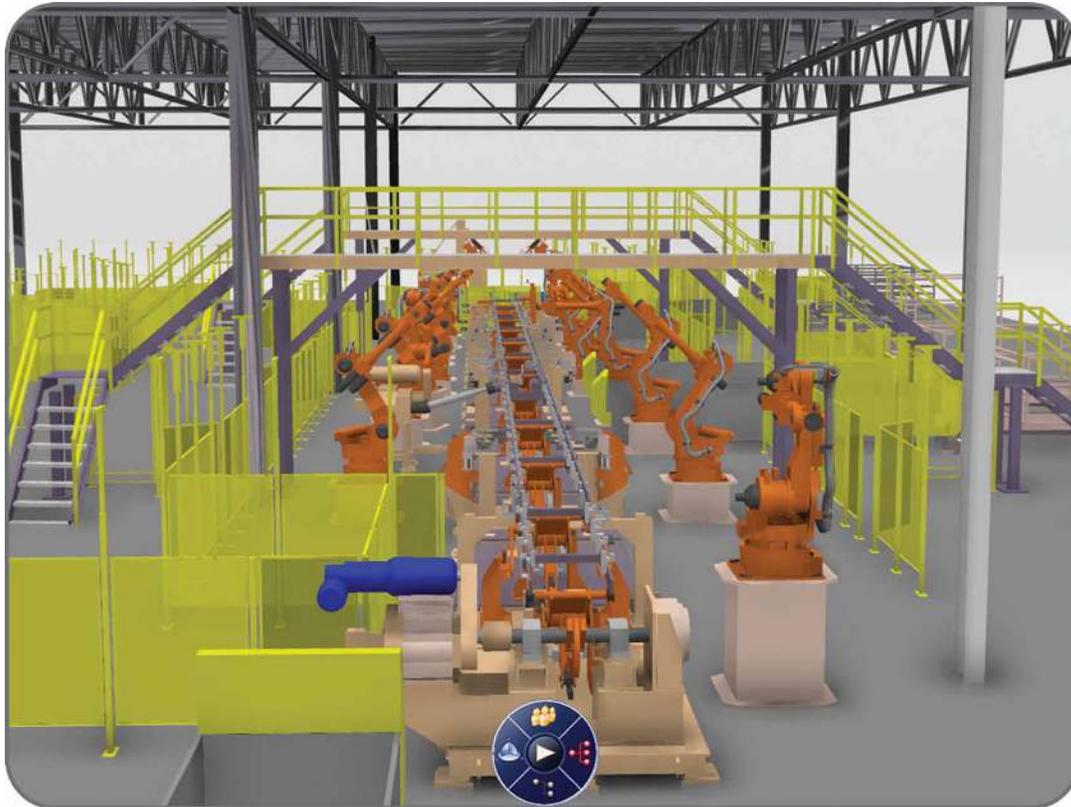
to various tools such as Microsoft Excel. QUEST provides possibilities to operate production variables in the virtual factory such as the duration of machining processes. These variables allow us to analyze the effects on different equipments of factory (Bzymek *et al.*, 2008).

The Simulation Control Language (SCL) and the Batch Control Language (BCL) can be incorporated into the simulation model to handle a complex production process. Full documentation allows us to use those languages that can be found in QUEST. Using this tool, users can view and prevent potential problems related to industrial flows, and improve existing processes. QUEST is powerful to design industrial models. In fact, it analyzes and visually represents data and complex manufacturing processes to facilitate the representation and the understanding of different manufacturing processes.

#### 5.4. Reviewer and Our Proposed Approach

These tools of flow management are available today on the market and they presented many solutions for modeling, optimization and simulation of production processes. The users of these softwares have a particularly important role in this field: the experts can predict the evolution of charges of a production system throughout its operation, which allows to deduce several obstacles for simple users (René & Chevance, 2001). All these products tend to improve 3D rendering with each new version, confirming the market demand to disseminate the results to a wider audience. But they keep the following limitations:

Figure 6. Human-Machine interface of Delmia (Delmia, 2006).



- They require expertise in flow management, implementation and exploitation of results of flow simulation.
- Absence of interactions with the simulation: visual 2D represents the final results of the simulation in the form of an animated film. The only way to change the presentation is to re-configure the model of simulation.
- There is no consideration of human constraints (feasibility analysis and assessment of fatigue).
- There is no consideration of the dynamic behavior of the elements of the scene.

Our main objective is to develop a solution that combines a flow simulator with a virtual reality system while gradually refining the performance of the simulation model through dynamic data exchange using practical computings and virtual reality techniques. The challenge is to apply the concept of dimension I<sup>3</sup> “Interaction-Immersion-imagination” (Burdea & Coiffet, 1993) to develop an abstraction layer between the techniques of simulation and industrial actors on integrating virtual reality techniques. For this we propose to tackle this issue of flow simulation using virtual reality techniques to immerse the user in an industrial 3D scene that simulates different manufacturing processes.

## **6. VIRTUAL REALITY AND ITS CONTRIBUTION TO THE INDUSTRY**

In this section, we will mainly introduce the virtual reality technology and its contributions to industrial design, numerical production, virtual training and the simulation of industrial processes through examples of previous research works that address issues related to the industry.

### **6.1. Virtual Reality**

The Virtual reality as defined by Arnaldi, Fuchs & Tisseau (2003), is: « Scientific and technical domain exploiting computer science and behavioral interfaces to simulate in a virtual world the behavior of 3D entities that interact in real time with each other and with one or more users in pseudo-natural immersion by means of sensorimotor channels ». The immersion and interaction present the most important phenomena for applications VR, for this we should implement techniques which allow to immerse the user in a virtual world via sensory-motor interfaces whose purpose is to deal with virtual processes. The user receives a set of information through these sensory-motor interfaces such as: return immersive 3D on a big screen, force feedback through a haptic arm which reflecting the collision with virtual objects etc. The interaction with the virtual scene requires an interface of sensorimotor control as haptic arms for seizure of virtual objects, the motion capture system which can control a virtual avatar, data gloves etc. The VR technology is used in several domains such as video gaming, health, biology, military operations, education, learning and training etc. Today there are several types of virtual reality applications such as tele-presence applications for virtual conferences (Kantonen, Woodward, & Katz, 2010), the tele-operation (Tarault *et al.*, 2005) and industrial applications (e.g. validation ergonomic positions work (SIMCORE & CLARTE, 2013)), the immersive applications for visualization the specific results for the analysis of complex data and decision support (Eddy & Lewis, 2002).

Today, this technology became available for the industrial world, having been reserved for long time by major public research centers. Often considered as an extension of the simulation, the VR is distinguished by the fact that it offers a good level of immersion (display, touch etc.) to users. The VR allows the modern industry to simulate industrial processes in an efficient manner; it gives the opportunity to interact with the simulation model. A virtual simulation system includes a set of sensorimotor interfaces and controls the behavior of simulation in comparison with models programmed.

### **6.2. Virtual and Augmented Reality for Industrial Design**

The aided design of virtual reality is a terminology of modern industry. This concept was introduced by Richir & Fuchs (2003). Today there are several research projects whose aim is to find solutions to meet the needs of virtual design. May be mentioned VR4D: Virtual Reality for Design of CLARTE (VR4D, 2013) which is a solution to help create virtual reality for design. The VR4D project presented a tool of virtual reality which allows a construction of small spaces because living areas integrated into land or air buildings represent an important industrial challenge. Several industrial organizations today promote the use of virtual reality systems in various stages of design and model validation. There are other projects which tackle the virtual design as VirtualiTeach (VirtualiTeach, 2013): This project integrates firstly a complete hardware platform based on the technologies of virtual and augmented reality, and secondly a

set of software applications implementing an educational content inherent to the teachings concerned. The objective of this project is to follow up the design of mechanical parts and its car mounting. This is done by immersive situation in learning environments for visualizing the interaction with what is usually invisible such as the distribution of heat in a room with a coloring process.

Other researchers are using augmented reality technology to address issues of design and virtual simulation. Lee *et al.* proposes a design method of numerical production environments based Mixed Reality technology (Lee, Han, & Yang, 2011). This method allows integrating virtual components with others real, in a virtual production system with the aim of establishing a better configuration of a production system. Other researches targeted collaborative projects for the design in PLM environment (Product Life-cycle Management). This approach integrates knowledge based on engineering of industrial process; it uses multi-agent systems in platforms of virtual reality. Researchers at LSTB (Laboratory of Systems and Transport of Belfort) are working on the development of this approach. They propose an architecture for collaborative systems (Mahdjoub *et al.*, 2010) which allows aiding the design of industrial processes, and the analysis and simulation of these processes in a virtual environment are using techniques and tools of virtual reality. Lindskog *et al.* have used the mixed reality technology (virtual and augmented) and 3D imaging techniques to study the design of industrial systems (e.g. production lines and workstations) before their real implementation (Lindskog *et al.*, 2013). This allows evaluating the implementation of a new machine and its configuration before actually installing.

There are other types of systems that allow the prototype design. Choi *et al.* show in their paper a system for virtual prototyping (VP) for digital manufacturing of multi-material prototypes to facilitate rapid product development (Choi & Cheung, 2008). This system is based on an immersive environment “CAVE”, whose objective is to allow a team of designers to analyze the quality of product design and to collaborate on their design work. Thanks to a simulation module, the system enables to evaluate and modify the models without any loss of materials prototyping. This type of system improves collaboration and communication of a team of designers working on product development.

Stark, Israel & Wöhler (2010), and Wiese *et al.* (2009) have developed a hybrid immersive environment for modeling virtual prototypes with VR technology. They noted that current modeling tools are only paper and CAD systems, even if they are complementary to some extent, there is still a lack of fluidity and intuitive interaction with the model. The figure below shows a designer that is about to model a prototype with the system of VR, and right figure shows the transformation of the model to a final prototype.

Today, there are several systems that support the model creation and modification in an environment of RA based on the use of interaction tools in 3D. Construct3D (Kaufmann & Schmalstieg, 2003), is a project developed for mathematical and geometric uses. The constructions of primitives can be created and displayed in a 3D space, as shown in the figure below.

Other environments of computer aided design and AR such as ARCADE, have been developed to facilitate the interactive design of model as shown in figure below (Ng, Ong, & Nee, 2010), where users can create new designs by modifying and combining virtual and real objects. The user can create and modify 3D models using methods of interaction based on markers. This design approach allows users to draw models; it's visualized and contextualizes then in a real design space. Ng, Oon, Ong & Nee (2011) have presented a design environment based on motion capture of fingers in the context of AR. Using gestures of fingers, the designer can visualize and manipulate a 3D model in an environment of AR, also evaluate the design and make changes that will be taken into account in the model as shown in the

Figure 7. Design of VR prototype (Stark, Israel & Wöhler, 2010).



Figure 8. The system Construct3D (Kaufmann & Schmalstieg, 2003).

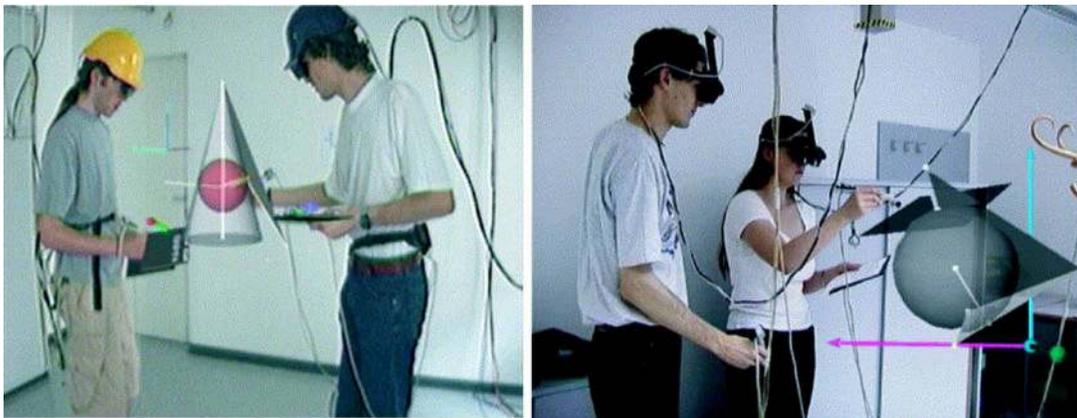
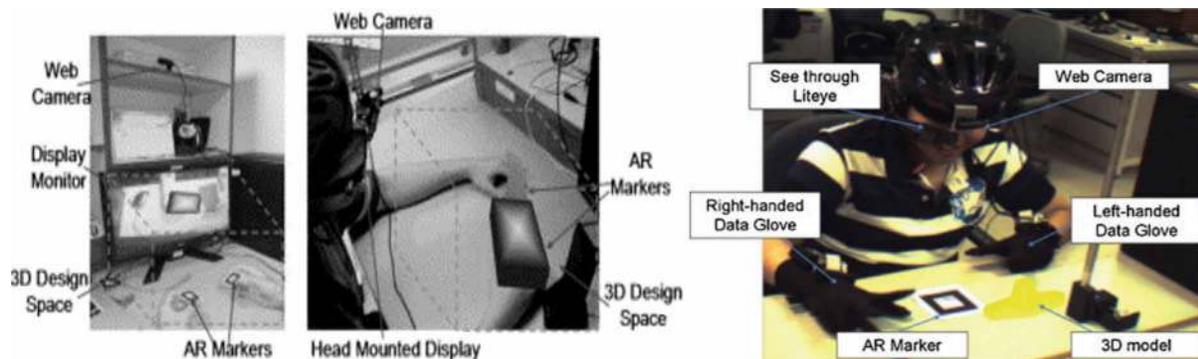


figure below: GARDE. This allows the user to contextualize the model in the work environment and to take into account the spatial information of the real stage for the implementation of the model. GARDE is a prototyping tool augmented and it benefits at the same time the benefits of a physical and virtual prototype, such as realism of the model, the ease of modification and contextualization.

In industrial environments textile type, we need an accurate representation of the virtual model, the virtual shadows can improve communication between users by providing locations and gestures of other users in a collaborative design system. The shadows do not allow us to locate the vertical position and

Figure 9. AR-3D modeling (Ng, Ong, & Nee, 2010) (Ng, Oon, Ong & Nee, 2011).



can only provide a direction approximate of pointing. Therefore, it is not easy for the user to choose a specific characteristic of a complex model. A collaborative design environment, including the visualization features VR and AR has been suggested by Chryssolouris *et al.* (2009).

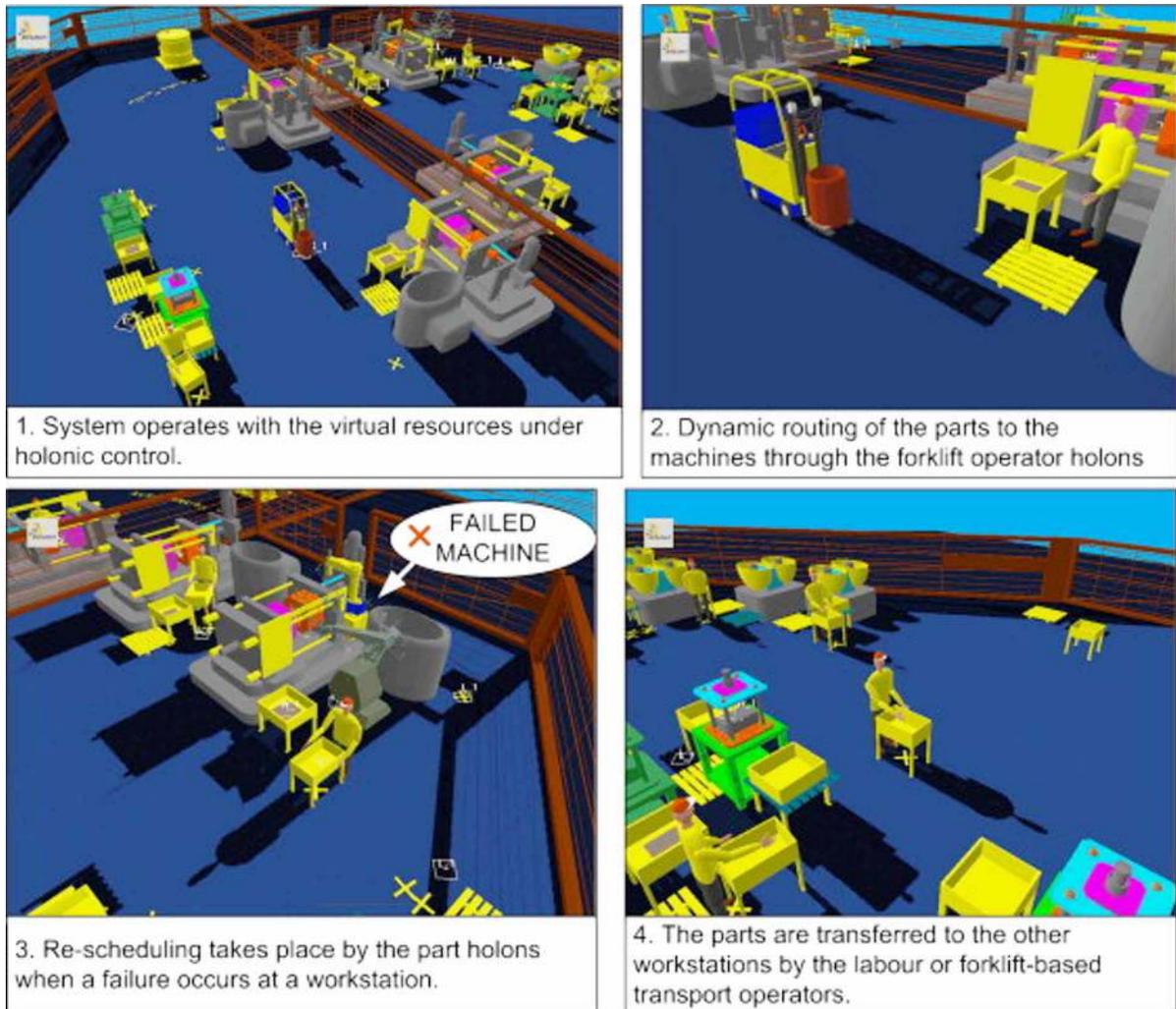
To cope with the competitiveness in product design, Pouliquen *et al.* (2007) propose a solution based on virtual reality techniques. The researchers have been worked on the modeling of virtual hands to interact with models of a virtual environment; the authors integrate the requirements of health and safety. In his work, Pouliquen shows the design techniques of virtual hands which are coupled with gloves equipped with a motion capture system and a device of force feedback. With this system, the operator can interact with the models of a virtual environment in real-time.

Some specific searches to the design of industrial cables conducted by Raymond, James, & Graham (2009) led to the development of a VR system for modeling virtual cables. This system is called COSTAR (Cable Organization System Through Alternative Reality), which allows to design, assemble the plans of cables, to analyze automatically the design activities and to generate assembly plans in an immersive environment of VR. Bal & Hashemipour (2009) propose a methodology based on virtual reality to improve the process of design and implementation of holonic control systems in manufacturing practice. The main objective is to implement a holonic controller in small and medium-sized of manufacturers. As part of this research, Bal *et al.* have launched a case study in a manufacturing factory format of molding with a medium pressure. Thanks to the virtual factory, architecture of holonic command for a manufacturing system has been implemented for the dynamic scheduling of machines in a factory of average dimension, to ensure of the robustness necessary to treat the productive disorders.

### 6.3. Virtual and Augmented Reality for Numerical Production and Virtual Training

To manage the various processes of industrial production, industry actors are now using a new generation of technologies and innovative tools. Several researches in virtual and mixed reality address the issues related to industrial production in general, as well as visualization, manipulation, presentation and use of production models. Mention may be made to one work in this area, a project launched by the electronics giant Canon which is based on mixed reality technology (MR System, 2012). This work presents a system to aid the design and development of new industrial products, it allows designers to visualize

Figure 10. VR module for the control of transport operators (Bal & Hashemipour, 2009)



and interact with the product in collaboration with virtual three-dimensional objects placed in a real environment. The main objective of this system is to reduce the number of prototypes needed to develop a new product for mass production while compressing costs and minimizing environmental impact.

One of the key issues in using virtual reality for the simulation of complex industrial sites is to ensure the consistency of the models used at the different steps of the design process. Furthermore, reusing these models for the virtual training is needed to support various learning scenarios. Designing these environments independently to existing CAD models would result in unrealistic costs and extra workload. Recent works has been done to propose a unified approach of system modeling that ease the reuse of existing models for the production of informed virtual environments (Chevaillier *et al.*, 2011). This approach makes the virtual environment the single source of information, used (1) to support the real-time simulation of the environment, (2) as the shared knowledge-base of the virtual agents (e.g. Operators on a production line), and (3) as learning resources for educational agents (Marion, Querrec & Chevaillier, 2009). In this approach, not only geometrical files, but also the semantic modelings of

Figure 11. Canon MR System (MR System, 2012)



the industrial process (including procedures) are processed as input data. It is then possible to design non-specific VR simulation platforms and to develop generic educational agents as in (Buche, Bossard, Querrec & Chevaillier, 2010). This model-based approach is based on the standard modeling language SysML (Querrec, Vallejo & Buche, 2013). This approach has been successfully applied to the design of next generations of aircraft carriers (Marion, Septseault, Boudinot & Querrec, 2007). It is possible to evaluate different configurations for the decks and to estimate system-level capacities and to validate takeoff, landing and refueling procedures before the building of the vessel has started. Very similar approaches have been followed by (Barot *et al.*, 2013), (Edward *et al.*, 2008) and (Gerbaud *et al.*, 2008).

Other works deal with the problems of process planning and the production lines. The Boeing researchers have used the mixed reality technology for the implementation of a solution to assist in the design of cockpits (Caudell & Mizell, 1992). In general, such researches allow optimizing the methods of industrial production. This can be done by allowing for example operators to easily understand assembly procedures by displaying information on parts with images that indicate the order of assembly in a manufacturing line. As regards to the introduction of a finished product, the augmented reality provides the important techniques for prototyping process. For example, in the automotive industry, this technology has been used to evaluate the interior by superimposing different car interiors, which is generally available only with 3D models in the initial stages of development, on the model of the actual car (Fründ *et al.*, 2005).

In 2000, research conducted by Duffy & Salvendy (2000) has been presented as the first studies that address human and organizational aspects of the development of global products and virtual training in industries of manufacturing and services. Other works launched by Ladeveze *et al.* (2010) which present an interactive system of VR destined primarily for training. This system allows us to have a haptic real-time guidance for the assembly of CAD objects or tasks dismantling. The principle is to guide the operator through an artificial haptic orientation or choose not to follow the path and automatically search new routes for the purpose of training operators for assembling mechanical components of ALSTOM.

To address the needs of learning and training using simulation techniques in virtual reality, research launched by Manca, Brambilla & Colombo (2013) shows training approach based on virtual reality. This approach allows to improve the cognitive preparation of operators addressing the three components of the consciousness of situation (Experience: to master the factory and these units; comprehension: understanding their meaning and purpose, learning: how to project the current situation in the near future). This work discusses the benefits of integration and interconnection of a dynamic process simulator with a dynamic crash simulator to train operators (particularly field operations) to master the abnormal situations and to recognize the anomalies and malfunctions. The author has implemented this research in a deployed application on the VR platform as the figure below shows.

#### 6.4. Virtual, Augmented Reality and the Simulation of Industrial Processes

The use of existing tools today for the simulation of various industrial processes, requires a good knowledge and expertise in the relevant field. Many industrial actors do not have this purely technical expertise. Therefore to allow them to participate in the analysis, optimization and validation of simulation models of different processes, many researchers sought to develop innovative solutions that allow for an abstraction between the methods and simulation techniques and non-technical stakeholders. Dangelmaier *et al.* (2005) propose a VR system to visualize a 3D simulation of a manufacturing line as shown in figure below. The objectives of this system are to assist users in the design phase of production models, validate these models and help optimize a production system.

There are other works that deal with specific issues such as production simulation in aerospace. Caggiano & Teti (2012) propose an innovative solution for digital simulation. The main feature of this solution is to aid the design and simulation of an existing cell of manufacturing components of aircraft engines to be improved by automated robotic deburring. Why the researchers put in place an application of 3D motion simulation is to illustrate the design of handling systems of materials. This system uses a discrete event simulation to analyze the different scenarios and improve the performance of the manufacturing cell.

Figure 12. The operator is immersed in the virtual environment (Manca, Brambilla & Colombo, 2013)



Figure 13. Visualization a simulation of a manufacturing system (Dangelmaier et al., 2005)



Multiple approaches and specific methods of design engineering and simulation of production processes are possible today thanks to various technologies. Tolio *et al.* (2013) seek to develop a new concept that offers the possibility of integrating various tools for design, simulation and analysis in a single solution. This concept allows supporting interoperability between these tools throughout the life cycle of production. The researchers in the field of architecture are generally concerned with solutions of simulation and learning of construction modes. Goulding *et al.* (2012) propose a VR solution for the simulation and learning of the most important techniques in construction of buildings. The main goal of this solution is to provide a work environment that allows different actors of industry (e.g. project managers, construction managers, architects, designers, suppliers and manufacturers) to have a multi-disciplinary learning via a VR simulation of a construction site.

Lee, Han & Yang (2011) work on a simulation system based on mixed reality to simulate industrial operations in a virtual factory. This system enables manufacturers to launch virtual operations in order to analyze the feasibility of a solution in a real context and see their evolution over time. Leu *et al.* (2013) present in his article a state of the art which describes the various methods used to develop CAD models and the systems of simulation for the assembly of prototypes, planning and training. The author also present methods for the generation of CAD models from digital data acquired. This concerns the capture of movement, the assembly modeling, as well as human-machine interfaces. Leu et al. introduced a method for exchanging data between a CAD system and a VR system. This article described the implementation of these methods and provides examples of application of simulation based on a virtual model for the assembly of prototypes, planning and training. In a recent study addressing the treatment of simulation and control of different stages of PLM, Fillatreau *et al.* (2013) propose a solution of virtual reality that allows manufacturers to navigate in a 3D scene, and manipulate virtual components, whose purpose is to simulate and validate the various operations of a stage of PLM. The main objective of this system is to enable companies to improve the traceability of project reviews, decisions and documentation in all phases of the PLM.

Mujber, Szecsi & Hashmi (2004) propose in their article a classification of industrial applications VR, according to which there are three groups: design (modeling and prototyping), operations management (planning, simulation and training) and manufacturing processes (machining, assembly and inspection). This demonstrates a wide range of demand of VR in the industry. Today the VR is far from reaching all stages of PLM (e.g. validation of product requirements, validation of simulation models, simulation of

flow, acceptance of products: are not really addressed by VR applications). The existing studies in the literature that address the integration of VR in different stages of PLM always focus on a particular stage.

Today, in the current market there are tools of simulation and planning of industrial platforms that are already marketed and use 3D technology. These systems are often used for the simulation of the fabrication and the implementation of a plant of factory in an industrial platform. We present in the figure below three commercial products, Tecnomatix Factory FLS (2013) by Siemens, Teamcenter Manufacturing Plant Simulation (2013) by UGS and MPDS4 Factory Layout (2013) by CAD Shroer. These products have a good market share in industry. All systems of VR quoted in this part of state of the art are quite similar because they all provide a visual platform with a 3D rendering. These tools are designed to meet the following industrial needs: design of prototypes, validation of maintenance process and machining, the validation of the ergonomics of various industrial operations, simulation of plans of the furnishings, the simulation of the manufacturing process, the evaluation of the establishment of industrial components in a virtual platform, the simulation of machining and assembly operations etc. These systems 3D simulation are used to visualize and refine the theoretical results before setting up the actual process.

Several researchers are beginning to implement the results of their research in the design and evaluation of manufacturing systems through augmented reality applications. Gausemier & Frund (2002) have established a system of AR which allows designers to define and evaluate their models of manufacturing systems utilizing a webcam and markers in a real environment, as shown in the figure below. Other similar systems are presented by (Doil & Schreiber, 2003). These AR systems follow the same concept of VR systems.

Marc, Belkacem & Marsot (2007) propose a method for validation of simulations, presented as a tool to three layers (Simulator, Simulated, Simulation situation), the tool consists of a projection system and a force feedback interface. The validation method of the proposed simulations in this paper is developed in a complementary module of the system; the internal validation is based on the capability of the simulator to reproduce the features of the real system. The validation includes an apparent validation (realism control) and functional validation (controlling the behavior of real technical system).

In the world Aerospace, Harris & Morgenthaler (2004) present with their team of experts in visualization 3D their development of simulation tools for virtual prototyping. For realizing the tests on flight operations and visualize in real time the design and planning of the missions of aerospace as the two figures below shows. There are other innovative solutions using immersive 3D visualization to simulate planning, optimization of phases of technical design of future aerospace missions.

Takeda *et al.* (2008) have developed a simulator for the maintenance system remotely using software of robotic 3D simulation. This simulator is connected to a manipulator control system that was developed

Figure 14. Simulation tools of manufacturing processes



Figure 15. Design of manufacturing systems in AR (Gausemier & Frund, 2002)



Figure 16. The functioning of deployment of Titan IV / Milstar (Harris & Morgenthaler, 2004)



as part of the maintenance system. It allows reconstructing positions of the manipulator using position data transmitted by the engine through a local network. It can also be used for operator training. In the context of research in the field of design and numerical simulation, Xinhua, Youhui & Qi (2011) propose a system of virtual montage that is based on 3D simulation tool « Delmia ». The technique is to create a virtual prototype and simulate the whole assembly process in a virtual environment « Delmia ». This system allows avoiding or reducing the production of physical models, therefore it can not only improve the quality and efficiency of the montage, but also to shorten the cycle of product development and to reduce production costs.

The design process of automated manufacturing systems typically involves physical prototypes, which are expensive, to validate the interactions between hardware and software components. Weber-Jahnke & Stier (2009) propose a VR system which aims to improve the prototyping process by making virtual

prototypes. The approach proposed in this paper presents a combination of a VR engine capable of simulating in 3D laws of physics rigid bodies with industrial modeling software to control the prototype simulated using virtual sensors.

Today, virtual reality tools for the simulation of manufacturing processes present a lack of realism and interaction. Despite the remarkable progress in the development of algorithms for collision detection for convex objects, only the collision detection algorithms for non-convex objects remained limited. Tesic & Banerjee (1999) propose a methodology to encapsulate the characteristics of virtual objects for collision detection and automatic procedures for creating virtual objects and their separation into convex pieces. This methodology is suitable for interactive simulation, it can be used in many contexts such as: the virtual assembling, the simulation of industrial robot, also in processes where the modeling precise has a high level of collision detection such as robotic paint, robotic welding and the operation of machining to numerical control.

There are other sectors of industry that requires the use of techniques of simulation and evaluation such as construction. According to Li, Chan & Skitmore (2012), the construction is probably the most dangerous sector in Hong Kong, accounting for 76% of fatal accidents in the region, twenty times more than any other industry. Li *et al.* proposed a safety assessment method presented by a 4D interactive evaluation system that provides an improved security technique. This system allows interacting with risky scenarios and a range of possible operations for treaties, the method provides a grid of evaluations of operation chosen by users.

The strategic constraints of health type and legality in the industrial world are pushing researchers to study and simulate the noise of machinery in a factory environment. Aurich *et al.* (2012) proposed a new concept to study the level noise in an industrial context, the establishment of a method of virtual reality using the acoustic measurements of a real factory to have a realistic simulation. This approach allows to reduce the downtime during the improvement process and to test the different scenario of improvement. To represent the simulation results, the researcher uses a CAVE (cave automatic virtual environment). This system provides modules to check the noise level taking into consideration the various regulations.

## **7. CONTRIBUTION TO THE SIMULATION OF VIRTUAL MANUFACTURING**

The main contribution of this chapter is to present an innovative approach, also an architectural design of our VR system which allows simulating the flows of production, to estimate the states of a manufacturing process, to validate the operations of assembly and to interact in real time with a simulation of the considered manufacturing process.

This system is implemented in our VR platform, where the user will be totally immersed in a virtual scene in 3D. This system allows the user to move in the virtual stage and to change the point of view of the virtual camera through the capture of movement. To manipulate and interact with the objects in the virtual scene we use the VR joystick. The interactive VR system is connected to a flows simulator as shown in figure below (Figure 22), which allows to visualize a simulation of flows of production in the course of execution and to interact with it by changing its configuration and its parameters on the VR platform. This system democratizes the use of simulation tools by rendering accessible to any industrial actors, the techniques and methods of the simulation of production systems. Such an approach makes it possible for the industrials to have a global vision of their systems of productions to estimate the weak points so as to be capable of bringing corrective actions.

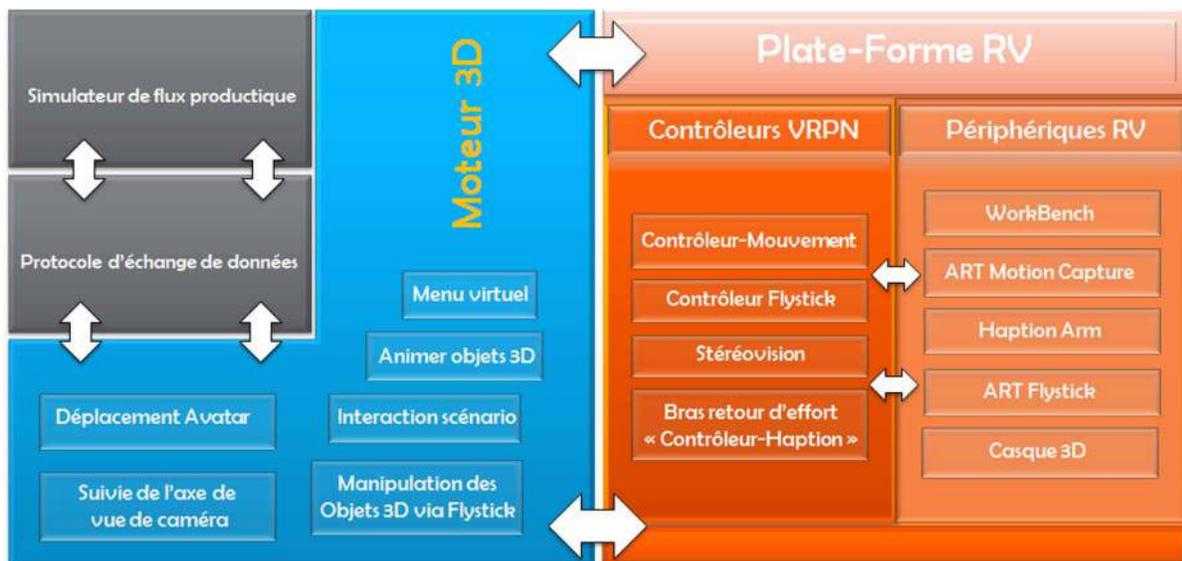
## 7.1. Architectural Design

The virtual reality environment is a mixture of sensory-motor systems, a 3D technology and the development of computer programs. The development of an innovative system based on virtual reality requires the design of an architecture that describes the different parts of the system, the overall integration of modules and devices of the virtual reality platform and ensures interoperability in the system.

We present in figure below an architectural diagram that summarizes the overall structure of the system to achieve. This architecture allows the system to be broken down into four main parts: the simulator of production flow, the data exchange protocol, a 3D modules and a platform VR.

- *Production flow simulator*: The industrial engineers use specific tools to design and simulate the production process. In our approach, the Arena tool will be integrated into the virtual reality system proposed, in order to have immersive and interactive simulations. The integration of this tool requires the development of a communication layer between Arena and our VR system.
- *Protocol for data exchange*: For a good analysis of the results of a simulation of flow through the VR system, it is necessary to develop a communication protocol to ensure data exchange in real time between the Arena and the VR system tool.
- *Modules 3D*: The implementation of an immersive and interactive simulation in a VR environment requires the development of processing modules of virtual objects (Moving avatar, Following the axis of camera view, handling 3D objects via Flystick, Menu-virtual, animate 3D objects and interaction-scenario). These modules run around a 3D engine (e.g. Unity3D, Virtools).
- *VRPN controllers*: it's the software part of the platform VR. This section integrates the various controllers that allow connection between devices VR and 3D engine. The development of these controllers is based on the framework VRPN (Virtual Reality Peripheral Network: This frame-

Figure 17. Architecture of our VR system for the simulation of production flow



work is used to connect devices of VR in a cluster). For example the “Controller-Movement” has a connector between the “Motion Capture ART” and the 3D engine, this connector is used to transmit and represent the motion capture data in the 3D engine via the network.

- *Peripherals VR*: This block integrates the sensorimotor part of the platform VR. This module understands the different devices and their connections.

## 7.2. Functioning of System

The architecture presented above provided a comprehensive overview of the system that we want to develop. This architecture also presents the different possible connections between the various system modules. This system will allow to immerse the user in a virtual 3D simulation and to interact with it via the peripherals of VR platform. The application allows the user to move in a virtual environment using a motion capture system (sensors and IR cameras). For the capture and manipulation of industrial objects in a virtual environment, you can use a Flystick (of ART) or a Wiimote. The main feature of our system is to run a simulation of production flow in a virtual reality scene. To this end, we developed 3D processing modules that allow to represent the results of the simulation tool (e.g. Arena or Wintess) in a 3D environment through a transmission module and data synchronization. This system allows for more interaction with the 3D environment to edit and re-setup the simulation run by the engine of the simulator tool. The interaction with the 3D scene can be performed using a haptic force feedback (e.g. Haption). The use of this type of interface provides indeed a good fluidity of interaction with virtual objects and adds sensation to the experience of virtual simulation.

## 7.3. Technical Environment

The development of this approach requires the use of software and hardware tools specific for virtual reality. We present in this section the main tools that are used throughout this project.

### 7.3.1. Hardware Tools of VR Platform

The VR platform of our laboratory includes the following elements:

- *WorkBench*: it is a virtual reality device that allows visualization in relief on a dual-screen device as shown in figure below. This equipment allows immersing the user in a virtual reality experience of high level. This device facilitates the work on virtual prototypes for the functions of formation, assembly of technical parts or the assistance in the maintenance. The Workbench consisting of two perpendicular screens, including a horizontal, is located approximately 1 m from the ground.
- *ARTrack “motion capture system”*: designed by the ART Company. This system consists of four infrared cameras, an outfit “mocap” with a set of retro-reflective passive markers (see figure below) and a controller computer. This concept allows recovering 3D position and orientation of all markers in the scene of the VR platform. To control virtual objects, the system offers a Flystick equipped with buttons, two analog axes for orientation and an active marker for its location in the real environment.

- *Virtuoso 6D*: “Haptic arm” the system is designed by the company “Haption”, it consists of a computer controller and an arm of force feedback. This device is a bidirectional sensorimotor, it allows to user to exert a force on the arm and also to have a force feedback following an action.

### 7.3.2. Software Tools of VR Platform

For the development of our system, the following software will be used: Arena®, Unity3D® and Microsoft Visual® C ++, as well as specific libraries for virtual reality as VRPN for the development of different modules of the system.

- *Arena* ®: software of design and simulation of industrial production process, this tool is based on the SIMAN engine to simulate processes with discrete events.
- *Unity3D* ®: This is a 3D engine, it can be called as: a development package of 3D environments. This tool will allow us to develop industrial 3D scenes, the modules of interacting with objects in the scene and rendering simulation scenarios.
- *Microsoft Visual C ++*: software for development projects in computer language C ++. It will be used to develop interfaces between devices VR and 3D engine. These interfaces will allow us to generate a layer “DLL: Dynamic Link Library”, which establishes a connection between Unity3D and VR platform.

*Figure 18. VR Platform at ENISE.*



## 8. PERSPECTIVES

In recent years, several research works have been done to virtualize certain industrial processes such as simulation of assembly of pieces, simulation of production flow etc. To deal with such problems, we encountered some technical and scientific obstacles such as: the development of a data exchange protocol between a simulation tool and a VR system, the choice of a part of the simulation to virtualize, the behavioral programming operation of a virtual factory and the coupling between the UML diagrams and the others based on discrete events. Our work was part of a project called Optiflux in collaboration with Renault Trucks. This company is interested in the results of this work and begins to run the simulation to virtualize their production lines.

For our future work, we aim to develop a virtual reality system for online simulation. This system will connect a platform VR with an industrial information system (e.g. ERP) and a central system of control/command of machines. The objective of this system is to provide real-time the current operation of the factory, to analyze and simulate this over time and to take control over the machines of different production lines for reconfigure and improve the production processes.

## 9. CONCLUSION

Today, virtual reality is used in many industrial settings such as training, decision support, helping with maintenance; simulation of industrial operations, etc. In this chapter, a new approach is developed for popularizing the manipulation of simulation of industrial processes. This approach allows for the user to visualize and interact with an industrial simulation, and it allows for the industrial actors to visualize the functioning of their factories with a 3D visualization. This approach is based on the VR technology and the behavioral programming; this has enabled us to develop an immersive and interactive VR system to bring the user into a 4th dimensions “sensation” via specific peripheral devices of VR. The main goal of this work is to enable different industry actors to participate in the analysis and improvement of industrial processes.

## REFERENCES

- Abdulmalek, F. A., & Rajgopal, J. (2007). Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of Production Economics*, 107(1), 223–236. doi:10.1016/j.ijpe.2006.09.009
- Achanga, P., Shehab, E., Roy, R., & Nelder, G. (2006). Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management*, 17(4), 460–471. doi:10.1108/17410380610662889
- Ait Hssain, A., & Dunod, E. D. (2000). *Optimisation des flux de production: méthodes et simulation*. Dunod.

- Arnaldi, B., Fuchs, P., & Tisseau, J. (2003). *Traité de la réalité virtuelle*. Les Presses de l'École des Mines de Paris.
- Aurich, J. C., Yang, X., Schröder, S., Hering-Bertram, M., Biedert, T., Hagen, H., & Hamann, B. (2012). Noise investigation in manufacturing systems: An acoustic simulation and virtual reality enhanced method. *Journal of Manufacturing Science and Technology*, 5(4), 337–347. doi:10.1016/j.cirpj.2012.09.010
- Baglin, G., & Capraro, M. (1999). *L'Entreprise Lean Production ou la PME compétitive par l'action collective*. Presses Universitaires de Lyon.
- Bal, M., & Hashemipour, M. (2009). Virtual factory approach for implementation of holonic control in industrial applications: A case study in die-casting industry. *Robotics and Computer-integrated Manufacturing*, 25(3), 570–581. doi:10.1016/j.rcim.2008.03.020
- Barot, C., Lourdeaux, D., Burkhardt, J.-M., Amokrane, K., & Lenne, D. BAROT. (2013). V3S: A Virtual Environment for Risk-Management Training Based on Human-Activity Models. *Presence (Cambridge, Mass.)*, 22(1), 1–19. doi:10.1162/PRES\_a\_00134
- Bel, G., & Kieffer, J. P. (2002). *Pilotage assisté par la simulation discrète, Méthodes du pilotage des systèmes de production*, 99 - 127. France: Hermès Science Europe Ltd.
- Berchet, C. (2000). *Modélisation pour la simulation d'un système d'aide au pilotage industriel*. France: National Polytechnic Institute of Grenoble.
- Buche, C., Bossard, C., Querrec, R., & Chevaillier, P. (2010). Pegase: A generic and adaptable intelligent system for virtual reality learning environments. *International Journal of Virtual Reality*, 9(4), 1–13.
- Burdea, G., & Coiffet, P. (1993). *La Réalité Virtuelle*. Paris: Hermès Sciences Publications.
- Bzymek, Z. M., Nunez, M., Li, M., & Powers, S. (2008). Simulation of a machining sequence using delmia/quest software. *Computer-Aided Design and Applications*, 5(4), 401–411. doi:10.3722/cadaps.2008.401-411
- Cad Shroer MPDS4 Factory Layout. (2013, August). Retrieved from: <http://www.cadschroer.com/index.php?screen=1&ziel=ProductsMPDS&thema=mask1.php&id=351&land=com>
- Caggiano, A., & Teti, R. (2012). Digital Manufacturing Cell Design for Performance Increase. *Procedia CIRP*, 2, 64–69. doi:10.1016/j.procir.2012.05.041
- Caudell, T., & Mizell, D. (1992). Augmented reality: an application of heads-up display technology to manual manufacturing processes, *Proceedings of the Hawaii International Conference on Systems Science, HI, USA*, 659-669. doi:10.1109/HICSS.1992.183317
- Chevaillier, P., Trinh, T. H., Barange, M., Devillers, F., Soler, J., De Loor, P., & Querrec, R. (2011). Semantic modelling of virtual environments using MASCARET. *Proceedings of the Fourth Workshop on Software Engineering and Architectures for Realtime Interactive Systems, IEEE VR*, Singapore.
- Choi, S., & Cheung, H. (2008). A versatile virtual prototyping system for rapid product development. *Computers in Industry*, 59(5), 477–488. doi:10.1016/j.compind.2007.12.003

- Chryssolouris, G., Mavrikios, D., Pappas, M., Xanthakis, V., & Smparounis, K. (2009). In L. Wang & A. Y. C. Nee (Eds.), *A Web and Virtual Reality-based Platform for Collaborative Product Review and Customisation* (pp. 137–152). Collaborative Design and Planning for Digital Manufacturing. doi:10.1007/978-1-84882-287-0\_6
- Claver, J.-F., Pitt, D., & Gelinier, J. (1996). *Gestion de flux en entreprise: modélisation et simulation*. France: Hermès Science Publications.
- Cordier, M. O. (2006). Comparing diagnosability in continuous and discrete-events systems. In *Proceedings of the 17th International workshop on principles of Diagnosis*. 55–60.
- Crute, V., Ward, Y., Brown, S., & Graves, A. (2003). Implementing Lean in aerospace-challenging the assumptions and understanding the challenges. *Technovation*, 23(12), 917–928. doi:10.1016/S0166-4972(03)00081-6
- Dangelmaier, W., Fischer, M., Gausemeier, J., Grafe, M., Matysczok, C., & Mueck, B. (2005). Virtual and augmented reality support for discrete manufacturing system simulation. *Computers in Industry*, 56(4), 371–383. doi:10.1016/j.compind.2005.01.007
- Dangelmaier, W., Fischer, M., Gausemeier, J., Grafe, M., Matysczok, C., & Mueck, B. (2005). Virtual and augmented reality support for discrete manufacturing system simulation. *Computers in Industry*, 56(4), 371–383. doi:10.1016/j.compind.2005.01.007
- David, R., & Alla, H. (1999). *Du Grafset aux réseaux de Petri*. France: Hermès Science Publications.
- Delmia/Quest User Manual*. (2006). Delmia/Quest.
- Demeter, K., & Matyszczok, Z. (2010). (in press). The impact of lean practices on inventory turnover. [Corrected Proof.]. *International Journal of Production Economics*.
- Doil, F., & Schreiber, W., A. T. P. C. (2003). Augmented Reality for Manufacturing Planning. *Proceeding of the Workshop on Virtual Environment*, 71-76.
- Duffy, V. G., & Salvendy, G. (2000). Concurrent engineering and virtual reality for human resource planning. *Computers in Industry*, 42(2-3), 109–125. doi:10.1016/S0166-3615(99)00065-2
- Eddy, J., & Lewis, K. (2002). Visualization of multidimensional design and optimization data using cloud visualization, *ASME Conference Proceedings*, 899-908. doi:10.1115/DETC2002/DAC-34130
- Edward, L., Lourdeaux, D., Lenne, D., Barthes, J. P., & Burkhardt, J. M. (2008). Modelling autonomous virtual agent behaviours in a virtual environment for risk. *International Journal of Virtual Reality*, 7(3), 13–22.
- Fillatreau, P., Fourquet, J.-Y., Bolloc'h, R. L., Cailhol, S., Datas, A., & Puel, B. (2013). Using virtual reality and 3D industrial numerical models for immersive interactive checklists. *Computers in Industry*, 64(9), 1253–1262. doi:10.1016/j.compind.2013.03.018
- Fontanili, F. (1999). Intégration d'outils de simulation et d'optimisation pour le pilotage d'une ligne d'assemblage multi-produit à transfert asynchrone. University of Paris XIII, France.

- Fründ, J., Gausemeier, J., Matysczok, C., & Radkowski, R. (2005). Using Augmented Reality Technology to Support Automobile Development. *Lecture Notes in Computer Science*, 3168, 289–298.
- Gausemier, J., & Frund, J. M. C. (2002). AR-Planning Tool Design Flexible Manufacturing Systems with Augmented Reality. *Proceedings of 8th Euro graphics Workshop on Virtual Environment*, 19-25.
- Gerbaud, S., Mollet, N., Ganier, F., Arnaldi, B., & Tisseau, J. (2008). GVT: a platform to create virtual environments for procedural training. *Proceedings of IEEE VR Conference*, 225-232. doi:10.1109/VR.2008.4480778
- Gesellschaft, F. R. I. (2006). Carl Adam Petri und die Petrinetze. *Informatik-Spektrum*, 29(5), 369–381. doi:10.1007/s00287-006-0107-7
- Giua, A., & Seatzu, C. (2007). A system theory view of Petri nets. *Advances in Control Theory and Applications*, 353, 99–127.
- Gogg, T. J., & Mott, J. R. A. (1993). Introduction to simulation. In *Proceedings of the 25th conference on winter simulation*, 9-17. doi:10.1145/256563.256571
- Goulding, J., Nadim, W., Petridis, P., & Alshawi, M. (2012). Construction industry offsite production: A virtual reality interactive training environment prototype. *Advanced Engineering Informatics*, 26(1), 103–116. doi:10.1016/j.aei.2011.09.004
- Harris, E. N., & Morgenthaler, G. W. (2004). Planning, implementation and optimization of future space missions using an immersive visualization environment (IVE) machine. *Acta Astronautica*, 55(1), 69–78. doi:10.1016/j.actaastro.2003.11.002 PMID:15786593
- Jayaram, S., Jayaram, U., Kim, Y., DeChenne, C., Lyons, K., Palmer, C., & Mitsui, T. (2007). Industry case studies in the use of immersive virtual assembly. *Journal of Virtual Reality*, 11(4), 217–228. doi:10.1007/s10055-007-0070-x
- Kantonen, T., Woodward, C., & Katz, N. (2010). Mixed reality in virtual world teleconferencing, *Proceedings of the IEEE Conference on Virtual Reality*, 179-182.
- Kaufmann, H., & Schmalstieg, D. (2003). Mathematics and Geometry Education with Collaborative Augmented Reality. *Computers & Graphics*, 27(3), 339–345. doi:10.1016/S0097-8493(03)00028-1
- Kilpatrick J. (2003). Lean principles. *Utah manufacturing Extension Partnership*.
- Klingstam, P., & Gullander, P. (1999). Overview of simulation tools for computer aided production engineering. *Computers in Industry*, 38(2), 173–186. doi:10.1016/S0166-3615(98)00117-1
- Kracik, J. F. (1988). Triumph of the lean production system. *Sloan Management Review*, 30(1), 41–52.
- Ladeveze, N., Fourquet, J.-Y., & Puel, B. (2010). Interactive path planning for haptic assistance in assembly tasks. *Computers & Graphics*, 34(1), 17–25. doi:10.1016/j.cag.2009.10.007
- Lafortune, C. S. (2008). *Introduction to Discrete Event Systems* (2nd Ed.). Boston: Springer - Verlag.
- Lee, J., Han, S., & Yang, J. (2011). Construction of a computer-simulated mixed reality environment for virtual factory layout planning. *Computers in Industry*, 62(1), 86–98. doi:10.1016/j.compind.2010.07.001

- Lee, J., Han, S., & Yang, J. (2011). Construction of a computer-simulated mixed reality environment for virtual factory layout planning. *Computers in Industry*, 62(1), 86–98. doi:10.1016/j.compind.2010.07.001
- Leu, M. C., ElMaraghy, H. A., Nee, A. Y., Ong, S. K., Lanzetta, M., & Putz, M. et al. (2013). CAD model based virtual assembly simulation, planning and training. *Manufacturing Technology*, 62(2), 799–822.
- Li, H., Chan, G., & Skitmore, M. (2012). Visualizing safety assessment by integrating the use of game technology. *Automation in Construction*, 22(0), 498–505. doi:10.1016/j.autcon.2011.11.009
- Lindskog, E., Berglund, J., Vallhagen, J., & Johansson, B. (2013). Visualization Support for Virtual Redesign of Manufacturing Systems. *Journal of Procedia*, 7(0), 419–424.
- Lindskog, E., Berglund, J., Vallhagen, J., & Johansson, B. Visualization Support for Virtual Redesign of Manufacturing Systems. In: *Procedia* 7, Nr. 0, S. 419 – 424, 2013. doi:10.1016/j.procir.2013.06.009
- Mahdjoub, M., Monticolo, D., Gomes, S., & Sagot, J.-C. (2010). A Collaborative Design for Usability approach supported by Virtual Reality and a Multi-Agent System embedded in a PLM environment. *Computer Aided Design*, 42(5), 402–413. doi:10.1016/j.cad.2009.02.009
- Manca, D., Brambilla, S., & Colombo, S. (2013). Bridging between Virtual Reality and accident simulation for training of process-industry operators. *Advances in Engineering Software*, 55, 1–9. doi:10.1016/j.advengsoft.2012.09.002
- Marc, J., Belkacem, N., & Marsot, J. (2007). Virtual reality: A design tool for enhanced consideration of usability “validation elements”. *Safety Science*, 45(5), 589–601. doi:10.1016/j.ssci.2007.01.004
- Marion, N., Querrec, R., & Chevaillier, P. (2009). Integrating knowledge from virtual reality environments to learning scenario models. A meta-modeling approach. *Proceedings of the International conference of Computer Supported Education*, 254-259, Lisbon, Portugal.
- Marion, N., Septseault, C., Boudinot, A. & Querrec, R. (2007). GASPAR: Aviation management on aircraft carrier using virtual reality, *Proceedings of Cyberworlds*, Hanover, Germany.
- Markt, P. L. & Mayer, M. H., (1997). WITNESS simulation software: a flexible suite of simulation tools, 7(10), 711-717.
- Motwani, J. R., & Ullman, J. (2007). *Introduction to Automata Theory, Languages, and Computation*. USA: Prentice Hall.
- Mujber, T., Szecsi, T., & Hashmi, M. (2004). Virtual reality applications in manufacturing process simulation. *Journal of Materials Processing Technology*, 155, 1834–1838. doi:10.1016/j.jmatprotec.2004.04.401
- Murata, T. (1989). Petri nets: Properties, analysis and applications. *Proceedings of the IEEE*, 77(4), 541–580. doi:10.1109/5.24143
- Ng, L. X., Ong, S. K., & Nee, A. Y. C. (2010). ARCADE: A Simple and Fast Augmented Reality Computer-Aided Design Environment Using Everyday Objects. *Proceedings of IADIS Interfaces and Human Computer Interaction 2010 Conference*, 227–234.

- Ng, L. X., Oon, S. W., Ong, S. K., & Nee, A. Y. C. (2011). GARDE: A Gesture-based Augmented Reality Design Evaluation System. *International Journal of Interactive Design and Manufacturing*, 5(2), 85–94. doi:10.1007/s12008-011-0117-9
- Pegden, C. D., Sadowski, R. P., & Shannon, R. E. (1995). Introduction to Simulation Using SIMAN. New York, NY, USA: McGraw-Hill, Inc.
- Pouliquen, M., Bernard, A., Marsot, J., & Chodorge, L. (2007). Virtual hands and virtual reality multi-modal platform to design safer industrial systems. *Computers in Industry*, 58(1), 46–56. doi:10.1016/j.compind.2006.04.001
- Querrec, R., Vallejo, P., & Buche, C. (2013). MASCARET: create virtual learning environments from system modelling. Engineering Reality of Virtual Reality, *SPIE Electronic Imaging Conference*, San Francisco, CA, USA.
- Raymond, C. W., James, M., & Graham, R. (2009). Automated design process modelling and analysis using immersive virtual reality. *Computer Aided Design*, 42(12), 1082–1094.
- René. Chevance., J. (2001). Méthodologie en matière de performance des systèmes. Techniques de l'ingénieur. Techniques de l'ingénieur, Paris.
- Richir, S. & Fuchs, P. (2003). Réalité virtuelle et conception Méthodes. *Techniques de l'ingénieur*.
- Shah, R., & Ward, P. T. (2003). Lean manufacturing: Context, practice bundles, and performance. *Journal of Operations Management*, 21(2), 129–149. doi:10.1016/S0272-6963(02)00108-0
- SIMCORE & CLARTE. (2013, August). Ergo-wide: Analyse ergonomique en réalité virtuelle. Retrieved from: <http://www.simcore.fr/Ergonomie.asp>
- Sreng, J., Lécuyer, A., Mégard, C., & Andriot, C. (2006). Using visual cues of contact to improve interactive manipulation of virtual objects in industrial assembly/maintenance simulations. *Journal of Visualization and Computer Graphics*, 12(5), 1013–1020. doi:10.1109/TVCG.2006.189 PMID:17080829
- Stark, R., Israel, J. H., & Wöhler, T. (2010). Towards Hybrid Modeling Environments-Merging Desktop-CAD and Virtual Reality-technologies. *Annals of CIRP*, 59(1), 179–182. doi:10.1016/j.cirp.2010.03.102
- System, M. R. a product design support system of CANON, (2012, May). Retrieved from: <http://www.actinnovation.com/innovation-technologie/canon-mr-system-realite-augmentee-4831.html>
- Takeda, N., Kakudate, S., Nakahira, M., Shibamura, K., & Tesini, A. (2008). Development of a virtual reality simulator for the ITER blanket remote handling system. *Fusion Engineering and Design*, 83(10-12), 1837–1840. doi:10.1016/j.fusengdes.2008.05.042
- Takus, D. A., Profozich, & David, M. (1997). ARENA SOFTWARE TUTORIAL, *Winter Simulation Conference*.
- Tarault, A.; Bourdot, P.; Vézien, J. & Sacari. (2005). An immersive remote driving interface for autonomous vehicles, *Computational Science – ICCS*, 3-15.

Teamcenter Manufacturing Plant Simulation. (2013, August). Retrieved from: [http://www.robertirobotics.com/ugs/efactory/emplant/\\_files/fs\\_tecnomatix\\_em\\_plant.pdf](http://www.robertirobotics.com/ugs/efactory/emplant/_files/fs_tecnomatix_em_plant.pdf)

Tecnomatix Factory Layout Simulation. (2013, August). Retrieved from: [http://www.plm.automation.siemens.com/zh\\_cn/Images/7656\\_tcm78-64291.pdf](http://www.plm.automation.siemens.com/zh_cn/Images/7656_tcm78-64291.pdf)

Tesic, R., & Banerjee, P. (1999). Exact collision detection using virtual objects in virtual reality modeling of a manufacturing process. *Journal of Manufacturing Systems*, 18(5), 367–376. doi:10.1016/S0278-6125(00)87639-6

Tolio, T., Sacco, M., Terkaj, W., & Urgo, M. (2013). Virtual Factory: An Integrated Framework for Manufacturing Systems Design and Analysis. *Procedia*, 7, 25–30.

VR4D: Virtual Reality for Design, (2013, August). Retrieved from: <http://www.lecolededesign.com/fr/actualites/bdd/actualite/1247>

VirtualiTeach. Assistance de Conception, CLEMI, CLARTE & CEA-List, (2013, August). Retrieved from: <http://www.ac-creteil.fr/retrouvezlactualite-avril2013-pedagogieconcrete.html>

Weber-Jahnke, J. H., & Stier, J. (2009). Virtual prototyping of automated manufacturing systems with Geometry-driven Petri nets. *Computer Aided Design*, 41(12), 942–951. doi:10.1016/j.cad.2009.06.012

Wiese, E., Israel, J. H., Zöllner, C., Pohlmeier, A. E., & Stark, R. (2009). The Potential of Immersive 3D-sketching Environments for Design Problem-solving. *Proceedings of 13th International Conference on Human-Computer Interaction*, 485–489.

Womack, J., & Jones, D. (2005). *System Lean: Penser l'entreprise au plus juste*. Village mondial, 2ème édition, Paris.

Womack, J. P., Jones, D. T., & Ross, D. (1990). The Machine that Changed the World. *The International Journal of Human Factors in Manufacturing*, 4(3), 1522–7111.

Xinhua, L., Youhui, L., & Qi, L. (2011). Virtual Assembly and Simulation of Vibration Sieve Based on a Human-Interface Environment. *Procedia Engineering*, 15(0), 2988–2992. doi:10.1016/j.proeng.2011.08.562

## KEY TERMS AND DEFINITIONS

**3D Interactions:** A form of human-machine interaction where users are able to move and perform interaction in 3D space. Both human and machine process information where the physical position of elements in the 3D space is relevant.

**3D Visualization:** A variety of technologies that make images and movies appear more lifelike in print, on the computer, in the cinema or on TV. Known as “stereoscopic imaging” and “3D stereo”, people sense a greater depth than they do with 2D and feel they could reach out and touch the objects.

**Augmented Reality:** A live direct view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, 3D objects.

**Industrial Design:** A process of design applied to products that are to be manufactured through techniques of mass production.

**Simulation of Industrial Processes:** Process simulation is a model-based representation of production, evaluation, chemical, physical, and other technical processes and unit operations in software.

**Virtual Manufacturing:** The modeling of manufacturing systems using audiovisual or other sensory features to simulate or design alternatives for an actual manufacturing environment, or the prototyping and manufacture of a proposed product using computers.

**Virtual Reality:** An immersive multimedia or computer-simulated life, replicates an environment that simulates physical presence in places in the real world or imagined worlds. Virtual reality can recreate sensory experiences, which include virtual taste, sight, smell, sound, and touch.