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Toward Cloud-based Manufacturing Ecosystems

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Abstract

Manufacturing industry is facing the impact of dynamic market and intense competition. Cloud computing enables the offering of manufacturing services over the Internet. The sharing of resources and capabilities between different stakeholders on cloud-based solution in collaborative relationships is widely accepted to be a fundamental support to business and physical production. The purpose of this study is to explore the approaches moving toward a cloud manufacturing ecosystems and presents possible implication for practice.

Keywords: Manufacturing ecosystems, virtual enterprise, supply chain management, cloud manufacturing.

1. Introduction

Manufacturers are facing impacts from multiple advanced technologies, and they have to make changes toward a new era of physical production and create a new business environment. The business ecosystem, originated from the metaphor of natural ecosystem, offers a niche for each business participants to operate, form collaboration and compete in a dynamic and sophisticated relationship (Moore 2006; Gawer & Cusumano 2014). Apple's AppStore is a well-known and often mentioned reference of a business ecosystem where a large central operator offers to smaller agents (i.e., software developers) an access to the market and simultaneously to the mobile phone end-users by using a profit-sharing scheme and a process for financial transactions. In the context of manufacturing, similar aims have been presented by 3D printing web portals, such as Ponoko and 3D-Hubs. Manufacturing-oriented portals are being introduced for the exchange of production related data and managing supply chains related transactional information (Hao, Shamsuzzoha & Helo, 2013). These portals can be described as manufacturing ecosystem.

The concept of manufacturing ecosystems also relates to other concepts, such as networked value chains, holonic enterprises, virtual enterprises (Gunasekaran & Ngai, 2004), distributed manufacturing (Fujii et al., 2000) and in some extent to non-hierarchical networks (Shamsuzzoha et al., 2016). Interestingly, various actors who get involved in related business operations could be the participants of a particular business ecosystem. In manufacturing industry, they are customers, manufacturers, researchers, suppliers, technology providers, policymakers, and even competitors (Tsai, 2016). Within manufacturing ecosystem, the actors develop, and create products and services together to the same target customers, which is especially crucial for global market demand.

The advances in cloud technology, Internet of Things (IoT), and big data analytics enable new models of collaboration and competition in the field of manufacturing and supply chains (Ren et al., 2015; Wu et al., 2013), such as smart manufacturing, intelligent manufacturing, Industry 4.0, etc. Many companies are currently testing the business potential of portals in connecting the manufacturing machinery to the cloud (Huang et al., 2013). The concept of cloud manufacturing provides an operating framework to realize the collaboration (Chen et al., 2017). Cloud manufacturing is a manufacturing paradigm that use cloud computing, network, IoT, service computing and manufacturing enabling technologies that transforms manufacturing resources (both hardware and software) and capabilities (i.e. the performance of production and manufacturing) into the cloud as manufacturing services (Tao et al., 2011; Zhang et al., 2014; He and Xu, 2015). Cloud manufacturing enables decentralized service control and management.

Although manufacturing ecosystem and cloud manufacturing have been proposed in previous studies, it is still challenging for manufacturers to understand the practical approaches of adopting advanced technologies and collaborating with other stakeholders in the business ecosystem. It is essential for the manufacturers to have cognizance of how to and when to collaborate across organizational and geographic boundaries (Yang, Weber & Gabella, 2013). There is a need for comprehensive analyses of processes and mechanisms that enable collaborative solutions across the manufacturing ecosystem by adopting with cloud-based technologies.

2. Ecosystems

Recently, the collaborative business models exist in a variety of forms in the manufacturing industry. For instance, virtual factory is an objective-oriented collaboration model among SMEs (small and medium sized enterprises) for a temporary business opportunity (Hao, Shamsuzzoha & Helo, 2013). Extended enterprise repents a model and a dominant enterprise extends it boundaries to other suppliers (Alfaro, Rodriguez & Ortiz, 2005). Grid manufacturing business model provides a pool of distributed and heterogeneous manufacturing resources (Ai et al., 2013). Manufacturing ecosystems and cloud manufacturing are the two central concepts needed for developing psychical production toward on-line real-time systems. Many companies integrate advanced technologies for a stronger manufacturing organization and for broader manufacturing ecosystems. Cloud computing and cloud-based services are the enablers for conducting operations within the manufacturing ecosystem.

2.1. Business ecosystems

Economy and biology have many common features. Rothschild (1990) introduced a concept of bionomics and described economy as a business ecosystem with transactions between agents. By drawing an analogy between biological ecosystem and business ecosystem, the performance of each company is dependent on the performance of the whole (Moore, 1998). In the natural ecosystem, each specie has its own significant role and impact on the evolution of other species. In this way, they construct a closely inter-depending community. In the business ecosystem, each company cannot develop fully without the same achieving level of others. Business ecosystem describes a loosely connected business community sharing a common goal and business purpose among different relevant stakeholders to deal with uncertain business environments (Moore, 1998). However, the stakeholders have different structural properties or attributes (Wulf & Butel, 2017). This concept could extend the broader of companies, and create a bigger view of cross-industry collaboration among different companies (Rong et al., 2013).

An ecosystem is a metaphor that highlights the interdependence of all companies in the business environment (Nachira, Dini & Nicolai, 2007). The co-evolving and developing relationships among companies are considered as the approaches for innovation and evolution of companies participating in the business ecosystem (Moore, 2006). In other words, in order to create favourable and innovative business environmental conditions, it is important for companies to develop in ecosystems or clusters with each other.

In the business ecosystem, two main structure have been discussed. First is "keystone" model which is dominated by a large company (or a number of large company) that is surrounded by a large number of small suppliers. Second model is composed of mainly SMEs that complement one another and collaborate in a more dynamic structure (Nachira, Dini & Nicolai, 2007; Razavi, Krause & Strømmen-Bakhtiar, 2010). Platform development is a key way to manage different actors and deal with the turbulent market in the business ecosystem (Moore, 1998). It is a major enabler of the business ecosystem. The platform is designed to leverage the available information within entire ecosystem. These two types of ecosystems are supported by internal platforms and external industry platforms, respectively (Gawer & Cusumano, 2014). Implementation of platforms can help companies to learn about the surrounding ecosystem, and also to understand their position within this ecosystem (Kress, Pflaum & Löwen, 2016).

Business ecosystem has been called as digital ecosystem as well because the use of advanced IT (information technology) tools can support intensive collaborations (Camarinha-Matos et al., 2009). Digitalization has brought new aspect on business ecosystems as network formation, transactions and deformations on the technology-enabled platform. This can be referred to digital business ecosystems (Nachira et al 2007). The digital business ecosystems aim to provide companies an open and reliable platform to interact with each other (Razavi, Krause & Strømmen-Bakhtiar, 2010).

Boundaries typically produce constraints and limitations. The adoption in business ecosystems can weaken the boundaries between and within companies. IoTs, 3D printing, robotics, and other technologies are driving a blurry boundary of companies. Also other fundamental boundaries, such as humans and machines, producers and consumers, and physical and digital are rapidly blurring in the business environment and economy (Eamonn, 2015). Therefore, the concept of digital business ecosystem emphasizes the coevolution between the business ecosystem and its partial digital representation (Nachira, Dini & Nicolai, 2007).

2.2. Manufacturing ecosystems

A distinctive characteristic of many ecosystems is that they form to achieve something together that lies beyond the effective scope and capabilities of any individual actor (or even group of broadly similar actors). All the actors are sharing resources and within the ecosystem. This phenomenon is not only applied in OEMs (original equipment manufacturers) but also applied to SMEs in the manufacturing industry. Nowadays, customers are more and more demanding in the manufacturing industry. It becomes a primary challenge and even a high priority to meet rapidly rising customer expectations. Therefore, many manufacturers are seeking a way to develop a mutually beneficial network with other stakeholders and build a flexible ecosystem that leverages strategic partners and digital technologies. Authors such as Basole et al. (2015) have studied such dynamics by analysing which companies operate with each other and what kind of network is the result of dynamic behaviour. However, today's manufacturers are struggling to keep up, because most of the companies are rigid and geographically restricted in their current production networks (Rasmus and McKinney, 2017).

There are different actors in the manufacturing ecosystems, such as suppliers, distributors, logistics partners, and so on. They play a significant role in the entire journey of manufacturing, from innovation, design, production and distribution, to aftersales services (Rasmus & McKinney, 2017). All these actors play together, to improve efficiencies and to optimize product and service levels.

Besides different actors, different departments are also tightly integrated into the manufacturing ecosystem. Hao (2016) provides a collaborative model across three different organization levels and the information sharing level. The manufacturing ecosystem includes all possible aspects of product development and production processes. Due to fast-evolving technologies enabling information flow and communications, integrated information management can remove the barriers and costly obstacles between different departments and ensure all departments can work together in parallel by information sharing mechanisms.

As additive manufacturing gains momentum, manufacturers will be able to buy digital representations of products (standard and proprietary) through emerging digital marketplaces and augment them via value-added digital services to meet specific marketplace needs. Once designs are completed, products can be produced in-house, via a contract manufacturer, or through an ad-hoc 3D printing service. These marketplaces and services will help manufacturers dramatically reduce costs and time across innovation, design, and production (Rasmus & McKinney, 2017). Layers of digital manufacturing ecosystems

Based on previous research and existing cases in the market, the manufacturing ecosystem can be viewed from three aspects: (1) partners are the actors in the ecosystem (Freitag, Westphal & Guglielmina, 2012), (2) businesses delivering value to the ecosystem, and technologies which are enabling of the ecosystem (Camarinha-Matos et al., 2009), as shown in Figure 1.

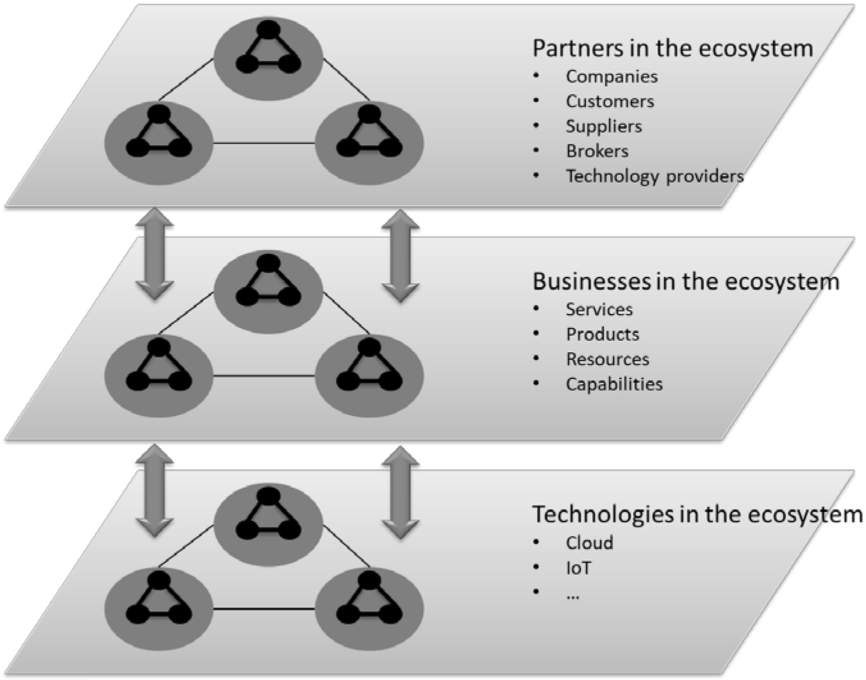

Figure 1. Stack view of the Ecosystem in Manufacturing Industry

3. Cloud manufacturing

Cloud computing has been regarded as one of the significant technical enablers and new business strategies for the manufacturing industry (Tien 2011; Xu 2012). In the manufacturing sector, cloud computing can be adopted as an industry-specific vertical cloud, namely cloud manufacturing (Xu 2012). Under this circumstance, not only the computing resources are provided as services, but also the entire manufacturing business. The concept of cloud manufacturing refers to use of cloud computing technologies in the context of manufacturing (Xu 2012). Sub-technologies such as virtualization, service-oriented architectures (SOA), IoT, advanced computing, Internet connectivity and manufacturing enabling technologies can transform manufacturing resources and capabilities into the cloud as cloud services and distinguish control logic from actual operations and execution side (Li et al., 2018; Zhang et al., 2014). This creates a potential driver for distributed global manufacturing.

Virtualization of objects related to manufacturing enables processing machines and components in virtual space offline and once prepared released to real-space (Verdouw et al 2015). Product design related interactions between the designers and manufacturers have been studied (Wei et al. 2013) and some authors such as Wu et al (2014) suggest that cloud-based design and manufacturing will present a new paradigm. Distributed software architectures based on open interfaces such as SOA can enable the use of distributed computing resources (Tao et al 2011).

The concept of Manufacturing as a service (MaaS) is about introducing manufacturing related services which can be offered in a cloud to complete a task. Examples of applications presented in recent related studies include: selling machine capacity (e.g. 3D printer) online (Wu et al., 2015); providing visibility for supply chain collaboration (Manthou, Vlachopoulou & Folinas, 2004; Luo et al 2011); production planning and scheduling as a service (Helo & Hao 2017); manufacturing execution system serving multiple factories (Helo et al 2014); collaborative delivery of customized products (Shamsuzzoha et al 2015); and collaborative smart process monitoring (Shamsuzzoha et al 2016).

Cloud manufacturing ecosystem is an environment that combines distinctive manufacturing broker, independent manufacturers, product designers, customers, and IT solution providers working together. The centralized control enterprise is named as a manufacturing broker. It is responsible for collecting customer orders, design a process model, describe the manufacturing process and then assign appropriate manufacturing enterprises (in this scenario, they are called as partner factories) to accomplish the manufacturing processes. The manufacturing broker designs all the dynamic cross-organizational manufacturing processes, and a set of existing partner factories perform the actual tasks in each production step. Each manufacturer can perform different manufacturing processes according to its own capacities and capabilities. Product designers are responsible for integrating customer requirements and different product properties together to make correct decisions of production. Product designers can reuse patterns and design rules from previous work and improve upon prior art and the work of others. On the other hand, customers can also place order directly to the manufacturing enterprises with their own design. IT solution providers deliver the foundation and solutions for collaboration in cloud manufacturing ecosystem. However, the providers are not necessarily separate organization. Manufacturing enterprises can act as IT solution providers as well.

Three main types of manufacturing ecosystem portals have been identified (Figure 2). The main difference between the types is based on value chain position. Each ecosystem portal is hosted by different focal company in the value chain. The types are (1) manufacturer-customized portal, (2) general open manufacturing portal, and (3) machine builder portal.

Type I: Manufacturer-customized portal

Manufacturer-customized portal is hosted by manufacturing enterprises and it only servers a single manufacturer at the time. Relationship to customer placing an order is dyadic. There are no other participants in the transactions and the value chain is controlled by the manufacturer. The main benefit of using cloud technology is to automatize and systemize the communication process. The process is initiated by placing an order by customers. For instance, customers can directly use parametric products, which are licensed designs. Customers can also upload own models to getting an instant quote. Customers can buying products which have existing designs or past order history. Product design services are also available for customers when they request customized products.

Type II: General open manufacturing portal

General open manufacturing portal is providing manufacturing services for multiple manufacturers. Technically the cloud system needs to be multi-tenant. For an end-user, this combines offering of several potential manufacturers into a virtual manufacturing portal, where capabilities and capacities may be evaluated with past performance and current price. In most of the cases, this portal is provided by IT solution providers. However, manufacturing companies and brokers with sufficient IT capacities can also host this portal. The end users of this portal can be customers, manufacturing brokers, or manufacturing companies.

Type III: Machinery provider portal

In machinery provider portal, the manufacturing ecosystem is hosted by the company providing machinery. The system is multi-tenant and the ecosystem is built around the similar machinery located at different manufacturers' locations. Machinery provider can offer specific services around the solution including: capacity leasing services, remote monitoring, maintenance services and remote advisory services. When machinery utilization is low, capacity may be leased to other portal members according to smart contracts. In this case, the users are manufactures who require more machinery capacities.

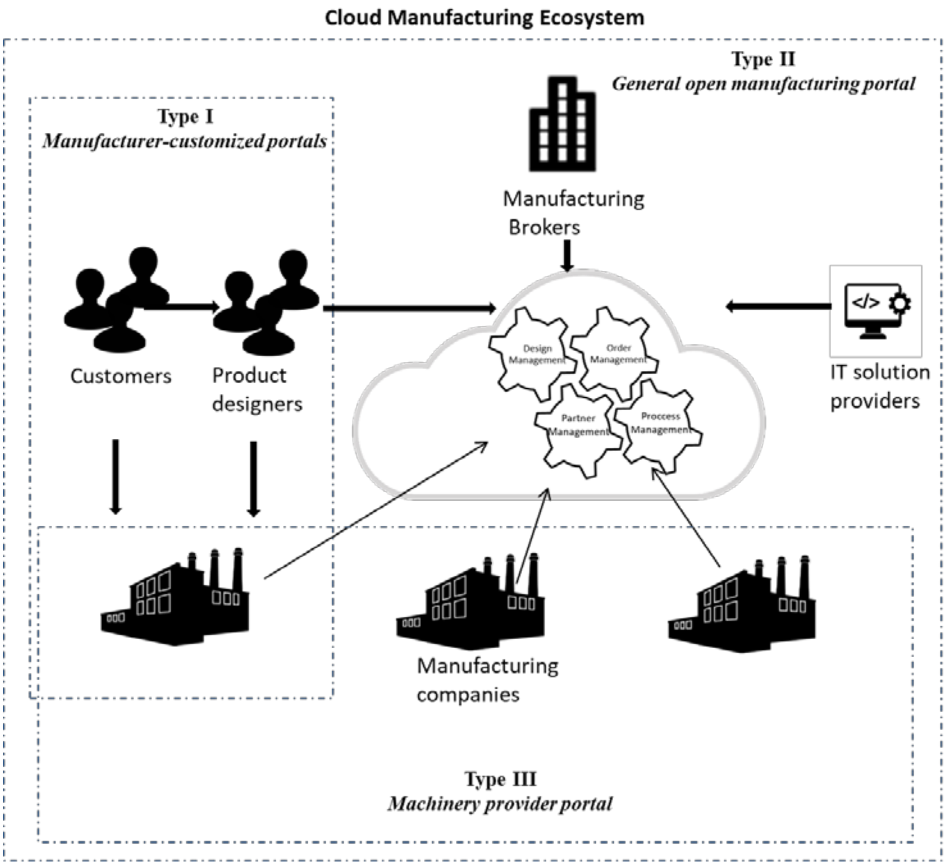

Figure 2. Cloud manufacturing and manufacturing ecosystem portals

The purpose, customer focus and main functionality varies on each of the three main types. Type I portals aim for adding sales by simplifying the customer process; Type II portals can profit by selling virtual capacity from the ecosystem and offering cost competitive solutions for small batch manufacturers. Type III portals can focus on capacity leasing and fractional ownership of assets within the ecosystem. Table 1 summarizes host, purpose, benefits for host, users, and key functionality for each the ecosystem portal type.

Table 1. Portal types for connected manufacturing.

	Type I: Manufacturer-customized portal	**Type II: General open manufacturing portal**	**Type III: Machine provider portal**
Host	Manufacturing company	Manufacturing broker / Manufacturing company /IT solution provider	Manufacturing company
Purpose	Add sales; Reduce time for offer and order handling; Sell parametric product	Make profit by selling virtual capacity	Enable machine sales; Leasing
Benefits	•Keeping company identity and customization according to the manufacturer •Automated price/cost online calculators •Cost and time savings with online CAD/CAM and order placing mechanisms •Automated order flow systems	•Possibility to increase customer basis •Platform for automated price/online cost calculator •Cost and time savings in market communication •Automated order flow system •A possibility to choose from a variety of manufacturers to make an order •Evaluation of design in terms of manufacturing prices	•Providing a marketplace to connect manufacturers •Eliminating the idle time of production and improving productivity •Increasing the return on capital investment of high-tech machines
Users	Customers; Product designers	Makers, small batches	Machine owners who cannot afford to own machinery capacity
Functionality	Offer, order intake, product design	Online pricing, selling designs orders, feedback, payments	Tool for monitoring actual use

4. Prototype implementation

CloudEcosystem is a reference implementation for cloud manufacturing ecosystem portals. Each portal type presented has own characteristics and requirements for implementation. However, the common parts include the functionalities of managing users and their roles, managing the asset hierarchy of machinery and process for order-fulfilment. Similar software components can be used in all three type configurations. For instance, each manufacturer may have its own customized portal (Type I) and offer functionality for order-fulfilment, on the other hand, a generic open manufacturing portal (Type II) can query prices from each factory and offer visibility toward the end-customer, not only the cost-wise, but also the production-wise. This architecture running on the cloud platform enables various configurations. The presented CloudEcosystem software demonstrates an example of implementation of such system. Figure 3 illustrates functionality for adding company entities to ecosystem, sharing and making and selling designs and buying an existing design. Each functionality needs to be operated in a multitenant cloud.

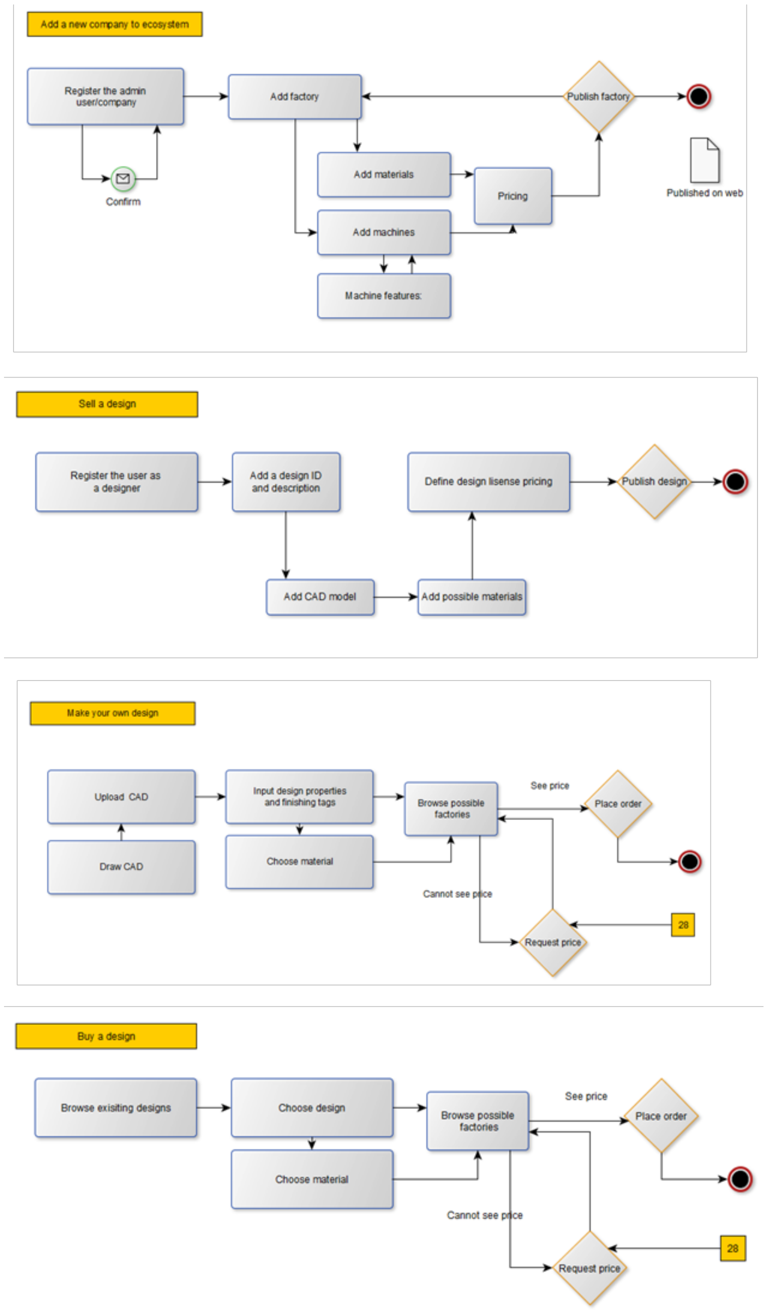

Figure 3. Functionality for adding companies to ecosystem, creating, buying and selling designs.

Figure 4 shows user interface screenshots from the prototype version of the software which is able to complete the process from user authentication, design upload or selection, price estimation, comparison of manufacturers and order placement. Part geometry can be visualized, parameterized and limited edits are possible as well. Confirmed orders are tracked and information about the supply chain updates is kept in the portal. Manufacturing assets can be presented in a hierarchy or linked together to form a line type of layout for the delivery.

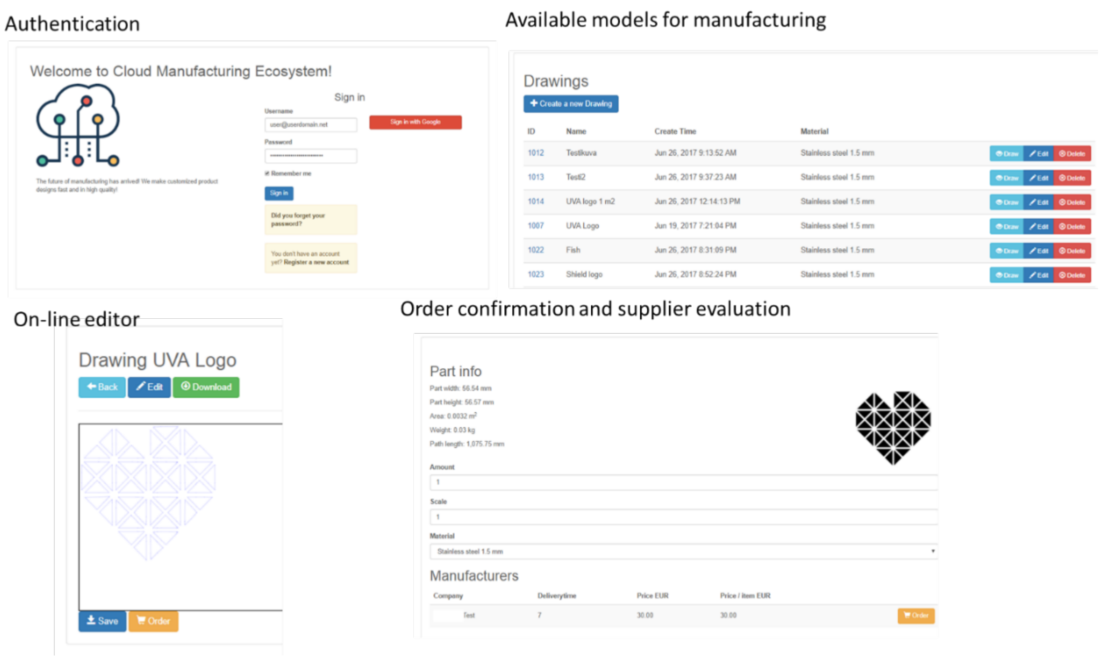

Figure 4. User interface screenshots of a manufacturing portal.

5. Conclusions

Digital technologies are deployed in manufacturing industry to significantly enhance transparency and collaboration among manufactures. New technologies also help manufactures to develop and operate in a flexible ecosystem. Scalable cloud-based computing infrastructures empower building multi-tenant manufacturing environments with functionality supporting ecosystem like interaction. Current leading industrial solutions are coming from additive manufacturing domain as many supporting software has been built on cloud from the beginning. Similar functionality can be built to support traditional manufacturing processes such as cutting, milling, extruding, welding and assembly operations in various industries. The presented CloudEcosystem software demonstrates an example of implementation of such system. The experiences from 3D printing and other advanced digital manufacturing should be enhanced for other manufacturing technologies.

The concept of cloud manufacturing ecosystem is still new. It describes the multitude of manufacturing participants with one world, including customers, product designers, IT solution providers, manufacturing brokers, and manufactures. It is also possible to include other participants who are willing to join the business ecosystem. In other words, the ecosystem is a comprehensive collaboration model. Co-creation and co-delivery are inherent in the ecosystem. In order to increase the maturity of the ecosystem, it is critical to understand different collaboration models and different types of portals to support the collaborations.

The benefits of cloud manufacturing ecosystems can be considered from two aspects: market-related and organizational-related. For the market reasons, the cloud manufacturing ecosystems should increase the activities/profit from collaborative businesses, help to cope with market turbulence, and explore new market/new products. For organizational reasons, it increases the management level of manufacturing resources and capabilities from existing infrastructure.

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