A Knowledge-based Approach to Enhance the Workforce Skills and Competences within the Industry 4.0

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***Abstract*—One of the significant challenges of Industry 4.0 is the realization of a more *sustainable manufacturing* along the whole factory life-cycle, which has an impact on three different dimensions: economical, social and environmental. Whereas the economic and environmental dimensions have been widely discussed in many works and progressively integrated in production processes, there is still a shortage of studies aiming at incorporating the social dimension. Consequently, economic planning and policies lack the full acknowledgment of human rights, education, health and gender diversity. With this study, we aim at aligning the technological panorama of Industry 4.0 with the social dimension of sustainable manufacturing, by proposing a semantic model based framework as a reference architecture to enhance social sustainability in manufacturing. Finally, a case study is presented, in which factory environments try to meet workers capabilities and desiderata, by augmenting the quality of life and ensuring people health, at work or in their community during their entire life, while ensuring productivity.**

***Keywords*–Social Sustainable Manufacturing; Industry 4.0; Teaching Factory; Knowledge-Intensive Systems; Cyber-Physical Systems; Semantic Web.**

I. Introduction

In recent years, new trends in manufacturing and automation have embraced *circular economy* models, which emphasize the design and implementation of a new sustainable industry changing at different dimensions: economical, societal and environmental. The concrete realization of this changing tune has been made possible by the adoption of new technological solutions and paradigms coming with the fourth industrial revolution, also known as *Industry 4.0* [1][2]. This latter promotes the computerization of manufacturing grounding on some design principles, such as interconnection, information transparency, decentralized decisions and technical assistance; while the key enabling technologies underpinning it are Internet-of-Things (IoT), Cyber-Physical Systems (CPS) and Smart Factories [3]. One of the main strengths of Industry 4.0 is the creation of intelligent cross-linked modules, holding a great opportunity for realizing sustainable industrial mechanisms on all three dimensions previously mentioned: economic, social and environmental. The value creation in Industry 4.0 can be profitably realized through the adoption of human-centered technologies, which put the human operator (or the knowledge worker) at the center of the innovation process. This vision is in line with the European Commission strategy as reported in [4], where, it is pointed out that, in order for European industry to be competitive and flourishing, it is needed to ensure workforce with the right skills. Indeed, one of the key priorities for the Factories of the Future (FoF) 18-19-20 Work Program [5] is focused on the human factor, addressing in particular the development of competences of the workers in synergy with technological progress. Some of the technological enablers addressing this objective, which have also acknowledged in this work, are: (i) models for individual and collective sense-making, learning and knowledge accumulation; (ii) workers interconnection with machines and processes and developing context-oriented services towards safety practices and decision making. In particular, the work introduced in this paper follows three inspiring paradigms described as follows. Firstly, the *Teaching Factory* concept, which aims to align manufacturing teaching and training to the needs of modern industrial practice. According to this new paradigm, future engineers and knowledge workers (i.e., workers whose main capital is knowledge) "need to be educated with new curricula in order to cope with the increasing industrial requirements of the factories of the future" [6]. Secondly, it exploits the *Visual Approach* concept to manufacturing [7]. In this regard, the efficiency of workers can be enhanced by Augmented Reality/Virtual Reality (AR/VR) systems, such as headmounted displays together with Learnstruments [8] or by using new Information and Communication Technologies (ICTs) for implementing *gamification* in order to support decentralized decision-making. Finally, we have the adoption of *Knowledge-based* systems, which use proper formalisms (semantic-based languages or ontologies) [9] in order to represent the knowledge hidden in the product or production process. All the above paradigms contribute to realize the envisioned concept of Smart Factory, as a thorough Cyber-Physical System allowing safety, wellness and continuous training inside the factory (Figure 1).

Acknowledging the great interest for the human factor in modern factory, this work proposes a multi-layered framework as a leading architecture satisfying the requirements of social sustainability. The framework will be applied to a concrete case study, which demonstrates the use of advanced technologies from the Industry 4.0 panorama in order to create a user-centred factory environment.

The reminder of the paper is structured as follows: Section 2 collects some previous works in defining a conceptual model in Industry 4.0 both from academics and industrial research groups. Section 3 describes the framework highlighting the leading principle that have inspired it. Section 4 presents a

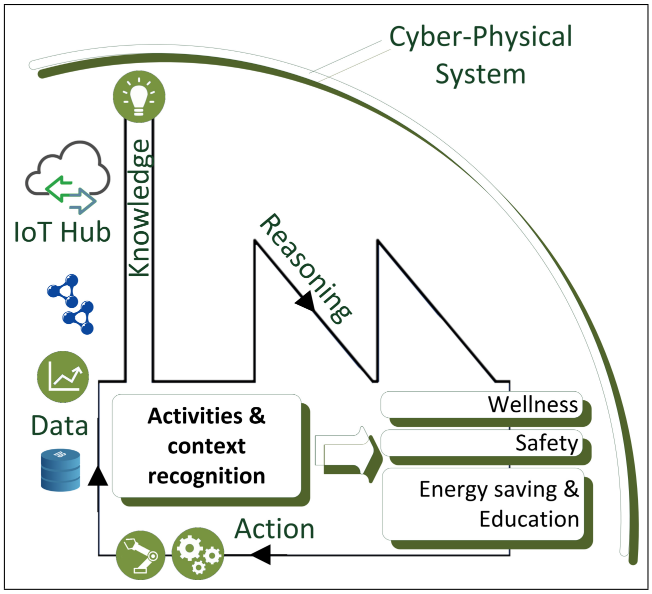

Figure 1. The Smart Factory as a Cyber-Physical system

case study aiming at demonstrating the applicability of the conceptual framework introduced in this work. Finally, the last section summarizes the main findings outlining future research investigations.

II. RELATED WORKS

With the advent of Industry 4.0 and even before, new spreading paradigms, such as *lean manufacturing* and *advanced computer-based manufacturing*, conceptual models or frameworks have been thought in order to clearly highlight the concepts and relationships resulting from the new perspective proposed by the paradigm. Lee et. al. [1] proposes a "5C architecture" for Cyber-Physical Systems in Industry 4.0 manufacturing systems. It is intended to provide a step-by-step guideline for developing and deploying a CPS for manufacturing application. The architecture is layers-based and includes the following levels:

- *Smart connection*. It acquires accurate and reliable data from machines and their components. Data might be directly measured by sensors or obtained from controller or enterprise manufacturing systems such as Enterprise Resources Planning (ERP), Manufacturing Execution Systems (MES), Software Configuration Management (SCM) and Coordinate Measuring Machine (CMM);
- *Data-to-information conversion*. It performs some computational task like multidimensional data correlation, degradation and performance prediction in order to infer information from the data;
- *Cyber*. It acts as central information hub in this architecture by collecting data from all the machines and performing analytics tasks to extract additional information that provide better insight also by taking into consideration historical data coming from machines;
- *Cognition*. It properly presents the acquired knowledge to expert users supporting the correct decision to be taken;
- *Configuration*. It represents the feedback from cyber space to physical space and acts as supervisory control to make machines self-configure and self-adaptive.

Another valuable architectural model is the "Reference Architectural Model Industrie" (RAMI) 4.0 [10]. This model combines the fundamental elements of Industry 4.0 in a three-dimensional layer model including the "Hierarchy Levels" axis, the "Life Cycle & Value Stream" axis and finally the orthogonal vertical axis. The first axis ranges over the different functionalities within factories or facilities and retraces what is provided by the International Electrotechnical Commission (IEC) 62264 document [11]. Such functionalities intersect with the second axis, which represents the life cycle of facilities and products and is based on IEC 62890 [12]. Finally, the vertical axis includes the decomposition of a machine into its properties structured layer by layer: asset, integration, communication, information, functional and business. Within these three axes, all crucial aspects of Industry 4.0 can be mapped, allowing objects such as machines to be classified according to the model, thus providing a common understanding of Industry 4.0 technologies.

The Open Platform Communications Unified Architecture (OPC UA) [13] is the new standard of the OPC Foundation providing interoperability in process automation. It provides a Service-Oriented Architecture (SOA) for industrial applications from factory floor devices to enterprise applications by specifying an abstract set of services mapped to a concrete technology. A communication stack is used on client- and server-side to encode and decode message requests and responses. Also, this architectural model includes a bottom level of data acquisition from heterogeneous data sources, which provide the server implementation with data requested by the client. OPC Ua does not provide Application Program Interfaces (APIs) implementation for client-server communication but a Web service-based implementation that allow heterogeneous clients to communicate with different implementations of server (exploiting Microsoft, Java or C-based technologies).

Among the commercial solutions, which take advantage of a semantic-based approach, it is worth mentioning the Global Real Time Information Processing Solution (GRIPS) [14] developed by Star Group, a software framework that enables intelligent processing capabilities by linking information objects. Specifically, by allowing a geographically distributed and multi-lingual authoring of structured and linked information units, GRIPS supports the creation of product knowledge while enabling semantically linked knowledge management on all business-critical objects. The GRIPS authoring and information processing model distinguishes three layers of information processing: semantic content base layer, publication/document types and structures layer, publishing channels layer. By exploiting the semantic-based enabling technologies, it benefits not only product communication, but also marketing, sales, after sales and the end customer. Moreover, the framework allows enhanced re-use of software components, standardization, cost reduction, quality, sustainability and protection of investments, seamless integration, and so forth.

In [15], the authors proposed a system approach to support sustainability of manufacturing from three perspectives: energy, material, technology. Finally, the use of knowledge-based models for enabling context-awareness in the context

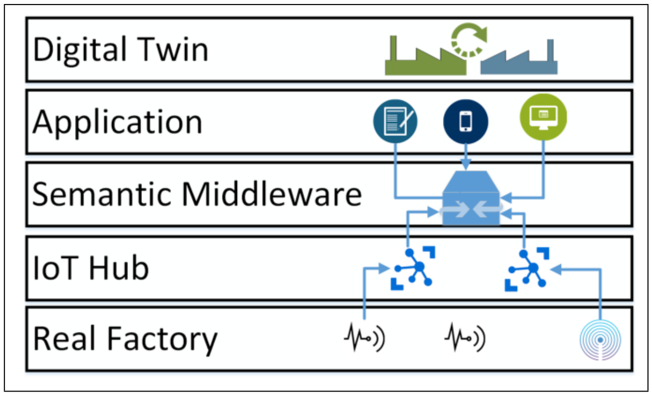

Figure 2. Conceptual framework for the Social User-centered Manufacturing in Industry 4.0

of Smart Home, which can be borrowed in the Smart Factory scenario too, has already been explored and experimented by the authors in [16].

III. THE CONCEPTUAL FRAMEWORK

Figure 2 depicts the layers-based conceptual framework proposed in this work. The leading principles at the base of the framework are: (i) highlight the cutting edge technologies and paradigms belonging to Industry 4.0 in order to meet the social sustainable manufacturing requirements involved in our case study; (ii) separate technologies and solutions according to different layers having in mind the production processes, from the design phase to its realization; (iii) emphasize the *digital synchronization* between the real and digital factory acknowledging the continuous exchange of data and feedback between the factory and its mirror image in the cyberspace.

Starting from the bottom, the *Real Factory* layer represents a unique level of acquisition for data coming from inside or outside the factory. To this level belong data collected from the shop-floor acquired for example through a distributed sensors network (wireless sensors networks) such as in-line inspection and monitoring data, wearable devices, proximity sensors like eBeacon. This layer is also called to operate a preliminary adaptation and integration of data acquired from heterogeneous sources, also just at a syntactical level such as data cleansing and syntactic alignment in order to let them be interoperable and usable by the software tools at the upper levels of the framework [17] [18].

The *IoT Hub* is conceived as the layer in which the in-depth knowledge of product-process and production systems is elicited from raw data collected at the bottom level. Once elicited, the product-process knowledge can be represented through standard or *de facto* standard languages and technologies so that it can be shared and understood by human and automated agents. The adoption of such formalisms in modelling the information about products, processes and production systems opens several perspectives in managing the complexity of data models used in modern manufacturing scenarios. Furthermore, with the rise of Big Data and Big Data Analytics technologies [19][20], we are witnessing the trend of moving data, applications, or other business components from an organization's on-premises infrastructure to the cloud, or moving them from one cloud service to another. This trend has lead to a new manufacturing paradigm, the *Cloud Manufactruing*, developed from existing advanced manufacturing models and enterprise information technologies under the support of cloud computing, Internet of Things, virtualization and service-oriented technologies, and advanced computing technologies [21].

The *Semantic Middleware* layer at the centre of the framework represents a sort of *gateway* responsible for a systematic integration of data, eventually semantically annotated data [22][23], coming from the enterprise data sources (local databases or legacy database) and from outside (distributed storage or Web of Data). This layer is responsible for: implementing the proper approach to transparently access data from multiple clients, by taking into consideration security, reliability, redundancy and trustability issues, providing reliable mechanisms to publish new data from the upper level applications or by the bottom line and make them available to all interested agents in a real-time or near real-time fashion with respect to changes in critical data. A publisher-subscriber mechanism or an Event Condition Action (ECA) architecture can be used in order to implement such functionality [24]. To this level belong one of the key component used in the scenario described in the next section, i.e., the Digital Factory Model (DFM), which can be conceived as an *omniscient* module able to understand the representation models underlying the whole product life' cycle, the production process and system and the Virtual Individual Model of workers engaged in the production process and their skills.

The *Application* layer embraces different tools used in computerized manufacturing. There exist many Digital Tools that support engineers and designers in different phases of product life-cycle. For example, Computer Aided Design (CAD) software help users in creation, modification, analysis or optimization of a design and are used to increase the productivity of the designer, improve the quality of design, and, importantly, improve communications through documentation. To this level also belong the Virtual Tools, i.e., Augmented Reality Systems (like AR headset and visors), which implement the Visual Approach to production process already described in the introductory section, being one of the solution adopted in the demonstration scenario. Finally, the Smart Tools include all Business Intelligent tools and Analytics [20] used to analyze data and get insight from them to support expert user in the decision making process (e.g., Opinion Mining tools or Information Visualization tools). Proper info-graphics or information visualization tools are necessary to completely transfer acquired knowledge to the users [19] [25].

The highest level of the framework is the *Digital Twin* level. It resembles the Cognition level of the 5C architecture [1], i.e., at this stage proper presentation of the acquired knowledge throughout the lower levels must be provided. Additionally, in this level takes place the digital synchronization: there must be a constant synchronization between the real factory and its replica in the digital world. Such synchronization requires that produced data or acquired by physical sensors spread at the shoop-floor level must be passed to the digital tools, which in turn elaborate them via sophisticate analytics or simulations in order to provide feedback and reactions that impact real-time over the real factory. The Digital Twin is underpinned by representational models about the whole factory. In particular, the demonstration scenario described in the next section rely above three representational models, which formally describe the digital replica of the factory: the *Digital Factory Model*, the *Virtual Individual Model*, and the *Skills Virtual Model*.

IV. USER-CENTRED WORKPLACES: A CASE STUDY

The case study presented here is focused on the production process of wooden furniture, such as sofas, dispensers, chairs and so on. This case study is significant because, on the one hand, the adoption of innovative technologies can improve the whole production process making it more competitive and lean, while, on the other hand, the need for a hand-made production as the most important added value for customers, significantly reduces the freedom of action in terms of processes automation and innovation deployment. Thus, most of the process innovation is user-centred, i.e., it needs to be addressed towards the direct support of human operators activities rather than towards sophisticated machinery.

Typically, human operators involved in this scenario have to deal with two different kinds of issues, which will be further discussed as follows. At first, the operators are not interchangeable in the assembly line, since she/he is formed for (and is in charge of) accomplishing a specific task (e.g., drilling, assembly of parts, cutting, etc.); therefore, *job rotation* is not applicable, and thus, the company has great difficulty in distributing the workload, for example, when it must deal with peaks of requests for a certain product (requiring specific workings) or in the case of unavailability of some resources. Moreover, the lack of a proper job rotation may result frustrating for worker who is forced to perform the same operations all the time. Secondly, the high variety of wooden products along with the mass customization may require an extra effort for workers in order to deal with the rapidly change of work instructions, without the help of technologies. For example, the use of traditional hard copy manuals, instead of technologies based on a Visual Approach, will force the operator to continuously check out the instruction sheets (due to the strong difference among assembling sequences of different products models), and this can lead to a waste of time, which can significantly grow depending on worker experience and on the frequency of production of different models. Conversely, the proper adoption of a Visual Approach supported by technologies, will provide just-in-time information delivering, following the principle of transferring the right information at the right person at the right time.

What we expect from the implementation of user-centred workplaces is: reducing non-value adding activities; reducing mistakes from employees and suppliers; reducing time for employee orientation and training; reducing search time in navigating the facility and locating tools, parts and supplies; reducing unnecessary human motion and transportation of goods; increasing productivity supporting sustainability, mainly from a social perspective. Workers will no longer perform their tasks routinely; instead, they will have to undertake varied and mostly unstructured tasks, depending on the needs of the dynamically changing production process. Teams should/will include flexible and remote ways of working and interacting with the systems as well as with other workers.

As shown in Figure 3, the case study involves different actors and components: the operators, an AR equipment, the Digital Factory Manager (DFM) and the virtual models. It also involves different technological solutions which support such components: an Augmented Reality System, with annex headset or visors like the Oculus Rift, a distributed sensor network, which is spread throughout all machinery and operators, intelligent software robots like *chatbot* able to assist the human operators in accomplishing their tasks, in a high level of abstraction, and finally, representational languages such as ontologies [26], belonging to the Semantic Web technologies panorama [27]. The latter are used for formally representing the knowledge about the whole factory and the involved actors through three virtual models:

- *Digital Factory Model*, which represents the entire production system including the production process and the final product with its parts. It borrows some concepts and idea from the Virtual Factory Data Model introduced in [28];
- *Virtual Individual Model*, which is a formal conceptualization of the operator profile. It includes biographic info (gender, age, language and so on), capabilities and eventually disabilities or impairments, work aspirations and attitudes, training activities and courses the worker has already taken part. This model is based on the Virtual Individual Model provided within the Pegaso project [29] and provides a formally multi-faceted description of the operator within the factory;
- *Skills Virtual Model*, which provides a formal representation of the skills the operator need in order to perform each single phase of the production process and is informed by the knowledge of product and its parts, processes, competencies and operator capabilities.

These formal models need to be properly integrated in order to be used by the DFM, exploiting well-known techniques for ontology integration existing in the literature [22]. Furthermore, related to each model there is an extensional part (the model instance) that need to be persisted through storage technologies such as RDF Stores or TripleStore [24]; One of the key components of the entire case study is the DFM, which can be conceived as an *omniscient* module able to understand the representation models underlying the whole product life' cycle, the production process and system and the Virtual Individual Model of workers engaged in the production process and their skills. With all these information at hand, the DFM is able to infer the right allocation of people to production process phases by ensuring that individuals with proper skills and capabilities (or maybe attitude or desiderata) are engaged in activities that best fit the worker characteristics, this way, realizing the transfer of the right information at the right person at the right time. The synergistic use of these technologies allows the implementation of a close-loop between the real factory and the its digital replica.

With the support of the technologies mentioned above, framed in each layer depicted in Figure 2, it is possible to imagine a demonstration scenario as follows. Once the operator is ready to start her/his work, she/he approaches the workstation and is immediately recognized through proximity sensors like eBeacon. By accessing her/his profile, represented in the VIM (Virtual Individual Model), the system is able to verify if the operator properly fits to do a certain job over a certain machine. Both the Digital Factory Model and the

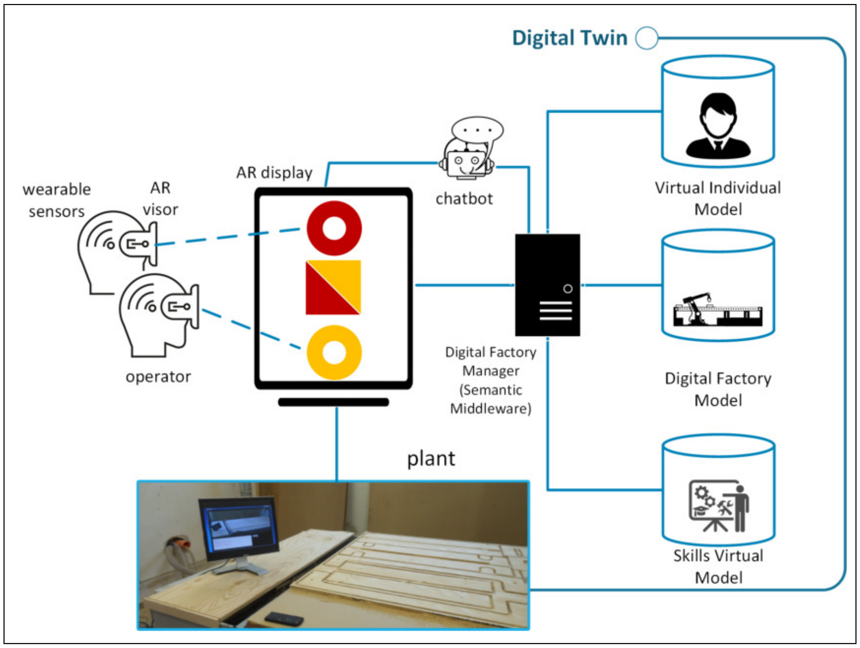

Figure 3. Case study conceptual overview

Skill Virtual Model allow the system to know which skills are needed to use a particular machine, and which machine has to be used in carrying out a specific task for producing a particular item or component of a final product. The operator profile also contains a report of operator performances in accomplishing specific tasks and her/his preferred tasks. The personal record also contains info like impairments, such as, for example, visual or audio deficit, which can be used by the system in order to adjust, for example, the work surface lighting. The operator faces a work plane with all the parts of which the piece is made, but does not know how the different parts should be mounted (or because the operator is not trained or because the piece is new). The operator is guided step-by-step to accomplishing the work by the use of AR equipment, which are constantly connected to a DFM, via wireless networks. The latter constantly informs the operator about the procedures to be followed when accomplishing a certain task. A distributed network of sensor is pervasively used in order to monitor the worker positions with respect to machines and the advancement of her/his work.

In this study, we modeled the skills of the various operators and mapped with the operations to be performed. This way, the AR system is able to display the full piece of work, superimposed on what has so far built by the operator, to provide a clear idea of how to continue the work that is being done. The AR system also displays a preview of the finished piece on the basis of the piece produced so far and on the basis of the drawings in 3D as designed by the CAD. 3D drawings are displayed as a virtual silhouette of the part still to be worked on. The AR display is also provided with a chatbot interface, which allows the user, via a speech recognition system or via a wireless keyboard, to interact with intelligent software robots able to answer the operator questions in a high level of abstraction. The chatbot also acts as an info request router being capable to forward a request to a human operator recognized able to respond according to her/his profile and experiences, as modeled in the Virtual Individual Model. Any updates in the production process or in hardware and software components of machinery can arise the need for a professional upgrade of the operator that is promptly reported by the system, this way ensuring a continuous learning within the factory. The synergistic use of different technological solutions makes the workplace smart, i.e., a sustainable work environment which is attractive for workers, tailored to their specific needs and able to ensure well-being, continuous training and education, by also augmenting overall productivity.

V. CONCLUSIONS

In this work, a conceptual framework for social manufacturing sustainability in the rise of Industry 4.0 has been proposed. The idea of the framework is to put in evidence how the cutting edge technologies under the Industry 4.0 umbrella can support the fundamental principles of social sustainability. In order to demonstrate this, intelligent cross-linked value creation networks have been realized by turning the traditional factory in a Cyber-Physical System, which implements the concept of Teaching Factory and uses knowledge-based systems and a Visual approach to production process. A case study has been presented in order to verge the layered framework introduced on a real case study aligning the needs encountered with the technological solutions belonging to each layer. The paper demonstrates how the framed technologies can help in implementing the user-centred environment within the factory. This is conceived as a smart workplace, which is attractive for workers, tailored to their specific needs and able to ensure well-being, continuous training and education, and sustainability without lessening productivity. Future lines of researches will investigate the adoption of more sophisticated and complete knowledge models of the production process also by applying the proposed framework to other industrial scenario.

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