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A VIRTUAL FACTORY TOOL TO ENHANCE THE INTEGRATED DESIGN OF PRODUCTION LINES

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Abstract: Virtual manufacturing concepts have been adopted by most of the industrial companies, including the small and medium ones, to face the global competition and deal with the top challenges of manufacturing industry, i.e. improving the quality, reducing the delivery time and decreasing the costs. However, most of the virtual manufacturing methodologies, tools and software systems are not integrated well enough to perform the required activities in an efficient manner. The attention is usually focused on local and specific proficiency, thus jeopardizing the sharing of information between the departments, the parallelization of work and the communication along the product or factory life-cycle. Indeed, the transmission of data and results is usually difficult and carried out by means of expensive and/or time-consuming manual work. This paper presents a software tool, named Design Synthesis Module (DSM), to face some of the afore mentioned problems by adopting the approach proposed by the Virtual Factory Framework project, consisting in a holistic virtual environment that integrates several decoupled functional tools sharing the same data model to support the design and management of factories. The proposed solution represents one of the tools integrated in VFF and aims at improving the proposal and design phases of production lines in terms of quality, time and cost by supporting the management of production system configuration data across several departments. DSM support the bidding and system design activities by enabling a quick evaluation of system configurations, easy adjustments and reuse of data, and the concurrent design and integrations with other tools.

Key words: virtual factory, integrated design, concurrent design, production lines, life cycle cost analysis.

1. INTRODUCTION

The manufacturing industry is today facing extraordinary challenges. Manufacturing industries are evolving towards digitalisation, networking and globalization [15]. In the course of a rapidly advancing information technology, digital tools and systems are applied in all industrial branches supporting a great variety of different tasks along the lifecycle of a factory. The application of digital tools in factory design projects is constantly growing; approximately 64% of the projects use the support of design and simulation tools, as written in [6]. Because of the complexity in tackling product design and manufacturing as a whole, software tools are traditionally designed to focus on specific issues and tasks [14]. But the wide range of software tools and applications used in virtual manufacturing today – for data processing, for graphical representation of manufacturing devices, for planning purposes, etc. – have to efficiently integrate, collaborate and interchange information among all manufacturing processes. It is not enough to be efficient and effective towards their own goals, since this practice has drawbacks when considering requirements of networked collaboration [7] and concurrent engineering for the design of products, processes and production systems. In this case, a major challenge is to enable the integration and harmonisation of the knowledge of the company through the use of multidisciplinary and varied software tools [11, 14]. In the nowadays international pressure and competition of the globalized market another important factor the companies should consider for increasing the competitiveness while ensuring high quality products and services is having quick responses to business requests and opportunities. Manufacturing companies have to develop their ability to prepare offers for customers in the least possible time, overcoming the customer expectations by providing several solutions for one inquiry, having the possibility to easily reconfigure and adapt an existing or already designed system. In the end, reducing the overall time-to-market for their products is a crucial aspect for companies to increase their market share. Another challenge the manufacturing companies have to face is dealing with often changes. Companies work on quite stable product categories produced in high volumes but, at the same time, they must cope with frequent product modifications and short product life-cycles [12]. Dealing with change is one of the most fundamental challenges facing organizations today [9, 16]. The generation and propagation of changes create a multitude of possible scenarios that companies must face in order to stay competitive. The scenarios are often unpredictable and this represents a major cause of complexity when operating in dynamic manufacturing environments together with a lack of unified solution approaches [14].

Recent research efforts seem to individuate the concept of reconfigurability as the answer to the need for facing continuous changes in the production problems [5]. In Wiendahl *et al.* [16] the reconfigurability concept is defined as the operating ability of a production system or device to switch with minimal effort and delay to a particular family of work pieces or subassemblies thorough the addition or removal of functional elements.

Besides reconfigurability, also flexibility is a key requirement to be met by manufacturing organizations and their systems in order to overcome the changes that may appear. While as shown above reconfigurability is the operative ability of a manufacturing system to switch to a particular family of part types, flexibility is somehow a broader concept involving the tactical ability of the entire production and logistics areas to switch between families of components [14]. However, flexibility cannot be properly considered in the decision making process, if it is not defined in quantifiable terms. Alexopoulos *et al*. [1] presents an interesting method of modelling and assessing the flexibility of a manufacturing system. A more in depth research direction was the introduction of a focused flexibility paradigm. The ability of designing production systems whose flexibility degree is customized on the present production problem and, at the same time, it takes into account future product evolutions, can lead to a competitive advantage [14]. Focused flexibility may represent an important means to rationalize the way flexibility is embedded in manufacturing systems. Focused Flexibility Manufacturing Systems – FFMS [13] represent a competitive answer to cope with the analyzed production context since they guarantee the optimal trade-off between productivity and flexibility.

Another concept that is researched and has synergies with reconfigurability, flexibility, adaptability and changeability is the co-evolution. Co-evolution involves the repeated configuration of product, process and production system over time, to profitably face and proactively shape the market dynamics namely “changes”. By properly managing co-evolution a company will be capable of continuously operating at a point that preserves the feasibility and profitability of the transformation process the company performs, in spite of the dynamic context and the uncertainty of available forecasts [14].

The topics pointed out above – integration and collaboration of software tools used in virtual manufacturing, concurrent engineering, reconfigurability, flexibility and adaptability of manufacturing systems – are addressed both by the software providers and scientific community. 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) have been developed in these areas.

The complexity of the afore mentioned problems asks for support tools to effectively address all these problems in all phases of the factory lifecycle. Major ICT players already offer all-comprehensive Product Lifecycle Management suites supporting most of the processes. However, they do not offer all the required functionalities and they lack of interoperability. Moreover, Small and Medium Enterprises cannot afford the present expensive PLM software suites. An answer to the problems and requirements highlighted so far can be given by the large-scale European project focused on development of a new Virtual Factory Framework (VFF) that can be defined as “An integrated collaborative virtual environment aimed at facilitating the sharing of resources, manufacturing information and knowledge, while supporting the design and management of all the factory entities, from a single product to networks of companies, along all the phases of the their lifecycles”. The VFF should provide a ground-breaking framework for a new Virtual Factory

(VF) but also democratize its usage thanks to new open technologies that are also exploitable by SMEs. Moreover, the VFF aims at promoting major time and operating cost savings, while increasing the performance in the design, management, evaluation and reconfiguration of new or existing factories [10]. VFF is aggregating a series of decoupled software tools that implement various methods and services for factory design, performance evaluation, management, etc. In this paper we are presenting one of these tools, named Design Synthesis Module (DSM), which deals with several of the general problems addressed by VFF: integration of various software tools, collaboration and parallelization of work, easy reconfigurability by quick adjustments of system configurations, data reuse, work automation, enable concurrent design. DSM will address all these in the context of offers/bids preparation and system design activities held by manufacturing companies. As mentioned in this section, one of the success keys is to prepare offers for customers in a very short time and as much as possible to include several options/solutions for the customer in one proposal. Although there are already several software tools on the market (*i.e.* Enovia, TACTIC, Arena, Teamcenter) addressing some of the problems listed above, it seems there is no one that deals with all of those issues together and in the same time being specialized on offer preparation and pre-design activities and being also affordable by SMEs.

2. PROBLEM STATEMENT AND VFF

As highlighted in the Introduction section, the manufacturing companies have been innovating a lot during the past years, in order to improve their competitiveness, business performance and to be able to increase their market share. As shown in Tolio *et al*. [14] the current challenge in manufacturing engineering consists in the innovative integration of the product, process and factory worlds and the related data, aiming at synchronizing their lifecycles. The effective collaboration and integration of many dispersed actors across various departments being involved in different production flow activities stands at the basis of time-efficient and cost-efficient manufacturing innovation.

Knowledge sharing and management is additionally one of the very important aspects to be considered here since a consistent number of data files have to be shared and exchanged by the various groups of engineers involved in offers preparation, pre-design and design activities. Additionally, the quantity of information managed by a company increased significantly during the last decade together with the boom of information technology. As suggested by Mahdjoub *et al.* [6], the design process has to be rationalized to manage knowledge, skills and technological patrimony. The challenge is that most enterprise information systems are not well integrated or maintained. Data and information can be transmitted anywhere at any time in an e-manufacturing environment. The value of integrated and collaborative software is given by how easy it enables decision making among manufacturers, designers, suppliers, partners and customers.

As already mentioned in the previous section, beside the integration of different sorts of collaboration tools, another challenge faced by the industrial companies today is the ability to quick adjust system configurations and reuse the data. This ability has a great applicability in the today’s frequent changing manufacturing environments but also for preparing offers to customers and providing several options and solutions for the same inquiry, in a very short time. In virtual manufacturing, the new software tools are trying to cover also these aspects of reconfigurability and flexibility of systems, so that solutions in the direction of production system modularisation and reconfigurability have been adopted by more and more industrial companies. In addition to extensive collaboration and adaptive system configurations, the integrated system design involves concurrency. Concurrent engineering is a work methodology based on parallelization of tasks (i.e. performing tasks concurrently). As written in Wang and Nee [15] the ideal process of concurrent or simultaneous engineering is characterized by parallel work of a potentially distributed community of designers who know about the parallel work of their colleagues and collaborate as necessary. The process is approached as a “whole”, the accumulation of results is not performed sequentially. The activities are interdependent and they are performed in parallel but with frequent integration points facilitated by clear interfaces. The goal of looking at all the systems and components together is to make sure they work and integrate in harmony rather than against each other.

There are two theories that stand at the basis of integrated and concurrent engineering. The first one redefines the basic design process structure that was used for decades. The new idea is that all elements of a production system's life-cycle should be taken into careful consideration in the early design phases. The conventional way based on a sequential design flow, sometimes called the 'Waterfall Model', does not involve from the beginning all affected parties in the process and therefore their needs, areas of expertise or insights are not taken into consideration. Using the conventional-sequential method, incompatible elements of design are not discovered until late in the process, when it is usually more expensive to make changes. In contrast, the integrated design process requires an iterative approach, multidisciplinary collaboration, including key stakeholders and design professionals, from conception to completion. The collaboration between designers has to converge towards optimizing engineering design cycles. The second theory says that all design activities should be occurring at the same time, meaning concurrently. The concurrent nature of these processes significantly increases productivity and quality, aspects that as mentioned above are very important in today's manufacturing competition.

These theories are the key to the success of concurrent engineering because they allow for errors and improvement needs to be discovered early in the design process when the representation of the system is still in a more abstract or at least virtual state. By locating and fixing these issues early, the design team can avoid what often become costly errors as the project moves towards more complicated and eventually physical representation.

Figure 1 shows a graphical representation of the difference between the conventional system design approach and respectively the iterative/concurrent approach. Applying the new theories does not mean that all problems are solved. Many organizational and managerial challenges arise when applying these methods. Opening the design process to allow concurrency creates problems of its own: ensuring compatibility between the different collaboration tools, enabling the communication between engineers, etc. There must be a strong basis for teamwork since the overall success of the methods relies on the ability of engineers to effectively work together. Often this can be a difficult obstacle, but using proper processes and software tools, this obstacle can be successfully passed.

Although different sorts of collaboration tools already exist and are used in the nowadays factories, new and innovative models, methods and procedures have to be developed to increase the collaborative and team-based planning, the integrated planning approaches, the parallelization of the work among several departments, and the concurrent design. Considering the above mentioned challenges 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 [8, 9]. All these concepts are addressed by the European research project Virtual Factory Framework. The goal of VFF is to create the next generation Virtual Factory meant also to stand at the basis of future applications in this research area.

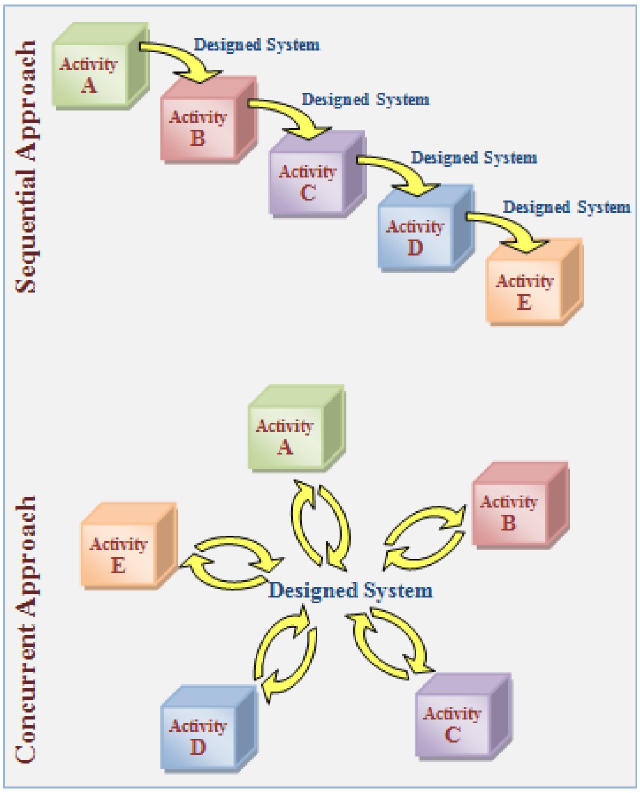

Fig. 1 – Sequential *vs.* concurrent system design.

VFF aims at supporting various factory activities and to facilitate the sharing of resources, information and knowledge related to manufacturing processes. It implements the framework for a collaborative virtual environment based on object-oriented technologies. This framework is based on four key Pillars: (I) Reference Model, (II) Virtual Factory 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. 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 long 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 is implemented thanks to the Factory Image that can be considered as a picture of the factory state and a particular and specialized type of VF module [10]. Although VFF is a research project, its goal is to have very practical and exploitable results for industrial enterprises and to support them facing the nowadays challenges. Based on international standards and advanced techniques a series of dissemination, exploitation and validation strategies are developed within VFF. Several industrial use cases are designed within the validation scenarios. The framework will be validated based on these scenarios and its impact on the real factories will be evaluated. The VF Manager is the core of VFF and handles the common space of abstract objects representing the factory. The VF Manager orchestrates the VFF functional modules and guarantees data consistency and data availability among them. Thus, VF Manager has to be designed to be able to deliver data to a large variety of tools involved in the factory planning process. In conclusion, the final goal of the VFM design and implementation consists in obtaining an open integration platform representing a common and shared communication layer between already existing and newly developed software tools to support the factory design and management. This final goal leads to the definition of several requirements: platform independent interfacing capabilities, management of concurrent access and data consistency, management of evolving factory data, data safety, addition of customized functionalities, response time [10] and a semantic web endpoint which enables stakeholders to query virtual factory models with the required level of granularity for a more efficient and selective data access [4]. The preliminary architecture of VFM proposed by Sacco *et al*. [9] was related to a VF Data Model based on the XSD/XML format. However, the XSD technology alone is not suitable for data consistency checks and knowledge representation. A viable solution has been identified in the adoption of ontology as means for data and relationships representation, promoting knowledge integration in the data-model [4]. According to its latest architecture, the Information Exchanging Platform (IEP) is the main component of the VFM and provides VF modules with a high level access to the two functional cores of VFM: the Versioning Layer and the Semantic Layer. The Versioning Layer contains the VF Data Repository where all the shared data are stored. The evolution of the factory data is managed by the versioning system that organizes and updates the set of virtual factory instances. The Versioning System guarantees the data safety as well, since it allows restoring an older version at any time, thus preventing data losses due to user errors. Moreover, rollback methods can be used in case of data inconsistencies due to broken connections or other factors, always ensuring data safety [9]. The Semantic Layer provides to the modules the possibility to perform SPARQL queries and to select and aggregate information as well as being fed with data required for their processes. Semantic validations of VFF models can be also triggered through this layer. Additionally, the models can be serialized in output files in the RDF/XML format which is used by the VFF data model ontology.

The VF modules are decoupled functional software tools that operate independently but they are all using the same Factory Data Model. They are designed and implemented in order to cover one or more of the factory life-cycle phases. They have to be seen as collaborative tools targeted for cost-effective and rapid creation of knowledge-based factories as well as for increasing the performance in design, management, evaluation and reconfiguration of new or existing production facilities. The holistic aspect of VFF is ensured by the broad range of these functional modules. These functional modules are designed in close collaboration with the interested industrial partners who are aimed to be the final users of the modules. The exposed functionality of the VFM is implemented web services that have been identified as a suitable and widely adopted solution to guarantee platform independent interfacing capabilities, thus all the functional modules are required to implement a web service client according to the WSDL file [3] describing the published interface [10]. In this way, all of the functional modules have to respect the same set of interfaces defined by the VF Manager and thus the advantage is that they can be easily integrated.

As already introduced in the previous section, Design Synthesis Module (DSM) is one of the VFF functional modules focused to facilitate the integrated and concurrent design of production systems, as well as preparation of offers for existing or potential customers. Similar to the whole VFF, the DSM module is going to be implemented in a sufficiently generic and flexible manner so that it can be used by a wide range of industrial companies facing similar problems related to customer proposals preparation, re-configurability of systems, integration and concurrency of pre-design and design activities; not only for the industrial partners of VFF. But more details about DSM will be provided in the following section.

3. DESIGN SYNTHESIS MODULE (DSM)

In order to win a competition, locally or globally, customer satisfaction has to be treated with the highest priority. This has led to the need of creating configurable and customizable systems and to even more complex manufacturing processes. Designing structures of easy reconfigurable manufacturing systems for a potential customer has become one of the desired targets. In these circumstances the offer preparation process is critical for industrial companies because it is characterized by strict time constraints and because it has the crucial role for winning an order from the customer. It is a highly critical activity because it has a great impact on the revenues of the technology provider company. If the bid is not won, the entire effort and cost spent during this phase are potentially lost. Additionally, this phase has to be carried out in a very short time period – usually 2 or 3 weeks. Since several departments are involved it is clear that parallelization of the work across these departments would speed up the process and make the whole phase more efficient. Although usually each department has a specific function in the proposal process, there are overlapping and interdependent activities, very often making the concurrent work impossible. Presented in more detail, the proposal phase consists of the following activities: Technical Proposal; Cost Estimation; Macro-Level Design Planning; Macro-Level Manufacturing Planning; Macro-Level Acquisition Planning; Macro-Level Buy-off Planning. Nowadays there are still many industrial companies that are using excel files to store the data related to the configuration of the production resources that are used to design a manufacturing/assembly system. This happens although several departments have to work on the same set of files. This means that sometimes the employees have to wait for each other's work in order to start theirs, since it is not possible to work in parallel. Additionally, there are certain cases when the usage of data coming from various sources of information (catalogues, standards, older projects, etc.) involves a lot of time-consuming search and copy-paste activities since there is no integration between these sources of information.

The DSM module, as part of VFF, address the above mentioned problems and try to offer suitable solutions to all of them. Its main objective is to improve this process as well as the design & development phase of an industrial company specialized on creating production systems. This goal is acquired by facilitating and speeding up the integrated work of the departments involved in these business processes. DSM aims at providing a shared access to explore and modify concurrently the configuration of the production system and its resources and components. DSM is a desktop software application integrated with Virtual Factory Manager for accessing the central VFF data. Additionally, it has a local storage in order to provide offline availability of data. The synchronization of the local storage with the VFF Data Repository may be performed by user request or automatically – depending on the user preferences.

The production resources required for the production systems that are going to be created reside in the VFF Data Repository and they are retrieved to DSM by the VF Manager. However, if a new production resource is needed, then the user can design a new resource by accessing various databases that are external to the VF Data Repository and which are however reachable by DSM. These newly created production resources together with their characteristics and sub-components is also stored in the VFF Data Repository and can be used in later projects or by other users. The access to external databases is necessary because at the moment it is not foreseen that the VF Data Model deal with very detailed representation of data regarding the components of a production resource (*e.g.* a machine tool). In the scope of VFF, a production resource is considered as a black box receiving input and providing an output. The external databases which are accessed by the DSM module might be catalogues of components selected to design a production resource or technical standards that can be used to estimate the characteristics of the resources (e.g. MTBF) and/or processes (*e.g.* time to execute a manual operation).

The module performs automatically computations of estimations for costs, reliability, etc. which are now done manually using excel files. The application assists the calculation of the Life Cycle Cost (LCC) of a production system. Some costs can be directly calculated by the module (*e.g.* total investment cost of machine tools), whereas other costs (*e.g.* energy cost, spare parts cost) can be estimated by other VF modules by exploiting the defined characteristics of the production resources. The time of the proposal process is expected to be significantly shortened thanks to DSM module by: speeding up the definition/evaluation of the production resources; enabling a quick reuse of data; enabling a concurrent design and characterization of the production resources. From the conceptual point of view, the module will split the handled data in two important categories. The projects will contain the information related to the new production systems which are prepared. Each new offer inquiry is seen as a new project. To cover one of the missing capabilities so far – each project may contain several solutions for the same biding preparation. Each solution will contain in fact the definition and characteristics of the production line resources chosen to be part of the respective system. On the same project, several users can work in parallel since all the data is easily shared through the VF Data Repository and VF Manager.

The master data will contain all of the resources (stations, equipment, tools, etc.) that can be used and reused in projects to create solutions for customer inquiries. From here the elements are taken and used in projects. Always a copy is created when such an element must be part of a specific solution, so that it can be customized then for that solution without affecting the basic characteristics of the element which resides in the master data or other projects. Once a new resource created into a project is expected to be reused in other projects, it can be published to the master data. But this operation is limited only to a certain user role. And in general, all writing operations on the master data will require a special privilege, since the modifications here have to be done with care, as they impact the basic set of resources for all future projects. One important aspect is that the master data is usually different from one manufacturing company to another. That's why DSM provide support for easy configuration of the master data structure based on an XML definition. This way we make sure that the tool can be used for a wide range of production systems. Other useful features that will be provided by the DSM module are: export/import of master data objects, projects, parts of projects to external files in different formats (*e.g.* export/import to/from Excel, export to PDF, etc.); data security based on users and roles – using the capabilities provided by VF Manager; freezing a project solution which is considered final, so that accidental modifications cannot be performed later on (e.g. freezing the proposal phase solutions once the project is in design phase); search capabilities for all kinds of elements; easy copy-paste of objects from other projects to the current solution; easy drag & drop of objects from master data to projects; each user can customize his user interface (look & feel).

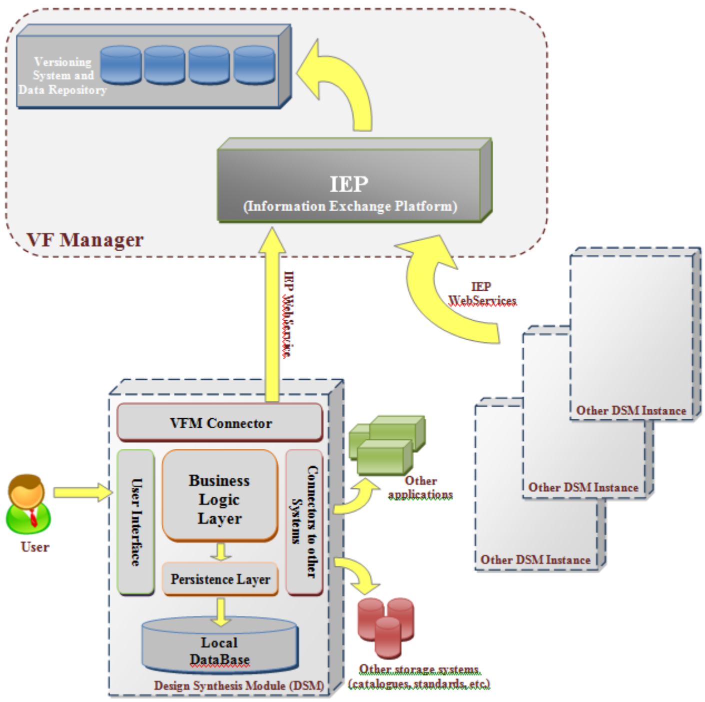

Fig. 2 – Design Synthesis Module Architecture.

Figure 2 shows the multi-layered architecture of DSM. The module provide a stand-alone user interface for being accessed by the user. An additional web user interface may be also provided in the future but it is not in focus at the moment. The stand-alone user interface was required because the users need to be able to work off-line with the application. As seen in the diagram, the module provide a connector for interacting with the VF Manager for accessing resources from the VFF Data Repository. The VFM Connector takes care of the web service client implementation and the connection state mechanism since the VF Manager will be accessed through its IEP WebService interface. The SPARQL query language is used in order to access the semantic data. However, DSM is not a semantic application and thus it access the semantic representation only to extract and modify “plain” data. In fact, this is one of the goals of future versions of DSM – how to profit from the semantic information which is available thanks to the new representation of VFF data model and thanks to the new architecture of the VF Manager. Other connectors are designed for DSM in order to access the third party systems and data storages (*e.g.* catalogues, standards). The core of the DSM module is represented by its business logic layer which handle the entire data processing, computations and logic operations. Another issue DSM is to deal with, as well as any other VFF functional module, is the fact that the data received from the VFM is in RDF/XML format [2].

4. CASE STUDY: COMAU

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: Factory Design and Optimization, Factory Ramp-up and Monitoring, Factory Reconfiguration and Logistics, and the final scenario named “Next Factory” and aims at demonstrating the applicability of the VFF on the entire factory lifecycle. This integrated scenario focuses on the woodworking and automotive sectors represented by Homag AG and COMAU Powertrain SpA [9].

COMAU is a global supplier of industrial automation systems for the automotive manufacturing sector offering full service, from product engineering to production systems and maintenance services, together with a worldwide organization. Similar to other industrial organizations, COMAU is competing in a dynamic marketplace that demands short time-to-market and agility in production. There are five business phases carried out by COMAU when dealing with the problem of supplying a production system: proposal (concept/pre-design), design and development, build & install, run & monitor, performance improvement, but only the first two are important for the topic of this paper. All these activities would benefit if adequate and integrated virtual factory methods and tools were available [10]. In the proposal phase COMAU receives a bid inquiry from a potential costumer and prepares one or more technical and commercial offers for the production system. Some very high-level design activities are involved. Once the order is won, COMAU receives the final specifications and starts the final design of the production system. The pre-design information that was prepared for the proposal phase is of great value for the design phase. Employees of several departments are involved in these two phases as well as in the other ones. They need to collaborate very well for a successful result. Several documents/files are produced by COMAU to support the proposal activity: CAD drawings of the production system layout, Excel files with description of the production system configuration and its resources, etc. The second category is of interest for us in this case. The Excel files are used by the different departments and there is one such file created for each station that will compose the production line. Thus, only one file/station is shared by several departments and it is not possible to work in parallel. Also, filling in the excel file is time consuming. Moreover, several design loops can be necessary to present the final proposal due to several reasons: technical improvement (process and resources modification), or commercial improvement (decrease the solution costs), or even modifications required by the client himself during the proposal phase. The system configuration modifications cause changes in the efficiency and productivity of the designed solution. When the configuration of a machine is changed, then the reliability and maintainability parameters need to be updated; when the configuration of the system layout is changed, then efficiency of the system is usually modified even if the productivity is the same. In general, both the investment cost and the operating cost will change, and therefore the Life Cycle Cost (LCC) will change as well. One other limitation is that due to the constraints caused by the existing time-consuming process, the ability of proposing new and alternative solutions takes a long time. The

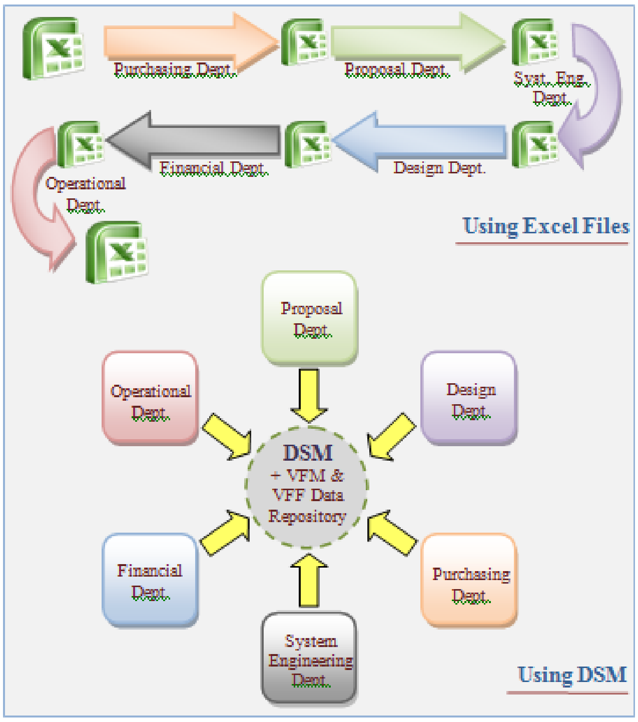

Fig. 3 – Departments collaboration before/after DSM.

proposal of several alternative solutions would be fastened and beneficial if COMAU would be helped to: speed-up the design of the solutions, this way having time also for preparing alternatives; perform a complete and detailed Life Cycle Cost (LCC) analysis of the production system during the proposal phase. Once the negotiation between the customer and COMAU is successful, an order containing the detailed specifications is issued and the design and development phase is starting. The activities carried out during this phase are similar to those carried out during the proposal process. Nevertheless, the level of detail of the data describing the production system is higher. However, the files produced during the proposal process are taken as reference to start the design and development phase. Several departments work together, again, to configure a refined version of the production system. The improvement needs highlighted above in the case of COMAU are addressed by VFF and in particular by DSM. The following goals are set for DSM in relation to improve COMAU processes: efficient and effective management of data and information about the production system configuration to be shared between the COMAU departments; tools to support the system design activity by quickly evaluating the performance and cost of the production system configurations and its resources. In particular, the creation of simulation models needs to be as much automated as possible. With the help of the DSM module, COMAU aims at speeding up the choice of the macro-components when designing the machine configurations. This can be done by selecting the electromechanical and mechanical macro-components from a database. Moreover, each macro-component should be associated with relevant technical data such as MTBF (Mean Time Between Failures)/MTTR (Mean Time To Repair), preventive maintenance (both when the machine is running and when it is stopped), etc. In addition, it will be possible to add information about the spare parts and dedicated operators' costs, thus enabling the evaluation of the LCC of macro-components, machines or even entire production systems. Additionally, having the shared access provided by DSM, the several design loops that exist today in the proposal phase can be reduced. By integration with another VFF module, the visualization of 3D design of the production system layout will be possible to be triggered from DSM. Moreover, the integration of some of the already adopted support tools would result in the possibility to bring more activities in parallel, reducing the time required during the design process.

Figure 3 shows the integration between departments is working now related to the definition of production system configuration and how it is expected to work once the DSM module is in place. The flow for creating a machine configuration which will be supported by the DSM module is the following: the machine/station configuration is described in terms of macro-components with their associated cost. Afterwards COMAU employees analyze the macro-components of the machine, trying to decompose them into elementary components. Then, each component is associated with reliability and maintainability values that are derived from a database. The global MTBF, MTTR, MTTA (Mean Time To Assist) and the workload for autonomous, preventive and corrective maintenance will be estimated thanks to reliability theories (not implemented as part of DSM). The MTBF and MTTR are characterized by appropriate statistical distributions that may be exploited then by analytical models (*e.g.* discrete event simulation models) implemented by other modules of VFF with which DSM will collaborate.

5. CONCLUSIONS

DSM is expected to increase the efficiency and effectiveness of the activities involved in proposal and design phases by: parallelization of the work for several departments; avoiding the use of the existing heavily spreadsheet files; avoiding manual computations; enabling concurrent and integrated design; speeding up the definition/evaluation of the production resources; enabling integration with other tools; enabling quick reuse of data (from other proposals, other projects), facilitating easy adjustments of the proposals; exploring and modifying the resources and components of the production system (their characteristics, attributes, etc.); designing new production resources; accessing external data bases (components catalogues, standards, etc.) and other tools; supporting the calculation of the Life Cycle Cost (LCC) for the production system; export/import capabilities; roles-based data security. One of the directions of future research, addressed by following versions of DSM, will be to check how the semantic information and knowledge (not data) provided by VF Manager can be used by DSM to improve even more the processes it is aimed for.

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