A Business Ecosystem Approach to Industry 4.0

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Abstract

Industry 4.0 has been the focus of increasing scientific interest. It has been shown, in particular, that it creates large efficiency and flexibility gains. But most of the literature emphasizes on the intra-organizational benefits of Industry 4.0 without giving much thought to the impacts on the rest of the stakeholders. The goal of this paper is the analysis of the implications of Industry 4.0 *outside* the organization. We study this problem in the framework of an *ecosystem* that brings together all stakeholders. We propose a Cloud-based Design and Manufacturing platform as the embodiment of the ecosystem, leading to a Factory-as-a-Platform business model. In this model, the factory extends its Industry 4.0 capabilities through a platform connecting all the participants of the ecosystem.

Keywords: Ecosystem; Platform; Complementary; Industry 4.0; Manufacturing; Production

1. Introduction

The widespread adoption of emerging technologies has led to a paradigm shift in the business models of firms. While in the industrial era, giant companies relied on *supply-side* economies of scale, most Internet era giants run *demand-side* economies of scale. That is, in a world of network effects, the relationships with users constitute the new sources of competitive advantage and market dominance (Van Alstyne, Parker y Choudary 2016).

This transformation is shifting the weight from hardware to software as the main source of functionality in manufacturing firms, which can then adapt continuously to changing environments thanks to the interconnection of systems. This reduces the need for optimal designs from start, allowing them to evolve based on product use data. This means that innovation comes from the outside, instead of from inside, of firms. The traditional phases of design, fabrication, execution and service of traditional industrial plants can now get enriched by data on the patterns of demand of customers. Industrial companies such as Bosch, Siemens or General Electric are already using Internet of Things (IoT) and data analytics to find and eliminate production inefficiencies, giving raise to new Industry 4.0 schemas. A valid question is whether those companies do really get the best out of the combined use of those emerging technologies.

We start by noting that an interesting aspect of the penetration of the internet technologies into Industry 4.0 systems is that it can go far beyond its uses in production flow processes. Yao and Lin (2016) propose a socio-cyber-physical (SCP) manufacturing system that draws together additive manufacturing (mass manufacturing) and smart manufacturing (mass customization) (Wang Yi Ma 2017), (Strandhagen, et al. 2017). The latter enhanced with online information exchanges between the firm and the customers. Hence, the future of manufacturing lies in the interplay of innovation and sustainability, in which manufacturers proactively create new markets for customized products in an interactive environment (Yao, Zhou, et al. 2017). These authors provide a comprehensive framework that takes into account the potentialities of some emergent technologies that can be embedded in the architecture of SCP production systems. From a management perspective, it is relevant to analyze how firms shape their business, redefining their relationships, and build on network effects to capture more value.

This new competitive environment is described in the management literature as an “ecosystem” comprising a production platform and all the complement providers making it more valuable to consumers (Ceccagnoli, et al. 2012), (Gawer and Cusumano 2008). Peripheral firms are connected to a central platform via shared or open-source technologies and/or technical standards (Jacobides, Cennamo and Gawer 2018). By connecting to loosely affiliated ecosystems, firms are able to create a global network of partners they don’t even know beforehand able to generate highly valuable products and services for their users (Parker, Van Alstyne and Xiaoyue 2016). Key concepts in the smart factory literature, namely mass manufacturing and customization, can be associated to the ecosystems concepts of co-evolution among stakeholders and co-creation of value to customers (Adner 2006).

In this paper, we argue that the entire ecosystems theory provides a valid framework for new business models incorporating the contributions of emergent smart technologies. Many companies have reinvented themselves on the basis of the opportunities created by those technologies. For instance, Ford Motor Company announced the creation of a subsidiary firm to expand the scope of its business beyond automobiles to cover also smart mobility solutions (Newcomb 2016). In the re-invention phase, incumbents, technological entrepreneurs and digital giants all use powerful new approaches and techniques to solve fundamental business problems (Venkatraman 2017). This also applies to Industry 4.0 environments that can easily shift from manufacturing to factory-as-a-platform model by essentially using connected modes of manufacturing allowing different ways of production.

The challenges posed by such reinventions require strategies for the creation of value for the entire ecosystem, instead of merely for the firm. Adamson et al. (2017) claim that cloud-based manufacturing models, like Cloud Manufacturing (Xu 2012), will require the development of new business models. Traditional hierarchical models will no longer be competitive since massive online exchanges will improve substantially the agility and innovativeness of production processes, becoming able to satisfy quickly the demands of customers (Strandhagen, Vallandingham, et al. 2017), (Rossit, Tohmé and Frutos 2019). New models should facilitate the participation of dynamically structured fabrication entities through online collaborations. In this work we present the concept of ecosystem in the context of Industry 4.0 and illustrate how to implement a manufacturing to a Factory-as-a-Platform model.

The aim of this work is to present a Factory-as-a-Platform model which allows to associate Industry 4.0 technologies with all the advantages of online platforms, connecting directly and fluidly the stakeholders in the ecosystem. The support for this model is provided by the Cloud Based Design and Manufacturing (CBDM) architecture (Wu, et al. 2015), which covers from the design of prototypes to the production of final goods. In this way, Factory-as-a-Platform extends the potentialities of Industry 4.0 by associating the factory with all its complements in the ecosystem. Industry 4.0 provides real time support to all the players in the ecosystem, favouring the creation of value.

In order to present the concept of ecosystem in the context of Industry 4.0 and illustrate how to implement the transition from a traditional factory to a Factory-as-a-Platform model it is necessary to consider research from both management and manufacturing disciplines. Hence, we review topics related to business models transformation based on platforms. In addition, we conduct a literature review addressing smart factories' themes such as Cyber-physical Systems and cloud manufacturing.

This article is organized as follows. Section 2 presents the notions drawn from Management studies that will be used in our discussion. Section 3, on the other hand, presents the concepts of the manufacturing literature that are useful for us. Sections 4 and 5 are devoted to analyze in detail our proposal.

2. Background concepts from Management literature

2.1. Business Ecosystems

Platform competition emphasizes the role of network effects. Due to network effects, a large number and range of stakeholders accumulate around the platform, which forms the business ecosystem (Rong, Lin, et al. 2018). These authors identified three main streams of research on ecosystems, each one focusing on some of its constituents. The first one focuses on individual firms and new ventures, and views the ecosystems as a community of organizations, institutions, and individuals that impact those firms as well as their customers and supplies (Teece 2007) as cited in (Rong, Lin, et al. 2018)). The second set of studies focuses on a focal innovation and the set of components and complements that support it, and views the ecosystem as a collaborative arrangement through which firms combine their individual offerings into a coherent, customer-facing solution (Adner 2006) as cited in (Rong, Lin, et al. 2018). The third stream focuses on platforms and the interdependence between platform sponsors and their complementing partners, who make the platform more valuable to consumers (Ceccagnoli, et al. 2012), (Gawer and Cusumano 2008) as cited in (Rong, Lin, et al. 2018).

All these approaches conceive a business ecosystem as an economic community in which a variety of inter-related stakeholders co-evolve. It creates value and brings competitive advantages to the participating companies by initiating, identifying, and integrating stakeholders (Rong, Lin, et al. 2018). Some authors describe these ecosystems using the notion of coopetition – i.e. cooperation among competitive organizations (Bengtsson and Raza-Ullah 2016), (Bradshaw and Palmer 2010). The term was conceptually established several years ago but with the emergence of digital transformation relationships among companies are redefined.

2.2. Platforms

Information technologies, as the Internet, mobile networks, cloud computing and social media, have reduced the need of holding a physical infrastructure. This has given raise to platform businesses such as Amazon, Uber, Airbnb or eBay, which are disrupting the established incumbents in their industries. Those platforms constitute online environments taking advantage of network-induced economies of scale (McAfee and Brynjolfsson 2017). These authors observe that some of the most important attributes of information goods are that they are free (once something has been digitalized, it becomes essentially free to make additional copies), perfect (a digital copy is exactly identical to the original version) and instantaneous (networks allow the immediate transfer of information goods). On the other hand, these platforms do not just allow the exchange of digital products but also that of physical world's goods and services

The digital expression of a business ecosystem is a platform that provides the infrastructure and rules for a marketplace, bringing together producers and consumers. Platforms comprise four types of players engaged in value-creating interactions. The owners of the platforms control their intellectual property and governance (as Google owning Android). Providers serve as the platforms' interface with users (mobile phone companies support devices that run Android). Producers create their products (e.g. Android apps), and consumers use them (Van Alstyne, Parker and Choudary 2016). When a platform is opened up to allow external contributions, the demand for the owner's products goes up thanks to the complementarities with those of the producers. Platforms do thus take advantage of those network effects, harnessing the collective power of the crowd. Opening up platforms provide more benefits to the owner, by creating a greater volume and variety of contributions, motivations and ideas than the owner alone could have mustered. These contributions increase consumer surplus and push up the demand curve for complementary products. Owners also infer from data customer's preferences (McAfee and Brynjolfsson 2017).

2.3. Crowdsourcing

The key to the success of a business ecosystem is the co-evolution of stakeholders and the co-creation of value with the customers (Adner 2006). That is, companies in a business ecosystem do not only work cooperatively and competitively but also co-evolving around new innovations to satisfy the needs of customers (Rong, Hou, et al. 2010). Co-creation refers here to settings in which communities produce marketable value in voluntary activities mediated through platforms, conducted independently of any established organization (Karhu, et al. 2011). Companies are figuring out how to take advantage of crowdsourcing their problems to the contributing participants in the value chain (McAfee and Brynjolfsson 2017). *Crowdsourcing* is defined by Jeff Howe (2006) as the act of taking a job traditionally performed by a designated agent (usually an employee) and handing it over to an undefined, generally large, group of people in the form of an open call. There are different types of crowdsourcing: cloud labour (Amazon's Mechanical Turk), crowd creativity (Youtube), distributed knowledge (Wikipedia), open innovation (Innoventive.com), crowdfunding, etc.

In particular, IoT platforms allow many forms of crowd participation. For example, mobile crowd-sensing methods leverage not only the power of physical things connected to the internet but also the wisdom of the crowd. This is achieved by facilitating the observation and measurement of particular phenomena using user-owned mobile and wearable devices (Ziouvelou and McGroarty 2017). Other applications of crowd-driven IoT platforms are in traffic navigation, city noise monitoring, and emergencies.

Cloud labour services constitute a particularly useful form of crowdsourcing. A coordination platform serves as an interface between requesters who need to get work done and a large crowd of workers willing to carry it out (Kern 2014). Sometimes requesters do not want to bring together an entire crowd but just to find out, as quickly and efficiently as possible, the right person or team that may help with some task.

3. Background concepts from Manufacturing literature

Industry 4.0 involves the creation of "smart factories" able to adapt their production processes assigning more efficiently their resources. The key technologies on which such factories can be based are IoT, Cyber-physical Systems (CPS), Cloud Computing and Big Data.

CPS physical resources with incorporated computational capacities (E. A. Lee 2008), integrating physical aspects of production processes with their associated data processing aspects. In particular, they include computers and integrated networks that monitor and control physical processes using computations and communication loops to improve the quality of the production activities. These systems can be applied to a wide range of areas, from pacemakers to national energy grids (Wang, Törngren and Onori 2015), but their largest impact is on industrial activities (L. Monostori 2014) (Lee, Bagheri and Kao 2015). In particular, CPS obtains real-time information of the physical processes of production and submits them to data processing facilities involved in decision-making (Rossit and Tohmé 2018). This, in turn, yields the integration of the different control levels of ISA-95 in a single system, providing reliable decisions on the fly (Rossit, Tohmé and Frutos 2018). The production system can thus be flexibly adapted and reconfigured at the different scenarios that a firm can face. It is even possible to create CPS able to "self-configure" (Wang, Törngren and Onori 2015), (Rossit, Tohmé and Frutos 2019) yielding higher levels of productivity by adapting to changing (Strandhagen, Alfnes, et al. 2017).

These advantages can be further increased by means of the interaction with Internet technologies. The Research and Innovation funding program for 2007-2013 (FP7) of the EU established that a future networked society had to be grounded on four feet: Internet by and for

People (IoP) (Lyons 2017), Internet of Contents and Knowledge (IoCK), Internet of Things (IoT), and Internet of Services (IoS) (Yao, Zhou, et al. 2017).

IoT links cyber and physical systems making fabrication processes intelligent. IoP connects all the participants, eliminating the barriers between producers and consumers, creating online communities for the design, creation and sale of products. IoS uses the internet as a medium for the exchange of services by applying technologies like Service Oriented Architectures (SOA) or Cloud Computing (Sanchez 2018). Finally, IoCK transforms data (generated, for instance, by intelligent objects connected through the IoT) into information/knowledge that can be used in manufacturing systems (Yao and Lin 2016). While all these uses of internet are currently in use, they will become even faster and cheaper, facilitating closer interactions between customers and production units, connected in platforms.

Cloud Computing, in turn, provides ways of accessing and sharing resources in a virtual dynamically scalable way through the Internet. Users only pay for the resources they really use, without having to incur in huge initial investments. For companies this means that lower costs and larger yields can be achieved reducing risks and increasing the accessibility to consumers and providers (Wang and Wang 2018). Cloud computing enables the linking of manufacturing resources and capabilities of companies and thus optimizes internal and external logistics (Strandhagen, et al. 2017). For the NIST Cloud Computing is defined as "*a model for enabling ubiquitous, on-demand access to a shared pool of configurable computing resources (e.g. computer networks, servers, storage, applications and services), which can be rapidly provisioned and released with minimal management effort or service provider interaction*" (Mell and Grance 2011).

The NIST also specifies 5 features that characterize Cloud Computing systems: (i) being demand-driven (customers place their requests that are automatically satisfied), (ii) wide network access (through mobile phones, laptops, etc.), (iii) the computational resources can simultaneously provide to different users, (iv) high demand-elasticity (increasing requests are immediately satisfied) and (v) services are measurable (servers can be monitored and controlled) (Mell and Grance 2011).

Big Data tools provide means to assess the performance of systems and detect patterns in consumption. In manufacturing, these tools allow analyzing large volumes of heterogeneous and multi-source data generated along the life cycle of industrial production (Li, et al. 2015). The ensuing databases are characterized by 5 V's (Chen, et al. 2014): *volume* (large amounts of data), *variety* (data comes in different formats and is generated by different sources), *velocity* (data is generated and renewed by fast processes), *veracity* (data is used to reduce error levels, inconsistencies, incompleteness, ambiguities, noise and other kinds of inaccuracies) and *value* (the marginal worth conveyed by data). Industry 4.0 environments are ready for the implementation of Big Data analytics (Rossit, Tohmé and Frutos 2019), thanks to the sensors that provide information on events and states, while managing levels provide market data (Babiceanu 2016). The systematic computational analysis of data outputs from these environments will help to make "informed" decisions, improving the quality of the Smart Manufacturing processes. For these reasons, data-driven systems are necessary requirements for the implementation of Industry 4.0 environments (Tao, et al. 2018).

3.1. Digital Twin

All the aforementioned technologies allow the efficient integration of the different functionalities of a production system. In terms of a control specification ISA-95 of 5 levels, all the processes that can be digitalized, other than those that require human decisions (as the definition of the goals of the firm), will be absorbed in Industry 4.0 systems (L. Monostori 2014) (Rossit and Tohmé 2018). This integration can be both at horizontal and vertical levels. The vertical integration covers from level 0 of ISA-95 to Manufacturing Execution Systems (level 3 of ISA-95) (Rossit, Tohmé and Frutos 2018), as shown in Figure 1. These levels, handled by CPS translate the physical events into data, creating a *digital twin* of the production system. Figure 2 shows a scheme of how a Factory Industry 4.0 is composed, starting from the Physical Factory in the physical space and how is the virtualization of events and physical components in virtual or digital components in the cyber space. That is, an event X_i in the physical Space, and is traduced into an event $X_i´$ in the cyber space. Both components, Physical and Digital, constitute the Factory Industry 4.0.

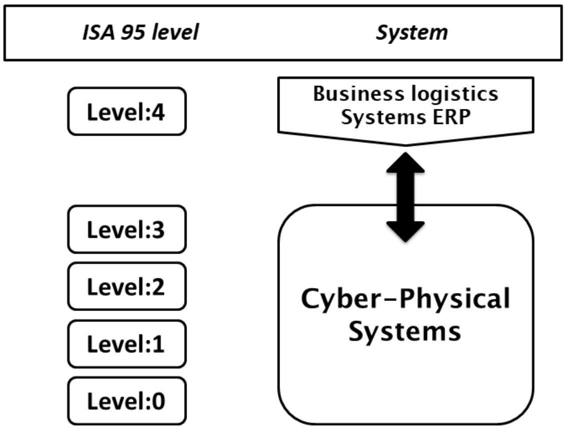

Figure 1. ISA-95 levels integration

This representation can be used for different purposes. One instance is the control of the health of the different productive resources and assets of the organization (Lee, Bagheri and Kao 2015). But more relevant for this article, is that the digital twin provides useful information about the real workload of the production system, which can be used in planning and business strategizing (Parsanejad and Matsukawa 2016) (Rossit, Tohmé and Frutos 2019). Managers can simulate the inner workings of the plant under different scenarios, providing further information that contributes to better decisions on the entire production process.

In turn, since CPS not only gets information about the real world but is also able to perform physical actions, it becomes possible to enact substantial modifications on production systems. It becomes thus possible to improve their efficiency in an adaptive and synchronous way (Wang, Törngren and Onori, Current status and advancement of cyber-physical systems in manufacturing 2015) (Rossit, Tohmé and Frutos 2018).

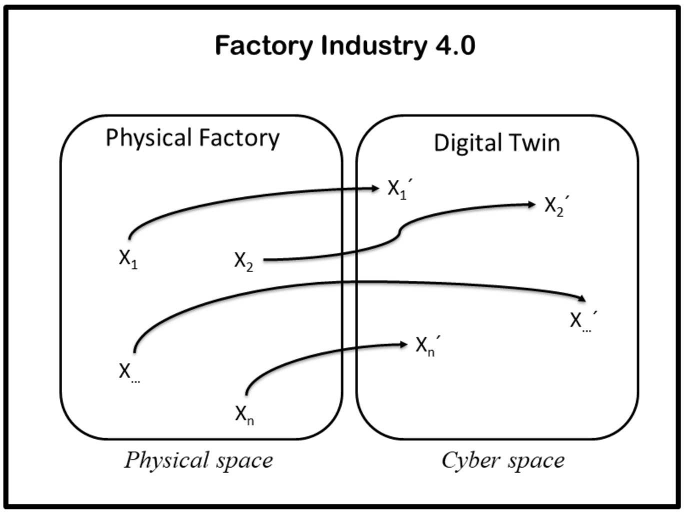

Figure 2. An Industry 4.0 factory consists of the physical factory and its Digital Twin

3.2. Cloud Manufacturing

The incorporation of new technologies led to novel production architectures like Cloud Manufacturing. Cloud Manufacturing is a service-oriented architecture that uses Cloud Computing to relate design and innovation activities to production ones (Xu 2012) (Wu, et al. 2015). More specifically, starting up from NIST’s definition of Cloud Computing, Xu (2012) redefined Cloud Manufacturing 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*". Cloud Manufacturing, thus, promises elasticity and adaptability through the on-demand provision of resources and services, allocating them through a pay-as-you-go system. In this way, Cloud Manufacturing can adequately address the challenges that SME companies face nowadays, as for instance the lack of basic technologies, the restrictions to the access to external resources and capacities, the lack of skills to manage complex IT systems, as well as the inability to procedures to share efficiently resources and capabilities (Wang and Wang 2018).

3.2.1. Cloud Manufacturing concepts

Figure 3 depicts the architecture of Cloud Manufacturing systems (Adamson, et al. 2017). We can distinguish three main agents in this architecture: the Provider, the Cloud Manufacturing operator and finally the Costumer. The Provider is the agent that holds the physical production resources, managing the resource layer in the architecture. The Cloud Manufacturing Operator, bridges the gap between the ends of the production system. This operator has to handle the main layers of the architecture, starting with the Perception layer, which manages the data obtained from CPS-like systems, translating them into a format friendlier towards the rest of the layers. The Virtualization layer, is in charge of virtualizing the resources and fabrication capacities (which become digital twins), encapsulating them into Cloud Manufacturing systems. These resources and capacities are easily accessed by other components of the system. The Cloud Service Layer manages systems, services, resources and tasks, being compatible with different activities and service applications as, for instance, those involved in the description, registration, publication, composition and monitoring of systems. The last layer of the Cloud Manufacturing Operator is the Application Layer, in which the Provider's services are delivered, allowing customers the possibility of selecting the different properties of pieces, under the constraints of size, material and tolerances defined by customers. Finally, the customer layers is called Interface Layer, linking them with the Cloud Manufacturing operator, facilitating the submission of requirements and the exploration of systems already available. Other designs of Cloud Manufacturing architectures, developed for instance by Xu (2012) includes less layers and subsumes the virtualization layer in the domain of the Provider. Adamson, Wang, Holm & Moore (2017) review Xu's (2012) as well as other architectures presented in the literature. In general, these designs have in common a three-agent scheme (as in Figure 3) with finer details varying according to the approach and implementation in each case.

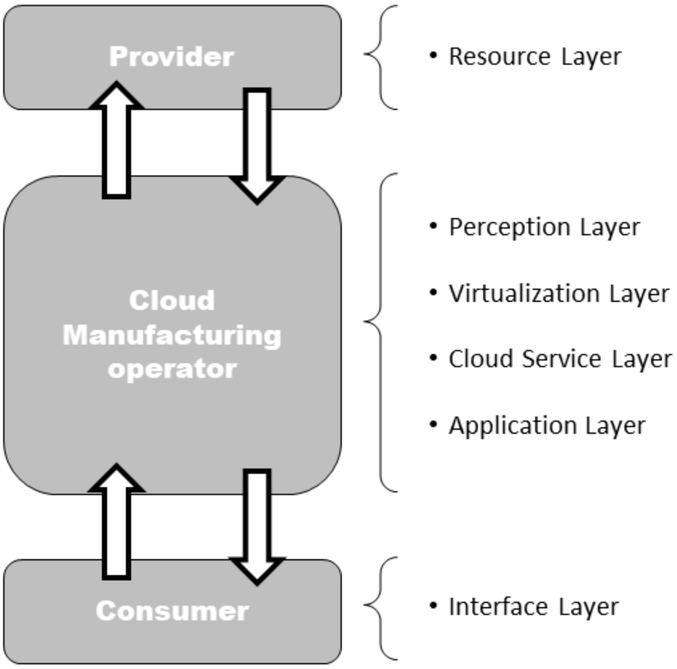

Figure 3. Cloud Manufacturing Architecture: main agents and their dependent layers.

Cloud Manufacturing intends to solve fabrication problems. It starts with customers requiring fabrication services in order to execute a self-contained task, contacting providers of those services through the architecture of the system. To provide manufacturing services in the cloud, their specifications must be clearly stated (Wang and Wang 2018). To illustrate the relation between services, capabilities and resources we refer the reader to Figure 4. We show in it that Cloud Manufacturing Services are nested inside Manufacturing Capability, which in turn reside inside Manufacturing Resources. The characterization of each of these components is as follows:

- Manufacturing Resources: it provides manufactured and non-manufactured materials, including equipment, machinery, devices and smart processes.
- Manufacturing Capability: it amounts to the capacity of transforming thing in the domain of fabrication, using tools drawn from Manufacturing Resources.

- Cloud Manufacturing Service: it includes the packages of autonomous manufacturing services, rapidly configurable to satisfy the demands of customers. Their variability is large; CMS services can be randomly activated as well as been active in the long or short term and even strategically enabled.

Figure 4. Structure of a Cloud Manufacturing service.

A Cloud Manufacturing system implements Manufacturing Capabilities in the cloud encapsulating them as Manufacturing Services packages. Manufacturing Capability includes the capacity of designing, producing, experimenting, managing and communicating. In turn, each Manufacturing Capability is supported by Manufacturing Resources, be they hard or soft. In Table 1 we detail each of these concepts. The expression of a Manufacturing Capability to facilitate its acknowledgement by a Cloud Manufacturing Service requires a format, identifying the supporting resources and the resource/capability relations. Wang & Wang (2018), present an instance of a 5-tuple, relating each Capability to the associated resources, in such a way that the Cloud Manufacturing Service can identify those resources and its ability to provide its assistance.

Table 1. Manufacturing Capability and Manufacturing Resources.

3.2.2. Design requirements of Cloud Manufacturing architectures

Cloud Manufacturing provides for digital fabrication and design innovation, as shown by Wu et al. (2015). In an idealized scenario of smart drone deliveries, these authors postulate a Cloud Manufacturing architecture incorporating design processes in the cloud, as well as integral management of manufacturing services and supply chains. They postulate a series of 8 requirements that any Cloud Manufacturing design should satisfy:

Requirement 1: the system has to provide connections between customers and providers, supporting communications and information and knowledge flows.

Requirement 2: it has to allow elastic cloud storing of 3D design files, which can be shared and synchronized among the users.

Requirement 3: it has to provide the capacity to process large amounts of data in a parallel and distributed way, using open code programming languages.

Requirement 4: it must lend SaaS (Software-as-a-Service) to customers in a multi-tenancy structure in which a single instance serves several users accessing it through web browsers.

Requirement 5: it has to assign and control in an efficient and effective way the fabrication resources (like production cells and assembly lines). Flows of material and information on the availability and capacity of fabrication resources must be ensured, using IoT tools.

Requirement 6: the architecture has to provide users with X-as-a-Service applications (e.g. IaaS, PaaS, HaaS and SaaS).

Requirement 7: it must have a smart search engine allowing users to find fabrication resources in the cloud.

Requirement 8: it must provide on-line price quoting tools to rapidly budget commercial proposals that may arise inside the system.

Cloud technologies provide an opportunity to reframe manufacturing businesses, in particular for SME. Combined with SOA, it yields a framework for One-of-a-Kind production. Cloud Manufacturing shows to be more appropriate for catering specialized and personalized demands, thanks to it flexible and rapid reaction capacities (Wang and Xu 2013). It becomes thus imperative to postulate new models and business strategies able to generate value up for these potentialities.

4. Business model proposal

4.1. Factory-as-a-Platform

An ecosystem can be considered an umbrella of structures encompassing a platform. The smart factory operates as an orchestrator of the interactions among individual parties and a factory-wide platform facilitates those interactions. In this section, a hypothetic platform proposal is described. The smart factory is the owner of the platform and controls who and how can participate. Other actors are designers, retailers and investors. The platform broadcasts a general goal as well as some basic requirements. Designers publish their proposals and retailers vote for them. The digital twin simulates the most voted designs in order to generate data on their costs and manufacturing requirements. One of them is selected and given the information provided by the digital twin a layout for its production is submitted to the factory. Investors, provide the funding that allows starting the production of the new good (see Figure 5). In the following, we explore some issues that should be defined in order to build a platform.

- **Participants:** the smart factory (owner and platform manager), the designers (producers), retailers and investors (consumers).
- **Exchange of information:** the platform provides details of design projects enabling users (designers) to know the goal of the project and its basic requirements. Designers upload

designs and prospective ones are published. Retailers vote from them. Information on the selected design is published and funding is requested.

- **Exchange of services:** the platform provides the mechanisms facilitating the upload of designs and for retailers to vote for their preferred design. A crowdsourcing mechanism allows reaching out to investors for funding.
- **Exchange of value:** designers enhance their reputation with the votes received by their designs –even if they do not go into production. Thus, reputation plays the role of currency in the platform. The platform also gives designers access to specialized software tools in order to develop their projects. Retailers have the opportunity to vote for projects that are more promising according to their market and business knowledge. The platform may also support retailers with market data, financial calculators and other tools helping in the assessment of projects. Investors provide funding for designs that go into production and reduce investment risk thanks to the assurance given by the votes of retailers, who in turn reflect market insights.

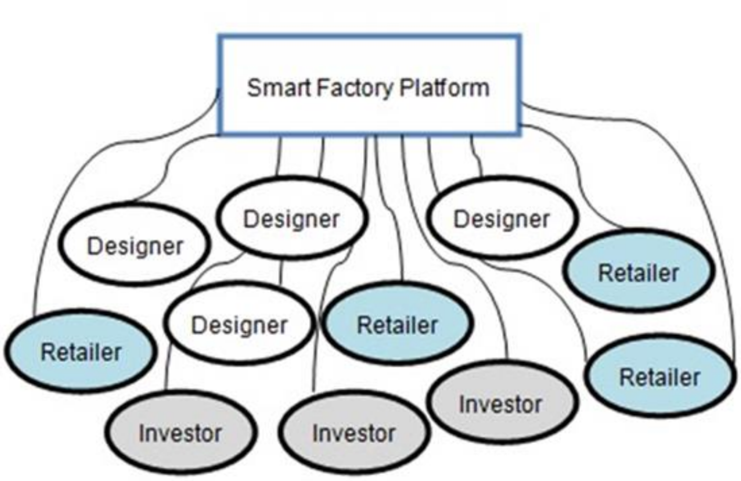

Figure 5. Smart factory as a platform

- **Monetization:** Higher value creation by designers on the platform attracts more retailers and investors, who, in turn, attract more designers and further value creation. This powerfully positive growth dynamics challenges monetization decisions. Platform business rarely charge all their users since this may discourage participation. A pricing choice is to charge members of one category of users provided they allow members of another category of users to participate for free (Parker, Van Alstyne and Choudary 2016). The smart factory platform may offer designers free participation as a way to attract innovative design projects. The platform may charge retailers for access. In this case, retailers looking for promising products to commercialize may have access to design proposals and have the right to vote. This form of monetization benefit both parties: designers are motivated to publish their best work on the platform, while retailers get access to new proposals and their vote counts. When a design is selected for production, investors pay the designer for the rights to produce and commercialize the design. The smart factory generates its profits with every project that goes into production.

- **Openness:** A platform is open to the extent that no restrictions are placed on participation in its development, commercialization, or use; or any restrictions are reasonable and non-discriminatory, that is, they are applied uniformly to all potential platform participants (Parker, Van Alstyne and Choudary 2016). The decision about the level of openness affects usage, developer participation, monetization, and regulation. The smart factory firm manages and sponsors the platform. The platform manager organizes and controls interactions, and also retains legal control over the technology (such as the software code that controls its operation). In order to facilitate extensions of the platform functionality, the firm may open its business to participation to extension developers. However, the platform is not open to all developers to protect the quality of the design proposals and to retain control over the revenue streams of the platform. Extension developers add features and value to the platform and normally are not employed by the platform management firm (Parker, Van Alstyne and Choudary 2016). The smart factory platform would benefit from tools to simplify transportation arrangements for retailers. In order to facilitate this extension of its platform functionality, the smart factory might open its business to participation by extension developers. To prevent poor-quality service providers joining the platform, an approval process is defined. Another type of developer is data aggregators who enhance the matching function of the platform by adding data from platform users and the interactions they engage in. Considering the confidential nature of the smart factory platform, it is a wise decision not to open to this kind of developers. Unauthorized disclosure of information about design proposals, costs, and manufacturing requirements should be penalized.

Another concern is related with an unrestricted participation of designers. Although the smart factory would like to facilitate participation, high-quality content is a major concern, otherwise retailers and investors may drive away from the platform. Designers should upload their projects using a platform tool to assure that the required data is provided (this facilitate screening of projects). Curation may also take the form of voting and feedback. A designer's reputation is based on past projects ratings. At the same time, platform managers need to continuously monitor designers' participation and suggestions to prevent designers will become discouraged to participate.

4.2. Manufacturing Architecture

The core of the Factory-as-a-Platform model is a system based on Industry 4.0 technology that connects all the stakeholders in a dynamical integrated structure, a *platform*. The factory, which already did the transition to Industry 4.0, provides the tools, in particular the digital twin, to carry out all the actions needed to reach the production phase. For instance, it can evaluate the workload of the factory and coordinate delivery dates, already in the evaluation of designs.

This factory can be embedded in the CBDM architecture since it can easily satisfy the requirements of the latter. For instance, the Digital Twin satisfies requirements 4 and 5 of CBDM, which prescribe the provision of software and applications needed for multi-tenancy participation. Requirement 8, concerning the ability to quote the resources demanded by the production process, can also be fulfilled by Industry 4.0 factories. Requirement 1, which involves the connection with stakeholders, Requirement 2 on the management of information flows and requirement 3 on the assessment of the data generated by the system are all satisfied thanks to the technologies already incorporated in the factory. Finally, requirements 6 and 7 are easily satisfied through the interactions in the platform, allowing the direct the connection among the interested parties.

Therefore, the Factory-as-a-Platform business model can be implemented in the CBDM architecture, yielding value to all the participants in the ecosystem.

4.3. Limitations of Platform Interactions in Smart Factories

A limitation of smart factories is that there still exist tasks that require a substantial human participation. There are in particular, three instances in which this is relevant for our proposal:

a) When the solution depends on the participation of large numbers of human users, like in the cases of reCAPTCHA (Law and Von Ahn 2011) or Wikipedia (Kaplan and Haenlein 2014). In the case of production plans we can point out towards the need of supervised training of expert components through Deep Learning or similar technologies.

b) When humans are just better in carrying out tasks. McAfee and Brynjolfsson (2017) analyze which abilities will remain essentially human in the future. Creative tasks are, until now, better handled by human beings but there are some (e.g. the generation of hypotheses (Spangler 2014)) that are starting their automatization. The limit to that may be found in tasks that require social skills like empathy, ability to work in teams, leadership, etc. (McAfee and Brynjolfsson 2017). In a factory this may be the case when parts of a design have to be modified on the fly in response to unforeseen collateral effects. The providers of inputs can be affected by this and thus may participate in the search of a solution. This is similar to addressing challenges by crowdsourcing the solution process (for instance, the Kaggle Data Challenge (Garcia Martinez 2017)).

c) When multiple alternatives are conceived and one must be chosen (as for instance when the best transport and distribution option is sought) and the different parties face disparate costs and benefits that have to be pondered and negotiated.

4.4. Illustrative example

In this section, we present an idealized manufacturing scenario based on currently existing technologies and the Factory-as-a-platform proposal. In this scenario, the platform aims to provide solutions responding to manufacturers of cosmetics and toiletries. The factory owns a range of filling equipment (bottle, jar, tube, stand-up pouch and doypack filling), labelling and wrapping machines (linear and rotary bottle or carton labelling, horizontal and vertical cartoning and tray packing).

Based on the requirements of a customer (cosmetic manufacturer), the platform crowdsources the design process. Online competitors create a new packaging or improve an already existing item. Anyone may join the design community and membership in the community grants access to submit a design. To submit a design, community members follow the requirements for the type of product (e.g. balms, creams, lotions), package (e.g. bottle, carton, display boxes, tube), and concept of the product defined by the cosmetic manufacturer. From a conceptual design perspective, crowdsourcing platforms allow the design team to solicit design ideas from more sources, thereby enhancing innovation.

Designs remain available for cosmetics manufacturer assessment and the highest scoring designs are selected and a digital twin simulates them in order to generate production data. The platform may also enable retailers to vote for designs. The benefit of this option is that in retailers vote there is an implicit knowledge about market demands. However, this decision depends on the customer preference about having full control on the design selection or not. After the design phase is finished, the design team builds a prototype for selected proposals and makes a decision about the design that will go into production. The platform may also support crowdfunding and investors may pay the designer for the rights to produce and commercialize the design.

Cloud-based manufacturing allows for rapid manufacturing capacity scalability by sourcing manufacturing tasks to qualified global suppliers. Also, if the design requires a processing that cannot be satisfied by the available equipment in the plant factory, cloud-based manufacturing allows retrieving a list of machines that are capable of producing the design.

5. Discussion

The Factory-as-a-Platform model integrates all the participants in the ecosystem. Designers provide the innovations, which the digital twin allows to evaluate; the retailers, who know the preferences of the market, evaluate the commercial viability of projects and investors provide funding. In this way the factory shifts the focus from the products to the customers. Then, the scale of production becomes measured not only in terms of the sheer volume of production but depends now also on its variety. The crowdsourcing solution facilitates identifying promising innovations, supporting it from outside the firm. Figure 6 summarizes all these interactions, showing all the relevant players in the ecosystem.

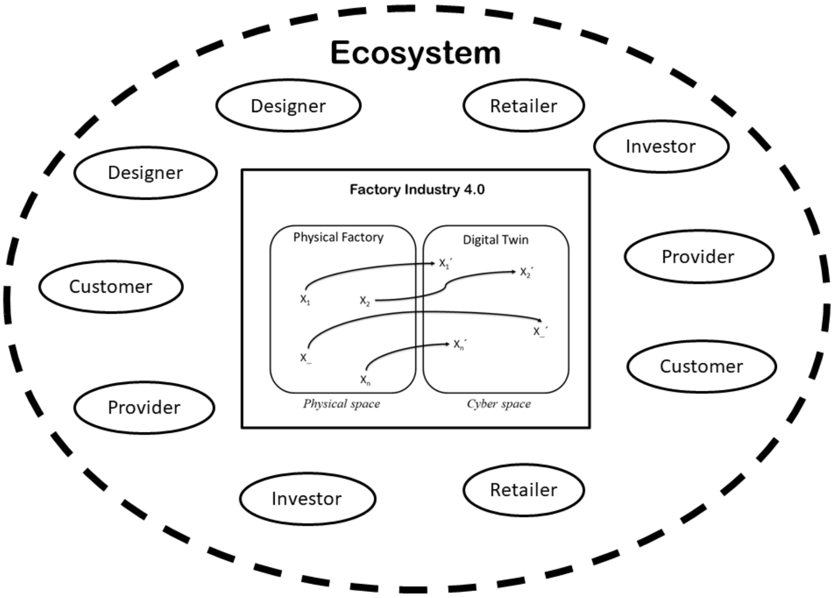

Figure 6. The Ecosystem of the Factory-as-a-Platform model.

The CBDM architecture on which this model is based supports the right information flows among those players, providing also the means to process the ensuing large volume of data. The different interventions of the components of the ecosystem can be shared synchronically by all of them and the virtualization of the resources and assets allows the simultaneous assessment of plans and the negotiation of delivery conditions of the physical output of the factory.

This architecture provides means to solve problems that Industry 4.0 cannot address by itself, like the generation of innovations. The platform connects the designers to all the stakeholders, in particular the retailers, who will evaluate their potential innovations. In turn, crowdsourcing facilitates finding funding to carry out the production of the new goods. This indicates that the entire chain, from the original design to the final production becomes negotiated and implemented on the platform, accelerating the life cycle of product generation. Along the way, producers and input providers intervene to suggest alternatives (cost reduction activities or the use of new kinds of inputs, for instance), in such way that the final production process generates value for all the participants in the ecosystem.

Industry 4.0, on the other hand, becomes the production engine for the entire ecosystem, relating the virtual realm with the physical one. Digital blueprints become transformed into actual products, in such way that the demand is assuredly satisfied. The use of Internet technologies leads to planning the completion of work orders as to deliver the goods to the customers in the requested dates.

All these features enrich the diversity and the differentiation between organizations, incorporating idiosyncratic tastes and demands into the design of products in an efficient way. Customers, in turn, get information about details of the production process of their requested goods, making the whole process more transparent for both sides of the market and ensuring that its focus is on the satisfaction of demands.

6. Conclusions

We addressed here the question of how Industry 4.0 can benefit from technological changes and how smart factories may transform their business models. The proposed Factory-as-a-Platform model provides the blueprint for the way in which the smart factory can lead a business ecosystem, who are the main players, the interactions between producers and consumers, how to maximize value for the whole ecosystem, and monetization and openness decisions. In turn, the Cloud-Based Design and Manufacturing architecture implements it, covering from the design of prototypes to the production of final goods. In this way, Industry 4.0 becomes enhanced, fulfilling further its promise of creating larger value for the stakeholders of the firms using it.

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