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HIGH VALUE ADDING VR TOOLS FOR NETWORKED CUSTOMER-DRIVEN FACTORY

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ABSTRACT

Current manufacturing systems, the typical instantiations of modern socio-technical systems called factories, have to solve highly complex tasks under increasing demands for adaptability, cost efficiency, maintainability, reliability, scalability and safety. The “Next Generation Factory”, approached as a complex long life product, has to be adapted continuously to the needs and requirements of the market. Furthermore the “factory” will have to take more and more into consideration social responsibility and, in particular, environmental sustainability. Based on these challenges the need of breakthrough Virtual Factory (VF) tools for cost-effective and rapid creation, management and use of the Next Generation Factory, in respect of its digital and virtual representation (called further on Virtual Factory), is more and more relevant for the purposes of the European Industrial Transformation. The paper presents a new VF approach coherent with the “Next Generation Factory” meant to advance the capability to simulate dynamic complex behaviour (organizational, engineering, …) over the whole life cycle of Product, Process, Plant and Network, thus fostering major time and cost savings, while increasing performance in the design, management, evaluation and evolution of new or existing facilities. The paper presents the underlying models and ideas at the foundation of this new conceptual framework for the high value adding tools also meant to lay the basis for future works and applications in this research area.

KEYWORDS

Virtual Factory, Product and Factory Life Cycle, Mass Customization, Customer-Driver Factory, Knowledge Integration

1. PROBLEM STATEMENT

1.1. MOTIVATION FOR HIGH VALUE ADDING VR TOOLS: USES & BENEFITS

European Manufacturing industries face an intense and growing competitive pressure brought forth by developing countries, which are entering the global market offering low-cost workforce for the production of labour-intensive and low-value added products. Moreover these countries are rapidly modernizing their production methods and enhancing their technological capacities as pointed out in Manu*future*, while in parallel their engineers' skills reached the level of US and European engineers as Chinese students with an extensive support of their government are trained overseas. To maintain competitiveness a response must be promoted based on the transformation of industry and its related business model meant to strengthen Europe's ability to compete in terms of high added value for the customer, since the cost-based competition is not compatible with the goal of maintaining the Community's social and sustainability standards.

This transformation can be achieved by developing tools for the design of customer driven adding value products and for the design, configuration and reconfiguration of flexible multi-site multi-nation production factories, meant to manufacture those customer driven products.

Virtual Reality tools in the manufacturing context can contribute to the following benefits:

- Quality: Design for manufacturing and higher quality of the tools and work instructions available to support production.
- Productivity: Optimise the design of the manufacturing system in coordination with the product design; first article production that is trouble-free, high quality, involves no reworks and meets requirements.
- Flexibility: Execute product changeovers rapidly, mix production of different products, return to producing previously shelved products.
- Responsiveness: respond to customer ``what-ifs" about the impact of various funding profiles and delivery schedule with improved accuracy and timeless.
- Customer relations: improved relations through the increased participation of the customer in the Integrated Product Process Development process.

These tools rely on a standardized, digitized product, process and factory description and its extended formalism, as proposed in (Pedrazzoli et al, 2006).

This paper takes into account the virtual modelling of the whole Product Life Cycle given a set of customer requirements that become the real drivers of the production process.

Sustainable Life Cycles Management

The modern view on manufacturing engineering resides in incorporating the Life Cycle paradigm into the factory as a whole, its corresponding products, manufacturing processes and technologies, under the so-called "Sustainable Life Cycles Management". One of the main foundations of the this approach, relevant for the European manufacturing Engineering community represents the "Product/Process Matrix Life Cycle" (Boer 96). This innovative approach supports the manufacturing enterprises to flexible and agile respond to changes and mutations in an international networked context (Alexopulos 07, Chryssolouris 96, Chryssolouris 06). It requires new concepts and industrial paradigms which have been developed and then successfully adopted and implemented, as Virtual Factory, and its combination with Physical Factory, the so-called Self-Innovating Factory, capable of responding to context changes, as required by Sustainable Production Paradigm (SIF) (Boer 01, Boer 04) . All these approaches and new concepts are essential for the path to sustainability by expanding the focus from the production site to the whole factory and product life cycle. The main goal of Product/Processes Matrix Life Cycle is to tightly integrate the design, manufacturing, delivering, selling, and recycling of a product with the life cycle of the connected processes. Founded on the above shortly presented "Product/Process Matrix Life Cycle", the "Sustainable Life Cycles Management" approach helps to reduce resource use and to improve the technical and social performance, in various stages of a factory and product's life (Aldinger 06, Constantinescu 06, Westkämper 06). By implementing the Life Cycle Management capability, considerable benefits, such as faster time to market, lower costs, reduction of rework and rejection dates and more component and technology reuse are achieved. Each factory follows a life cycle from its initial concept in the mind of an entrepreneur to the ecological dismantling, through a series of stages or phases. Figure 1 traces the factory's life along the investment planning, engineering, the process planning, the construction and ramp-up, the production, the service and maintenance, and finally the dismantling or refurbishment. Two states of factory and its manufacturing processes have been distinguished (Westkämper 06): "digital" and "virtual", making a clear difference between the models, methods, technologies and tools of advanced Manufacturing Engineering (aME) used. Digital factory represents the static image of a factory, modeled and re-presented by using digital manufacturing and modeling technologies. The projection of the factory into the future, through simulation and 3D/Virtual and Mixed Reality technologies represents the virtual factory. Applying the authors' concepts regarding the digital and virtual factory

(Westkämper 06), the factory life phases can be structured as follows. From investment planning to construction and ramp-up, the factory is digital. In these phases, it exists in its virtual form as well, being permanently optimized through simulation. Then the digital and virtual factory is constructed and ramps up. All remaining phases trace the real factory.

Simultaneously, the products, which will be manufactured in the factory, are passing through the main phases of their life cycle: the planning, development, design, rapid prototyping, production, usage and service and finally the recycling phase. By transferring the authors' concepts concerning the digital and virtual factory to the products, products are digital and virtual between planning and rapid prototyping phases. The real product lives from production to recycling.

The central part of Figure 1, the overlapping of the factory operation and maintenance and the manufacturing of products in the so-called production phase, represents the crucial and at the same time critical point, called "Crossing-Life Cycles Point".

Here, virtual products and factories become reality. The real product is built into the real factory. Then the manufacturing processes are implemented by using the most suitable technologies. At this point, all the already performed engineering activities and efforts are to be proved and verified. In this phase, the real factory has to be highly transformable in order to quickly respond to the changes occurring in the product world: frequent product launches, increased product complexity as a consequence of using advanced and emerging technologies, e.g. the fast development of micro and nano electronics, increased micro computerization, and new materials development.

The here presented approaches, the "Product/Process Matrix Life Cycle" and the "Sustainable Life Cycles Management" represent a simplified view of the complexity of manufacturing engineering as a whole. Both research directions present in two dimensions, respectively Product/Process and Product/Factory only a part of the "n-dimensional Space of Manufacturing Engineering Life Cycles". This point of view has to take into consideration all entities playing a relevant role on the manufacturing engineering area and its corresponding industries. Several such main units or "artefacts" have to be mentioned: Products, Processes, Technologies, Data /Information /Knowledge, Factories as products, and many others, which follow along their duration the Life Cycle philosophy. The future work of all involved authors will be oriented towards the extension of the mentioned approaches with other dimensions.

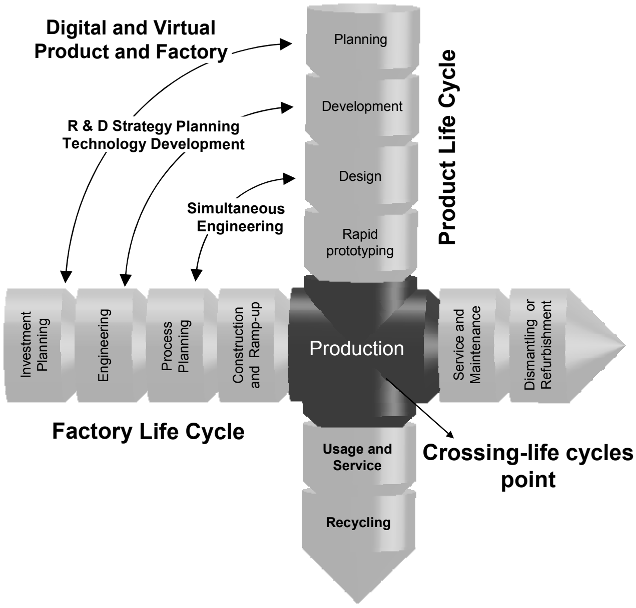

Fig. 1: The harmonization of Product and Factory Life Cycle under the "Crossing-Life Cycles Point"

Unified and Sustainable Life Cycle challenges and risks

An orchestration or harmonization of the specific life phases of product, manufacturing processes and technologies with the planning phase of the factory represents a great challenge. This approach is called Unified and Sustainable Life Cycles Management.

There is a risk associated with the things in the world, which have a life cycle themselves, as in a case of a factory. The manufactured products, the corresponding manufacturing processes and the technologies used, all these subordinated factory entities, have their own life cycles. Each life cycle can be represented, at the end, as independent software application; therefore, a software technology infrastructure has to be formulated to allow for the seamless linkage and integration of software application and systems, representing various life cycle aspects. Because phases of these life cycles tend to be independent of each other, the current challenges and then the research efforts have to be coordinated towards integrated and unified life cycle paradigm. This unified life cycle paradigm builds upon current technologies and is backwardly compatible while embracing future emerging technologies. Only when two of these life cycles coincide and one affects the other there is connectivity and a transfer of information at the interface. The current research approaches have to identify 1) linkage points (i.e., portals) between life cycles, 2) the type, and form of data passing between life cycles, and 3) conditions when life cycles interact and communicate. This is expected

to be overcome by developing and integrating new technologies and tools, e.g. information and communication technologies (ICT), digital manufacturing technologies, collaboration models and tools, used to trace factories, products, processes and technologies over their life cycle from engineering to the end of their lives. Several strategies to support the required orchestration have to be mentioned: applying the simultaneous engineering for bridging the product design and process planning, and the development of suitable strategies for R&D in order to link the product planning and development and factory investment and engineering. The last can be achieved through the development of advanced and innovative manufacturing technologies.
The envisioned solution for minimizing all risks and losses related to the Crossing-Life Cycles Point, is the development of an environment for factory life cycle, by collaboratively integrating the latest technologies and tools used to follow the factories and their products along their life cycles. The vision of this work represents the "transformable and adaptable factory" which has to react quickly and appropriately to the internal and external turbulences, by using new collaboration and integration models, methods and procedures along the value chain.

1.2. STATE OF THE ART OF PRODUCT-FACTORY VR TOOLS

Several research programmes and projects explored the opportunities related to the idea, introduced by (Jain 95) and (Krolak 96), of a reference framework for virtual design. Most of them exploited an existing suite (VEGA Multigen + Arena, or ad hoc application + Quest) developing ad-hoc applications as in ManuFuturing (Boër 97), MPA (Sacco 00, Sacco 04, Boër 00), IRMA, ARVIKA. These projects produced very good results but lacking of flexibility and reusability mainly due to the fact that they relied on non-standard, and non holistic data model of the factory and product. In projects as DiFac and CoSpace a clear architecture for a seamless, flexible and up-gradable solution for developing the VF is not apparent or emerging.

This topic is also highlighted as crucial in the NoE INTUITION.
Several actors are currently working on the VF topic, such as IPA, IML and IPK from the Fraunhofer Institute, ITIA from National Research Council, the University of Patras, the University of Buffalo and the Washington state University, the SKKU University in Korea or the Tokyo Denki University. One of the main problems encountered in the development of a VF is the availability of proper tools and framework (Mueller 02, Waller 02, Zhai 02)
Most of the previous projects and the above mentioned institutes focus on either the use of commercial tools (Superscape, DigitalMock-up, WorldToolkit) either on more low level software (Vega, Performer, OpenGL directly or customized set of libraries, such as the Unifeye SDK). The first approach faces the problem of excessively rigid tools for developing a complete factory and its functionalities, or too simple to have realistic results.
The second, besides the problem of starting from scratches with no defined framework, confronts with the need to offer complex simulation functionality, thus implying the need to integrate existing tools whose interface has to be studied and adapted. Finally, other projects are demonstrating the possibility to democratize the use VR tools, thus making them widespread, such as the IP KoBaS (Pedrazzoli 04).

2. A NEW APPROACH FOR VR TOOLS

The paper proposes a new approach exploiting the Virtual Factory Framework presented in (Pedrazzoli et al, 2006) in order to develop a customer driven product system enabled by Virtual Reality Tools. The result is an object oriented collaborative product design and factory planning environment, reliant on the Customer Driven Product Design Tools, meant to foster the sharing of networked factories resources, supply chain strategy, manufacturing information and knowledge (material, technology) through the whole life cycle of the product.
The foundation of such a system relies on a standardized, digitized product, process and factory description supported by the four pillars of the VFF:

- Standard Extensible Data model for Product and Factory,
- Event Driven Paradigm,
- Decoupled Functional Modules,
- Knowledge integration.

VR tools can be introduced as decoupled modules at both Product design and Factory design level of the product/process matrix life cycle.

2.1 VR TOOLS FOR CUSTOMER DRIVEN PRODUCT DESIGN

Customer addressed Virtual Reality tools are meant to supply the end-users with innovative design services for fostering the product customisation process (Boer 04). Moreover, the ultimate aim of the creation of this kind of modules can be identified in a production process that is

commenced, directed, and scheduled by individual customer.
The achievement of such a goal is based on the following research topics:

Standard Extensible Product Data Model, taking into account the requirements of customer driven personalization and integrated with the factory data model, hereinafter presented. The development of such a Data Model requires the harmonization of the characteristic of product and manufacturing processes, thus improving the exchange of information among the different actors (Customers, Shops, Factory, Suppliers).

Distributed software modules structured as decoupled functional modules capable to interact with the core (Pedrazzoli et al, 2006) for customer request/desire acquisition and analysis based on the different degrees of customization.

Massive acquisition of customer data. This represents valuable knowledge base for the analysis of the correlation of customer preferences with manufacturing and also gives the opportunity to address multi-nation customers to better penetrate international market.

2.2 VR TOOLS FOR FACTORY DESIGN

A customer driven paradigm requires the realization of tools for the design, configuration and reconfiguration of flexible multi-site multi-nation production factories, meant to manufacture those customer driven products.
Moreover, these tools should exploit the capabilities offered by virtual reality tools to support simulation of major activities and systems of multi-site multi-nation production systems, featuring mainly planning, decision support and validation capabilities.

The development of these factory related tools requires:

Standard Extensible Factory Data Model, taking into account the requirements issued from the approach of holistic and scalable modelling, of real time management of manufacturing data and of collaborative engineering and manufacturing networks. The development of the Standard Extensible Factory Data Model requires an orchestration or harmonization of the specific life phases of product, manufacturing processes and technologies with the planning phase of the factory. This approach is called Unified and Sustainable Life Cycles Management. The need to consider networks of factories leads to the necessity of refining the core data model proposed by the VFF core, implementing private data protection while still exposing the synchronization and consistency system through a “Public Core Projection”.

Distributed and Web Based Functional Modules based on an object oriented paradigm, meant to facilitate modelling of complex behaviour and functions through natural mapping abstractions and modular code development. The Event Driven Paradigm pillar of the VFF used at the core abstractions management enables a centralized synchronization of these decoupled modules.

Integration of Knowledge as engine for the modules. The primary objective is to achieve tools which can model a wider range of complex systems and support greater comprehension of the modelled phenomenon. Moreover, the integration of knowledge will deliver fundamental advisory capabilities as a companion distributed process and plant development.
According to this holistic multi-disciplinary product lifecycle, planning, engineering, and operation will take place within the same data model. Changes of the engineering model will automatically trigger changes in the shop floor systems and shop floor tools will document changes in the factory knowledge database. Exploitation of the benefits from web based applications will allow participation of the customer in the design process regardless of his/her location. The development of user friendly web based systems performing “personal assistant role” to the customer and real time feasibility analysis for the production of each individual product. At the same time automated knowledge storing systems will allow for knowledge capturing and encapsulation in future design operations. Common information systems between production facilities around the globe will allow for fast knowledge transfer and sharing thus assisting both customers and plants in customizing and producing the product respectively

3. CONCLUSIONS

The paper proposed a model to use high value added Virtual Reality Tools in order to integrate the customer in the production process The main concept is to develop decoupled modules capable to exploit the Virtual Factory Framework for direct collaboration between customers, designers of manufacturing systems and suppliers, covering the whole Product Life Cycle
Software development aiming at the collaboration and coordination of production plants, based on the customer requirements, will further promote the enhancements of business relations in the global context as defined in MANUFUTURE.
The proposed approach fosters efficient mass customization in manufacturing thanks to the new

approach to computer-aided manufacturing systems. The unique combination of low unit costs of mass production processes with the flexibility of individual and efficient customization will significantly improve the product quality and added value, and provides a reduction of time-to-market compared to the state of the art while promoting a radical industry transformation from traditional resource-based to customer centred, knowledge-based, adaptive and networked.

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