D2.2
Validated sCorPiuS Vision

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Executive Summary

Manufacturing is a key asset for Europe; considering its effect on services, it is a backbone for research, innovation, productivity, job creation and exports. De-Industrialization hit Europe, but both the world economic situation and EU initiatives are unveiling the pattern to reverse this trend.
Cyber-Physical Systems (CPS) will play a key role in this opportunity of re-industrialization of EU, especially considering that EU has 30% of the world production of embedded systems[1], especially in high added value sectors such as automotive, aerospace and healthcare. These technologies are leading to the creation of smart and virtual factories, as well as enhancing both the vertical and horizontal integration of supply and value chains.
The definition of a common shared vision of what "CPS in Manufacturing" is among the objectives of this document. sCorPiuS project proposes, based on that, a definition aiming to state their key characteristic and features.

Cyber Physical Systems *are* ***autonomous collaborating entities*** *able to sense, and act as physical objects (embedded systems), as well as communicate on global networks, compute and store data and information in the cyber world through their computerized companion (digital twin).*
Their key characteristics are:

- *the* ***overall lifecycle approach****, exploiting CPS both within and outside the shopfloor, with a pervasive data storing, organizing and sharing with different entities in different phases;*
- *the* ***ecosystem approach*** *which will derive from the full interoperability of systems based on shared vision and standards and their ability to defy rigid standardized hierarchies but create dynamic structures from their articulated functions;*
- *the* ***new added value services*** *for customers and operators, creating new value for companies, operators and customers, from the utilization, production and design processes via aggregation of multiple specific application components.*

The definition of a shared and inclusive vision that considers the multi-faceted nature of the manufacturing companies (i.e. product and factory lifecycles, automation and IT systems, supply and value chain integrations, etc.) is crucial for the future of CPS since it will keep the pace to address major interoperability issues and therefore one of the most important achievements of CPS, the ecosystem perspective.
Moreover it will enable a wider acceptance of CPS related hardware, infrastructures and software, enabling lower implementation efforts and costs.

[1] http://www.smart-systems-integration.org/public/documents/presentations/presentations-posters-at-the-eposs-general-assembly-annual-forum-engagement-day-2014-in-turin-24-26-september-2014/eposs-annual-forum-2014-25-september-2014/0_4_Khalil_Rouhana_EC_EU_Strategy_for_Electronic_Compents_and_Smart_system_Integration.pdf

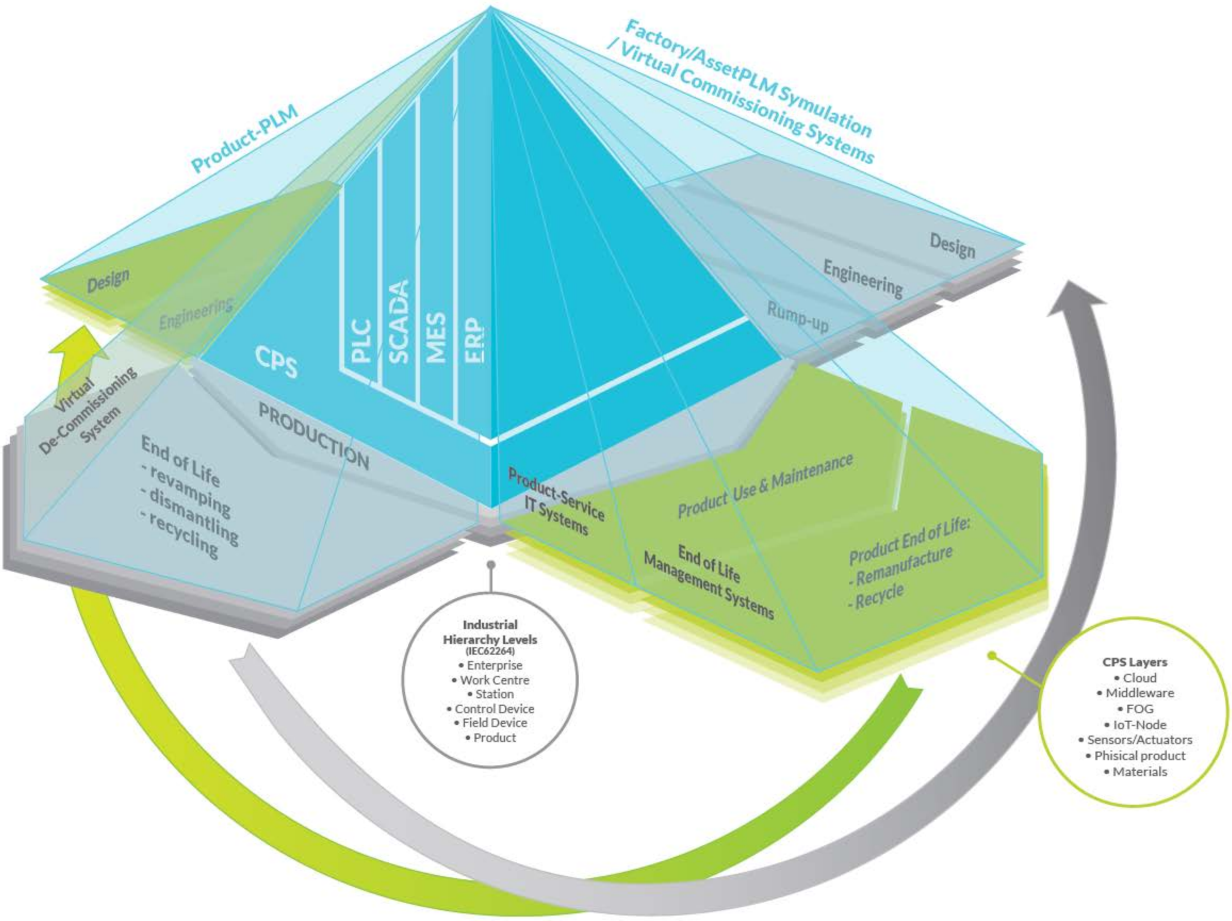

Figure 1: sCorPiuS – Product/Factory Lifecycle Automation Pyramid Vision

SCorPiuS vision is based on the product/factory lifecycle concept, the technical layers of the CPS infrastructures and the logical layers of the Industrial hierarchy of RAMI (IEC62264).
On this foundation a Product/Factory Lifecycle Automation Pyramid is represented taking into account different automation and IT systems currently present in manufacturing companies and providing a linkage between legacy systems and the CPS infrastructures.

This document incorporate observations to “D2.1 Gap Analysis on Research and Innovation and Vision” issued on Feb 2016 and the associated “Vision and Gap Analysis White Paper” issued on Mar 2016 emerged in two major validation events hold in Bruxelles on Apr 14th and in Barcelona on May 5th (as described in Deliverable D4.3 - Expert on CPS first public consultation workshop events). Other significant contributions were gathered in 1-to-1 conversations with sCorPiuS gurus and experts interviewed also for Research Roadmap validation.

1 Relevance of Manufacturing in Europe

Industry plays a central role in the economy of the European Union, accounting for 15% of GDP (compared to 12% in the US)[2]. It serves as a key driver of research, innovation, productivity, job creation and export. Industry generates 80% of the EU's innovations and 75% of its exports. Including its effect on services, industry could be considered the social and economic engine of Europe. In his speech to the Hannover Messe on Apr 14th, 2016 EU Commissioner Günther H. Oettinger clearly stated that "Industry is a central pillar of the European economy – the EU manufacturing sector accounts for 2 million companies and 33 million jobs. Our challenge is to ensure that all industrial sectors make the best use of new technologies and manage their transition towards higher value digitised products and processes, commonly known as **"Industry 4.0"**. At the moment, industrial manufacturing in the EU represents 15% of GDP. It is the main source of exports, a major source of investment in research and development, and it is also an important driving force for employment in other sectors. The European Union has set itself the target of increasing the contribution of industry to GDP and to reach 20% by 2020, given industry's great potential for growth and job creation."[3]
On the other side the competition at global scale and financial crisis seriously challenged even the existing levels of industrialization and employment, for that reason only a real paradigm shift in defining strategies, policies and approach is required. For this reason, Mr. Oettinger also stated that "to reach our objective, we need to act quickly and become the avant-garde of digital manufacturing." The identified pillars to address that have been clearly identified in[3]:

1. innovation in "digital-inside" products: opportunities arising from embedding digital technologies in any product and artefact are almost infinite.
2. a transformation in processes – "smart manufacturing": digital innovation affects the full product lifecycle "from cradle to grave". It ranges from product design and simulation tools to automation and shop floor controls and from logistics and supply chain management down to product tracking and recycling.
3. the use of digital technologies leads to radical and disruptive changes in business models including well-established industries such as automotive, lighting or textiles. These are changes that affect the way we do business and generate value in the future.

The adoption of the new technologies needs to overcome the large disparities in digitisation that exist today between industrial sectors, regions, large companies and SMEs.[3]
The role of SMEs and mid-caps is the backbone of EU economy. EU cannot leave them behind in this evolution process and specific actions need to be taken to ensure their complete involvement

[2] This publication refers to EU 28 and uses the European Commission's definition of "industry" as "manufacturing", excluding mining, construction and energy - Eurostat.
[3] EU Commissioner Günther H. Oettinger speech given at Hannover Messe on Apr 14th, 2016 https://ec.europa.eu/commission/2014-2019/oettinger/announcements/speech-hannover-messe-europes-future-digital_en

2 CPS in Manufacturing

2.1 The need for CPS

In the last decades, the manufacturing ecosystem witnessed an unprecedented evolution of disruptive technologies forging new opportunities for European companies to cope the ever-growing market pressure. Moreover, the race to create value for the customers has been hindered by several issues that both small and large companies have been facing, such as: shorter product life cycles, rapid time-to-market, product complexity, cost pressure, increased international competition, etc. To tackle these challenges manufacturing firms and research institutes developed in parallel new information and communication technologies (ICT) and manufacturing automation systems. The convergence between the virtual and the physical world in the form of **cyber-physical systems** (CPS) brought forth the opportunity for the fourth industrial revolution. The term cyber-physical system was coined in the US in 2006 (Lee, 2006) from the acknowledged importance of the tight integration between computing systems and information domain from one side and the physical world in manufacturing on the other.

2.2 What is a CPS?

Several experts provided definitions for CPS. Thus, in the literature it is possible to find several similar interpretations of CPS rather than a standard definition. Most of them state the scope of CPS and describe how the interaction between the virtual and the physical world is made (e.g. enabling technologies). In the table below are reported four definitions achieved from the efforts made in existing studies related to the state of the art of CPS.

Yu et al, 2015	“Cyber-Physical systems are an integration of embedded systems and the physical environment with global networks. In other words, the physical resources in CPS are globally networked and accessible from the outside. Based on this underlying architecture and together with the capabilities of sensing, computing and communicating, products can actively change the state of the physical environment.”
Monostori, 2014	“Cyber-Physical Systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet.”
Wang et al, 2015	“Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. In other words, CPS use computations and communication deeply embedded in and interacting with physical processes so as to add new capabilities to physical systems. A CPS may range from minuscule (a pace maker) to large scale (a national power grid).”
Hu et al 2015	“The ultimate purpose of using cyber infrastructure (including sensing, computing and communication hardware/software) is to intelligently monitor (from physical to cyber) and control (from cyber to physical) our physical world. A system with a tight coupling of cyber and physical objects is called cyber–physical system (CPS).”

Table 1: definitions of CPS in the literature

Based on the work carried out so far in the last 15 months, sCorPiuS project propose the following definition for **CPS**:

Cyber Physical Systems *are* ***autonomous collaborating entities*** *able to sense, and act as physical objects (embedded systems), as well as communicate on global networks, compute and store data and information in the cyber world through their computerized companion (digital twin).*
Their key characteristics are:

- *the* ***overall lifecycle approach****, exploiting CPS both within and outside the shopfloor, with a pervasive data storing, organizing and sharing with different entities in different phases;*
- *the* ***ecosystem approach*** *which will derive from the full interoperability of systems based on shared vision and standards and their ability to defy rigid standardized hierarchies but create dynamic structures from their articulated functions;*
- *the* ***new added value services*** *for customers and operators, creating new value for companies, operators and customers, from the utilization, production and design processes via aggregation of multiple specific application components.*

2.3 CPS as a digital twin

In order to interact with the surrounding environment (i.e. vertical and horizontal integration) CPS are equipped with embedded computing power capable to retrieve and elaborate real-time information from sensors, information systems, manufacturing resources, products, customers, etc. Consequently, exploiting this big amount of data in combination with new techniques such as cloud and high performance computing, innovative companies are now able to virtualize by means of 3D modelling software the physical objects of the factory. In manufacturing, this practice leads to several benefits, for example it allows to perform complex tasks such as assembly and maintenance in a simplified way by adding needed information into the field of view. For instance, Boeing, BMW and Volkswagen are incorporating these new technologies to improve their assembly processes[4].

2.4 CPS for European Manufacturing

CPS applied to Manufacturing have the potential to impact massively the European industry, economy and society. Europe accounts for 30% of world production of embedded systems specifically in the automotive, aerospace and healthcare sectors. For this reason, Europe is focusing on developing and capitalizing this sector through several initiatives and financial supports (e.g. FP7, Horizon 2020, ARTEMIS, I4MS). However, pervasive adoption for these technologies require definition and acceptance of new business models in order to make CPS be endorsed both in small and large companies. In doing so, several challenges need to be addressed, most of them are not specifically technical one, as example we can mention: privacy, security, dependability, genitive abilities, human

[4] http://www.popsci.com/scitech/article/2009-09/bmw-developing-augmented-reality-help-mechanics

interaction, ubiquity, standardization, robust connectivity and governance. The sCorPiuS Research Roadmap identifies these factors naming them as "Context Factors" (see D2.2). Accordingly, the fundamental requirements for introducing CPS in industry have been identified in sCorPiuS Roadmap:

- Adaptable to heterogeneous environments: integration with cutting-edge information systems, smart-devices and the existing environment (from old PLCs to smart object embedded in computing power).
- Capable of working in distributed networks: they should gather, transfer and store in a reliable manner all the information provided by smart sensors and actuators through the use of the IoT.
- Based on a modular open architecture: the interoperability has to be ensured across different platforms provided by several vendors along the value chain.
- Incorporate human interfaces (HW & SW based): integration of user-friendly and reliable service to make decision makers aware about the real time situation of the factory.
- Scalable: different scale solutions to provide fast processes reconfiguration.
- Fault tolerant: given by the encapsulation of models to activate prediction control loop and correctness of automation systems.

3 Relation with Previous Roadmaps and Initiatives on CPS

To define the sCorPiuS vision, with the aim of proposing a common and shared viewpoint on CPS, the work started taking inspiration from previous efforts; acknowledging how these have changed our way of seeing the manufacturing sector in general and how ICT is applied more specifically.

Table 2 Relation with previous roadmaps and Initiatives on CPS

Roadmap, initiative, project	Reference
ActionPlanT	http://www.actionplant-project.eu/
Pathfinder	http://www.pathfinderproject.eu/
LinkedDesign	http://www.linkeddesign.eu/
Factory of the Future 2020	http://www.effra.eu/attachments/article/129/Factories%20of%20the%20Future%202020%20Roadmap.pdf
Industrie 4.0	http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf
IMS2020	http://www.ims2020.net/
IIRA - IIC	http://www.iiconsortium.org/

For a detailed description please refer to D1.1 State of the Art on Cyber-Physical Systems

4 sCorPiuS vision

4.1 Relevance of a CPS vision in Manufacturing:

CPS are going to play a key role for EU manufacturing in the near future, however, as a new emerging technology, they lack a common and shared vision between stakeholders. Many initiatives (e.g. CyPherS, TAMS4CPS, Road2CPS, eScop, etc.) are exploring different possibilities and defining approaches for CPS deployment, which in the mid-term can result in failing one of the main possibilities offered by the IoT technology which CPS can exploit: the emergence of a CPS-based eco-system. This is an opportunity for the development of new business models and the provision of customer-centric services, for a deep innovation in production and logistics, for a leap in design innovation and engineering. Finally, a shared vision, together with standards fitting the needs of the different areas, will enable interoperability and wider acceptance of CPS related hardware, infrastructures and software, enabling lower implementation efforts and costs.

4.2 sCorPiuS vision

sCorPiuS vision **integrates the previous referenced architectures and visions** defining how the new automation pyramid will look like in the **overall conceptual view of product-factory lifecycle**. The CPS layers, as well as the industrial hierarchy levels have been taken as foundation of the overall perspective. sCorPiuS therefore takes into account the IEC62264 as RAMI, while the “CPS layers” are derived merging IIRA (IIC) and RAMI (Industry 4.0) concepts.
On top of the CPS layers, from an enterprise point of view, the sCorPiuS vision takes into account the different **legacy systems** whose CPS will have to interact with. The product-factory lifecycle perspective requires to include also automation and IT systems outside the production or even the factory.
sCorPiuS acknowledges that CPS intrinsic existence defies the concept of rigid hierarchical levels, being each CPS capable of complex functions across all layers and thus adopts an updated version of the pyramid representation, where the field level features CPS capable of articulated functions (thus in contact with all the pyramid layers) while still a hierarchical structure is preserved. Single CPS are hierarchically arranged in groups of CPS, to deliver specific functions. CPS elements, as long as they comply with the interaction standard, may be supplied by any automation provider.

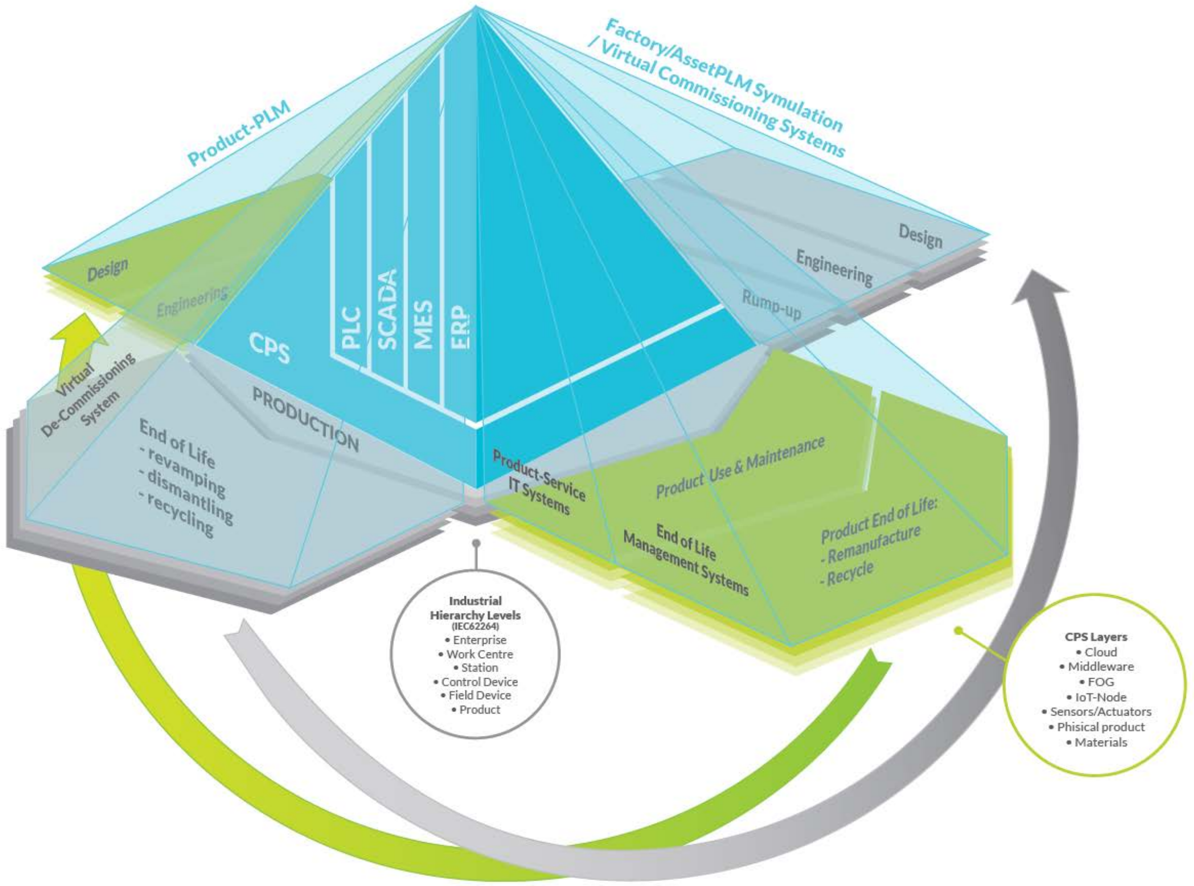

Figure 2: sCorPiuS – Product/Factory Lifecycle Automation Pyramid

The automation pyramid (ISA95) is therefore tilted but also extended to include all the IT systems whom are used outside the usual domain of automation, but have to be considered in an extended lifecycle perspective. The sCorPiuS Collaboration Pyramid therefore includes the CPS-Automation Pyramid derived from ISA95, but also Product Lifecycle Management Tools, covering the design and engineering phases of both product and factory, as well as Product/Service IT Systems, which will enable to develop and improve services, extending manufacturing companies business domains. End of life management systems – for products – and virtual de-commissioning systems – for factories – have been included.

This vision therefore links together the tools on the market (PLM, PLC, SCADA, MES, ERP) and under development (product/service IT systems, End of Life Management Systems, Virtual commissioning/de-commissioning systems) whose data and information are relevant to create a product-service centric closed loop collaboration.

On the product axes perspective both the **virtual product / product Type** (Design and Engineering) and the **"things"/ physical instances** are taken into account. Furthermore, on the factory lifecycle axes both the physical and digital factories are considered. This creates an overall map of the different systems, considering data and information flows that link all stakeholders in the manufacturing enterprise domain.

Within this vision, the manufacturing enterprise IT users can have access, depending on their roles and needs, to the data available within all the different represented systems, achieving therefore an in-depth knowledge that today is not available. Currently, manufacturing data are segmented, detailed and planned for a single scope, stored within the legacy systems – **information islands** – thus preventing the "**digital continuity**" that would let use them in the optimal way, independently from where and how they have been collected. CPS, creating a shared foundation for all the product/factory lifecycle phases will instead be able to provide all the needed information from the physical world while the Cyber-Physical-Collaboration environment will enable an efficient analysis, management, sharing and usage of the data and the knowledge elaborated from them and from the experience of involved people.

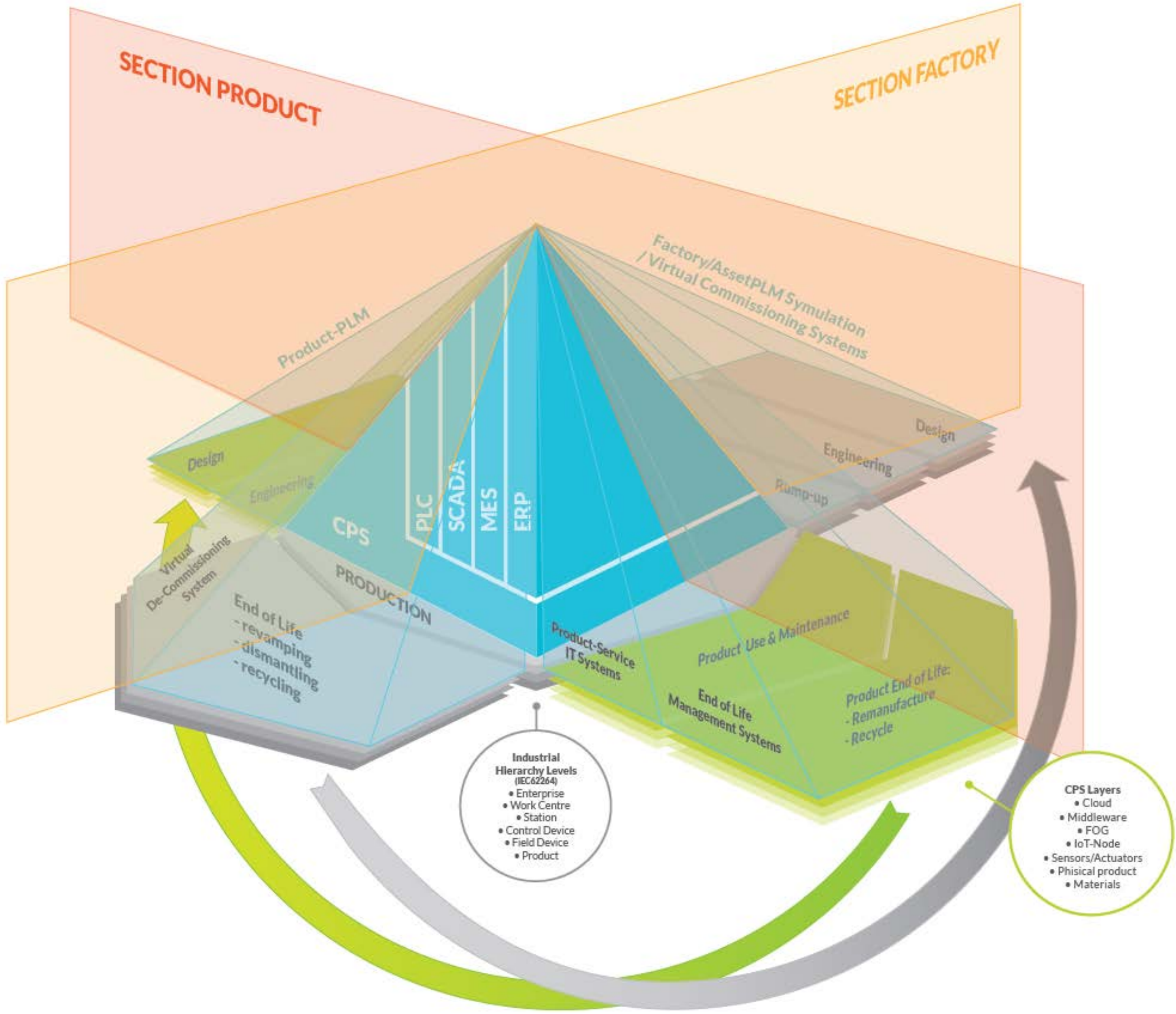

Figure 3: sCorPiuS – Sections

To clarify this vision, it has been analysed in two "sections"; the Factory Section and the Product Section, as shown in the following picture.
The graphical representation of the two sections will allow us to take a deeper look at the different aspects and meanings of the product/factory lifecycles and their related information and automation systems.

4.3 The Product – CPS

All the pyramid is based on the CPS layers, considering them as possible unifying layer among the lifecycle phases. The layers are fully exploited when the products are produced and become an instance, but are represented also in the design and engineering phases due to the potential CPS have for feedback loops.

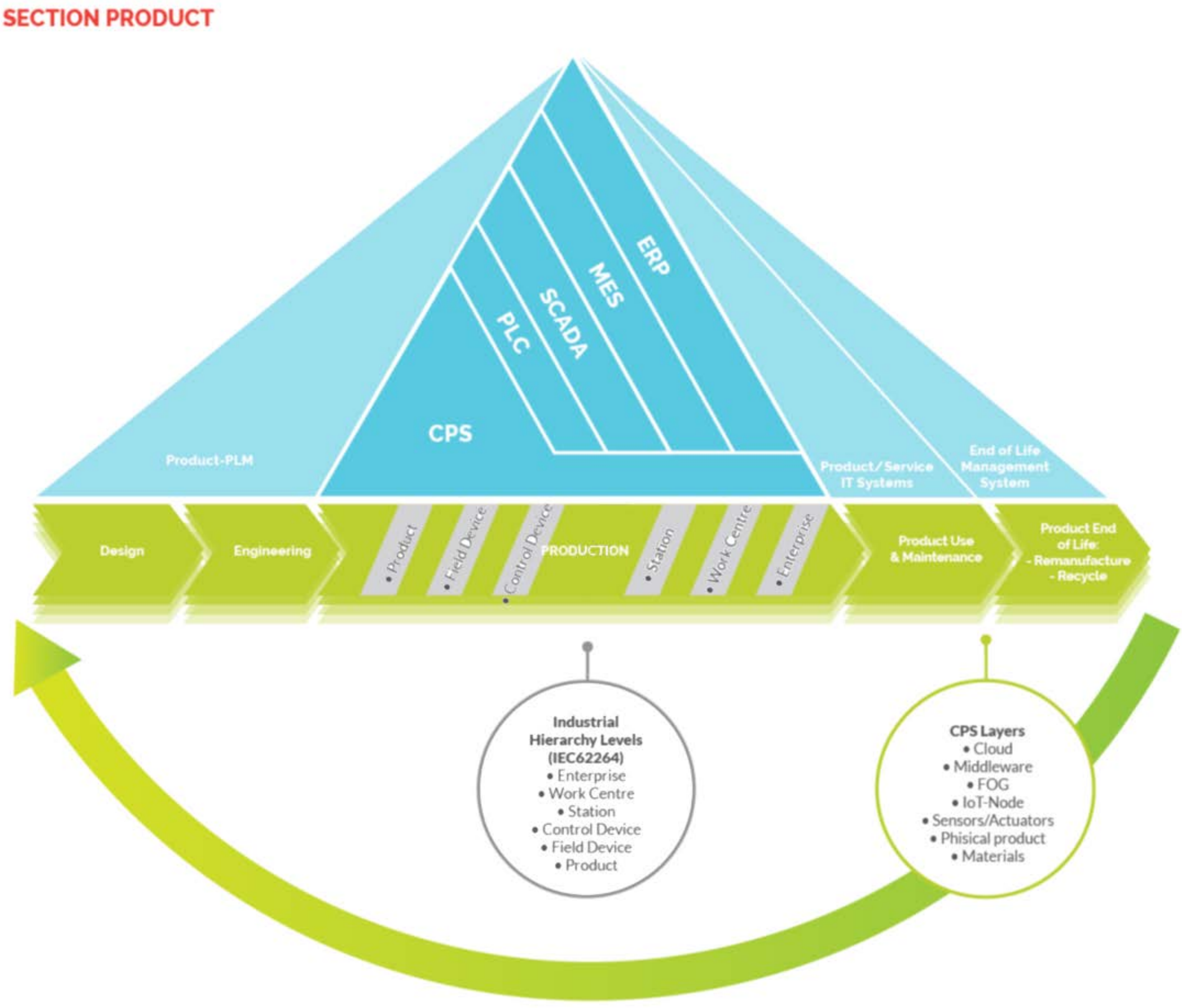

Figure 4: sCorPiuS – Product Section

The product section shows the different systems and subsystems involved during the different phases of the product lifecycle. It starts from the **product Design and Engineering**, where the **digital mock up** is used, within PLM systems to store and manage all **product-type** related information. Among these is also important to acknowledge the data and information coming from the closure of the **lifecycle data loops**, therefore feedback from production, use and maintenance, remanufacture and recycling. Design and Engineering systems therefore feeds the new automation pyramid, modified by CPS adoption.

Within the production phase, as inspired by RAMI, the CPS layers are merged together with the **Industrial Hierarchy Levels**, which are taken into account, even if CPS would be able to defy rigid hierarchies, for the logical aspect hierarchies will still represent for the functional and operative aspects. It's also important their relation with the logical structure of the automation pyramid.

The pyramid on top represent the existing legacy system whose functions will however continue to exist even in more distributed environments such those CPS will enable.

Once the product is **physical** and items/things exist, the **CPS layers** are fully exploited, not only for production and logistics, but also for the **use phase** of the product lifecycle. During this phase, the product is going to be used and maintained. New systems based on CPS and IoT, and able to support manufacturing enterprises to provide new product/service based offering, maximizing profit, sustainability and customer satisfaction[5] are emerging. Information and data acquired during the usage and maintenance of products through PSS will also be used during the final product lifecycle phase.

Also during the **End of Life Phase**, CPS will be able to provide additional services and new possibilities due to the information they provide on both the materials which each item contains (and therefore how to recycle it) but also on how the item was used and therefore if there are possibilities for remanufacturing or reuse. These data can be used to manage in a more efficient way the items through the waste management hierarchy, which indicates an order of preference for action to reduce and manage waste.

[5] Product/Service FOF cluster: http://www.fof-pss-cluster.eu/

4.4 The Factory/Asset – CPS

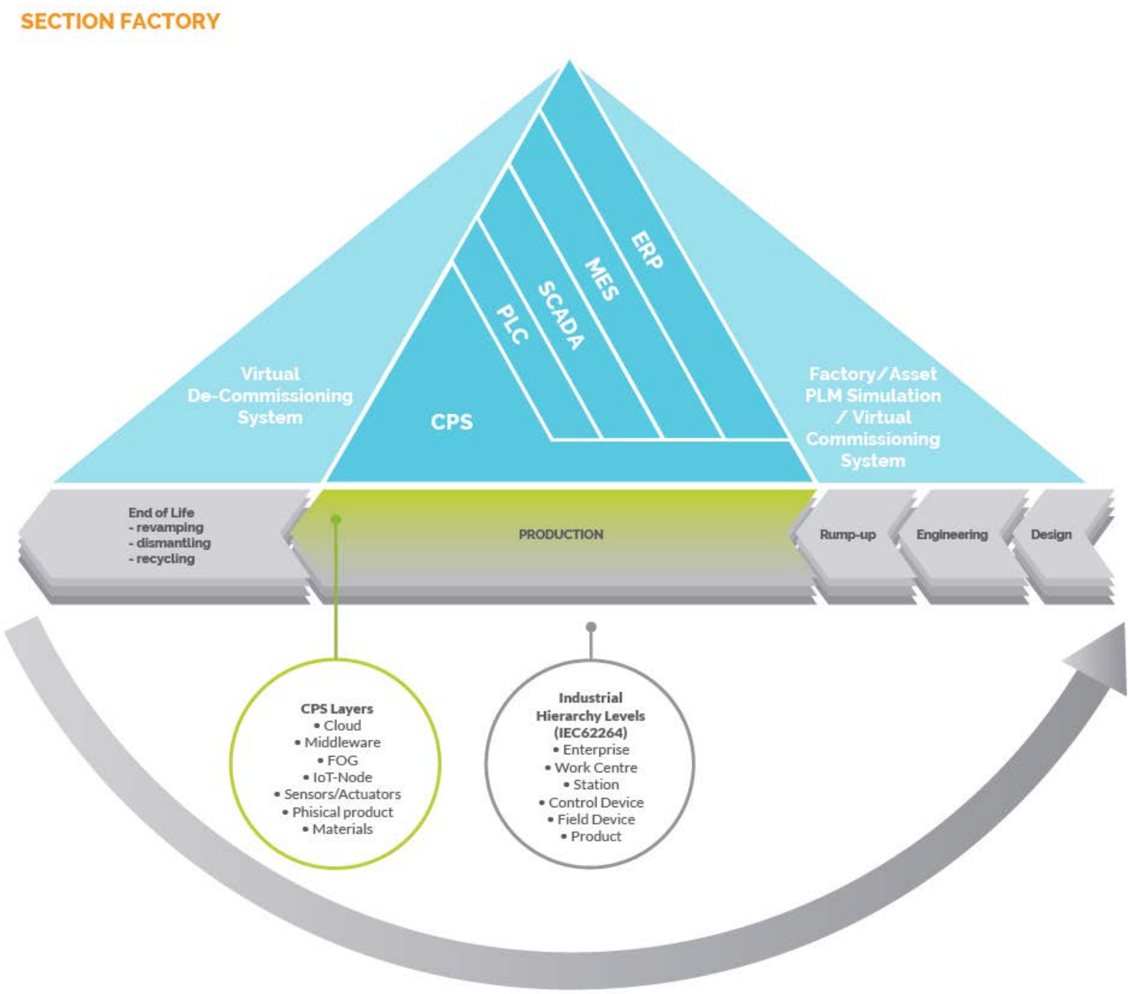

Figure 5: sCorPiuS – Factory Section

Taking now into account the **factory section**, CPS layers, logically and deeply merged with the industrial hierarchy levels are the foundation of also this branch, which, following the factory/assets lifecycle has been structured as IEC62264 suggests.
The lifecycle of a factory/asset starts from the **design and engineering**, while the c**onstruction/rump-up** brings the concept into reality and physical existence. These phases are managed by **PLM, simulation and virtual commissioning systems**, which supports the definition, development, installation and optimization of the factory.
Production is then the point where the two lifecycles intersect and CPS, organized and supported by legacy systems as suggested by the new automation pyramid, manages this complexity. This phase is followed by the "**end of life phase**" which has to be considered **recursively** since often revamping of existing factories and assets occur during the long life of the plant. These revamping will be based, on the data coming from the production, so to improve where is needed and focus the interventions where are needed. More and more factories are from the **brown field**, taking advantage of the already existing buildings, infrastructures and often assets, therefore the relevance of data usage for

revamping and re-commissioning the factory is leading toward specialized methods systems also to support these phases.
Finally, in case of **dismantling of factories and assets**, considering the value of the materials used, more and more focus will be into the de-commissioning and recycling. Specialized systems and approaches will take advantage of the CPS based data to offer sustainability optimization, taking care of both the economic and environmental aspects.

This vision has been first published in "D2.1 Gap Analysis on Research and Innovation and Vision" issued on Feb 2016 and the associated "Vision and Gap Analysis White Paper" issued on Mar 2016. The improvements from that documents are extracted from in two large validation events hold in Bruxelles on Apr 14th and in Barcelona on May 5th (as described in Deliverable D4.3 - Expert on CPS first public consultation workshop events). Other significant contributions were gathered in 1-to-1 conversations with sCorPiuS gurus and experts interviewed also for Research Roadmap validation, as well as in other presentations in different conferences and meetings, where the concept has been shown as presentation or informally to part of the audience (e.g. IoT week in Belgrad, PSS conference in Bergamo).

5 Conclusions and Outlooks

This deliverable presents and motivates the importance of Cyber-Physical Systems for EU manufacturing and tries to give a definition of these technologies when implemented in manufacturing. Then, it presents and describes the project vision on their future application. The overall vision related to CPS usage in manufacturing will take some years to be implemented, but will revolutionize the current concepts of factory automation, defying the traditional hierarchical levels, being each CPS capable of complex and cross-layer functions. This will enable a better usage of data and information as well as the adoption of more autonomous systems able to self-arrange and interact each other and with legacy systems, resulting in new possibilities to create efficiency and the development of new business models. To achieve these advantages however an eco-system perspective will also be needed, therefore a shared and inclusive vision has been developed and presented to foster people and organization to find synergies and areas of potential improvement.
This document is therefore a first outlook of this potential future. All the analysis in this deliverable have been developed with the scope of supporting the European Commission and EFFRA to make the factory of the future enabled by CPS.

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sCorPiuS Project : D3.1 Draft sCorPiuS Roadmap - http://scorpius-project.eu/

sCorPiuS Project : D1.1 State of the Art on Cyber-Physical Systems - http://scorpius-project.eu/