Different Perspectives of a Factory of the Future: An Overview

Giulio Salierno[1](✉), Giacomo Cabri[2](✉), and Letizia Leonardi[1](✉)

[1] Department of Engineering "Enzo Ferrari",
University of Modena and Reggio Emilia, Modena, Italy
{giulio.salierno,letizia.leonardi}@unimore.it
[2] Department of Physics, Informatics and Mathematics,
University of Modena and Reggio Emilia, Modena, Italy
giacomo.cabri@unimore.it

Abstract. *Digital factory*, and *Cloud Manufacturing* are two approaches that aim at addressing the Factory of the Future, i.e., to provide digital support to manufacturing factories. They find their roots in two different geographical areas, respectively Europe and China, and therefore presents some differences as well as the same goal of building the factory of the future. In this paper, we present both the digital factory and the cloud manufacturing approaches and discuss their differences.

Keywords: Digital factory · Cloud manufacturing · Industry 4.0

1 Introduction

European industrialists identify the radical change in the traditional manufacturing production process as the rise of Industry 4.0 [9]. Conversely, China mainland has launched his strategic plan named China 2025, to promote intelligent manufacturing as its primary direction. Both programs share the same goal about the realization of a Factory of the Future towards the development of an ICT-enabled intelligent manufacturing [14,25]. This need poses new research objectives which result in the development of new paradigms known as *Virtual Factories* for European factories, *Digital Factories* and *Smart Factories* with a widespread in both countries and *Cloud Manufacturing* finding its roots in China. Although both countries share the same goal, the context of implementation is different. This work aims to investigate the different perspectives in the realization of a Factory of the Future providing an overview of the major trends in the implementation and applications of cloud manufacturing in China, through a comparison with the European concept of Digital Factory. The paper is organized as follows. We start introducing the characteristics of *digital factories* discussing their extensibility as virtual factories (Sect. 2), then we describe the

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cloud manufacturing providing an example of its application (Sect. 3). Starting from the above descriptions, in Sect. 4 we propose a comparison between virtual factories and cloud manufacturing. Finally, Sect. 5 concludes the paper and sketches some future works.

2 Characteristics of Digital Factory

A *digital factory* refers to a new type of manufacturing production organization that simulates, evaluates and optimizes the production process and systems. Digital factories are not confined only to the production stage; instead, they extend to address the entire factory lifecycle.

The production process in a digital factory takes place from the early stage of product design down to the lowest stage of product planning and realization. As key features of the design stage, we can mention digital design, modeling, and simulations which contributes to shortening the time for designing and manufacturing products [32]. Moreover, modeling and simulation capabilities are extended to all tangible and intangible assets of the factory. 3D-motion simulation can be applied in virtual models on various stages to improve the product and process planning on all levels [11]. The digital factory represents a bridge for the existing gap between product design and manufacturing [10]. Thus, the digital factory covers the entire product lifecycle at different manufacturing levels with a focus on the virtual representation of manufacturing assets of the factory, virtual plant visualization, intelligent control and optimization of the product lifecycle through model simulation. To this end, the digital twin model is based on different models representing physical manufacturing assets (i.e., 3D-model, discrete event model), virtual simulation technology to simulate and predicts the performance of virtual models, as well as an integration platform to realize two-way connectivity between digital and real factory [23]. Moreover, in a digital factory the product design shifts from traditional 2D drawings, to a collaborative 3D model design based on CAD [31]. In this context, there are some important aspects to be outlined: (i) product performances (i.e., manufacturability, cost) are predicted by model simulations; thus the entire manufacturing process is optimized; (ii) product design is collaborative, meaning that multiple design departments (within the company boundaries) take part to the product design.

2.1 From Digital to Smart Factory

The design of an intelligent shop floor layer of a *digital factory* is related to the emerging concept of *smart factory*. A *Smart factory* connects the main actors of the supply chain (people, products, and materials) to realize seamless communication and integration (man-and-machine) for the smart manufacturing realization. The adoption of high-end manufacturing equipment (i.e., smart devices, industrial robots, and robotic arms) as well as the integration of well-established equipment with IoT devices and sensors, allows collecting real-time data and information from the factory floor. Smart factory adds decision-making capabilities to the shop floor as well as data collected from equipment is analyzed to improve the production process of the lowest manufacturing layer.

The digital factory represents a necessary prerequisite for the enabling of a *smart factory* which in turn is necessary for the development of the next generation of smart manufacturing. A smart factory enhances the capabilities of the digital factory improving the simulation results by providing real-time data of the shop floor as well as simplify the construction of faithful 3D models typical of a digital factory. A typical application collects data from the shop floor to realize realistic models thus improving the simulation results, see Fig. 1.

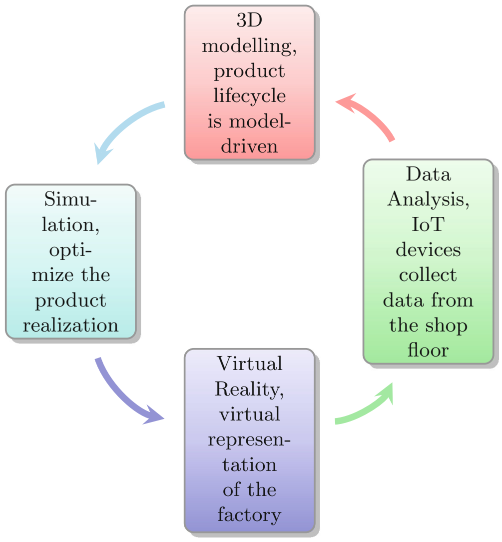

Fig. 1. Digital factory lifecycle. Smart factory enables the data collection

2.2 Digital Factory Applications

One of the key concepts of a digital factory is the representation of the physical objects composing the shop floor in a virtual space. The connection between the physical and the virtual world of a factory is realized through M2M OPC-UA protocol. 3D-Virtual Reality (VR) technologies replicate the shop floor in a virtual space and simulation results optimize the design process without the need for sample manufacturing. That is, through three-dimensional modeling, virtual simulation technology, the design layer predicts the performance of the production, and improves and optimizes the product lifecycle based on simulation results.

The core of the digital factory is represented by the integration of existing manufacturing systems at different operational layers as well as the adoption of 3D modeling technologies, virtual simulation and Virtual Reality/Augmented Reality technologies. The digital factory promotes technological support for the entire product life cycle by the creation of a digital twin model.

To this end, Authors of [17] propose a framework that enables the development of a feasible semantic model that supports easy creation of digital twins for physical assets of a factory. The virtualization of the shop floor hardware encompasses a data model that encapsulates the technical specification of the machines composing the factory floor.

Conversely, at the control layer, the virtual simulation plays a central role in modern manufacturing companies which adopt virtual reality for the design and verification of production systems as machines simulation, process verification, and factory layout planning and simulation. Simulation of virtual resources is made available through a variety of commercial tools such as Arena [28], DELMIA [4], Flexsim [7]. As an example, South Korea's Samsung Heavy Industries use DELMIA software to build a 3D layout of the factory floor and simulate processes in a virtual environment.

The model-based simulation also helps to identify bottlenecks in the production line whose identification in the real world would have required a long-term verification with high costs (i.e., to maximize the production by reducing the number of failures caused by poor processes and failures of mechanical parts). As an example, authors in [2] built a Flexsim model starting from real data of a packaging production line. The model helped in identifying machine failures of the hardware composing the shop floor. Therefore, continuously updating simulation models with monitoring data, improves the accuracy and precision of the predictions [19].

Augmented Reality is adopted to solve problems common to the current manufacturing plant. The increasing cost of labor and the loss of knowledge due to the retirement of highly skilled employees are minimized through the adoption of Augmented Reality technology. As an example, AR is used to train newcomers by providing visual training on mastering manufacturing equipment. Information is displayed directly on the eye screen through the use of standard AR glasses. This approach not only reduces the cost of training newcomers but also enables to instruct employees to handle hardware failures by displaying procedures to recovery from failures, thus improving the production.

2.3 Relationship Between Digital Factory and Virtual Factory

The European concept of *Virtual Factory* is a major expansion upon virtual enterprises in the context of manufacturing. The virtual organization approach integrates collaborative business processes from different enterprises to simulate, model and test different design options to evaluate performance, thus to save time-to-production [5].

Both *digital* factory and *virtual* factory share common reference models for the realization of a Factory of the Future. In a digital factory, decision-making technologies play a key role in real plant simulation and optimization.

Similarly, 3D virtual environments and discrete event simulation models are proposed for modeling, simulating and evaluating manufacturing assets [5] in a virtual factory. On the contrast, while a digital factory is likely to define their operational boundaries inside the company, a virtual factory extends the factories capabilities across multiple organizations to provide a unified virtual environment to test, model and simulates factory layouts and processes.

Similar applications are found in a digital factory where its application extend design and production processes across multiple departments within the company boundaries. This trend emerges in companies which implement a digital factory to support a collaborative process among departments. As an example, the China Aerospace Science and Technology 211 company, adopt a full step-by-step design process ranging from 3D-to-process to 3D-to-site and 3D-to-factory. It can be outlined that process collaboration is driven by the adoption of 3D models through the entire development process. Therefore, three-dimensional modeling is a key enabler of a collaborative process promoting the sharing of product data flexibly within the digital factory boundaries.

Ultimately, there is a strong overlap between digital factory and virtual factory. While the digital factory provides cooperation within departments, the virtual factory extends this cooperation among multiple enterprises. Therefore, for the rest of the paper, we will refer to a virtual factory, as an extension upon the digital factory. The concept of collaborative manufacturing is also an important characteristic of cloud manufacturing described in the next section.

3 Characteristic of Cloud Manufacturing

Cloud manufacturing is an emerging trend in China, which takes benefit from cloud computing and information technology, to achieve resources sharing across small and medium-sized enterprises (SMEs). It has become a national trend due to rapid industrialization and advancement of information technology. Cloud Manufacturing can be defined as *a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction* [30]. Therefore, on-demand services, resources virtualization and decentralized services of centralized resources promote new forms of networked manufacturing to respond quickly to unpredictable demands of the market. Cloud Manufacturing inherits the concept of "everything is a service" from cloud computing and proposes a new paradigm of *Manufacturing as a Service* (MaaS), which encapsulates manufacturing assets (software tools, production systems, capabilities) into cloud services providing on-demand access to consumers. Further, cloud manufacturing promotes a new collaborative manufacturing business model represented in Fig. 2. The collaborative cloud manufacturing promotes the active role of the customers during the production process. Customers interact with manufacturers via a cloud platform by specifying their product requirements. Mass customization of products is enhanced by the creation of a network of enterprises (DMS) having different roles in the production process.

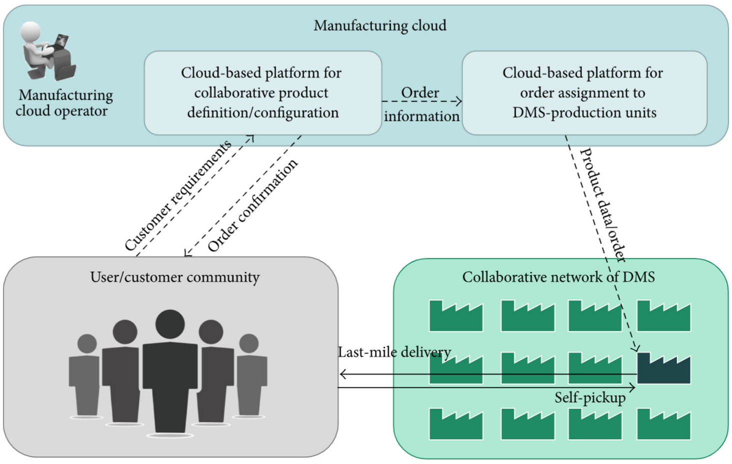

Fig. 2. Collaborative cloud manufacturing model taken from [6].

3.1 Type of Services

The nature of services provided in the cloud is extremely variegated due to the necessity to cover the entire product lifecycle of the traditional manufacturing process. According to [16], service delivery models (SDM) are typical of Cloud Computing, and they can be divided into: *Infrastructure-as-Service* (*IaaS*), *Platform-as-Service* (*PaaS*) and *Software-as-Service* (*SaaS*). In contrast to traditional cloud computing, services are provided both by cloud computing resources as well as manufacturing resources (smart robots, production systems, equipment). Services provided by the cloud can range from pure manufacturing services (i.e., equipment for product realization) to manufacturing software services (provided through a cloud computing resource). Cloud delivery models fit accordingly to the different manufacturing steps. As an example, considering the product lifecycle, the following delivery models are suitable for the different production stages:

- Product Design, Product Simulation and Product Management delivered as *SaaS*
- Product Planning delivered as *PaaS*
- Product Realization (requiring the use of physical equipment composing the factory floor) delivered as *IaaS*

In addition to the standard cloud manufacturing *services* mode, cloud manufacturing promotes a new form of enterprises collaboration through the on-demand access of virtualized and decentralized resources via a cloud platform. For example, virtual enterprises set up a collaborative network which supports a different form of coupling such as *loose* and *tight* coupling. According to the diverse enterprise needs, loose coupling is selected for occasional use of manufacturing assets while a tight coupling is chosen whenever a global manufacturing process relies on services offered by multiple enterprises. Therefore, a cloud architecture promotes enterprise collaboration through the enabling of multiple forms of alliances according to the diverse needs. Through the unified management of resources/capabilities, cloud manufacturing promotes the sharing of decentralized resources of manufacturing resources/capabilities highlighted by the manufacturing grid and also includes the integration and sharing of hard manufacturing resources.

3.2 Collaborative Deployment Models

Cloud manufacturing has four typical deployment modes inherited from cloud computing [30] (*public* cloud, *private* cloud, *hybrid* cloud, and *community* cloud).

- In the *public* cloud, service provider subscribes and publishes their services in a multi-tenant environment. A cloud platform provides on-demand use of services to an open community of customers.
- *Private* cloud restricts the operational mode within enterprises boundaries. In a private cloud, all actors belong to the same organization.
- *Hybrid* cloud mixes the previous mode to integrate different types of cloud (e.g., public, private or community). Forming a bridge, between different clouds, requires cloud owners to select proper resources sharing models. Authors in [18] proposed a framework for the development of hybrid cloud bridging multiple cloud platforms.
- A *community* cloud is shared among companies of the same community.

3.3 Some Examples of Cloud Manufacturing

The success case of cloud manufacturing in China mainly includes small- and medium-sized enterprises that have established their information systems [15]. Despite the cloud manufacturing aims to cover the entire manufacturing product lifecycle ranging from collaborative product design down to services integration and virtualization and sharing of manufacturing resources, at present, the development of a full-featured cloud manufacturing application case is still under development [16]. Nevertheless, many industries start to experiment with the development of a cloud manufacturing platform at a different level of awareness. The collaborative cloud platform proposed in [12] aims to balance uneven resources distribution and fragmentation in the integration of different services in the mold industry. The cloud platform acts as a trading platform where enterprises publish and trade their manufacturing assets. The main functionalities offered by the platform include enterprises registration as a service provider or customer, manufacturing assets registration, service discovery, service selection, service evaluation, transaction management.

Similarly, the features of the platform are extended [13] to enable integration at the process level as well as tight coupling of different manufacturing management systems (i.e., MES, ERP). The collaboration mode between enterprises is based on a social network model that guarantees interaction among partners in a relatively stable network environment. According to the diverse business requirements, enterprises seek new partners through the public market page,

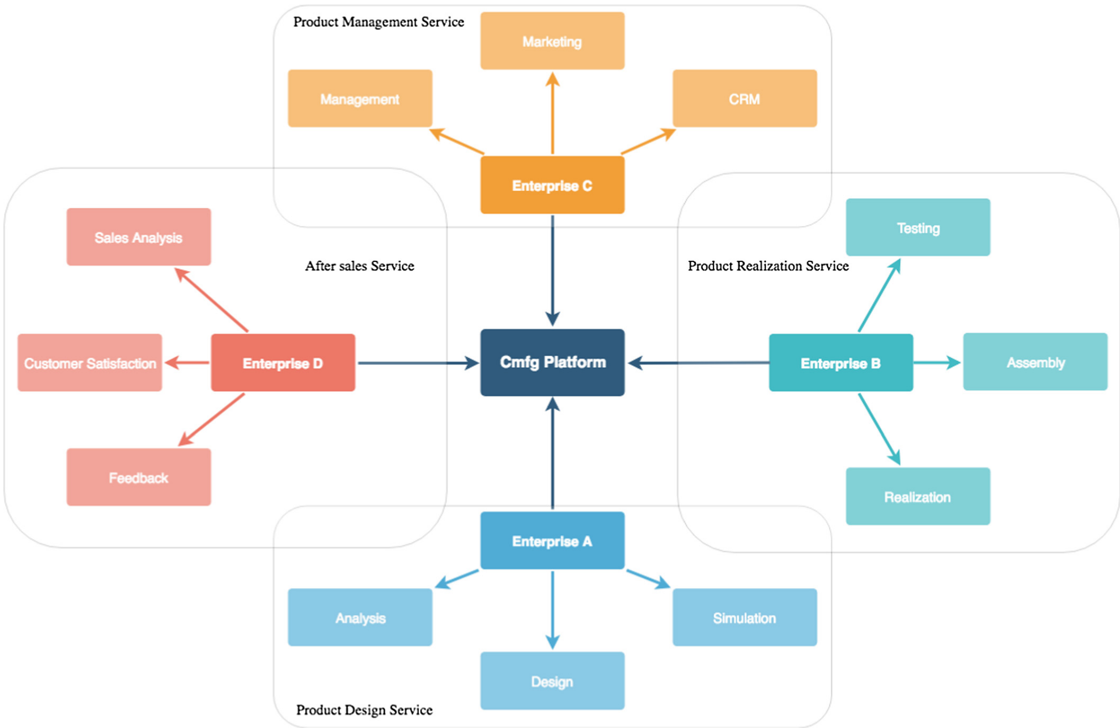

Fig. 3. An example of a collaborative network established via a cloud platform.

remove partners from an alliance or join multiple networks at the same time. The platform Tianzhi Net[1] enables enterprises business collaboration of local industrial chains [13]. The example reported in Fig. 3 shows a network alliance based on a social network model enabled by a cloud platform.

4 Comparison Between Cmfg and vF

In this Section, we compare the two approaches considering some aspects. Firstly we introduce the operational boundaries to examine the degree of interoperability across factories. Moreover, we examine different approaches to provide interoperability at each architectural layer. Then, we describe the main actors of a virtual factory and cloud manufacturing. Finally, we briefly introduce potential applications for simulating and optimizing a factory. Table 1 summarizes the comparison.

Operational Boundaries. While one of the goals of a virtual factory is the enabling of a wide collaboration to expand the business outside company boundaries, the cloud manufacturing encompasses resources virtualization, decentralized services, and collaborative deployment models to achieve enterprises collaboration. The concept of cloud manufacturing also includes dynamic resources

[1] www.cosimcloud.com.

allocation and different pricing models (i.e., pay-per-use, subscription, pay-for-resources) which not only open up powerful forms of collaborations but also promotes a networked production process to support the emerging trend of the mass-customization.

Data Interoperability. One of the major challenges in a virtual factory is enabling interoperability among SMEs. To this end, different works have been proposed in the literature to support interoperability. The cloud-based storage architecture proposed by [8] promotes the sharing of data across virtual factories activities through a Storage as a Service cloud model. The storage is based on the concept of buckets, which are specific isolated storage spaces managing data for the different data type. These buckets manage different types of data in multiple databases. In the European research project, Virtual Factory Framework (VFF) [29] the proposed Virtual Factory Data Model (VFDM) provides a unified common definition of data shared among the software tools connected to the framework, using a shared meta-language. Similar challenges arise in the cloud manufacturing where the goal is to enable interoperability in heterogeneous environments composed by multiple cloud services. Authors in [29] propose to deal with data interoperability issues in cloud manufacturing with an architecture based on Virtual Function Block (VFB). Data manipulation is driven by the function block which guarantees the data, related to the manufacturing process, to be consistent among heterogeneous cloud environments. To this end, a cloud manufacturing architecture [24] utilizes the OWL language to model Cloud resources, as well as other approaches, are proposed to provide a unified data modeling such: ontology-based models, cloud resources and services description based on XML language [29].

Service Interoperability. In a virtual factory, a collaborative process includes composition and integration of existing manufacturing services supported by technologies from the service-oriented computing (SOA) [22]. In cloud manufacturing, each manufacturing asset is virtualized via a virtual resource layer

Table 1. Key features of vF and Cmfg

	vF	Cmfg
Operational boundaries	Inter-factories	Expand to multiple heterogeneous cloud environments
Data interoperability	Common reference model for unified data representation (VDM)	Based on: OWL models, XML description language, Ontology-based models
Services interoperability	Service-oriented architecture	
Operational roles	Distinguish between resources consumer/provider and vF owner	Inherited from cloud computing
Simulation and optimization	As an IT platform provide optimization by simulations of the real plant of the factory	SaaS applications to monitor and controls the production process

and deployed as a service through a service-oriented layer, composing the cloud manufacturing (CMfg) architecture. For example, for virtual enterprises and collaborative networks, cloud manufacturing supports different forms of collaboration, such as loose coupling and tight coupling, and builds different forms of alliances through its highly flexible cloud architecture, as mentioned before. Cloud manufacturing enables the integration of decentralized social manufacturing assets to achieve high levels of sharing and collaboration. In cloud manufacturing, enterprises perform service development and provide manufacturing services to each other. It can be seen that the concept of cloud manufacturing and service-oriented manufacturing is completely consistent. Therefore, integration of cloud manufacturing services relies on the adoption of service-oriented architecture as in a virtual factory. As an example, we report the work of [27] in which authors propose a service-oriented architecture based on a service broker, to orchestrate services of multiple heterogeneous clouds.

Operational Roles. Finally, the Cmfg paradigm differentiates operational roles such as resources consumer, resources providers, and cloud operators. Although these roles are immutable in a standard cloud environment, as pointed out in the previous paragraph, the cloud manufacturing opens up new forms of collaborative models in which operational roles, as well as sharing policies, are interchangeable. Therefore, the roles of the actors in a multiple cloud collaborative environment need to be further studied to support a dynamic form of collaborations, flexible sharing policies, as well as diverse pricing models for each manufacturing asset. At the same time, the human role is taking into consideration during the design of a virtual factory [1]; in particular, the parties involved in a service-oriented virtual factory are defined as [22]: service provider, service consumer and service broker. These roles respectively identify the parties which offer physical services, the consumer of these services, and the owner who controls and governs the virtual factory. Therefore, although the virtual factory roles are coherent with the ones defined in the Cmfg, as proposed in the cloud, deployment models, as well as pricing models, need to be further examined to enable a flexible collaboration between virtual factories.

Simulation and Optimization. From a virtual factory as an IT platform perspective, the potential is extended to plan, simulate, control the shop floor to assess the future impact of production and maintenance planning decisions [26]. Similarly, in a cloud environment, cloud-based services monitor the production planning and control the discrete manufacturing environment (i.e., machine availability monitoring and collaborative and adaptive process planning [21], simultaneous shop scheduling, and material planning [20]).

5 Conclusions

Both *digital factory* and *cloud manufacturing* adopts different concepts for the realization of a Factory of the Future.

Despite sharing the same goal, the chosen directions differ under different points of view. From a common digital factory perspective, the aim is to automate and digitalize the intra-factory level with the help of new technological advancements such: virtual reality, augmented reality, and simulations to optimize the production of the shop floor. While from an inter-factories collaboration perspective, the most promising paradigms are the Chinese paradigm of cloud manufacturing and the European concept of virtual factory.

While the cloud manufacturing derives its roots from the widely accepted concept of cloud computing, the virtual factory forms its basis in the manufacturing environment. In this paper, we have introduced both the approaches, and we have proposed a comparison based on the main features of the two concepts.

Additionally, to further expand business between European and Chinese factories is necessary to examine interoperability issues between digital factories and cloud manufacturing better. With regard to future work, we are studying how to enable interoperability in digital factories [3].

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