VFF: Virtual Factory Framework

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Abstract

The current complex market highlights the need of software tools supporting product engineering and manufacturing during the various stages of product and factory lifecycles. These are designed focusing on specific tasks, thus missing to satisfy the requirements of networked collaboration and concurrent engineering for the design and management of products, processes and production systems. A major challenge consists in the integration and harmonisation of the knowledge related to the factory of industrial companies by using a variety of multidisciplinary software tools. The topic is addressed by software providers and the scientific community, as demonstrated by the European project "Virtual Factory Framework" (VFF) that aims at developing an integrated framework to implement the next generation virtual factory. This paper describes the motivations behind the VFF concepts, together with the goals and the first results. Finally, it is presented how the Virtual Factory will be permanently synchronised with the Real Factory to validate its expected time and cost savings during the factory lifecycle phases.

Keywords

Virtual Factory Framework, Factory Planning, Factory Data Model

1   Introduction

Manufacturing has to cope with a more and more complex and evolving market environment. On the one hand the world crisis breaks the balance between demand and production; on the other hand the globalised market pushes for a continuous change. However, several critical aspects related to the rapid prototyping of factories have to be addressed. One key dimension is to provide sufficient product variety to meet diverse customer requirements, business needs and technical advancements, while maintaining economies of scale and scope within the manufacturing processes [Huang et al. 2005]. In this context, mass customization is one of the most discussed and promising concepts, since it can significantly increase sales by increasing customer satisfaction. Reconfigurable manufacturing systems facilitate the mass customization, whereas Flexible Manufacturing Systems (FMS) have been considered as a major enabler to the mass customization paradigm [Jovane, et al. 2003]. Approaches for incorporating flexibility in decision-making processes have also been proposed [Abele, et al. 2006; Terkaj, et al. 2009]. The introduction and implementation of Reconfigurable Manufacturing Systems [Koren, et al. 1999] and Focused Flexibility Manufacturing Systems [Terkaj, et al. 2009] are some of the proposed approaches. The current challenge in manufacturing engineering consists in the innovative integration of the product/process and factory worlds and the related data management and tools, aiming at synchronizing the *product*, *process* and *factory* lifecycles. Since dealing with change is one of the most fundamental challenges facing organizations today [Wiendahl, et al. 2007], much effort has been dedicated towards the development of change management approaches and methods [Tolio, et al. 2010]. In this context, the Manu*Future* technology platform has already proposed some activities to enable the transformation of the European Manufacturing Industry into a knowledge-based sector capable of competing successfully in the globalised marketplace [Jovane, et al. 2009]. In recent years several research projects (e.g. "Modular Plant Architecture" - MPA, "A configurable virtual reality system for Multi-purpose Industrial Manufacturing

Applications" – IRMA and "Digital Factory for Human-Oriented Production System" – DiFac) studied the opportunity to insert new digital and virtual technologies in the manufacturing sector.

The Virtual Factory (VF) paradigm can assist to answer to this need for innovation by addressing various key issues:

- Reduction of production times and material waste thanks to the analysis of virtual mock-ups of new products.

- Development of a knowledge repository where people can find any kind of stored material (designs or documents) in different versions.

- Improvement of workers efficiency and safety through training and learning on virtual production systems.

- Creation of a collaboration network among people concurrently working on the same project in different places.

Considering the market environment characteristics and the directions of ongoing research, it can be said that modern factories have to be modular, scalable, flexible, open, agile and knowledge-based in order to quickly adapt to the continuously changing market demands, technology options and regulations. The concept of a framework and a reference model providing a factory holistic view enables a wider perspective compared to the current state of the art, by describing the factory as a whole consisting of processes, dependencies and interrelations, factory modules and data flows [Pedrazzoli, et al. 2007]. The complexity of the problem asks for support tools to effectively address all the phases of the factory lifecycle. Indeed, the major Information and Communication Technology (ICT) players (e.g. Siemens PLM, PTC and Dassault Systèmes) already offer all-comprehensive suites containing software tools that have been developed or acquired in the recent years. These tools are called Product Lifecycle Management (PLM) software solutions and deal with most of the factory planning, design and deployment phases. However, the current approaches still do not meet the demands of industry and fail to provide all the required functionalities. It is suggested that comprehensive PLM solutions can provide an assistance to all the industrial applications, but even the most expensive and generic ones do not offer all the needed support and lack of interoperability. Many solutions strongly focus on mechanical details while neglecting the production system perspective. Moreover, it is still important to evaluate whether Small and Medium Enterprises (SMEs) can afford the present expensive PLM software suites. Indeed, SMEs have to face a critical trade-off when dealing with factory planning; there is need for more and more complex production systems and production networks to be competitive, but this leads to decrease the time horizon for the planning process and more support tools are needed. Usually only big companies can afford the large investments required by PLM software tools [Sacco, et al. 2009] and therefore SMEs are still looking for successful customised and less expensive solutions, which are more suitable for their size and needs [Consoni, et al. 2006].

An answer to the problems and requirements highlighted so far can be given by the development of a new Virtual Factory Framework (VFF) that can be defined as "An integrated virtual environment supporting the design and management of all the factory entities, ranging from the single product to the network of companies, along all the phases of the factory lifecycle". The VFF should provide a ground-breaking framework for a new Virtual Factory (VF) but also democratise its usage thanks to new open technologies that are exploitable by SMEs too. This paper presents the topics and goals of the new research project titled "Holistic, extensible, scalable and standard Virtual Factory Framework" [VFF 2010], highlighting its answers to the previously described requirements.

2   The Virtual Factory Framework - VFF

The Virtual Factory consists in an integrated simulation environment that considers the factory as

a whole and provides an advanced planning, decision support and validation capability [Jain 2001]. The VFF implements the framework for an object-oriented collaborative virtualised environment, representing a various factory activities meant to facilitate the sharing of resources, manufacturing information and knowledge. The VFF approach is expected to provide important advancements compared to the state of the art:

- development of an holistic view for the factory, both considering its physical dimensions and its evolution over time (factory lifecycle);

- definition of a reference framework for the factory planning activities;

- development of a shared and extensible factory data model for products, processes, resources and buildings to face the poor interoperability among different software platforms using proprietary formats;

- development of new planning methods and tools, in particular for the configuration and reconfiguration of production plants;

- synchronization between the virtual and real factory;

- democratisation thanks to an open and standard VFF that is interfaced with decoupled functional modules.

The VFF approach requires a factory planning procedure that defines and organizes all the factory lifecycle phases [Pedrazzoli, et al. 2007], ranging from investment strategic planning to factory dismantling. The comprehension of the planning activities and of the information flow among them is a fundamental step for the analysis of the entire factory planning process. A new planning framework allowing the parallelization of planning phases should be developed. It would provide a consistent data platform, intelligent project management support systems and the visualization of cross-links and interconnections between planning objects through a virtual prototype. A Virtual Factory Framework should promote major time and cost savings, while increasing performance in the design, management, evaluation and reconfiguration of new or existing facilities, supporting the capability to simulate dynamic complex behaviour over the whole lifecycle of the factory. Figure 1 represents a schema for the key concepts of the Virtual Factory Framework.
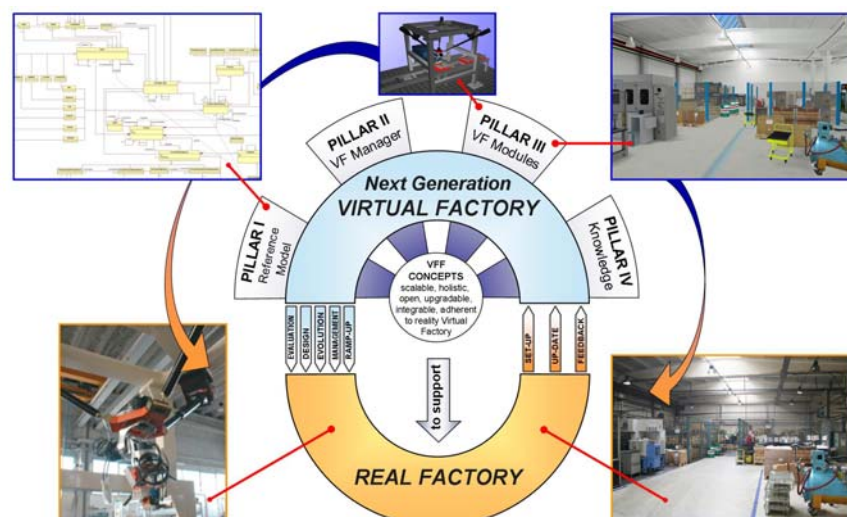

Figure 1: VFF concepts

This framework is based on four key Pillars: (I) Reference Model, (II) Virtual Factory (VF) Manager, (III) Functional Modules and (IV) Integration of Knowledge. All the functionalities required by the factory planning processes are provided by different decoupled modules (Pillar III) that work on a consistent reference factory model (Pillar I) thanks to the VF Manager (Pillar II) that plays an integrating role by interfacing all the modules.

2.1 Pillar I - Reference Model

The Reference Model establishes a coherent standard extensible Factory Data Model for the common representation of factory objects. Since the VFF framework has to deal with the interactions among different activities, it is not sufficient to have just one snapshot of the real production plant inside the data model, but it is necessary to take care of data evolution along the factory lifecycle phases. Moreover, several hypotheses of factory configuration could coexist during each lifecycle stage and various external modules could need to access and modify the same data, thus leading to severe stability and data consistency problems. The overall VFF architecture has been designed to obtain the needed level of system reliability for the management of these interactions and iteration loops. The proposed structure is based on a *versioning* approach for the data model, so that different versions of the same factory can be created and each version has its own traceable revisions.

The Factory Data Model development aims at formalizing the concepts of building, product, process and resource. The data model requires the orchestration and harmonization of the specific lifecycle phases of product, manufacturing processes and technologies together with the planning phases of the factory. This common data model can be considered as the shared meta-language providing a common definition of the information that will be governed by the VF Manager (Pillar II) and used and updated by the decoupled functional modules (Pillar III). The data model should be holistic and endowed with flexibility, extendibility, scalability, while integrating different knowledge areas [Colledani, et al. 2008]. Therefore, it will be necessary to develop and integrate different packages inside the data model, such as Strategy, Product, Process, Resource, System, and Building packages. Although a harmonized reference factory model does not exist yet, several data models have been presented in the literature to address specific topics. These works can be grouped according to the areas that have been previously defined for the packages. For example, the research initiative buildingSMART has developed a common data schema (ISO/PAS 16739) concerning the modelling of the building to represent and exchange relevant data among different software applications. STEP (ISO 10303) is a relevant standard for the formalization of product information, whereas Process Specification Language (PSL) is an approach to represent manufacturing processes and exchange process information and knowledge (ISO/CD18629 2002). Some research efforts have been done also to integrate the heterogeneous factory data. The STEP-NC standard (ISO 14649) presents a data model for integrating product and process information. ISO 15531 MANDATE standard defines a new paradigm in terms of manufacturing management information, considering at the same time product, process, and resource concepts. B2MML (Business To Manufacturing Markup Language) is an XML implementation of the ANSI/ISA 95 family of standards (ISA95), known as IEC/ISO 62264. B2MML can be used to integrate business systems (e.g. ERP and supply chain management systems) with manufacturing systems by modelling different factory entities.

The Factory Data Model will be developed as an XML file–based repository, since it supports versioning. Indeed, *versioning* is a key feature of the data repository and it will be implemented by means of a dedicated application (e.g. Subversion), so that several versions of the factory data can co-exist in the repository. The B2MML approach will be taken as a reference, even though not all the files will be stored in XML format, since some data are stored in binary format files.

2.2 Pillar II - VF Manager

The *VF Manager* is the core of the VFF and handles the common space of abstract objects representing the factory. This representation is based on the standard data model defined in Pillar I. The versioning approach chosen for the factory data model impacts on the VFF architecture at all levels, and in particular on the VF Manager internal architecture. Considering the characteristics of the data model (Pillar I) and the need to interface several decoupled modules (Pillar III), the structure of the VF Manager has been designed by adopting a *star network* architecture as shown in Figure 2.
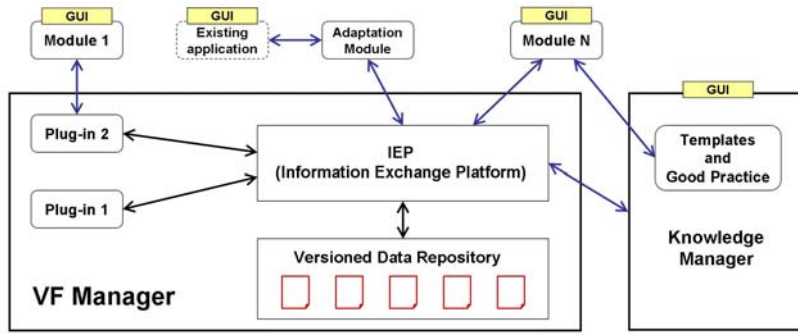
Figure 2: Virtual Factory Framework architecture

The VF Manager acts as a server supporting the I/O communications between the decoupled modules that need to access the data model that is implemented as a versioned file system. The data model is controlled by the VF Manager through the IEP (Information Exchanging Platform). Moreover, the VF Manager can provide other basic services to the modules by means of dedicated plug-ins. Different modules will access or modify partial areas of the factory data model at different times, thus the VF Manager must ensure data consistency and avoid data loss or corruption. If two users try to edit the same data of the same factory instance at the same time, then VF Manager has to guarantee the data integrity by adopting an appropriate locking mechanism. The decoupled modules can be developed with different programming languages, operating systems and hardware, therefore the VF Manager must be able to serve all of them by providing cross-platform services that can be accessed by remote applications. These requirements will be met by implementing web services based on XML contents that are provided via HTTP connections. This approach is feasible because the interactions between the VF Manager and the modules do not require a real-time communication. Indeed, data will be exchanged at discrete steps when the module starts working or modifications have to be saved in the data repository.

The Information Exchanging Platform (IEP) is the component of the VF Manager providing modules and plug-ins with a high level access to the versioned data repository where all the factory data are stored as files. The IEP offers data retrieval methods, resource locking mechanisms, and other functionalities enabling an efficient and safe data exchange. The interface of the IEP will be exposed as a set of web services so that it can be used by any module.

2.3 Pillar III - VF modules

The VF modules are the decoupled functional software tools that implement the various methods and services for the factory design, performance evaluation, management, etc. The VF modules can be located on a remote workstation (*Client Module*) or on the server where the VF Manager resides (*VF Manager Plug-in Module*). A Client Module can be based on any operating system, programming language or hardware. If the module can use the web services provided by the VF Manager, then the module directly accesses the data repository through the IEP. Otherwise, it is necessary to develop adapter modules to enable the communication between the VF Manager and the module (e.g. a commercial software tool). A Plug-in Module is implemented as a server application that accesses the data through the IEP and offers functionalities to the VF modules.

Considering the scope of the VFF approach, the necessary VF modules can be grouped into categories. For each category, different solutions can adopted according to the specific needs and the availability or not of commercial applications. The following key categories can be mentioned: visualisation modules for viewing the characteristics of the factory and support the activities carried out by other modules, KPI (Key Performance Indicator) modules, Discrete Event Simulation modules to evaluate the performance of the factory, presence and ergonomics modules, kinematic simulation modules, control modules for the emulation of the production systems, factory design modules to support the design of the factory layout and systems.

2.4 Pillar IV - Knowledge

Knowledge is the engine of the VFF concepts and it has to support the modelling of a wider range of complex systems and provide greater comprehension of the modelled phenomena. The Knowledge Manager is responsible of the knowledge repository that is designed according to an ontology-based approach. The Knowledge Manager will be endowed with a Knowledge Association Engine that extracts the knowledge from the repository by means of rule-based mechanisms and case-based reasoning techniques. The Knowledge Manager consists also of Factory Templates and Good Practice that can be used to support the decision making during the factory lifecycle phases. The knowledge can be exploited by a user through the GUI of the Knowledge Manager or the VF modules can directly access to the Templates and Good Practice.

3 The Real Factory

The collaboration between the four pillars leads to the realization of the Virtual Factory concepts. However, it must be stressed that the Virtual Factory is not self-contained and its existence is justified as along as it guarantees benefits for the Real Factory. Therefore, the Virtual Factory needs to be permanently synchronised with the Real Factory to achieve time and cost savings. The communication between the Real Factory and the Virtual Factory (cf. Figure 3) is implemented thanks to the Factory Image that can be considered as a picture of the factory state.
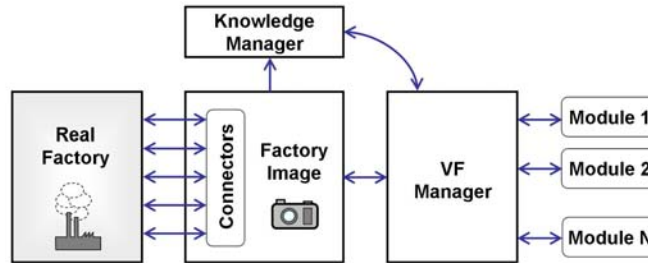

Figure 3: Real Factory and Virtual Factory

This picture is made by retrieving data from the Real Factory by means of appropriate physical connectors. The Factory Image aggregates and filters all the real data and passes them to the VF Manager. Indeed, the Factory Image is a particular and specialized type of VF module. The data coming from the Factory Image can be used by any module (e.g. KPI module, Visualization module, etc.) to support the decisions to be taken inside the Virtual Factory. Once these decisions are consolidated, they will be implemented in the Real Factory, thus closing the loop between the real and virtual factory. In the previous section it was stated that the communication between the VF Manager and the VF modules cannot be on real-time. This is true because of hardware and software constraints, but also because of architectural decisions related to the VFF goals. In the same way, the Factory Image and the VF Manager will not be synchronised on real-time. The frequency of the pictures taken by the Factory Image is constrained both by the adopted technologies and by the actual performance of the framework. Finally, a new Factory Image will be generated after a fixed time interval or when a module needs updated information.

4 Validation

Since the final goal of the Virtual Factory is to improve the performance of the Real Factory, it is necessary to verify the impact of the VFF approach. This need asks for the cooperation of industrial companies to define demonstration scenarios that aim at testing and validating the framework. Within the VFF project four demonstration scenarios have been designed by pairing different factory planning processes and industrial sectors represented by the project partners:

1. *Factory Design and Optimisation* in the machining sector. The VFF tools are used to design (or re-design) the factory, aiming at higher solution efficiency and effectiveness, and to optimise the configuration of the production systems. This scenario is developed with the cooperation of the industrial partners Compa S.A. and Ficep SpA.

2. *Factory Ramp-up and Monitoring* phases in the automotive and aerospace sectors. The VFF tools will help to monitor the real factory and improve the set-up activities during the ramp-up phase. Volkswagen Autoeuropa and Alenia Aeronautica SpA are the industrial partners involved in this scenario.

3. *Factory Reconfiguration and Logistics* in the automotive and white-goods sectors. The factory reconfiguration decisions can be supported by simulation and optimization tools, whereas logistics decisions need VFF tools to efficiently face variable demand by means of flexible networked operations. This scenario is developed with the support of the industrial partners Audi Hungaria Motor Kft. and Frigoglass S.A.I.C.

4. The final scenario is named "*Next Factory*" and aims at demonstrating the applicability of the VFF on the entire factory lifecycle. This integrated scenario focuses on the wood-working and automotive sectors represented by Homag AG and Comau Powertrain SpA.

Since the "Next Factory" scenario can help to better illustrate the goals of the VFF project, the remaining part of this section presents more details of the use case that is designed in cooperation with Comau. This use case deals with the design, implementation and ramp-up of a production system (machining and/or assembly lines) to produce parts for the automotive market. Two actors are involved in this kind of problem: the end-user (e.g. a client of Comau) and the technology provider (e.g. a supplier of production system like Comau). An end-user usually interacts with one or more technology providers when designing a production line, but it must be noted that the choice among alternative suppliers is mainly led by the purchase price, whereas the Life Cycle Cost (LCC) and the Total Cost of Ownership (TCO) are rarely considered, even though the consciousness of their strategic importance is growing among European companies.

A technology provider like Comau usually carries out the following activities when dealing with the problem of supplying a production system:

1. *Pre-design*. The technology provider receives the bid inquiry from the end-user and prepares one or more technical and commercial bids for the production system.

2. *Design*. After the negotiation with the end-user, the technology provider receives the order with its specifications and starts the final design of the production system. The more detailed are these specifications, the quicker and easier is the design phase.

3. *Implementation*. When the final design is approved by the end-user and the technology provider, the implementation of the factory design starts by issuing internal and external orders for building and assembling the required resources.

4. *Run and Monitor*. The implemented factory starts the production and the technology provider carefully monitors the execution of the operations.

5. *Ramp-up*. The technology provider analyses the performance of the Real Factory thanks to the data provided by the monitoring activity. The technology provider tries to match the actual performance of the factory with the expected one detailed in the order specifications.

All these activities would benefit if adequate and integrated virtual factory methods and tools were available. In particular, simulation tools for process, layout and cost planning would have a relevant impact. Since the industrial use case covers several phases of the factory lifecycle, a wide range of data is required as input. Most of the activities can be supported by existing software tools, but these tools should be integrated in a unique environment. For instance, Comau already uses software tools for PLM (Enovia by Dassault), database management, CAD (e.g. Autocad, Solidworks), simulation (e.g. Automod, Arena), human process modelling and simulation (Jack by Siemens), and for ergonomics analysis (Ergomost by Maynard). Moreover,

it would be useful to integrate the Virtual Factory with the machine monitoring system, and both of them with the factory logistics system. Nowadays several proprietary virtual simulation environments exist, but the main problem consists in the lack of integration among them. Therefore, it can be noted how the Comau use case is significant from a VFF perspective, since several key problems related to the VFF approach have to be addresses.

5   Conclusions

Starting from the analysis of the state of the art, this paper illustrated the structure of the VFF approach, its objectives and how to reach them, the innovative approach to the virtual tools and the idea of the factory as a comprehensive object to be innovated. The preliminary results regarding the structure of the framework have been presented to anticipate the upcoming developments of the related research project the will deal with the four pillars presented in Section 2. The whole framework will be validated over the industrial use cases that have been designed within the validation scenarios to evaluate the impact of VFF on the real factories.

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