On the Development of a Cyber-Physical Industrial Marketplace

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Abstract*—In recent years, we have seen breathtaking technological progress within Cyber-Physical Systems (CPS), the Internet of Things (IoT), Cloud computing, and intelligence and data analytics. These advances are indeed moving from research to the industrial shop floor and paving the way for the fourth industrial revolution, the Industry 4.0. Industry 4.0 is putting technology to work, disrupting conventional industrial processes at every level and driving the industry into becoming digital. All the technological progress has allow knowledge and information to be virtually available everywhere to anyone, leading to the emergence of new possibilities and business models. In a world where competition is global, the industry must be able to respond to unpredictable and rapid changes. The use of the Smart Component concept, integrated into the Cyber-Physical System architecture, allows for available data to be processed and used to improve productivity and production planning as well as allow for a better equipment use and better predictive maintenance practices. All this available data must be stored and accessible, which is where the Cyber-Physical Industrial Marketplace comes into play, providing an interface for automatic update of the industrial equipment technologies and functionalities on the fly. In this paper, an architecture for a Cyber-Physical Industrial Marketplace is presented and explored. Having the ability to collect data from the shop-floor equipment and update the Smart Components in a safe, reliable, and secure way, is the main goal of the proposed architecture. Creating an industrial marketplace that goes beyond the concept of online stores, is the next natural and logical step that will contribute to the servitisation of industrial business models.

Keywords*–*Smart Factories; Intelligent Production Systems; Industry 4.0; Cyber-Physical Systems; Marketplace.

I. Introduction

Smart Factories, Cyber-Physical Systems (CPS), Internet of Things (IoT), and Cloud computing are popular terms that are nowadays in the spotlight of current technology advances. These technologies offer many advantages and are at the core of the Industry 4.0 concept, which was at the basis of the Marketplace for Cyber-Physical Production Systems architecture presented in [1].

Industry 4.0: The term Industry 4.0, also recognized as the fourth industrial revolution, originated in Germany, from a project promoted by the German government with the goal of digitizing the manufacturing industry [2]–[5]. The first industrial revolution began in England in the late 18th century with the introduction of mechanical production equipment driven by water and steam power. The second industrial revolution started in the beginning of the 20th century and was based on mass production enabled by the division of labour and the use of electrical energy. In the beginning of the 1970's, the third industrial revolution was initiated with the use of electronics and IT to further automate production. This lead to today's industrial revolution, the fourth industrial revolution - Industry 4.0, with the use of CPS. With the Industry 4.0 new concepts and business models have emerged (Figure 1) [6]–[11].

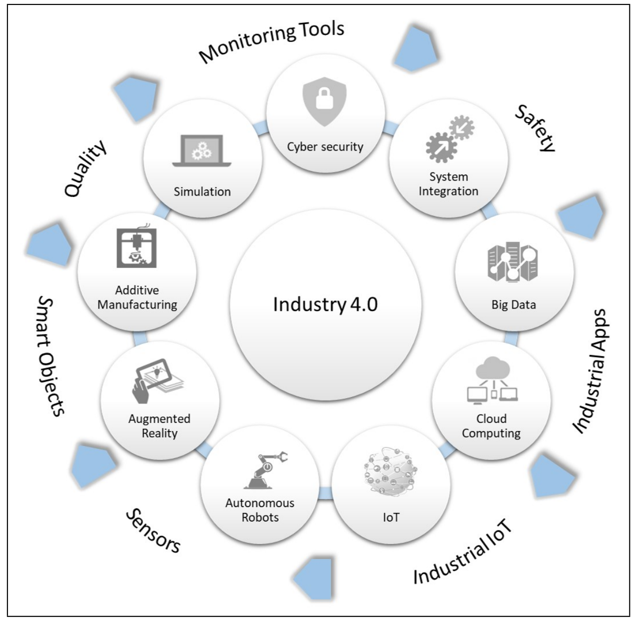

Figure 1. Industry 4.0

There are several key factors that must be present in a factory or in a system to be Industry 4.0 compliant: interoperability, information transparency, technical assistance, and decentralized decision making. Interoperability gives devices, machines, sensors, and humans the ability to connect and communicate with each other. Information transparency is achieved through the creation of a virtual copy of the physical world using the sensor data in order to contextualize information. Technical assistance has two main objectives: support humans in decision making and problem solving, and assist humans with tasks that are too difficult or too dangerous for humans. Decentralized decision making is reached through passing simple decisions to the CPS level, which becomes as autonomous as possible.

The Industry 4.0 has also created multiple challenges [12], [13], such as security, reliability and stability, integrity of the production system, loss of jobs, and fear of new technologies. Data security, in any business, is always a concern that is hugely increased when new systems and new ways of accessing the systems are introduced, which consequently also creates new risks of losing proprietary information technology

(IT) production knowledge. Although technology has come a long way, there are still some limitations to overcome, and for a CPS system to be successful, it must be reliable and stable, which can sometimes be difficult to achieve and to maintain. Having a production system with less human supervision can also be a barrier if integrity is not guaranteed, and less human jobs always lead to concerns in the work environment.

The manufacturing industry has traditionally been a top-down and centralized planning process. This way of working is fast becoming insufficient to respond to the constant changes in the new high-mix low-volume production environments. This is another reason for the strength that the Industry 4.0 concept has gain, and one of the ways to cope with these new production environments is through reconfigurability, which is facilitated by the technologies behind the Industry 4.0.

The concept of reconfigurability has been around for many years. Generally, reconfigurability can be though as the ability to repeatedly change and rearrange the components of a system in a cost-effective way. Koren *et al.* in [14] defined reconfigurable manufacturing systems as being "[..] designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality [..] in response to sudden changes in market or in regulatory requirements". Merhabi *et al.* [15] complement this definition with the notion that "re-configuration allows adding, removing or modifying specific process capabilities, controls, software, or machine structure to adjust production capacity in response to changing market demands or technologies [..] provides customised flexibility [..] so that it can be improved, upgraded and reconfigured, rather than replaced".

The equipment lifetime traditionally has several stages: it starts with its incorporation onto the production line, followed by its effective operation and maintenance phase, to its end use and consequent removal. It is possible through these steps to identify several critical points of intersection, which can potentially cause equipment downtime and possibly downtime of the production line, which ultimately is reflected in additional costs.

To aid the reconfigurability in the manufacturing industry, smart objects or smart components are being developed and used. Smart Components are defined as components that incorporate functions of self-description, communication, sensing, and control in order to cooperate with other smart components, analyse a situation, make decisions based on the available data, and modify their behaviour through feedback [16], [17].

Cloud Services: All the sensors and CPS that are being used and can be used in the industry, produce massive amounts of data that can be used to further improve the manufacturing process. The challenge is where and how to store all this data and how to use it. One way of dealing with this challenge is to use cloud based services [18]–[22]. The term "cloud" started to be used in the 1990's in the telecommunications field, when providers began using virtual private network (VPN) services for data communication [23], [24]. The National Institute of Standards and Technology (NIST) defines cloud computing as: "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." [25].

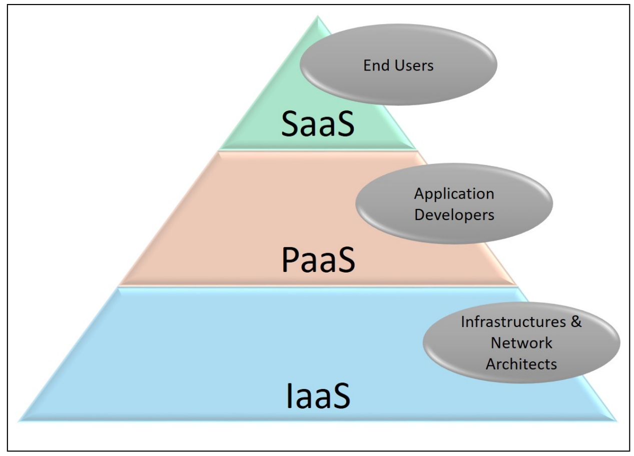

Figure 2. Cloud Services Model

The cloud computing concept provides three types of services that can be arranged as layers in a stack 2: the Software as a Service (SaaS), the Platform as a Service (PaaS), and the Infrastructure as a Service (IaaS). SaaS provide the user with the capability of running applications that are hosted in the cloud instead of locally, which can be accessed from various client devices. PaaS allow the user to deploy, to the cloud, user-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. IaaS provide the capability to provision processing, storage, networks, and other fundamental computing resources where the user is able to deploy and run arbitrary software, which can include operating systems and applications [24], [26]–[28].

As mentioned before, new business models are emerging in order to accommodate all these new concepts, technologies, and changes. One of these business models is what can be called of Industrial Marketplace. An Industrial Marketplace is a Multi-sided platform (MSP), also known as virtual Marketplace, [29], [30]. There are several definitions of what a MSP is, which are not always in accordance with each other [29], but there are two key features that are always present: (1) platforms, which provide the ability of direct interactions between two or more distinct sides, and (2) each side is affiliated with the platform. Furthermore, in order for a platform to be successful it must provide the ability of co-creation of value, interdependency and complementarity of components, surplus value for the whole system, and evolutionary growth [31].

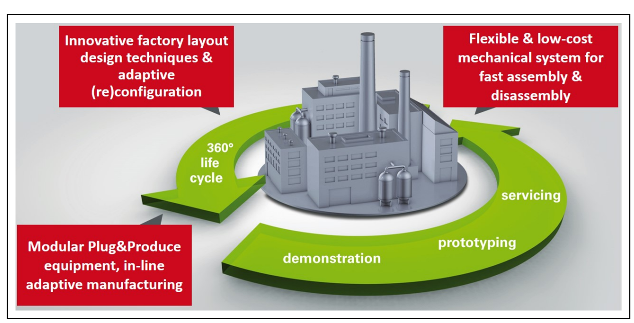

Figure 3. ReBorn Vision

ReBorn Project: As presented in [1], the architecture described is the result of combining the outcomes of two European projects: the Reborn project and the Selsus project. The ReBorn - Innovative Reuse of modular knowledge Based devices and technologies for Old, Renewed and New factories project [32], was a project funded under THEME FoF.NMP.2013-2 - Innovative re-use of modular equipment based on integrated factory design until August of 2016. The vision of ReBorn was to demonstrate strategies and technologies that support a new paradigm for the re-use of production equipment in factories (Figure 3). This re-use will give new life to decommissioned production systems and equipment, helping them to be "reborn" in new production lines. Such new strategies will contribute to sustainable, resource-friendly and green manufacturing and, at the same time, deliver economic and competitive advantages for the manufacturing sector. The developments made in ReBorn helped in the validation of technologies that extends production equipment life cycle, contributing to economic and environmental sustainability of production systems [9], [33].

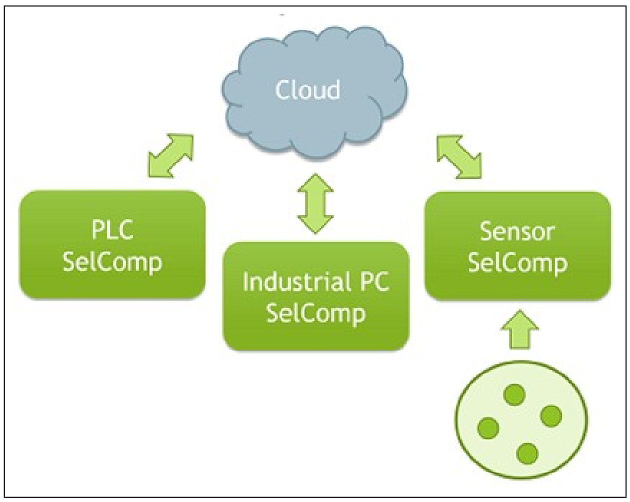

Figure 4. SelSus Vision

Selsus Project: The SelSus - Health Monitoring and Life-Long Capability Management for SELf-SUStaining Manufacturing Systems project [34] was a project also funded by the European Commission under the Seventh Framework Program for Research and Technological Development until August of 2017. The vision of SelSus was to create a new paradigm for highly effective, self-healing production resources and systems to maximize their performance over longer life times through highly targeted and timely repair, renovation and upgrading through the use of the Smart Component concept as a SelComp (Figure 4). These next generation machines, fixtures and tools with embed extended sensory capabilities and smart materials combined with advanced Information and Communications Technology (ICT) for self-diagnosis enabling them to become self-aware and supporting self-healing production systems. Distributed diagnostic and predictive repair and renovation models will be embedded into smart devices to early prognosis failure modes and component degradations. Self-aware devices will built on synergetic relationships with their human operators and maintenance personnel through continuous pro-active communication to achieve real self-healing systems. This will drastically improve the resilience and long term sustainability of highly complex manufacturing facilities to foreseen and unforeseen disturbances and deteriorations thereby minimizing energy and resource consumption and waste [17], [35]–[37].

In this paper, we propose an architecture for a Cyber-Physical Industrial Marketplace that results from combining the experience collected over the development of the ReBorn Marketplace, the SelSus Dashboard, and the combination of the functionalities of the Smart Components implemented on both projects. The objective is to have an efficient and easy to use Industrial Marketplace that provide a route for the flow of information from the equipment at the shop-floor, up to the Marketplace and back. Further, this proposed Cyber-Physical Industrial Marketplace will allow us to take advantage of all the current technological advances, and contributes for a safe and reliable way of using all the available information. Section II provides an overview of related work. Section III presents an overview of an Industrial Marketplace concept and Section IV describes the proposed Cyber-Physical Industrial Marketplace concept. Finally, Section V concludes the paper by exposing some final remarks about the concept and work developed.

II. Related Work

A digital marketplace can be viewed as a collaborative network that is formed in order to take advantage of new opportunities and explore new business models, as mentioned before. Nowadays, processing sensors and actuators have become common, more affordable and available, which is driving the wide adoption of Wireless Sensor Networks (WSNs) solutions. The WSNs can be found practically in all areas of everyday life, in applications such as environmental monitoring, military, or industrial fields, specially since data gathering is one of the pillars for the implementation of the IoT concept. Since WSNs typically contain small sensor devices, they have limitations on the memory, computation, energy, and scalability [38]. In order to fully use the potentialities of the WSNs, an infrastructure that is powerful, scalable, and secure must be implemented.

Llanes *et al.* [39] presented a survey of the main approaches that have been developed to deal with all the raw data collected by sensors. Sensors continuously collect data regarding a given event and send it to a gateway, which usually needs a specific protocol to process the received raw data. The main problem is that the various sensor manufacturers provide different communication protocols that use different message formats. This means that there is not a universal technology that can receive raw sensor data and support every message type for all the manufacturers. In the survey several solutions are described as well as the strengths and limitations of each one. An attempt to tackle this problem was made by Gonçalves *et al.* [40], where a Universal Gateway is proposed and presented. Shen *et al.* [41] provided an overview of recent developments of agent technology applied to manufacturing enterprises, which include enterprise collaboration regarding supply chain management and virtual enterprises, manufacturing process planning and scheduling, shop floor control, and also holonic manufacturing as an implementation methodology.

There have been other studies on how to manage the physical sensors. The Sensor Modelling Language (SensorML) [42] intends to provide standard models in a XML encoding for physical sensors' description and measurement processes. It is being used by the international non profit organization

Open Geospatial Consortium (OGC) [43] which is committed on making quality open standards for the global geospatial community.

As mentioned before, sensors from different manufacturers use different communication protocols, which makes sharing sensors and its information between applications difficult. Shneidman *et al.* [44] presented an infrastructure called Hourglass, which addresses the need for a software infrastructure that enables the rapid development and deployment of applications that use data from several, heterogeneous sensor networks. Silva *et al.* in [35] presented a flexible sensor integration solution. This flexible integration allows for a rapid graphical development of interpreters of raw data packets in the Cloud as well as its deployment for embedded execution at the WSN gateway level, for automatic data acquisition. Yuriyama & Kushida [45] proposed a new infrastructure called Sensor-Cloud infrastructure which can manage physical sensors on an IT infrastructure. The proposed Sensor-Cloud Infrastructure virtualizes a physical sensor as a virtual entity in the Cloud. Reis in [37] presented the implementation and use of the Sensor Cloud concept developed in the scope of the SelSus project. The goal was the easy integration, processing and visualization of sensor information within the industrial field. The main functionalities are the easy integration of sensors into a WSN regardless of their manufacturer, methods to pre-process data to be used for further decision making, and integration of new methods for statistical analysis.

This new paradigm of connecting and virtualizing sensors in a cloud infrastructure for data processing, is an active research field that is being explored by several researchers. Yan *et al.* [46], [47] proposed a cloud-based production system, across distributed data centers, which integrates several web and cloud computing technologies. A full connection model of product design and manufacturing in an IoT-enabled Cloud manufacturing environment, which uses the social networks to enable the connection of multiple parties, is also proposed. Zhang *et al.* [48] described a cloud manufacturing, defined for solving the bottlenecks in data and manufacturing applications. Alam & Saddik [49] presented and described a digital twin architecture reference model for cloud-based CPS, named C2PS. Neto *et al.* [50] presented the first steps in the development of a framework that takes advantage of several technologies like UPnP, OSGi, and iPOJO, which addresses some of the challenges needed to enable a Sensor Cloud in the shop floor. Chiang & Lee [51] proposed a smart manufacturing platform that can be used by small enterprises and start-ups. The heart of this platform is the communication pipeline, which allows component providers, original equipment manufacturer (OEM) factories, makers, and maker spaces that allow product development, to connect.

With so many solutions proposed and with so many different technologies that can be used, researchers have aggregate some of the available information through surveys. Alamri *et al.* [52] provided a survey of some of the most relevant work related to Sensor-Cloud infrastructure, its definition, architecture, and applications. Moçano *et al.* [53] analysed how the IoT can be used in the manufacturing industry, by proposing a metamodel for integrating the Internet of Things, Social Networks, Cloud, and Industry 4.0. Perera *et al.* [54] presented a survey over one hundred IoT smart solutions in the marketplace, identifying the technologies used, functionalities, and applications. The idea was to provide a guideline and a conceptual framework for future research in the IoT, motivating further developments by suggesting a number of potentially significant research directions. Albrecht *et al.* [55] examined the standards required for successful e-commerce architectures, evaluated the strengths and limitations of these type of systems and concluded, through the examination of the major platforms that have been developed, that there is a lack of a common or shared standard for marketplace architectures.

With the increase of the number of devices connected to the Internet, having centralized Cloud services will become unsustainable. This is leading to new paradigms such as Fog or Edge computing [56], [57].

Security and data privacy is currently one of the biggest restraints in the wide use of the technologies described previously. Many authors have addressed these issues of security and privacy over the IoT [58]–[64] and have proposed new approaches for securing and enabling reliability on sensor data [38], [65]. Nevertheless, there is still a great deal of work to be performed in areas such as cryptographic mechanisms, data, identity, and privacy management, as well as defining trusted architectures. Taylor & Sharif in [66] presented the main security threats faced by the industry as well as the main approaches for counteracting those threats. Zahra *et al.* in [67] also presented a concise survey on sensor network constraints, security requirements, attacks, and defensive measures. A RC5's algorithm was proposed, which provides good security against the four main types of attacks, even thought it is a simple encryption algorithm that still needs further testing.

The most common type of industrial marketplaces that can currently be found online are auction sites ([68], [69]) or digital stores, which are sites where companies present their products to be sold, like a normal store [70]–[72]. But there are also some companies trying to change their marketplace sites and make them more intelligent and take advantage of all the new technology available. One example is the Intelligent Plant company [73] that developed an app (App Store connect), which allows users that use their services and software to make their data available to the applications that are in their Industrial App Store. Another example is Advantech, which launched the WISE-PaaS Marketplace [74], an online IoT software store that features Advantech's exclusive software services, including IoT cloud services, IoT security services, and pre-packaged solution packages.

III. Industrial Marketplace

Although there are several platforms proposed for industrial marketplaces, there is still no truly intelligent, online, working industrial marketplace. There are several reasons for the lack of this type of Cyber-Physical Industrial Marketplace, which include security issues, a common accepted platform, and a common accepted communication mechanism. Another reason is trust. Most of the businesses in the industrial field are based on relationships built over time and where there is a high trust between the stakeholders [75].

The global marketplace has been evolving at a rapid pace over the recent years. Reduced lot sizes, customization and individualization in the product is the future of manufacturing. The challenge for manufacturers in this new trend of manufacturing is that neither the traditional theories of production planning and scheduling work in an Industry 4.0 environment.

One of the key elements that is at the base of a marketplace, industrial or of other type, is a platform. Smedlund and Faghankhani [31] define platform as *"Any physical or virtual space where different participants compose a market and a platform that participants orchestrate can be defined as a platform"*.

Platforms are typically composed of multi-layered structures, where the technological core element provides support for complementary technologies and software. Depending on the type of interactions between the participants, it is possible to identify different types of platforms such as: platforms that bring sellers and buyers together, platforms that help members of some group find a match in another group, platforms that measure transactions between participants, and platforms where participants share their input with other participants. Platforms can be classified as one-sided, two-sided, or multi-sided, depending on the number of participating groups. In n-sided platforms the users connect to each other, communicate and co-create value for themselves and for the other users and participants. The end-user must give something back to the platform, in order to benefit from the whole spectrum of platform functionalities.

Chen *et al.* in [76] defined online platforms, based on the definition of the European Commission, as *"digital platforms that enable consumers to find online information and businesses to exploit the advantages of e-commerce"*. They also classified online platforms into eight types according to user groups and business models: E-Commerce, Resource Sharing, Matching/Auction, Competitive Crowdsourcing, Non-competitive Crowdsourcing, Crowdfunding, Search Platforms, and Social Network Platforms. There are several factors for the success of online platforms such as the development costs, which are usually low for users because the main costs are associated with the development of the platform itself; the multi-sided revenue streams because on online platforms there is value created for all user groups involved; the online platforms have flexible scalability and can easily scale up operations; and online platforms are Widely accessible.

Nowadays there are two terms that often appear when one is talking about online business and that are often interchanged but that do have different meaning: e-commerce and e-marketplace. E-commerce is a business model where a given company buys products from several other companies and, through its web site, directly sells them to clients. E-marketplace is a different business model where the company that owns the web site only provides a platform, it does not directly buy or sell anything [77]–[80] (Figure 5).

Online businesses can be grouped into three big types of models as shown in Figure 6 [77], [81]:

- B2B - Business to Business is a type of transaction that is performed between businesses, such as a company buying materials or services needed for its production process, or re-selling products or services produced by others.
- B2C - Business to Consumer is when the transaction is between one business and its consumers who are the end-users of the product.
- C2C - Consumer to Consumer is a model where the transactions are executed directly between costumers.

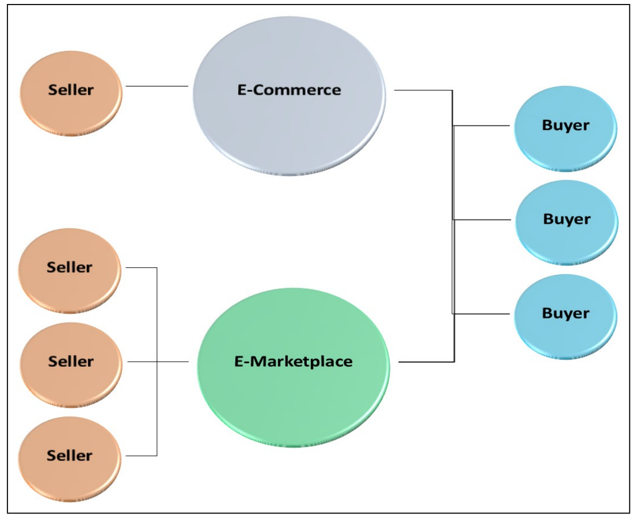

Figure 5. E-commerce vs E-marketplace

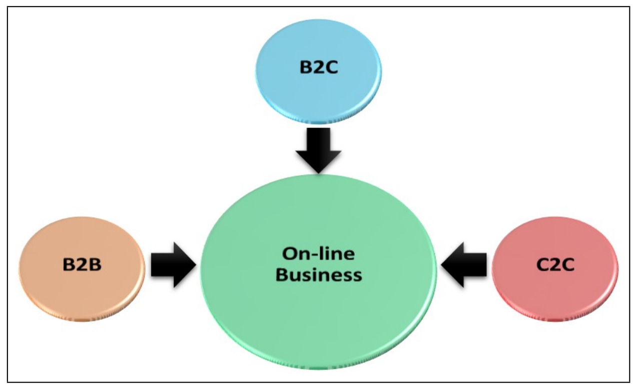

Figure 6. online Business Types

In order to properly define and establish the goals for the Cyber-Physical Industrial Marketplace concept, a set of requirements were collected and defined. These set of requirements allowed for the development of a workable marketplace, as well as provide a way of verifying the usefulness of the marketplace. With the intent of finding a valid and robust solution, it was necessary to validate all inherent functional and non-functional requirements, which in turn enables a full understanding of the customer needs and requirements. In order to satisfy the requirements of a real life application, some of the requirements were collected through a joint work with the Harms&Wende Karlsruhe – Germany Software Development team branch, which was part of the ReBorn project. The functional requirements collected are shown in Table I.

IV. Cyber-Physical Industrial Marketplace Concept

As mentioned before, in [1] the concept of a Marketplace for the cyber-physical production systems was presented. This concept emerged from the results of two European projects: the ReBorn project and the Selsus project.

Figure 7 presents what we consider to be the basic ideas that must be present in a Industrial Marketplace, specifically

TABLE I. Functional Requirements

Feature	User Management	Allow the creation of user accounts in a reliable and flexible way. User management functionalities such as user validation and customer data base management, by the platform administrator
	Access Control	Allow association of different roles to each user, which determines the type and amount of information available for that specific user
	Unlimited Products & Categories	Allow the unlimited creation of products and product categories
	Multi-Language	Support multiple languages on which information is displayed
	Gift Certificates	Allow gift certificates, which act as a key feature regarding platform growth, and inventory management
	Discount Coupons	Allow discount coupons to be generate at will, which is proven to be an important tool to product marketing
	Loyalty Program	Reward users which make multiple purchases on the marketplace, in order to increase the users commitment to the online platform
	Affiliates Program	Allow entities who are capable of selling and or promoting the marketplace products and services, or directing customers to it, in exchange for a percentage of a sale
	Search Optimization Tools	Search engine optimization in order to attempt to achieve the highest rank possible
	Product Reviews	Allow users to review products that are currently supported by the online platform
	Newsletters	Allow the platform administration the option to send bulk emails to existing customers, or customers that subscribed to a newsletter program
	Wish Lists	Offer the users the ability to create wish lists
Shipping	Shipping Filters	Display shipping costs according to product dimensions, weight, and delivery range of the items ordered
	Shipper Lookups	Offer a varied spectrum of courier delivery services regarding product shipping
Tax & Payment	Payment Options	Include built in support for payment gateways such as PayPal, and Authorize.net
	Tax Filters	Be able to take into account the appropriate tax rate applied to the customers country and state
Application Management	Industrial Equipment Software Update	Provide the latest application software releases upon request from each industrial equipment
	Full System Software Update	Allow, upon request by the client, a full system application software update up to the most recent and stable software version in a fully automated manner
	Specific Software Update	Allow individual update requests of each application
	Software Restore	Allow for software restore in case of any malfunction or defect is detected a regarding a particular software update
	Industrial Equipment Software Install	Allow for individual application installation as long as long as the application is compatible with the industrial equipment, and the industrial equipment owner possesses an available license for the to be installed application
	Industrial Equipment Software Uninstall	The industrial equipment upon uninstall of any application must notify the online platform

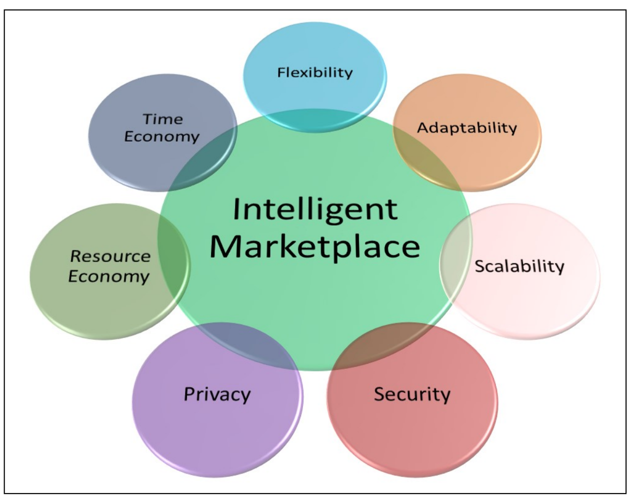

Figure 7. Proposed Solution Pillars

in a Cyber-Physical Industrial Marketplace. These basic ideas are the pillars of a Cyber-Physical Industrial Marketplace that is pointing toward the future:

- Flexibility - any future Industrial Marketplace must be flexible. In [82] flexibility is defined as "the ease with which a system or component can be modified for use in applications or environments other than those for which it was specifically designed". The marketplace must allow for new products or services exchange, and new protocols or technologies, through a seamless easy manner.
- Adaptability - is the way the marketplace internally adjust to flexibility. As time goes by and new technologies and applications emerge, an Industrial Marketplace must have the ability to adapt to new and different applications, through new technologies and protocols, without much effort.
- Scalability - any marketplace must be scalable, which means that it must be able to grow without losing functionality and flexibility. It must be able to deal with the natural increase, over time, of information and data flows.
- Security - is one of the most important aspects of these

type of businesses. For a marketplace to be intelligent it needs to be able to access a huge amount of information, ideally down to the equipment level. This introduces possible security breaches. Considering that in a marketplace many different kind of businesses are present with different kinds of security needs, the marketplace must be prepared to handle different security protocols.

- Privacy - walks hand in hand with security. For most companies, their information records are one of the most precious assets. This introduces the need for privacy and authentication. As in security, the marketplace must also be able to handle different schemes of privacy and authentication of users as well as of information.
- Resource Economy - in any business, small, medium, or large, there is a common goal: be able to save money to increase their profits. One way of accomplishing this is through a better resource management. Better resource management can be achieved through several ways, one of the most common is through cheaper materials or human force and by mass production of a single product. But the price of materials or workers can only decrease until a certain point, and although there are still many types of products that can be mass produce, customization is gaining strength. This means that new ways of resource economy must be found. The Cyber-Physical Industrial Marketplace can facilitate the development of these new ways such as new collaborations between different suppliers, reuse and re-purpose of machines, and creation of new services.
- Time Economy - another way of saving money in a business is by saving time. A well designed marketplace will allow for its users to save time through quickly supplying relevant information. In an Cyber-Physical Industrial Marketplace a user can find suppliers and partners easily and reach them with a simple click or message. This contributes to a more efficient and fast product design and production.

A. Proposed solution

With all the new technology that is virtually available everywhere to anyone, it is easy to imagine that everything can eventually be connected. This connectivity brings new information exchange channels, which leads to new business possibilities. Creating a marketplace that is more encompassing and with more functionalities than the current online stores, is the next natural and logical step.

The Cyber-Physical Industrial Marketplace, at first sight, works as a common online store. Users can register and buy products and sellers can also register and sell their products. The Marketplace is able to manage all the user and sellers accounts, as well as the shipping and payment services. This Cyber-Physical Industrial Marketplace is based on the ReBorn Marketplace [9], which is a multi-sided market, with service providers on one end and service consumers on the other.

As Figure 8 presents, the Cyber-Physical Industrial Marketplace is composed of several elements, such as sellers, equipment, services, buyers, platforms, and software. All these

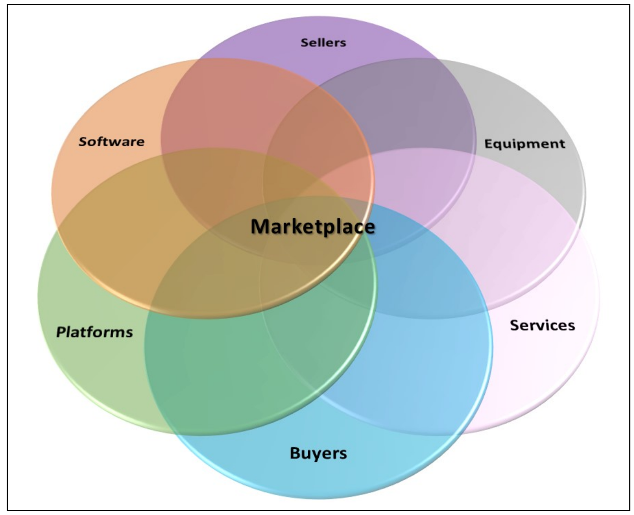

Figure 8. Cyber-Physical Industrial Marketplace Participants

elements can have more than one role. For example, a buyer can be a seller or service provider, or a service provider can also provide software and equipment.

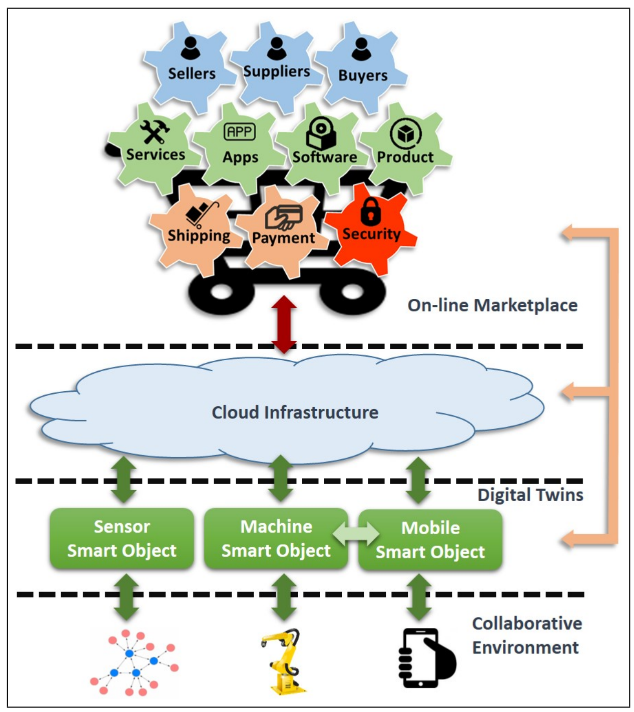

Figure 9. Cyber-Physical Industrial Marketplace Connection

Figure 9 provides a high level image of the proposed solution. As it can be seen, there are four main blocks in the proposed solution: the online marketplace, the cloud infrastructure, the digital twins, and the collaborative environment.

A key element in order to have an intelligent Cyber-Physical Industrial Marketplace is information. The bigger the amount of information available and the more precise the information collected is, the better and more accurate the management will be. Manufacturing equipment is becoming, itself, more intelligent and able of providing relevant and near real-time information. The problem is how to use this information, where to store it, and who or what has access to it. In the manufacturing world, information from the equipment is a desirable and often priceless asset. The right equipment configuration can be the difference between a top quality product and a medium or poor one. This has introduced a standstill in the widespread of industrial marketplaces. Another impasse on this type of business is that, although intelligent equipment is available, there is still a great amount of older equipment that has no sensors or any recent technology that allows gathering information.

In order to overcome these drawbacks the Smart Object concept was envisioned. The Smart Object can represent any element of the shop-floor such as machines, sensors, components, AGVs, smart-phones, and shop-floor operators with wearable sensor devices. The Smart Object is a digital representation of the shop-floor elements as shown in Figure 9, and it is based on the developments made in the ReBorn and Selsus projects. Both projects deepen and enhanced the smart component concept that was first developed in the European projects XPress [83], [84] and I-RAMP[3] [40], [85]. The main goal of these smart components was to enhance the equipment with new capabilities and functionalities. The Smart Object picks up on the results from these projects and takes it a step further. The idea is that the Smart Object can be treated as a black box. It can communicate with an equipment that already has sensors and is gathering information or it can have sensors added to it, in order to be used with older equipments that have no intelligence incorporated.

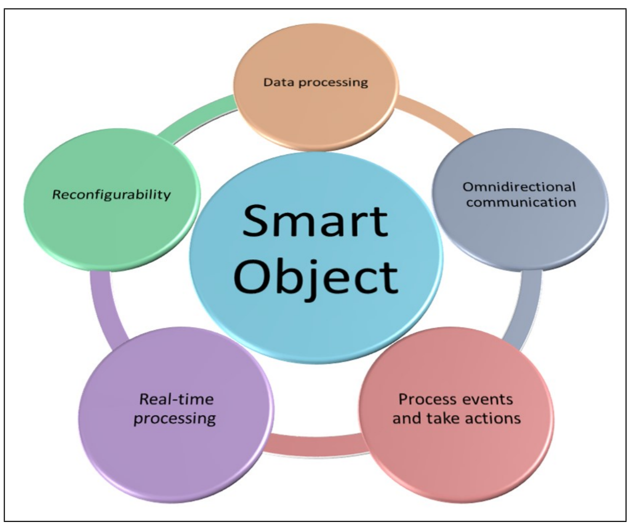

Figure 10. Smart Object Characteristics

The Smart Objects have five essential characteristics, which are presented in Figure 10 [17]. Smart Objects are reconfigurable because they are able of reconfiguring its internal operation in runtime and modular because they are able of extending its capabilities by adding new software modules, also at runtime. Smart Objects also have data processing capabilities, such as system state assessment and event and alarm detection. Another essential characteristic of the Smart Object is the omnidirectional communication and interface capabilities, which allow the system to communicate with devices at any level: lower level, such as sensors and machines; same level, such as other Smart Objects; or higher level, such as cloud servers and manufacturing systems. The Smart Objects are also able of processing events and of taking actions with a certain degree of intelligence and autonomy. The final characteristic is the ability for real-time acquisition, processing, and deliver of data collected.

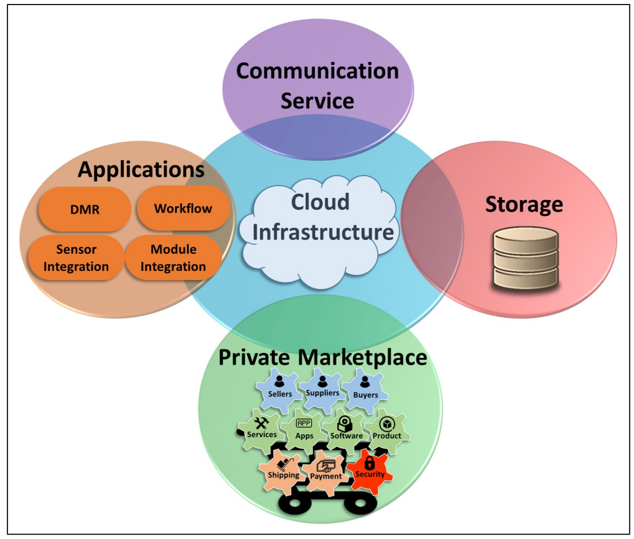

Figure 11. Cloud Infrastructure

The Smart Object can be considered as a bridge between the shop-floor and the virtual world. All the information collected and treated by the Smart Objects are sent to a cloud infrastructure. This infrastructure can be as simple or as complex as needed, depending on the type of business and the treatment that is required for the information collected. The Cloud Infrastructure is further detailed in Figure 11 and is composed by the following elements: communication service, storage, applications, and private marketplace.

The Communication Service is responsible for providing a way of exchanging information between the possible different platforms and software programs. This service has the capability of receiving and interpreting the requests to and from the Smart Objects, which allows all communications between the different levels of the system to be simple and clearly defined. In order for this communication the be easy and simple a semantic was defined [36]. There are two groups of possible communication: communication with the Cloud Infrastructure and communication with the Marketplace. In the Cloud Infrastructure, in order to directly communicate with the Smart Object three types of documents have been defined: the Smart Self Description (SSD), the Payload, and the Recipe Adjustment. These three documents are XML based. The SDD purpose is to allow the description of the shop-floor equipment. It has two main parts: meta information of the equipment, such as equipment manufacturer, serial number, equipment model, Smart Object name, and Smart Object unique identifier; and operational related data, such as which data needs to be collected and how, and to where it needs to be sent. The Payload document is has a very lightweight XML structure used to send operational process data to the Cloud Infrastructure. The Recipe Adjustment document is also a lightweight XML structure used to reconfigure the Smart Object processing process.

The Storage, as the name suggests, stores in form of a database, all the structural representation and operational data of the Smart Objects. This information will be accessible through the communication service and can be configured to determine what is stored, for how long, and who has permission to access it.

The Applications element encompasses a group of software applications that permits the easy interaction of the user with the system. These applications enable the user to control and reconfigure the system. Figure 11 presents some of the applications already developed: the Dynamic Modular Reconfiguration (DMR) [17], the Sensor Integration [35], the Workflow, and the Module Integrator [36]. The DMR purpose is to enable an easy and quick way of reconfiguring the Smart Object code responsible for processing data, which facilitates the reconfiguration and sensor integration in the system. The Sensor Integration is an application developed to aid the user to easily, though a graphical interface, define interpreters of the raw data packets. The purpose of this application is to allow the addition of new sensors by simply defining the type of message used and connecting the sensor on the shop-floor. The Workflow is also an application that intends to aid the user. The goal here is to allow the configuration of how data is process at a higher level, also through a graphical interface by means of a Directed Acyclic Graph (DAG) (Figure 12). The source nodes (red nodes) represent devices available that generate data, the intermediary nodes (blue nodes) are processing modules available to process data from source nodes, and the sink nodes (green nodes) that represent a higher level of processing. This allows to process multiple data sources and multiple Smart Objects, by simply drawing a DAG. The Module Integration application accede the integration of internal and external processing modules, which can be used in the DMR and in the Workflow.

The final element presented is the Private Marketplace. The idea behind the private marketplace emerged from the need of the industry to keep data private and local. The Private Marketplace is intended to be a copy of the online Marketplace, with all its features and services, but it is hosted on a private network. This Private Marketplace will act as a proxy between the online Marketplace and all the internal and private system elements. This allows for all the information collected by the Smart Objects to be sent and used by the Private Marketplace. This information can be used in applications such as maintenance planning or stock management. The Private Marketplace will allow to manage this information and facilitate the management of what can be uploaded into the online Marketplace. On the other hand, any software update or new feature that becomes available on the online Marketplace, can be downloaded to the Private Marketplace, through direct connection or manual update, and then be used to update the Smart Objects as needed.

Besides the three documents, described above, used by the Cloud Infrastructure to communicate with the Smart Object, there is also the need to communicate with the Marketplace, in order to have the ability to update the Smart Object software or to add new features, such as a security module or a new data processing algorithm. The communication with the Marketplace is performed through a RESTful Web Services,

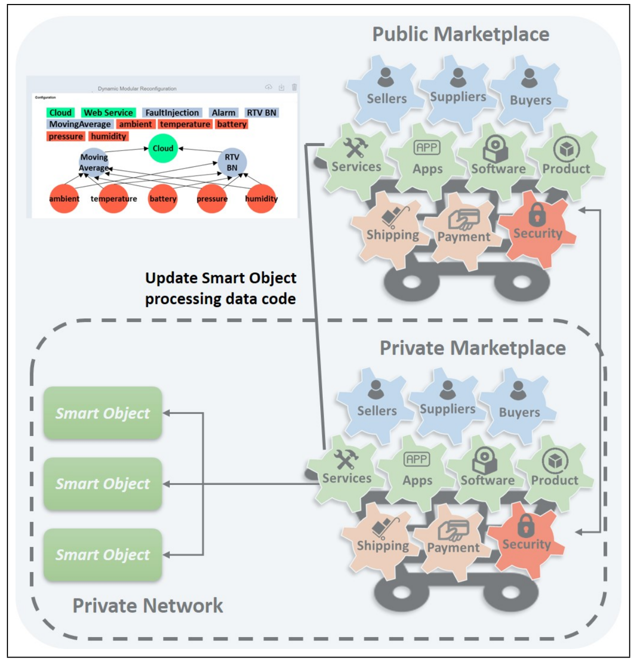

Figure 12. Dynamic Modular Reconfiguration Application

which is a Representational State Transfer (REST) web service based architecture. The REST was chosen because it is a web standard based architecture that uses the HTTP Protocol for data communication. In the REST architecture, every component is a resource and can be accessed by a common interface using HTTP standard methods, such as GET (a read only access to a resource), PUT (to create a new resource), DELETE (to remove a resource), POST (to update an existing resource or create a new resource), and OPTIONS (to get the supported operations on a resource). From the possible text representations that are supported the JSON and XML where chosen.

The online Marketplace, as shown in Figure 9, provides several services and functionalities. There are several functionalities that are inherent to an online marketplace. These inherent functionalities include all management related to users, products, shipping, and payment as presented in Table I. The management activity encompasses operations that include adding, deleted, or changing information from users; adding, deleting, changing information from products, and keeping track of the products stocks; keeping track of shipment activities; and manage all payments related activities. But aside from all these regular activities, in order to be considered intelligent and a Cyber-physical Industrial Marketplace, it must provide other services that can aid users on their activities. For example alert the user for equipments that are similar to what the user is searching or provide updates on new software or new complementary equipment compatible with what that the user has acquired.

A key functionality for a Cyber-Physical Industrial Marketplace is the ability to manage the shop-floor equipment. As mentioned before, a direct connection between the shop-floor and the internet, is not desirable and most of the times not even possible. This restriction was behind the concept of the Private Marketplace. As mentioned before the Private Marketplace is a copy of the online Marketplace, which can execute all the services, in a private setting with no online connection. But this Private Marketplace can also synchronize with the online Marketplace all the information collected by the Smart Objects that has been defined as not private, and also receive updates from the online Marketplace.

One important feature is the Industrial Software Manager. This manager is responsible for the management of the application content of each Smart Object. This allows the upgrade of the Smart Object software, in an easy and simple way, facilitating the integration of new technologies and functionalities in the industrial equipment on the fly.

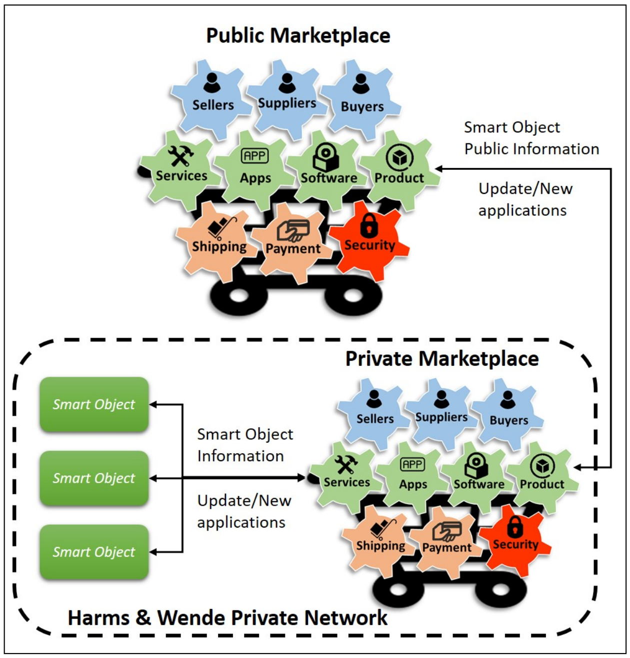

Figure 13. Practical example

The implementation of the Private/Public Marketplace concept was tested at the Harms&Wende (HWH) Karlsruhe [86], as part of the joint work collaboration within the ReBorn project. HWH is a component supplier specialized in welding control systems for various sectors, offering resistance welding equipment in form of control devices as well as quality assurance systems. HWH customers are often welding machines manufacturers who use the HWH welding control units.

Figure 13 provides an overview of the implementation of the Private/Public Marketplace concept presented. As it is shown, there are three main components: the Smart Objects, the Private Marketplace and the Public Marketplace. For the test performed at the HWH, the Smart Object was implemented on a dedicated hardware platform, a RaspBerry Pi SBC, to enable an easy implementation and test of the concept. Inside the Marketplace, as previously stated, there is the Industrial Software Manager, which, in the case of the Private Marketplace, locally manages the application content of each equipment's Smart Object, while the equipment is installed in a production line. This Industrial Software Manager can receive requests and update the Smart Object software, through a REST based web service [9]. The Industrial Software Manager in the Private Marketplace can synchronize its information as well as receive updates from the Industrial Software Manager in the Public Marketplace.

Another important and crucial feature is the Security Manager. This manager facilitates the possibility of having a security layer over all the communications that occur within the system, from the Smart Object up to the online Marketplace. This manager will provide privacy and authentication modules, that can be configured to use different algorithms, and which can be added to every element of the system.

The purpose of the Maintenance Manager, as can be inferred from the name, is to aid in the maintenance planning. Using predictive algorithms based on the information collected by the Smart Objects, the Maintenance Manager can aid in the scheduling of the equipment's maintenance, in order to minimize the production down time. But this manager can also be useful in a different scenario. Consider an equipment supplier that wants to increase their business by adding maintenance services to its portfolio. Many equipment suppliers sell across the country and even to across countries. The Maintenance Manager, based on the information collected by the Smart Objects, can provide a maintenance or inspection schedule that takes into account the geographical placing of the equipment as well as the current state of the equipment. This will allow the equipment supplier to minimize the travelling costs and also provide a more active preventive maintenance service. The Maintenance Manager will generate possible maintenance routes, based on configurable variables, such as minimize costs or travel time.

As mentioned before, one key functionality of this type of systems is to be able to change, on the fly, what is being processed in the Smart Objects. With that in mind, the Simulation Dashboard was defined. As the Maintenance Manager, this Simulation Dashboard can be used in two distinct scenarios. It can be used privately by a company that needs a new functionality for its Smart Objects or it can be used by developers that want to sell new modules for the Smart Objects on the Marketplace. The Simulation Dashboard facilitates the design, implementation, and test of new features, such as new metric calculations or a new form of processing raw data in the Smart Objects. After the user implements and tests, through simulation the new functionality developed, it can be sent to the Smart Objects or stored in the online Marketplace to be sold.

B. Advantages and disadvantages of a Cyber-Physical Industrial Marketplace

With the digital revolution, business models have changed and evolved. Online Marketplaces are growing at a fast pace. They provide a way for companies to quickly and easily find new costumers and expand their business. They also provide a way for new opportunities to establish partnerships between traders and suppliers. Using online Marketplaces reduces marketing costs compared to other sales channels. It also allows for new opportunities for overseas sales, without the costs of setting up stores across different countries. Being able to operate a round-the-clock business reduces time constraints and problems with international trading hours.

For buyers, online Marketplaces are also a quick way to find companies, design and produce prototypes, and buy products easily. Online Marketplaces provide a convenient way to compare prices and products from a single source. Using a credible online Marketplace contributes to the building of a greater level of trust between the sellers and the buyers. It also improves the level of transparency, through the availability of prices and stock levels in an open environment.

The downfall of online Marketplaces is thrust or more exactly the lack of trust. The online Marketplaces can provided a venue for bad players to set up store-fronts and traffic in damaged, counterfeit, or falsely products. Another issue also related with trust is the management of the information that can be exchanged, how can privacy and security be guaranteed. Credit card fraud is also a huge concern when dealing with online Marketplaces businesses.

V. Conclusion

Industry 4.0 has brought to light new concepts and technologies. Cyber-Physical Systems, the Internet of Things, and Cloud computing pave the way for the Smart Factories concept. Within the Smart Factories approach, a large amount of data is available to be used. All the available data can be processed using data analytic algorithms, which can then be used to improve productivity and production planning as well as allow for a better equipment predictive maintenance. In a world where competition is global, the industry must be able to respond to unpredictable and rapid market changes. Manufacturing systems must become flexible, easily upgradable, and allow for new technologies and functions to be readily integrated. This creates the need for novel manufacturing control systems able to cope with the increased complexity required to manage product and production variability in mass customized manufacturing.

A solution for this challenge is through the Smart Components concept, a logical encapsulation of the manufacturing industrial equipment. To organise and store information of industrial machines, not only for potential customers to check and compare different devices, but also to provide an interface that allows for automatic update of the industrial equipment technologies and functionalities on the fly, a Cyber-Physical Industrial Marketplace is key.

In this paper an architecture for a Cyber-Physical Industrial Marketplace is proposed. This work is the result of combining some of the results and experience collected over two European projects: the ReBorn and the Selsus project. Within these two projects, the contributions produced, which are also at the basis of this proposed architecture are the ReBorn Marketplace, the SelSus Dashboard, and the combination of the functionalities of the Smart Components implemented on both projects.

The ultimate goal of the proposed architecture is to provide an efficient and easy to use Industrial Marketplace that encompasses all the activities related to the manufacturing field. The objective is to provide a route for the flow of information from the equipment at the shop-floor, up to the Marketplace and back. This proposed Cyber-Physical Industrial Marketplace will not only provide a virtual shop for equipment but also for smart components, software, and services. In order to be truly intelligent, this marketplace must also be flexible and configurable in order to adjust to each user needs. The proposed Cyber-Physical Industrial Marketplace allows to take advantage of all the current technological advances, and contributes for a safe and reliable way of using all the available information.

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