Achieving the Sensing, Smart and Sustainable "Everything"

Dante Chavarría-Barrientos[1(✉)], Luis M. Camarinha-Matos[2], and Arturo Molina[1]

[1] Tecnologico de Monterrey, School of Engineering and Science, 14380 Mexico City, Mexico
{dante.chavarria,armolina}@itesm.mx
[2] Faculty of Sciences and Technology and Uninova – CTS, Nova University of Lisbon, 2829-516 Monte Caparica, Portugal
cam@uninova.pt

Abstract. The vast diversity of current sensing devices and mechanisms enable the creation of data-rich environments which gives the opportunity to create smart systems. The smartness of systems must transcend individual interests and fulfill collective aspirations and environmental needs. Therefore, new products, processes, enterprises, communities and any kind of systems must be envisioned as Sensing, Smart and Sustainable (S^3). This paper discusses the trends and challenges for S^3 applied to everything. Furthermore, it suggests that the knowledge produced in the field of collaborative networks might be used to leverage the S^3 capabilities.

Keywords: Collaborative networks · Sensing systems · Smart systems · Sustainability

1 Introduction

The generalized use of technologies such as cloud computing, cyber-physical systems, big data analytics, and sensor systems lead to data-rich environments. In industry, these environments can promote an increase in productivity because they boost the creation of knowledge. Having access to the right information at the right time gives enterprises the ability to better compete and sustain their operations. Consequently, the idea of Sensing, Smart and Sustainable (S^3) Enterprise was recently introduced [1]. The S^3 Enterprise is concerned with the analysis and management of all data sources to feed smart systems that react rapidly and flexibly to environment changes. As a result, enterprises can become sustainable in the economic, social and environmental senses.

This research proposes the adoption of the S^3 concepts not only in enterprises, but in any human-designed system, e.g. products, processes (business and manufacturing), communities and cities. We call this vision as the S^3 of everything. The creation of S^3 systems will promote and rely on collaboration, information access, open innovation, and sustainable development. However, the concept must be well studied to be adopted by practitioners.

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As a contribution in this direction, this paper discusses the trends and challenges when developing the S^3 of everything. Section 2 provides a definition of the S^3 concept and a brief literature review of current approaches in developing these systems. Section 3 introduces a list of challenges to make this vision a reality. Finally, Sect. 4 describes the enablers while trying to identify further research opportunities.

2 The S^3 Concept: Sensing, Smart and Sustainable

The sensing enterprise, the smart organization and the sustainable enterprise are the concepts that give birth to the S^3-Enterprise vision where the S^3 concepts were used together for the first time. The sensing enterprise [2] can anticipate future decisions by using multidimensional information that enhances its global context awareness. The smart organization [3] is defined as an enterprise that is internetworked, knowledge driven, and therefore able to adapt rapidly in response to opportunities. Finally, the sustainable enterprise maintains its economic, social and environmental dimensions when it operates [4]. Figure 1 tries to capture the S^3 characteristics of generic systems based on such definitions. The conceptual model proposed details the S^3 system definition, and each of the characteristics are explained next.

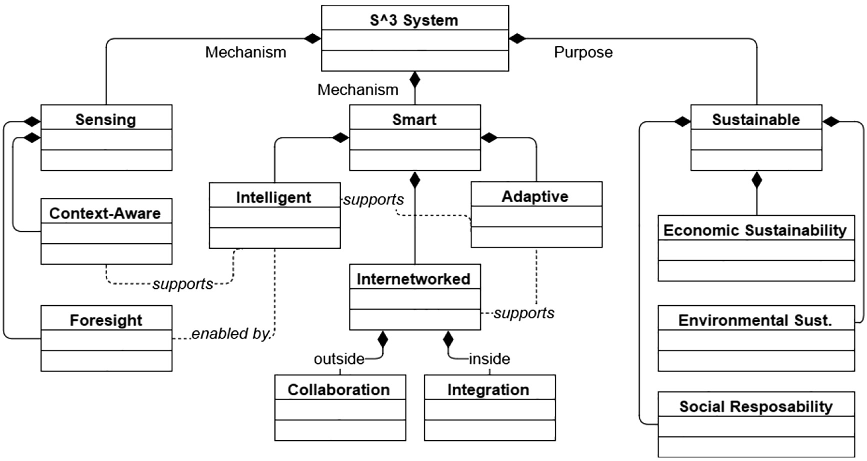

Fig. 1. A conceptual model of a Sensing, Smart and Sustainable system

Context-awareness is a key characteristic of any sensing system which refers to the acquisition of relevant information to make better decisions. 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 information, while usability gives a purpose that helps designers in prioritizing monitoring efforts.

One of the associated goals when acquiring information is the foresight ability which is proposed as a second characteristic of a sensing system. To anticipate its future, the system must have a reasoning mechanism that makes inferences.

Predictions are enhanced when the information is captured in real-time. A smart system is based on intelligent artefacts which imply the use of information to make decisions. An autonomous cognitive reasoning facet is needed to use the information effectively and efficiently. The intelligence is reflected in the way the system decides.

Internetworking is a characteristic of current smart systems that can be approached at two levels. At the external level, it refers to the collaboration with other systems whose interaction provides value to the system tasks. At the internal level, interconnectivity is used to provide integration of the system's parts. Both levels suggest the creation of collaborative networks.

Using the internetworking and knowledge-based capacities, a smart system must be able to adapt to disruptions on its environment. The adaptability of a system can be enhanced by having a wide range of operating conditions or by having reconfigurability to change its type of operations to provide new capabilities. The first approach provides faster response times; however, it increases complexity.

The notion of sustainability is typically divided in three pillars. The economic dimension is maintained when the system produces more than what it costs. Therefore, the goals must be to minimize operational costs while increasing productivity or value generation. In addition, a sustainable system must participate in the co-creation of a world where humans survive and thrive. Being socially responsible is therefore an obligation. Finally, environment sustainability refers to a resource consumption rate that allows the environment to restore itself. Complementarily, the production rate of wastes must be less than the absorption capacity of the ecosystem. Collaborative networks have been discussed as a major pillar of sustainability implementation [5].

As shown in Fig. 2, different application areas can be found for the deployment of the S^3 concept. Products, processes, enterprises, business environments, communities

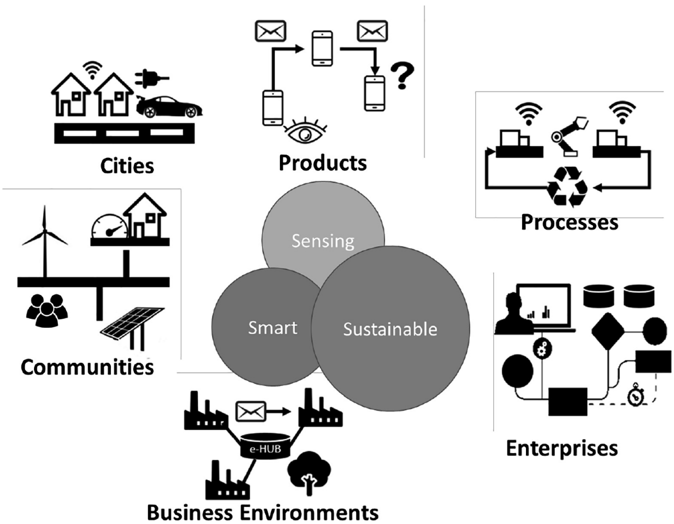

Fig. 2. Some application areas for Sensing, Smart and Sustainable concepts

and cities improve their functionality and behavior when they become Sensing, Smart and Sustainable. Let us now have a closer look at each of them:

S^3 Products. Customers want cheaper, personalized and innovative products with better quality and reliability [6]. The S^3 products idea is an approach to satisfy these requirements. Miranda et al. [7] have proposed the product model (See Fig. 3) 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 [8]. These products have a mechatronics characteristic since they integrate mechanical, electronic and IT components. But they have more interaction with geographically distributed parts, and even relying on external components or services to provide product's functionality [9]. 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 components, smart components and connectivity. For physical components, new smart materials need to be introduced to provide proactive behavior. The smart components, conformed by processing, storage and user interfaces, must be enhanced towards intelligent control, AI planning, and machine learning, in order to provide the product functionality in different conditions and following customers needs. Finally, the connectivity components are for interaction of the products with other products and different actors during the product lifecycle. The sustainable characteristic is realized by

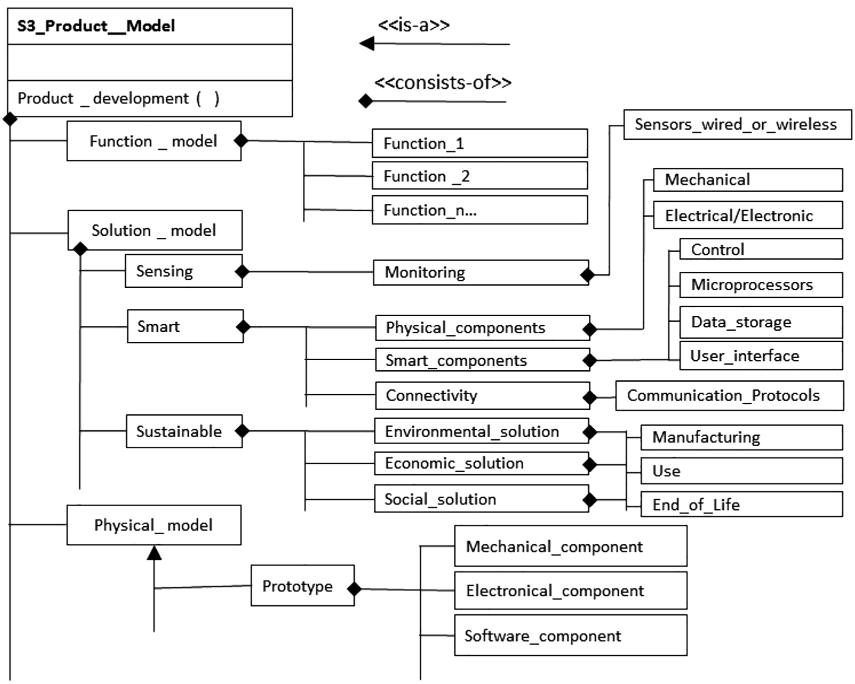

Fig. 3. Sensing, Smart and Sustainable Product Model [7]

adopting sustainable product development which includes traditional product requirements criteria (economic, quality, market, technical feasibility) but adds environmental and social impacts [10]. 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 lifecycle approach is currently used to measure their economic, social and environmental impacts [11]. Adding sustainable considerations to the Smart Product concept is a step towards S^3 products.

S^3 Processes. In todays' world, innovation drives economy, 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 everchanging environment in the digital economy. Figure 4 shows an S^3 material transformation process using the morphological definition provided in [12] 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 [13]. The continuous monitoring and processing will be provided by the use the emerging technologies i.e. Internet of Things, Cloud Computing, Big Data, embedded systems. Autonomous cooperative elements will connect in situation dependant ways, conforming Cyber-Physical Production Systems [14]. The production processes used by most industries are not sustainable [15]. In fact, traditional industrial production is linked to environmental disruptions, such as global warming and pollution, and consumption of nonrenewable 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 [16]. Intelligent technologies for sustainable energy management are been developed to this end (energialab.com). These processes are related to the concept of Industry 4.0 where the cooperative interconnectivity will also affect the business processes and the data must be trusted without always knowing their origin. As a consequence, benefits such as scenarios anticipation, increased resources

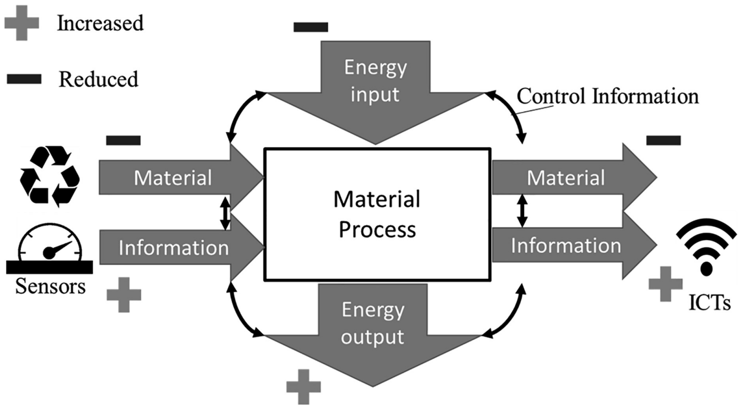

Fig. 4. Sensing, Smart and Sustainable Material Processes

efficiency and reduced risks will be found [17]. Business and engineering processes in Industry 4.0 promote sustainability [18].

S^3 Enterprises. If enterprises want to thrive in the ever-changing business environments, they need to operate efficiently and adaptively. The S^3 Enterprises [1] will achieve this through various mechanisms that promote sustainability. All type of sensors in all hierarchical levels of the Enterprise [19] will give the self-awareness needed to operate efficiently, Additionally, digitalization will be the mechanism that supports the foresight ability and transformation of enterprises by providing modularity and reconfigurability [20]. For becoming intelligent, model-based engineering and operation would guide the enterprise behavior. The concept of service is adopted as a building block that describes the operation of the enterprise providing reconfiguration capability. For heterogeneous supply networks, a core ontology will facilitate the exchange and interoperation of information systems. These systems can rely on intelligent autonomous agents that need executable models. The executable models will enable the creation of Enterprise Operating Systems [21], where enterprise operations are controlled and executed through computers. For sustainability, the indicators will include the fulfilment of survival and purpose needs of the socio-ecological system in which it is emerged [22]. According to the S^3 vision, enterprises must follow the road to sustainable development by minimizing consumption (e.g. energy, goods, and water); maximizing societal and environmental benefit, rather than prioritizing economic growth; emphasizing delivery of functionality and experience, rather than product ownership; and promoting collaboration and sharing, rather than aggressive competition [23]. These goals should be pursued at each hierarchical level of the enterprise. Figure 5 shows the hierarchical levels together with some sensing requirements and decisions to be considered in a S^3 manufacturing enterprise.

S^3 Business Ecosystems. New business ecosystem should create a climate conductive to investments, innovation and entrepreneurship, which is supported by the progress of the ubiquitous and pervasive computing and networking, i.e. S^3 Business Ecosystems. Figure 6 illustrates the combination of concepts that define these ecosystems. For context awareness and foresight, these business environments will be in continuous contact with markets, harvesting opportunities and reacting to them. Social media in an important enabler to sense the customer preferences. In 2002, the European Commission coined the term Digital Business Ecosystem (DBE) referring to the achievement of innovation, openness, and sharing supported by a technical infrastructure to connect services and information among organizations [24]. DBE concept is applied to understand the interconnectivity of S^3 business environment. Additionally, the ECO-LEAD project [25] synthesized the ICT services (e-services) needed for the creation and operation of such ecosystems, facilitating dynamic creation of virtual enterprises, triggered by business opportunities. The services for the virtual enterprise include collaborative opportunity identification, partners search and suggestion, negotiation wizard (e-brokerage), CN modeler, decision support system, monitoring system, etc. To emphasize the collaborative aspects in business ecosystems, the term Collaborative Business Ecosystem was recently introduced [26]. For promoting intelligence and adaptivity, these environments are envisioned as Green Virtual Breeding Environment (GVBE) which is considered as an intelligent network of assets that are shared to create

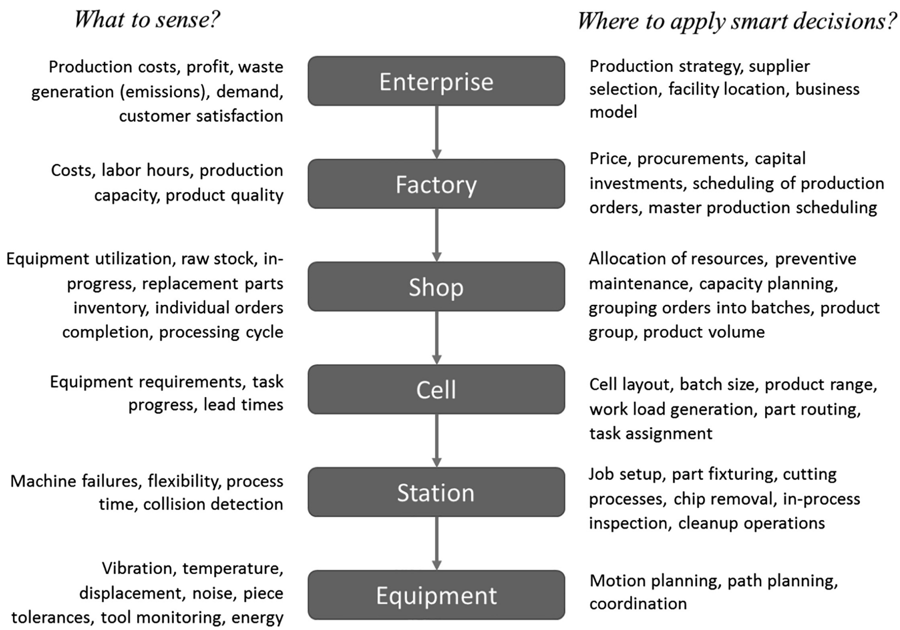

Fig. 5. Examples of what to sense and decide in a S^3 Manufacturing Enterprise

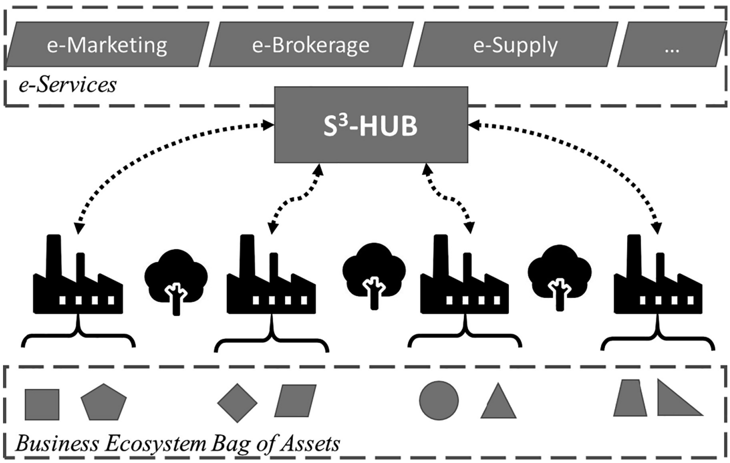

Fig. 6. A view of Sensing, Smart and Sustainable Business Ecosystems.

sustainable value [27]. This view of the GVBE gives the opportunity to consider business ecosystems as a bag of assets that must be assigned, monitored and managed by and in effective ways to save costs, co-create value, efficiently utilize resources and develop trust among Green Enterprises. The S^3 HUB [28] acts as the mediator among enterprise assets and provider of e-services. The S^3 HUB must also govern the sustainable issues of the Business Ecosystem. It should balance the cooperation and competition guaranteeing the health of all participants. Furthermore, it must verify that the environment and social impacts do not overcome the regeneration capacities. To this end, the HUB should promote the creation of a Circular economy, where all elements utilized are designed to reenter the biosphere safely.

S^3 Communities. Communities are the keystone of society; therefore, it is important to apply the S^3 concepts to them. The role of the Internet of Things (IoT) has been revised, giving birth to the concept of Smart Communities [29]. This concept is a first step in the definition of S^3 Communities, however the goals go further. It is important to consider that we have rural and urban communities. As seen in Fig. 7, solutions to rural communities must address, at the individual level, access to health, nutrition, education and development of competencies to work. At community level, it is important to have access to low cost clean energy, potable water, efficient management of waste, and local production systems to create the conditions for a sustainable local economy. The solutions for these challenges include mobile learning, self-employment using ICTs, green products and processes, sustainable and green housing, waste disposal technologies, renewable technologies, telemedicine, nutraceuticals and bioprocess. For urban communities, the term S^3 cities is proposed instead.

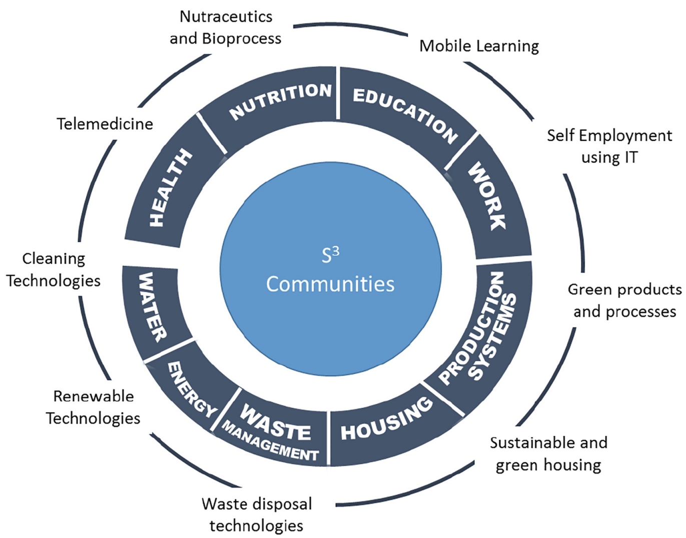

Fig. 7. Challenges and solutions for Sensing, Smart and Sustainable Communities (Rural).

S^3 Cities. These cities are defined based on the Smart city concept, and the ICT-enabled sustainable strategies (See Fig. 8). However, this is not the first time Smart and Sustainable cities have been defined. Hojer and Wangel [30] propose the term Smart Sustainable City as a "*city that meets the needs of its present inhabitants without compromising the ability for other people or future generations to meet their needs, and*

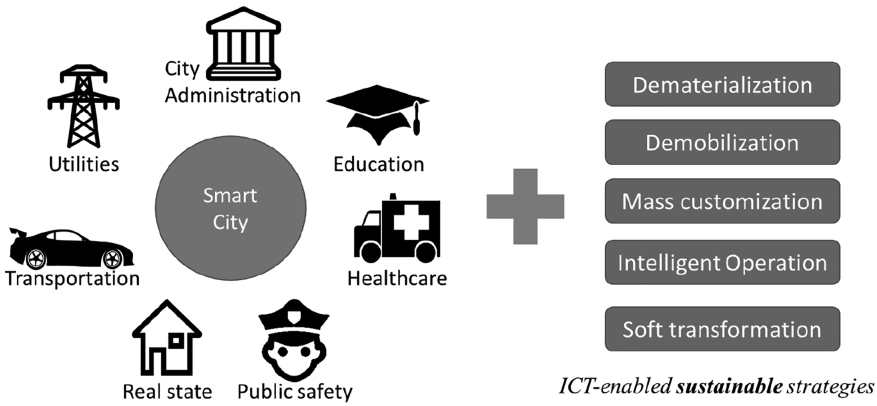

Fig. 8. Towards Sensing, Smart and Sustainable Cities (Urban Communities).

thus, does not exceed local or planetary environmental limitations, and where this is supported by ICT." The goal in S^3 cities is to select the ICT investments that cause the greatest benefit to environment and society. The Internet of Things must be used to provide Sensing as a service which promotes the development of activities such as waste management, smart agriculture and environmental management [31]. In addition, human interaction with technology should be monitored to provide a digital representation of the social phenomena [32]. The digital representation must be analyzed with Big Data technics to provide increasing quality of life. Seven core services have been enlisted as the components of the Smart City where the ICT-enabled intelligence can be applied to improve life quality [33] (i.e. city administration, education, healthcare, security, real state, transportation and utilities). In these cities ICT also improves sustainability by providing dematerialization, demobilization, mass customization, intelligent operation and soft transformation [34]. Effective materialization of these cities requires the involvement and collaboration of multiple public and private stakeholders.

3 Trends and Challenges

Despite the advances in different applications areas, the development of truly S^3 systems is still a challenging and not yet fully understood task. Following the model proposed in Sect. 2, Table 1 shows some challenges and the status related to the deployment of S^3. The status has been determined according to the literature review done in the previous section. The sensing challenges are mostly accomplished since current technologies allow collecting and keeping almost any type of data. This situation varies for the smartness-related challenges because often the "smart" label has been naively assigned to simple use of ICT. However, there is a need for further developments in smart facets, such as cognition and adaptability. Finally, the main challenge regarding sustainability is the ability to measure the impacts on society and environment to avoid partial and therefore incomplete approaches to sustainability. Current methods (e.g. Lifecycle assessment) need to be standardized and sharpened.

Table 1. Trends and challenges in S^3

Dimension	Status	Trends and challenges
Sensing		
Context-aware	●	-Raw sensor systems: There is available technology to sense almost any type of variable.
	●	-Data storage: Current solutions, such as cloud storage, provide the required capacity.
	●	-Real-time: The latency of signal processing in smart sensors is sufficient for most applications.
Foresight	◐	-Big data analytics: Current solutions offer reasonable results only when data is pre-organized and validated.
	◐	-Predictions: Artificial Intelligence (AI), machine learning and simulation provide first approaches to predict systems behavior.
Smart		
Intelligent	◐	-Common understanding: standards are a first approach, but core domain ontologies are needed to allow knowledge sharing.
	●	-Effective AI: current intelligent systems have proved to provide the required precision needed in standard applications.
	○	-Flexible AI: current AI systems are focused on specific tasks; flexible reasoning systems are needed in seek of adaptivity.
Interconnected	●	-Physical Interconnectivity: ICTs allow communication in different scenarios using different resources.
	◐	-Interoperability: hierarchical IT architectures need to be broken to allow a more open communication among system components.
Adaptive	◐	-Modularity: components must provide their functionality as on-demand services that can be accessed by both humans and bots.
	○	-Autonomy: an agile response depends on the ability of the system components to self-organize.
Sustainable		
Economic	●	-Value generation: Because technologies have a cost, the value propositions should overcome traditional proposals.
	●	-Economic assessment: Different KPIs and evaluation techniques are available to measure costs and profit of any system.
Environmental	◐	-Green technologies: Alternative technologies are being developed to substitute harmful resources.
	◐	-Environmental impacts assessment: Standards such as IS0 14000 are the first aproach in getting universal measure for impacts.
Social	◐	-Social developments technologies: ICTs have promoted varying befits to societies providing wide access to services.
	○	-Social assessment. There is a need to define clear and universal measures of social impact.

● - Solved challenges ◐ - Partially solved challenges ○ - Open challenges

4 Enablers to Achieve S^3 Realization

4.1 S^3 Technologies

The main component that is leading to the conceptualization of S^3 "things" is the advancement in ICTs and sensing technologies. These technologies alone (e.g. RFID, sensors, microprocessors and mobile networks) have the potential of supporting the S^3

"things". However, there is an aggregated version of such technologies that allow a straightforward adoption of S^3 concepts, i.e. S^3 Technologies. These technologies are integrated hardware, software, and network technologies that provide real-time awareness, advanced analytics, collaboration capabilities and adaptability to help in intelligent and sustainable decision making. An example is the smart grid because it promotes the use of renewable energy using of real-time information to balance supply and demand [35]. The Advanced Metering Infrastructure (AMI) is a key component that provides reliable, real-time data about each component of the power grid. The concept of Collaborative Smart Grid was recently introduced [36] to reflect a trend towards establishing collaborative networks among all stakeholders in a smart grid environment. Smart grids have enabled the creation of S^3 communities and cities. There is a need for similar developments that impulse the implementation of S^3.

4.2 S^3 Collaborative Networks (CNs)

As mentioned above and already evidenced in current trends, the area of CNs is a key enabler for the realization of the S^3 concept. In fact, all cases mentioned in Sect. 2 involve multiple entities – organizations/enterprises, people, smart machines, smart sensors, smart systems – which are typically heterogeneous, distributed, and with growing levels of autonomy. The "integration" and "interaction" of these entities – which are progressively more interconnected – into a consistent whole require effective collaboration among them in order to ensure proper (and desirably optimal) functioning.

Nevertheless, the full achievement of the S^3 vision raises several challenges for the CN research community, including:

- *Interplay among diverse networks:* various networks, with different life cycles co-exist in the same environment – e.g. networks of machines and networks of organizations or networks of people - and the interplay among these networks needs to be better understood and supported.
- *Hybrid value systems:* in some cases, e.g. smart cities, and smart infrastructures, there are actors (public and private) with very different value systems along the value chain. Finding ways of combining those diverse value systems is necessary in order to ensure healthy global behaviors.
- *Culture/training:* some of the mentioned application domains are often addressed from very partial perspectives, e.g. from a technology-only perspective, requiring the creation of a CN culture and training the involved human actors with the already vast knowledge base of the CN discipline.
- *S^3 KPIs:* a new set of performance indicators oriented to assess the level of S^3-ness in each application domain needs to be developed.

5 Conclusions

The S^3 of everything invites researchers to see the sensing and smart capabilities as a medium to achieve system sustainability. S^3 characteristics as requirements for system design would allow the development of systems that thrive and survive in the ever-changing world. This approach take the advantage of the technologies that are shaping the digital era. Furthermore, the usual design goals are taken further through considerations such as minimizing waste generation, enhancing working conditions, improving social conditions, and promoting green societies.

For adopting the S^3 conceptualization and setting the requirements of such systems, a generic description of each characteristic has been provided. This generic model is an initial step towards the construction of a formal and well-recognized vision of Sensing, Smart, and Sustainable everything. In addition, several challenges and their status have been introduced to guide and leverage research related to S^3 everything. Furthermore, collaborative networks have been identified as a major vehicle for S^3 realization. Nevertheless, the full realization of the vision requires further research. We expect that this preliminary work may encourage researchers to develop the area of S^3 of everything into a recognized and active approach for systems development.

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