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Enabling Systems for Intelligent Manufacturing in Industry 4.0

Sensing, Smart and Sustainable Systems for the Design of S^3 Products, Processes, Manufacturing Systems, and Enterprises

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In memory of my mom, Rosita, my dad, Arturo and my sister, Paty.
—Arturo Molina

I would like to thank Tecnologico de Monterrey, all my colleagues and students, my mother, my brother, my wife and my children for their constant support and love.

The opportunity to create a new product is called innovation.
—Pedro Ponce

To Aurora Mendoza, for inspiring me through the years with your experience, love and unconditional support.
—Jhonattan Miranda

In gratitude with the Tecnologico de Monterrey.

To my mother and father, Margarita and Juan Carlos. To my brother and sister, Eliud and Miriam. To my moon and stars, Patricia. For all your patience, support and love.
—Daniel Cortés

Preface

Nowadays, companies begin to reconceptualize and redesign their processes, applying new practices and operational strategies as well as using emerging technologies. One of the strategies is to use sensing, smart and sustainable technologies. The concept of sensing, smart and sustainable (S^3) technologies and systems will be presented in this book to guide the integrated development of products, manufacturing process, production systems and enterprises.

This book focuses on introducing sensing, smart and sustainable system theory to support the process of development of products, process, manufacturing systems and enterprises, named S^3 Systems. This new approach is embraced for the implementation of emergent information and communication technologies (ICTs) and artificial intelligence (AI) techniques. The book will introduce the reader about the relationship between intelligent manufacturing (IM), S^3 Systems and Industry 4.0. Also, the book will present a review of current approaches to design and develop technology-based products. Finally, an approach to develop sensing, smart and sustainable systems will be presented and samples of smart, sensing and sustainable product, process, manufacturing systems and enterprise (S^3 Systems) will be shown as case studies.

S^3 Products, Processes, Manufacturing Systems and Enterprises provide added value to users and engineers by incorporating specific characteristics and functions. Therefore, today, companies are using ‘integrated product, process, manufacturing system and enterprise development’ as a strategy for remaining competitive in the marketplace; thus, they can provide a new generation of systems offering solutions to contemporary social problems and responding to changing consumer demands. This new generation of systems are mostly technology based and consider sustainable objectives.

The S^3 concept gathers valuable information to react in agile and precise manners while the Integrated Product, Process and Manufacturing System Development reference model framework provides structure to respond to the challenges of the digital age. In the former, Sensing feature allows to collect data about the internal and external environment. Smart feature is the ability to control actuators, process data, generate information and sharing it to offer interconnectivity among stakeholders. Sustainable feature is measured as the positive impact of a company in three different areas: i) economic, ii) social, and iii) environmental. In the latter, the reference model framework improves, among others, three opportunity areas for the learners: i) structured processes, ii) industrial environmental knowledge and iii) technological adoption, due to the documentation generated throughout the methodology.

On the other hand, new concepts and systems have been implemented in manufacturing products such as social products that allow establishing several communication channels as products–consumers and products–products. These short of social channels are designed for constructing societies of products and consumers. Thus, the social concept in designing products is expanded. Moreover, the concept of smart product is changing according to technological advances. A few years ago, products making decisions by decision trees were considered smart machines. Now, the consumers are expecting to solve complex functions into the smart product, so considering a product smart needs to comprehend the levels of smart products and how they are also changing the manufacturing process. For instance, now robots that have been deployed in the manufacturing process help to reduce the number of defect workpieces and just-in-time production but the production robots could also be social robots to describe human emotions as Baxter, a robot for working into production lines, that has a face represented by a display. This display allows it to show several facial expressions determined by its current status. This kind of communication by human expressions approaches the robots to humans' operators. As a result, artificial intelligence could be considered as a set of algorithms that allows product designers to create a new level of smart products. Besides, sustainability could be considered as a holistic approach for covering product design and intelligent manufacture. Hence, sustainability could be implemented into flexible intelligent manufacturing products and services to different levels of sustainability have to be considered. Finally, sensing is the main characteristic of designing products. In fact, sensing is linked with smart feature in designing products since sensing gives information about the environment that surrounds the product. This information about the environment could be captured by a different kind of sensor such as nano-sensors that spend a minimum amount of energy so the wireless sensor could be designed using nano-sensor, and they can sense using piezoelectric materials for generating its supply energy. Thus, sensing is also a key feature for designing novel products.

Purpose of This Book

The aim of this book is to provide a review of intelligent manufacturing and smart, sensing and sustainable systems which could be considered the next generation of systems. Moreover, an overview of the main development tools is presented in order to describe how a S^3 is designed and achieved through taxonomies. In addition, each chapter is self-contained with all the main design tools and technical information that are required for giving the reader a complete description for each topic.

Audience

Researchers, engineering students (undergraduate and graduate) or practising engineers that are looking for practical guidance and hands-on tools for designing S^3 Systems and understanding the concepts of intelligent manufacturing. Moreover, this book could be used as a textbook into innovative product design courses as well as engineering products design. In fact, this book could be used for persons interested in designing products as a reference book because the book depicts every stage required for designing the new generation of products.

Outline

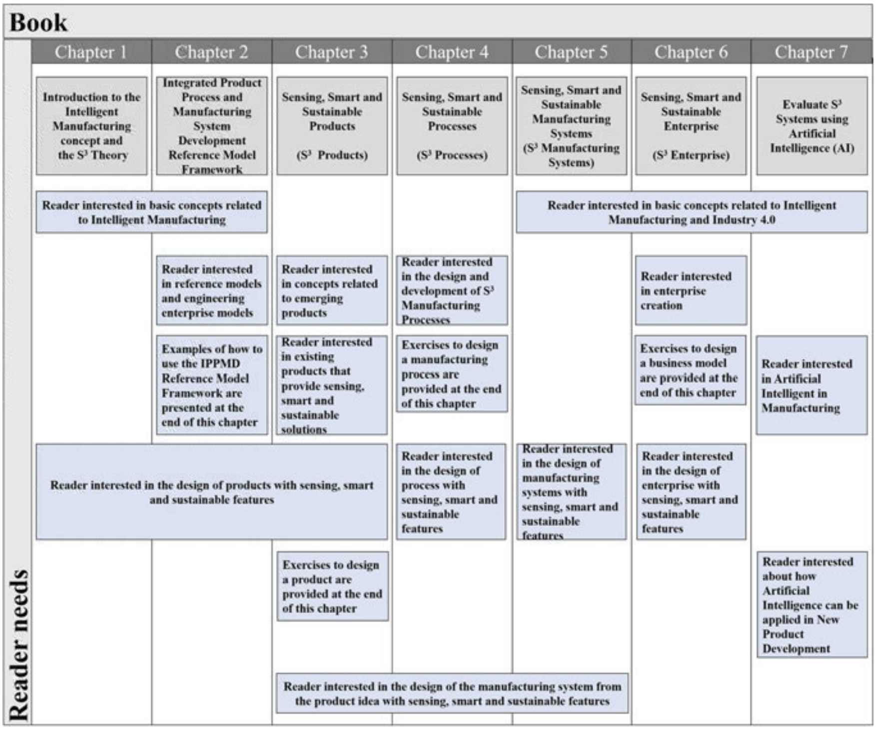
This book is organized in seven chapters below:

- Chapter 1 introduces the theory of sensing, smart and sustainable systems.
- Chapter 2 presents the integrated product, process, manufacturing system development (IPPMD) reference model framework. This reference model is used an as general model for the development of products, process, manufacturing systems and enterprises by implementing the theory of sensing, smart and sustainable systems.
- Chapter 3 gives a complete definition of sensing, smart and sustainable products, so the reader will understand how an S^3 Products is defined and the levels of each design feature. In this chapter, the reader will see a set of examples about how to implement the theory of S^3 in a product design. Finally, readers will analyse different examples of S^3 Products.
- Chapter 4 describes as a generic manufacturing process and its fundamental components. Then, an explanation of how to sense those variables and how to control those variables using smart controls is presented. A taxonomy of S^3 Manufacturing Process is presented to guide engineers in the process of adding functionalities of sensing, smartness and sustainability to manufacturing processes.
- Chapter 5 describes how S^3 Manufacturing Systems can be designed, modelled and created using the IPPMD reference model framework. We will review the theory of integrated manufacturing system to understand the fundamentals that support our systematic approach. Then, we revise the functionalities of sensing, smart and sustainability that could be applied to a manufacturing system. Finally, we describe a methodology to design S^3 Manufacturing Systems.
- Throughout Chap. 6, the best practices are identified and an easy to follow methodology is presented to guide individuals responsible for planning, designing and creating an enterprise. It provides a set of recommendations for the creation of a competitive enterprise concept including the definition of the business model, definition of strategies, use of performance measures, identification and evaluation

of core process and competencies and description of information and communication technologies that support the execution core processes to achieve the characteristics of sensing and smartness.

- Chapter 7 describes a novel methodology for creating new products. This novel methodology uses deep learning and adaptive neuro-fuzzy inference system (ANFIS) systems so the design process is partially autonomous. The methodology is explained gradually.
- Appendix A presents a review of relevant concepts related to Industry 4.0. Also, in this appendix, technologies and techniques used in this period are presented.
- Appendix B shows application of machine learning alternatives in manufacturing as well as a small description about the machine learning methodologies applied to manufacturing systems.

Chapters from 1 to 6 end with basic exercises for illustrating the presented concepts and designing tools.



Mexico City, Mexico

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Contents

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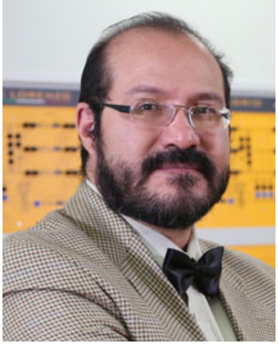

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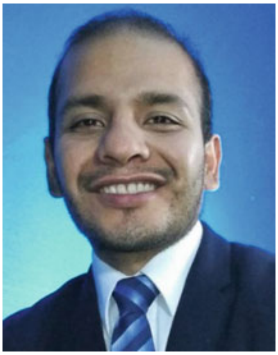

Jhonattan Miranda is a Researcher in the Product Innovation Research Group and Coordinator of the Open Innovation Laboratory at Tecnologico de Monterrey University in Mexico. He received the B.Eng. degree in Mechatronics from the Tecnológico Nacional de México, Cd. Hidalgo Campus and the M.Sc. and Ph.D. degrees in Engineering Sciences with a concentration in Manufacturing Systems and Product Design from the Tecnologico de Monterrey, respectively. He has co-authored different research articles in the areas of product design and innovation and concurrent engineering applied to the education and manufacturing sectors and has an invention in the area of machine tools. He is member of the Mexican National Researchers System.

Daniel Cortés Mexico City, 1993. He received the B.Eng. degree in Industrial Chemical Engineer and the M.Sc. in Business Administration. He has worked in the manufacturing sector for 3 years. He has worked in the development of innovative products at Tecnologico de Monterrey, co-authoring research articles. His research interests include discrete event simulation, product design, process design, manufacturing system design and enterprise business models.

Abbreviations and Acronyms

1G	First generation
2G	Second generation
3BL	Triple bottom line
3G	Third generation
3R	Reusable, recyclable, renewable
AF	Additional facility
AGV	Automated guided vehicle
AHP	Analytic hierarchy process
AI	Artificial intelligence
ANFIS	Adaptive neuro-fuzzy inference system
ANN	Artificial neural networks
AR	Augmented reality
ARIS	Architecture of integrated information systems
ASIC	Application-specific integrated circuit
ATO	Assemble to order
BOM	Bill of materials
BP	Back propagation
BPM	Business process management
BPMN	Business process management notation
BRIC	Brazil, Russia, India, and China
BTO	Build to order
CAD	Computer-aided system
CAE	Computer-aided engineering
CAM	Computer-aided manufacturing
CBL	Case-based learning
CC	Cloud computing
CE	Concurrent engineering
CIM	Computer-integrated manufacturing
CIMOSA	Computer-integrated manufacturing open system architecture
CITRIS	Center for Information Technology Research in the Interest of Society
CM	Cloud manufacturing
CNC	Computer numerical control

CNN	Convolutional neural network
CNO	Collaborative networked organizations
CO_2	Carbon dioxide
CoS	Configuration of services
CP	Commodity products
CPPS	Cyber-physical production systems
CPS	Cyber-physical systems
CPU	Central processing unit
CRM	Customer relationship management
CSCW	Computer-supported cooperative working
CTO	Configure to order
DAQ	Data acquisition
DAS	Data acquisition system
DDB	Distributed data base
DfA	Design for assembly
DfE	Design for environment
DfM	Design for manufacture
DfS	Design for sustainability
DfX	Design for excellence
DoS	Design of services
DP	Declining products
DPCPD	Deep proven conceptual product design
E/E	Electrical/electronical
ECM	Enterprise content management
EF	Enlarge facility
EIE	Enterprise integration engineering
EM	Enterprise model
EPS	Electronic Procurement Systems
ERM	Enterprise reference model
ERP	Enterprise resource planning
ETO	Engineered to order
FEA	Finite element analysis
FIFO	First in first out
FMEA	Failure mode and effects analysis
FMP	Few major products
FMS	Flee management system
FN	False negative
FP	False positive
FPGA	Field-programmable gate array
GDP	Gross domestic product
GE	General electric
GERAM	Generalised enterprise reference architecture and methodology
GIM	GRAI integrated methodology
GP	Growing products
GPU	Graphics processing unit

GRAI	Graphs with results and activities interrelated
GSM	Global system for mobile communications
HA	Highly automated
HMI	Human–machine interface
HP	High variety
HV	High volume
ICAD	Integrated computer-aided design
ICT	Information and communications technology
ID	Identification
IDEF0	Integration definition for function modeling
IIoT	Industrial Internet of Things
IM	Intelligent manufacturing
IMS	Integrated manufacturing system
IN	Innovation networks
INEGI	Instituto Nacional de Estadística y Geografía
IoT	Internet of Things
IP	Intellectual property
IPD	Integrated product development
IPPD	Integrated product and process development
IPPMD	Integrated product, process and manufacturing system development
IS	Increase shifts
ISO	International Organization for Standardization
JTBD	Jobs To Be Done
KPI	Key performance indicator
LA	Low automated
LAN	Local area network
LCA	Life cycle assessment
LIFO	Last in first out
LPD	Lean product development
LTE	Long-term evolution
LV	Low volume
M2M	Machine to machine
MAC	Manufacturing alliance of communities
MEMs	Microelectromechanical systems
MES	Manufacturing execution system
MHS	Material handling systems
MLP	Multilayer perceptron
mm	Millimeters
MNS	Matrix of needs and satisfiers
MOOC	Massive open online course
MP	Multiple products
MPD	Manufacturing process development
MTO	Make to order
MTS	Make to stock
NFC	Near-field communication

NP	New products
NPD	New product development
NTP	Non-traditional processes
ODP	Open distributed processing
OE	Outcome expectation
OKP	One of a kind product
OS	Operating system
PA	Partial automated
PAL	Permissive action link
PBL	Problem-based learning
PCB	Printed circuit board
PDM	Product development management
PEM	Partial enterprise model
PERA	Purdue enterprise reference architecture
PID	Proportional–integral–derivative
PLC	Programmable logic controller
PLM	Product lifecycle management
POL	Project-oriented learning
PPMD	Product, process and manufacturing system development
QFD	Quality function deployment
RFID	Radio frequency identification
RFLP	Requirements, functional, logical, physical
RM	Reference model
RmMT	Reconfigurable micro-machine tool
RP	Rapid prototyping
S^3	Sensing, smart and sustainable
SaaS	Software as a service
SBOM	System bill of material
SBU	Strategic business units
SCADA	Supervisory control and data acquisition
SCI	Supply chain integration
SM	Smart manufacturing
SME	Small- and medium-sized enterprise
SoC	Service on catalogue
SPC	Statistical Process Control
SPPS	Smart product–service system
SRM	Supplier relationship management
TCM	Tool condition monitoring
TN	True negative
TP	True positive
TRIZ	Theory of inventive problem solving (Russian acronym Tieoriya Riesheniya Izobrietatielskij Zadach)
TTSR	Time on task and success rate
UC	University of California
UML	Unified Modeling Language

UN	United Nations
USA	United States of America
USB	Universal Serial Bus
USB-C	Universal Service Bus Type C
USD	United States Dollar
UWB	Ultra-wide bandwidth
VHDL	Very high-speed integrated circuit hardware description language
VLSI	Very large-scale integration
VP	Virtual prototype
VR	Virtual reality
WAN	Wireless area network
WON	Wireless office network
WP	Working prototype
WSN	Wireless sensor network

Chapter 1
Sensing, Smart and Sustainable Systems Theory

The world is flat, hot and crowded but also it is connected [1]. The generalized use of technologies such as Internet, mobile technologies, cloud computing, big data analytics, cyber-physical systems, digital systems and sensors leads to a connected world. In this chapter, you will be able to understand the new challenges faced by a connected world supposed to be supported by intelligent system to enhance living standards of people around the planet. The concept of sensing, smart and sustainable (S^3) Systems will be introduced to tackle the challenges faced by communities around the world. These new types of systems driven by technologies enable the creation of intelligent systems, also named smart and connected systems and products [2]. Porter and Heppelmann state that smart, connected technologies will create a new path of innovation and will transform all industries because companies will have to re-invent their products, services and value-added offers. The chapter proposes the adoption of the S^3 concepts in communities and cities, in any human-designed system, e.g. products, processes, manufacturing systems and enterprises. We call this vision as the S^3 of everything [3, 4]. The creation of S^3 Systems will promote and rely on collaboration, information access, open innovation and sustainable development.

1.1 What Are the Challenges of a World—Connected and Intelligent?

People and its communities around the world are in need of basic products and services in order to improve their standards of living (well-being and health). We recognized that countries and governments are facing challenges to cope with provision of systems that gives citizens conditions to improve its way of life. A government receives from citizens tax payments to provide health, educational and security systems. Also, it is their responsibility to protect nation´s natural resources and bio-ecosystems that are at risk because of climate changes. Companies receive from their

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customer payment for products and services that allows them to have a comfortable life. However, governments and enterprises are failing to satisfy worldwide demands from people to have, as individual, access to better health, education, nutrition and work. Also, people's communities are lacking of clean energy, potable water, high quality waste management systems, sustainable housing and transportation and production systems to have suitable work to improve their income. In the world today of 7+ billion people, there are 4 billion that live with less than 8 USD a day with very poor conditions regarding drinking water, transportation, eating, cooking and living [5]. There is a need that new technologies (nano-bio-info-cogno) improve the conditions of all people around the world [6]. The new revolution of Information Technologies and Cogno Sciences is creating new concepts that are expected to reduce cost, time to market, improve quality and increase availability of products and services: Healthcare 4.0 [7], Agri-Food 4.0 [8], Education 4.0 [9], Operator 4.0 [10], Energy 4.0 [11], Industry 4.0 [12] and Smart Cities [3] (Fig. 1.1).

The proposal is to design and create 4.0 concepts by using the theory of S^3 Systems. The theory of S^3 Systems can promote an increase innovation and productivity because they boost the creation of knowledge and its rapid application to product and services. Having access to the right information at the right time gives enterprises the ability to better compete and sustain their operations [13]. Also, government can satisfy citizen´s demands by improving public services.

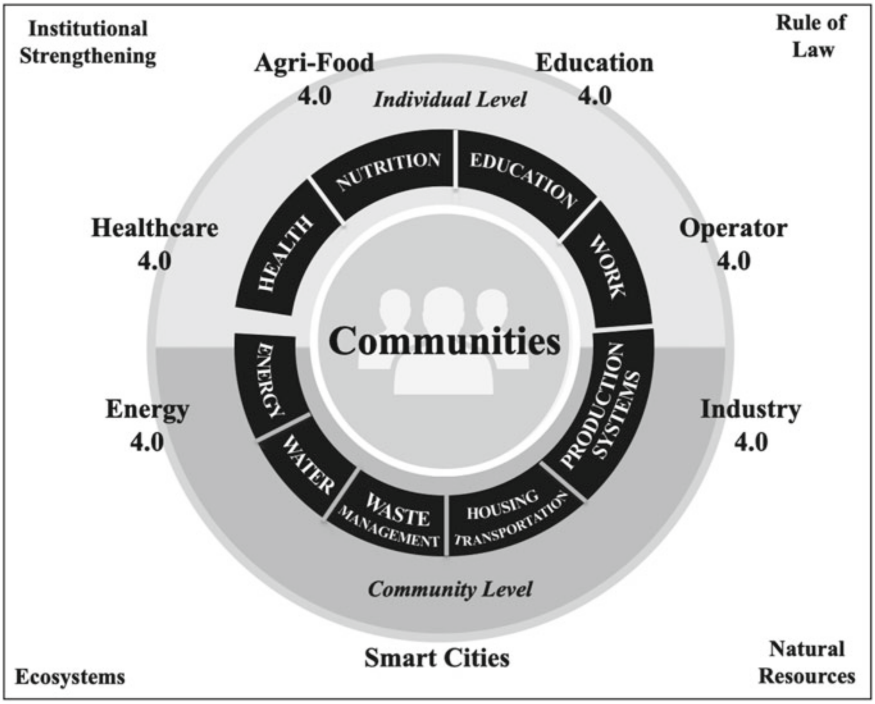

Fig. 1.1 Challenges and solutions of individual and communities

1.2 The S^3 System: Sensing, Smart and Sustainable

Figure 1.2 captures the S^3 characteristics of a generic systems based on such definitions. The conceptual model proposed details the S^3 System definition, and each of the characteristics are explained next.

Sensing: Context-awareness is a key functionality of any intelligent system which refers to the acquisition of relevant data and information for decision-making. Sensing is based on the use of sensors that could measure simple variables among other things temperature, vibration, noise, pressure, flow, proximity and acceleration. Also, a network of sensors can build to monitor more complex systems such as industrial environments, local or large transportation systems, environmental condition in close or open areas, security conditions in private or public areas, health care of individuals or communities or threat detection on national borders, buildings and cities. The monitoring activities of any sensing system must be directed towards reliability and usability. Reliability guarantees the level of trust needed to make decisions based on data and information, while usability gives a purpose that helps designers or engineers in prioritizing monitoring efforts. Other key functionality in sensing is **Foresight**. To anticipate its future, the system must have a reasoning mechanism that makes inferences. Predictions are enhanced when the data and information is captured in real time. The foresight capability is based on data and information collected and processed by analytics algorithms using the computing capacity of the sensor network / Internet of thing (IoT) / cloud computing. The decision of where the computing processing is being executed either in the sensor network or cloud will depend on the intelligent system designed capabilities.

Smart: A smart system is built based on **intelligent systems** using artificial intelligent techniques, which implies the use of data/information and automated reasoning

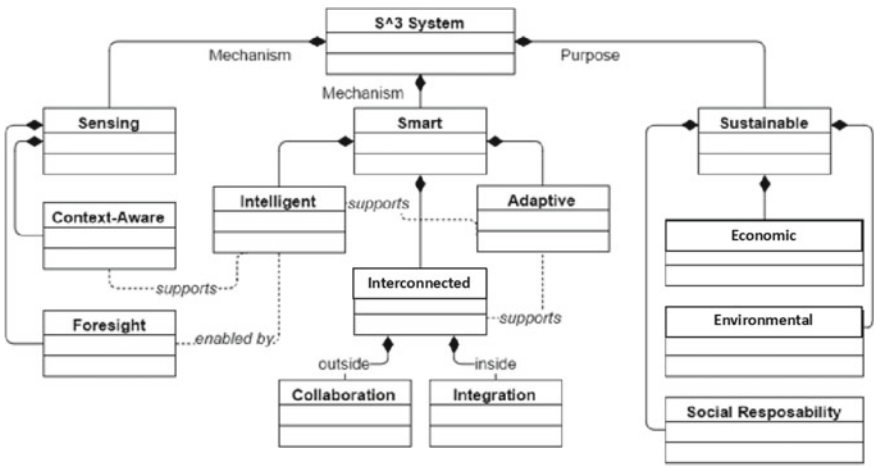

Fig. 1.2 Conceptual model of a sensing, smart and sustainable system

for decision-making. There are different artificial intelligent techniques such as genetic algorithms, artificial neural networks, fuzzy logic, depth neural networks and artificial organic networks [14, 15]. Depending on the application (design, classification, recognition, planning, scheduling, optimization, monitoring), alternative techniques can be used. Another characteristic of smart systems is **interconnected** that can be approached at two levels of **integration**: external (horizontal) and internal (vertical). At the external level (horizontal), it refers to the interoperability with other systems whose interaction provides value to the system tasks. At the internal level (vertical), interconnectivity is used to provide integration of the system's parts. In a product: physical, digital and electronic components; in a process: materials, energy, control and information; in a manufacturing system: manufacturing resources, information, knowledge and control strategies; in an enterprise: core processes, core competencies, information technologies and applications both levels suggest the creation of intelligent collaborative networks. Using the internetworking and automated reasoning capacities, a smart system must be able to adapt to disruptions on its environment. **Collaboration** is also an important functionality of the smartness of a system. This collaboration can be achieved with different approaches such as intelligent agents, collaborative networks and interoperability standards [16, 13]. The **adaptability** of a system can be enhanced by having the capacity of reconfigurability meaning to change its type of operations to react to a dynamic environment and also by having a robust design (intelligent control and automation) so it can adapt to a wide range of operating conditions based on data/information of sensing systems.

Sustainability: The notion of sustainability is typically divided into three pillars. The **economic** dimension is maintained when the system produces more than what it costs, it is profitable. Therefore, the goals must be to minimize operational costs while increasing productivity or value generation. In addition, a sustainable system must participate in the cocreation of a world where humans survive and thrive. Being **social responsible** is therefore an obligation. Moreover, the concept of social capitalism has been discussed to achieve economic and social impact at the same time [17]. Finally, **environment sustainability** refers to a resource consumption rate that allows the environment to restore itself. The concept of earth as our space ship with limitation of resources that must be reused/recycle/ restored. Complementarily, the production rate of wastes must be less than the absorption capacity of the ecosystem. In this regard, life cycle assessment has been introduced by many companies to redesign raw material acquisition, product (reduce, recycling, reuse), green manufacturing process, distribution channels and logistics, product use and post-service, product end-life [18, 19, 20]. The importance of measuring the footprint of all operations in a company has been arised by the sustainable development goals proposed by the United Nations (UN). The future concept has been defined as circular economy which allows networks of companies in collaboration with governments to achieve full sustainability in a product value chain [21].

As shown in Fig. 1.3, we will apply the S^3 concept to products, processes, manufacturing systems and enterprises in order to improve their functionality and behaviour when they become sensing, smart and sustainable systems. Let us now have a closer look at each of them.

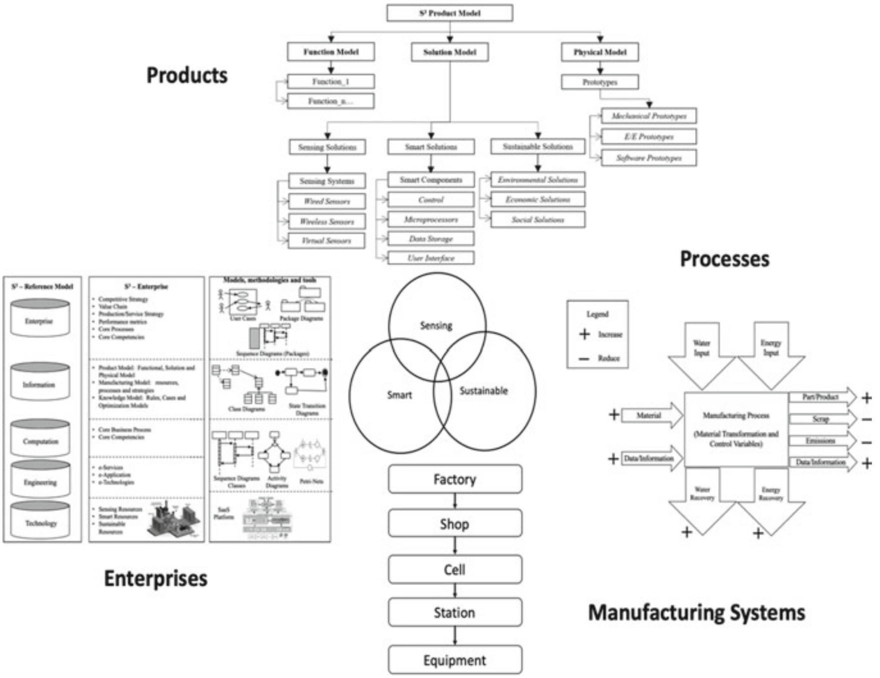

Fig. 1.3 Sensing, smart and sustainable products, processes, manufacturing systems and enterprises

S^3 Products. Novel products require more sophistication compared with traditional ones; the production of them must cover different aspects expected from prosumers and generate solutions in different schemes, especially those related to sustainability. Customisation, sustainable impact, reputation and contact are some of the characteristics expected from novel products. Integrating sensing, smart and sustainable characteristics to the product, it generates manufacturing goods which cover the expected outcomes of the potential consumers. Thus, S^3 Products are sustained in a methodology to create, including the consumers in early phases of the development for new innovative products, and validating the opinion when redesigning existing ones. S^3 Products are supported with the integration of value chain and collaboration from the suppliers, enterprise operations and consumer and at the same time, including technology, resource and information channels to accomplish financial objectives from the enterprise. As explained by Porter and Heppelmann [2], smart and connected products will change forever the perception of what a product´s functionality is and what we can expect from them. In [22], we have proposed the product model for the S^3 Products based on different approaches such as smart products where computational technologies are utilized to join physical processes with cyber-representations (See Fig. 1.4). These products have a mechatronics functionality since they integrate mechanical, electronic and information technology components. But they have more interaction with geographically distributed

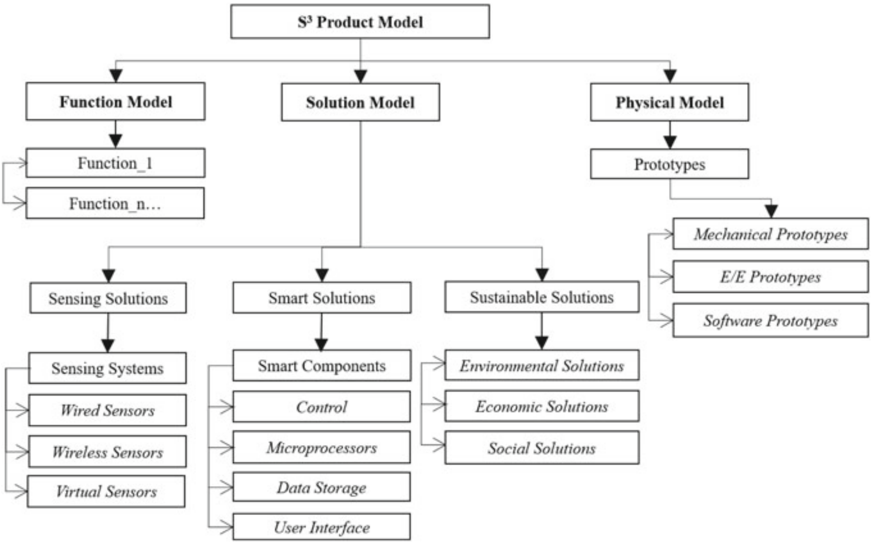

Fig. 1.4 Sensing, smart and sustainable product model

parts and even relying on external components or services to provide product's functionality. The sensing characteristic of S^3 Products involves all types of sensors which provide additional information to enhance context-awareness and self-description. The smartness characteristic is divided into the physical and smart components and connectivity. For physical components, new smart materials need to be introduced to provide proactive behaviour. The smart components, conformed by processing, storage and user interfaces, must be enhanced towards intelligent control, artificial intelligence planning and machine learning, in order to provide the product functionality in different conditions and following customer's needs. Finally, the connectivity components are for interaction of the products with other products or processes and different actors during the product life cycle. The sustainable characteristic is realized by adopting sustainable product development which includes traditional product requirements criteria (economic, quality, market, technical feasibility) but adds environmental and social impacts [23]. Thus, the S^3 Products must produce benefits such as reduced volume of hazardous material and raw material in general, reduced energy consumption and elimination/reduction of waste. For developing sustainable products, the life cycle approach is currently used to measure their economic, social and environmental impacts [24]. Adding sustainable considerations to the smart and connected products concept is a step towards S^3 Products. Chapter 3 will describe in more detail the taxonomy of S^3 Products and its development process.

S³ Processes. In today's world, innovation drives economy, and therefore, new products are being introduced at a faster and faster pace. The processes (manufacturing and business) need to adapt to this rate. We propose the S^3 Processes as solutions for the ever-changing environment in the digital economy. Figure 1.5 shows an

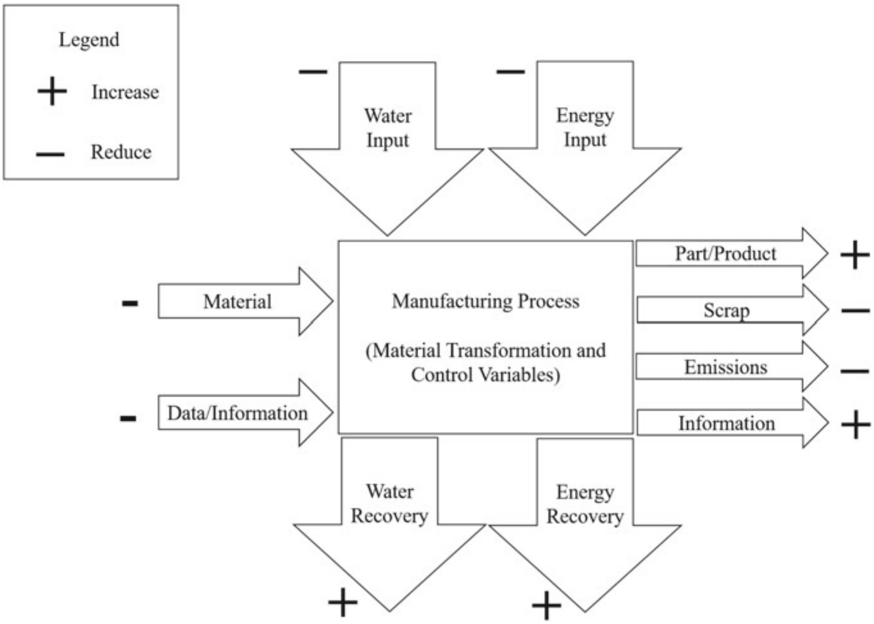

Fig. 1.5 Sensing, smart and sustainable manufacturing processes

S^3 material transformation process using the morphological definition to illustrate what is expected in a S^3 Manufacturing Processes. The processes should become smart and sensing, which implies that there is a continuous monitoring of operations which gives processes the ability to create the desired products in efficient and flexible ways. The production processes used by most industries have not achieved the desirable sustainability [19]. In fact, traditional industrial production is linked to environmental disruptions, such as global warming and pollution and consumption of non-renewable resources. However, in S^3 Processes, the energy and material utilizations should be minimized, and the production waste reduced to almost zero seeking sustainable production [23]. Intelligent technologies for sustainable energy management are been developed to support in this endeavour [11].

Figure 1.6 depicts traditional business core process of what a company must do: create, make and sale products, also offer after sales services to customer. These processes are usually supported by technologies and applications. For product;s creation CAD/CAM/CAE/PLM. For products manufacturing (make) ERP/MES/SCADA and shop floor technologies such as sensors/RFID/wireless sensor networks (WSN) and real-time control systems. For sales and customer services usually CRM—customer relationship management systems. To achieve an improved level of continuous monitoring, processing and smart decision-making emerging technologies are being integrated such as Internet of things, Internet of services, cloud computing, big data and analytics. Autonomous cooperative elements will connect in situation dependant ways, conforming Cyber-Physical Production

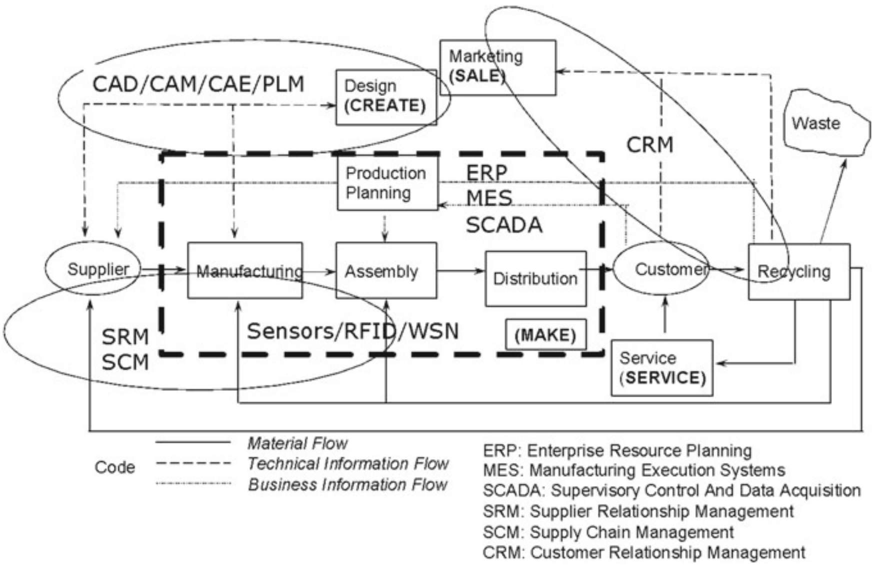

Fig. 1.6 Enterprise business process and some examples of enabling technologies

Systems (CPPS). Later, we will discuss how all these new technologies support the concept of Industry 4.0 and S^3 Systems where the cooperative interconnectivity will also affect the business processes and the data must be trusted without always knowing their origin. As a consequence, the benefits of such scenarios anticipation are both: increased resources efficiency and reduction of risks. Business and engineering processes in Industry 4.0 are promoting sustainability [25]. Chapter 4 will be focused on describing in detail the taxonomy of S^3 Process and how they can be designed and develop.

S^3 Manufacturing Systems. The S^3 Manufacturing System is concerned with all levels automation (enterprise, factory, shop, cell, station, equipment) in order to include technologies to sense and make decision intelligently. Figure 1.7 shows the hierarchical levels together with some sensing requirements and decisions to be considered in a S^3 Manufacturing System and enterprise. The right selection of smart machine, material handling equipment, tooling, CNC, PLC and real-time controls, monitoring and scheduling strategies is key to achieve a high-level intelligent system. Also, it is important to design the concept of dual twins (digital and physical) to extend the capacities of flexibility and reconfigurability of the manufacturing system. These are the foundations to design a next generation of intelligent manufacturing system. Chapter 5 will present all the functionalities and characteristics of S^3 Manufacturing Systems and how an intelligent manufacturing system can be designed using the concepts of sensing, smart and sustainable systems.

S^3 Enterprises. The S^3 Enterprise is concerned with design of a business model, strategies, its information models, definition of core processes and core competencies, integration of computational resources and manufacturing technologies to