A Marketplace for Cyber-Physical Production Systems: Architecture and Key Enablers

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***Abstract*—With the Industry 4.0, which can be referred to as the fourth industrial revolution, the concept of Smart Factories has emerged into the spotlight. This new trend in automation and manufacturing encompasses a wide range of technologies such as Cyber-Physical Systems (CPS), the Internet of Things (IoT), and Cloud computing. The conjunction of these technologies creates new opportunities at all levels, such as technological, economical, and societal. In this paper, an architecture that combines results from two European R&D projects is presented. The aim of the proposed architecture it to allow a step forward in utilizing all the advantages of the Industry 4.0 concept and the technological advances. The ultimate goal of the proposed architecture is to allow the existence of a flow of information from the physical equipment in the shop-floor up to an on-line Marketplace, and to allow a safe and reliable way of using all the information.**

***Keywords*–Smart factories; Intelligent Production systems; Industry 4.0; Cyber-physical systems; Marketplace.**

I. Introduction

Today, sensors can be found in just about anything, from home appliances, mobile phones, cars to complex health equipment or industrial equipment. These sensors continuously produce enormous amounts of data concerning some type of event. All these different available sensors provide heterogeneous raw data, which is provided at different formats and with no common semantics to describe its meaning. Sheth, Henson, and Sahoo [1] described this paradigm as ”too much data and not enough knowledge”.

This paradigm is being leveraged by the development of components and systems called Smart Components. Smart Components in manufacturing are defined as components that incorporate functions of self-description, communication, sensing, and control in order to cooperate with other smart components, analyze a situation, make decisions based on the available data, and modify their behavior through feedback [2].

Over the past few years, many projects have been dedicated to these issues. Among those projects there are two in particularly that have been focused on bringing knowledge to all the collected data, in industrial environments: the ReBorn - Innovative Reuse of modular knowledge Based devices and technologies for Old, Renewed and New factories project, and the SelSus - Health Monitoring and Life-Long Capability Management for SELf-SUStaining Manufacturing Systems project.

The ReBorn project [3] 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. 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 production equipment to extend its life cycle, contributing to economic and environmental sustainability of production systems [4] [5]. The concept of modular production equipment may also be re-used between different production systems, after servicing and upgrading. This new business paradigm will move from an equipment-based business to a value added business, where equipment servicing and equipment knowledge are main drivers.

The SelSus project [6] is 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 is 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 (SelSus Component). 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.

The current work consists on an architecture that enables the connection between Wireless Sensor Networks (WSNs) in a manufacture context with an open marketplace. This architecture intends on bridging the gap between the results achieved in both ReBorn and SelSus projects, namelly the ReBorn Marketplace and the Selsus Dashboard.

This paper is organized in four more sections. In Section II, a brief overview of related work is presented. Section III presents the previous results that are the basis for the work proposed in this paper, and in Section IV the proposed architecture to be implemented is described. Finally, Section V concludes the paper by exposing some final remarks and the next steps for future work are identified.

II. Related Work

Nowadays, sensors and actuators have become more affordable and available, which contributed to the wide adoption of WSNs solutions, used for monitoring of physical and environmental conditions into several applications.

WSNs are an emerging technology that exhibits a great potential and that can play an important role in many applications. It is becoming common to use WSNs in a variety of applications areas such as environmental monitoring, military, or industrial fields, specially since data gathering is one of the pillars for the implementation of IoT concepts. However, since they typically contain small sensor devices, WSNs present some constraints, such as limitations on the memory, computation, energy, and scalability [7]. To take full advantage of the WSNs potentialities an infrastructure that is powerful, scalable, and secure must be implemented.

Llanes *et al.* [8] 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 problem is that the various sensor manufacturers provide different communication protocols that use different message formats, so there is not an universal technology that can receive raw sensor data and support every message type for processing further the received information. In the survey, several solutions are described, as well the strengths and limitations of each one. Also, an attempt was made by Gil *et al.* [9] to provide an Universal Gateway in order to mitigate this problem. Shen *et al.* [10] 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. Sensor Modeling Language (SensorML) [11] 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), which is committed on making quality open standards for the global geospatial community.

As mentioned before, sensors from different manufactures use different communication protocols, which makes it difficult to share sensors and its information between applications. Shneidman *et al.* [12] 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. Yuriyama & Kushida [13] propose 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.

Several research work has been performed regarding this new paradigm of connecting and virtualizing sensors in Cloud infrastructures for data processing. Yan *et al.* [14] propose a cloud-based production system, across distributed data centers, which integrates several web and Cloud computing technologies. Yang *et al.* [15] propose 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. Zhang *et al.* [16] describes the Cloud Manufacturing (CMfg), defined for solving the bottlenecks in the data and manufacturing applications. Alam & Saddik [17] present and describe a digital twin architecture reference model for the cloud-based CPS, named C2PS. Neto *et al.* [18] 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.

Alamri *et al.* [19] provides a survey of some of the most relevant work related to Sensor-Cloud infrastructure, its definition, architecture, and applications. Moano *et al.* [20] analyse 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.

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 [21] [22].

A huge requirement that is slowing the advances and the wide use of the technologies described previously is the security and data privacy. The security and privacy issues over the IoT have been addressed by several authors [23]–[29], which propose new approaches of securing and enable reliability on sensor data [30] [7]. Nevertheless, there is still a lot of work to be done in areas such as cryptographic mechanisms, data, identity, and privacy management, as well as defining trusted architectures.

III. Previous Results

The work proposed in this paper, arises from the idea of combining some of the results accomplished in the ReBorn and SelSus projects. In both projects, the achieved results are based on the concept of a Smart Component, which has different designation in each project, namely VERSON in ReBorn and SelComp [31] in SelSus. A Smart Component, as mentioned before, is an intelligent agent-based representation of industrial equipment in manufacturing environment, which enables both complex machines and sensor & actuators of added value functionalities, such as self-description capabilities and standardized communication skills. These are useful for inter-device collaboration and process optimization, based on analyses of collected environmental and context data, for proper decision making regarding actuation and equipment behavior modification.

In the following sections, a brief overview of the ReBorn and SelSus projects is presented as well as the results that are used for the proposed architecture, namelly the ReBorn Marketplace and SelSus Dashboard.

A. ReBorn Marketplace

As mention before, the ReBorn main goal was to demonstrate strategies and technologies that support a new paradigm for the re-use of production equipment in factories (Figure 1).

This new paradigm builds on self-aware and knowledge-based equipment that needs functionalities to collect and manage information regarding their capabilities and their evolution

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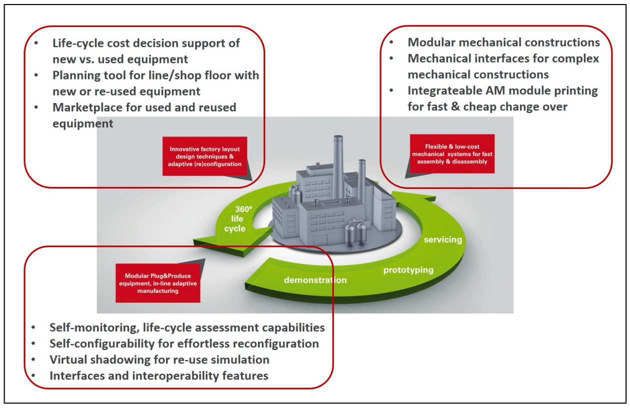

Figure 1. ReBorn re-use approaches

over time, maintenance, upgrade or refurbishment operations over its lifetime and information of use and wear. To enable this, versatile and modular, task-driven plug&produce devices, with built-in capabilities for self-assessment and optimal re-use were implemented, along with strategies for their re-use and models for factory layout design and adaptive configuration.

These new technologies were demonstrated in the context of intelligent repair, upgrade and re-use of equipment, the re-design of factory layouts and flexible & adaptable production on shop floor within several industrial demonstration scenarios. This demonstration scenarios include a flexible pick&place machine, a multi-purpose on demand 3D printing module, a condition monitoring and virtual programming, a modular and self-configuring servo press, and tools for planning and assessment as presented in Figure 2. Having ReBorn technology available, significant reduced the efforts when setting-up and ramping-up production systems, enabling a significant step towards 100% re-use of industrial equipment.

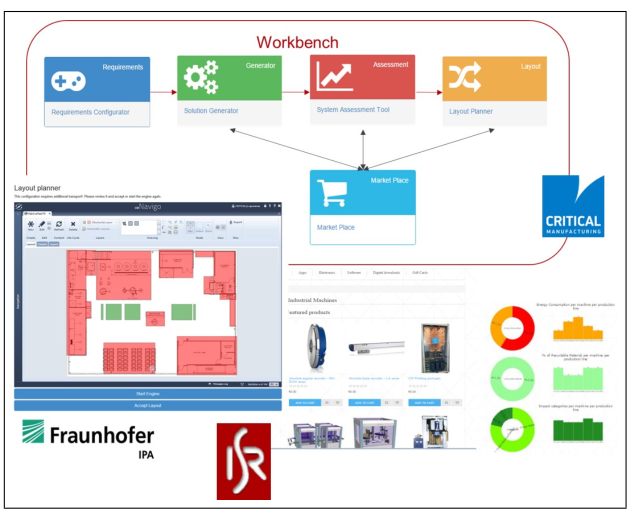

Figure 2. Tools for planning and assessment

One of the resulting technologies of the ReBorn project is the Marketplace represented in Figure 3. This tool is a platform that allows equipment owners and buyers to have a common ground to communicate. The ReBorn Marketplace [5] offers its services in an online platform format, as a Platform as a System (PaaS). PaaS enables the creation of an evolving market between actors, which would be difficult to reach without this platform. PaaS comprises different participant groups, making a multi-sided market possible.

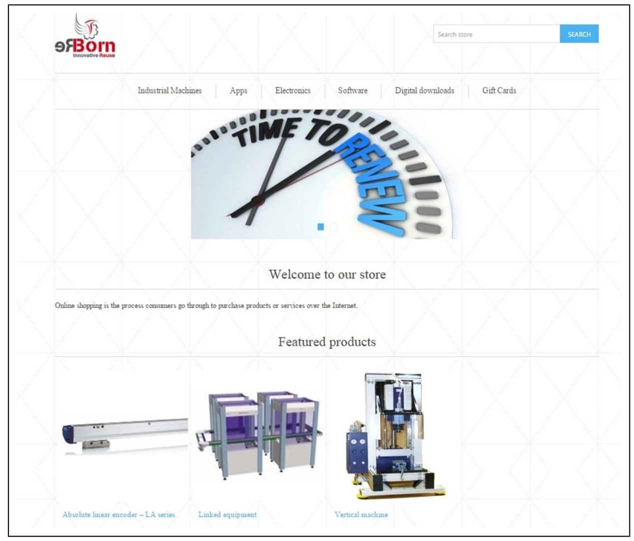

Figure 3. Marketplace

The ReBorn Marketplace is a n-sided market, with service providers on one end and service consumers on the other. This will attract service suppliers in order to respond to the demand side of the platform. The demand side, in the Marketplace, is comprised of any potential end-user to the platform offerings. Service consumers comprise the Marketplace participants, which mainly relate to the ReBorn Marketplace service offerings. The Marketplace service suppliers can normally be instantiated by any entity capable of offering its services to the platform while altogether adding value to the platforms base proposition. Service suppliers are Original Equipment Manufacturer (OEM) who provide mainly machines and components, as well as equipment information, functionalities (software), and operations. Entities capable of providing complementing services to the platform, in order to co-create value, are labeled as complementors. Complementors can be, for instance, independent software developers that provide additional equipment functionalities.

Figure 4 provides a high level overview of the ReBorn Marketplace architecture. The Marketplace has all the basic functionalities such as management of clients, vendors, and products; general administration of the Marketplace; and services related to payment methods. Additionally to these basic functionalities, for the ReBorn Marketplace it was necessary to developed modules that provide the ability to communicate and manage the VERSONs, one being the Plugin Manager. The Plugin Manager main functionality is to allow the management of the application content of each equipment smart component, it is an easy and simple way of allowing the upgrade of the smart component software. The Plugin Manager allows the integration of new technologies and functionalities in industrial equipment on the fly. It will be extended in the new architecture.

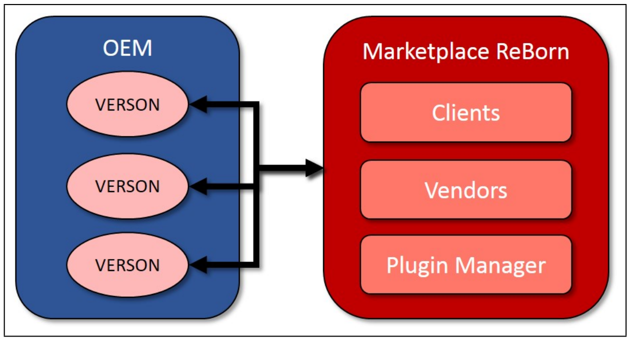

Figure 4. Marketplace Architecture

B. *Selsus Sensor Cloud*

The SelSus vision will be achieved by the development of a new synergetic diagnostic and prognosis environment, which is fully aware of the condition and history of all the machine components within a system or factory and is in constant knowledge enriched dialog with their human personnel. In Figure 5 the overall project architecture is presented.

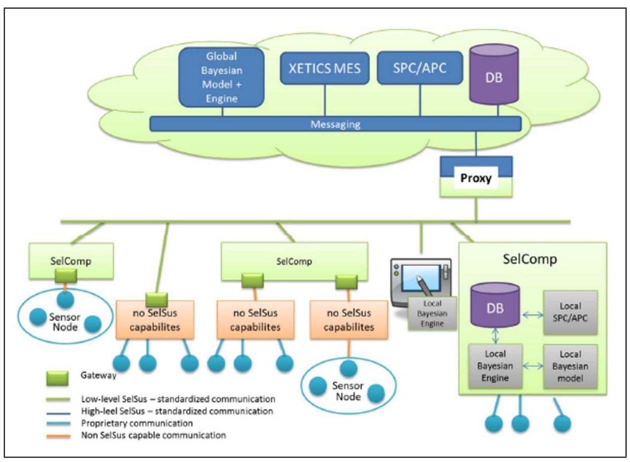

Figure 5. SelSus Architecture

One key area explored in the SelSus project is related with industrial WSNs and Cloud Systems that ranges from sensor integration, sensor data visualization, statistical processing and access, where sensors, external to the process, used for machine monitoring are introduced at the shop-floor level [32].

Sensor information is considered one key element for machine behavior modeling and process optimization, due to the possibility of gathering not only data from machine parametrization (variables that control the process) but also from the observable impact of this parametrization in the final quality of the product. Moreover, this type of information builds knowledge that, despite allowing an immediate perception of the process conditions, it can be used in a myriad of applications. These applications range from predictive maintenance where a failure of a certain machine can be predicted within an interval of confidence, to the optimization of a certain process to minimize the cost without jeopardizing the product quality, and even learning if a process is drifting from what was defined in the design phase.

The concept of the Smart Component in SelSus [32] is applicable to both machine and WSNs, and is a virtual representation of these shop-floor components. This means that different Smart Components, where one represents a machine and the other a WSN, are both uniquely identified in the Cloud that is able to receive inter-device data. This way, it is possible to visualize and analyze independently the information from each component or correlate data information from a group of different Smart Components.

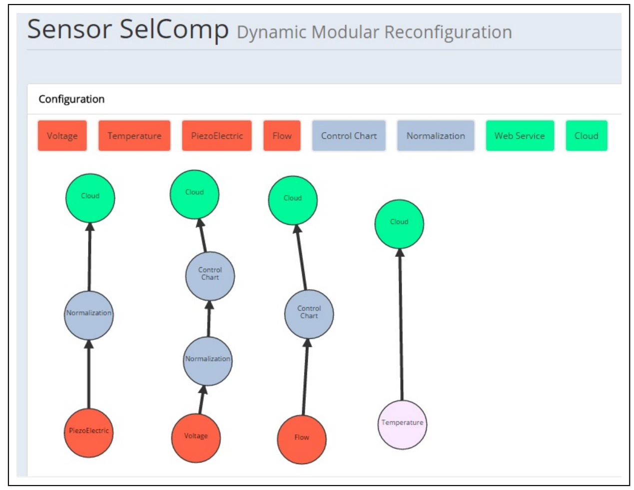

Figure 6. SelSus Dashboard

The SelSus Sensor Cloud, as seen in Figure 6, is a graphical tool that enables the user to dynamically change the configuration, reconfiguration, of a Smart Component. This configuration is drawn by using a directed acyclic graph, composed by three different types of nodes: 1) Interfaces or End Nodes (Web Service and Cloud); 2) Modules (Control Chart and Normalization); 3) Sensors (e.g., Voltage, Temperature, PiezoEletric, and Flow). Currently, there are two available Interfaces or End Nodes: Cloud and Web Service. These are called End Nodes because are the nodes that can only receive information. The Cloud node means that sensor or processed information can be sent to the Cloud, and Web Service means that the same information can be sent to an external entity.

The SelSus Sensor Cloud is used for data acquisition, storage, processing, visualization and access purposes. This type of solution was chosen due to the necessity of easy collection of data from multiple components, quick visualization of manufacturing process dynamics, statistical processing for monitoring purposes, and information exchange to other external applications.

IV. Proposed Architecture

The ReBorn Marketplace already has several services implemented and running. One of these services is the ability of the equipment Smart Component communicate data directly to the Marketplace. This information is stored by the Marketplace and can be used by other external applications.

On the other side, the SelSus Sensor Cloud allows the user to reconfigure the methods used to process the sensor data locally at the SelComp level, even before the raw data from the components is synchronized with the System Level.

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One of these methods allows the user to graphically develop an interpreter of raw sensor data packets at the gateway level for automatic data acquisition. The SelSus Dashboard also provides a Statistical Analysis section to enable some of the potentialities of using different data analytics and machine learning algorithms to analyze machine and sensor data, available at the Sensor Cloud level, which can be used in the reconfiguration process of the Smart Component.

The proposed architecture consists on connecting the ReBorn Marketplace with the SelSus Dashboard, extending the functionalities of both tools. By taking advantage of the already developed applications, the efforts can be applied to the development of the missing bridge between the two projects and the new needed functionalities. Figure 7 presents the overall architecture of how to combine the developments from both projects, ReBorn and SelSus.

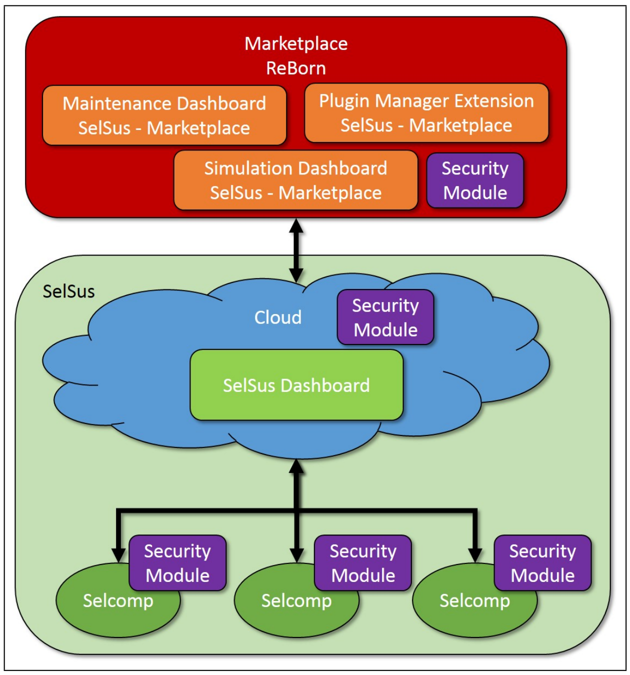

Figure 7. Proposed Architecture

As it can be seen, there are several blocks that compose the architecture shown in Figure 7. These blocks can be divided into three main blocks: (1) SelSus developments (SelComp and SelSus Dashboard); (2) ReBorn developments (ReBorn Marketplace); and (3) new developments necessary to bring the two tools together (Maintenance Dashboard, Simulation Dashboard, Plugin Manager Extension, and Security Module). All these blocks will be described in the following sections.

In order to implement this new architecture, new components and functionalities will have to be developed and integrated with the already existing tools. As shown in Figure 7, the Maintenance Dashboard, Simulation Dashboard, Plugin Manager Extension, and Security Module will be implemented.

Most of the functionalities and components will be added to the Marketplace side. Some of these modules were already developed in SelSus and will be extended to be used in the Marketplace, namely the Maintenance Dashboard and the Simulation Dashboard. These modules enable trading software and services in the Marketplace, extending the ability to sell, buy, or rent equipment.

The Maintenance Dashboard's main goal is to allow for an easier planning of the maintenance scheduling of a company. As mentioned before, the Marketplace can receive information from the equipment's Smart Components, which is stored in the Marketplace. This information is useful in order to compare collected metrics from different equipments, which can be used to aid OEM to provide maintenance services to their customers.

Assuming that an OEM, besides selling equipment for several customers at different countries, is also providing maintenance services, which usually cover annual inspections of the equipment in the costumer facilities, the information stored in the Marketplace reveals to be very important. The OEM is able to better use their resources as well as save money by optimizing the traveling that is needed by the maintenance engineer, taking into consideration the actual status of the equipment. This also permits a more active preventive maintenance, allowing the generation and simulation of several possible maintenance routes, based on the equipment metrics and in the current context and environment where the equipment is located.

The Simulation Dashboard aims at simplifying the process of developing new functions that can be sold in the Marketplace and uploaded to the Smart Components. This Simulation Dashboard module will facilitate the design of new functionalities, metric calculations, and treatment of raw data of the Smart Components. The user will be able to design a new functionality and simulate it, in order to check if the behavior of the Smart Component is the desired one. The new functionality can then be stored in the Marketplace for selling.

The existing Plugin Manager will be extended in order to also manage the download of new functionalities, instead of being limited to Smart Components software updates. The extended Plugin Manager will be able to manage the downloads of all software, both functionalities and software versions of the Smart Component.

One of the issues, nowadays, referenced by the industry that hinders the wide use of the full functionalities of todays technologies is the lack of security as well as the lack of privacy. For that purpose, a Security Module will be implemented, in order to reinforce the system security, by adding privacy to every communications performed between the different tools.

As shown in Figure 7, the idea is to be able to have a Security Module in all the layers of the architecture. This Security Module will be configurable, in order to adapt to the needs of each layer and each OEM. The Security Module will have two main functionalities, namely privacy and authentication. This will be accomplished through the use of an encryption algorithm, which will use a public key encryption algorithm, in order to provide means of data encryption.

The communication between an OEM and the Marketplace is performed over the Internet, which is well known to be insecure if users are not authenticated and data exchange is encrypted. Other simpler encryption algorithms, such as symmetric keys, might also be considered to be implemented. The Security Module will have the ability to be updated with new methods, much like the Smart Component through the Dashboard.

V. CONCLUSION

Nowadays, sensors are widely available, mostly because they are becoming increasingly more powerful, diverse, and cheaper. With the Industry 4.0 the concept of Smart Factories emerged. At the core of this concept is the use of sensors to collect data. This collected data is then processed using data analytics algorithms, to be used for many different purposes such as monitoring or predictive maintenance. Over the last few years, a lot of research has been dedicated to this topic. Two such projects are the ReBorn and Selsus projects.

This paper proposes a new architecture that combines both ReBorn and SelSus results, namelly the ReBorn Marketplace and the SeSuls Dashboard. The idea is to use the results and developments already accomplished and take them a step forward. With the implementation of the described architecture, a flow of information will exist from the equipment at the shop-floor, up to the Marketplace and back. This will allow to take advantages of all the current technological advances, and allow a safe and reliable way of using all the available information.

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