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Enhancing the Workforce Skills and Competences by Leveraging a Human-Centered Knowledge-Based System in the Rise of 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, environmental, and social. Whereas the economic and environmental dimensions have been widely discussed in many research 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. This alignment is realized through a knowledge-based system able to represent, formally, both human factor and the principal aspects of the value creation chain inside the factory, thus promoting a human-centric workplace improving the social sustainability in manufacturing by not penalizing productivity. This work is an extended version of a previous work by authors, focusing on the description of the design and implementation details of the knowledge layer underpinning the whole system. Furthermore, 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, while ensuring productivity. Finally, since the research proposed in this article is a case study research, a well known methodology and related guidelines are exploited in order to study, analyze, evaluate and report the case.**

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 have embraced *circular economy* models, which emphasize the design and implementation of a new sustainable industry changing at different dimensions: economical, societal and environmental [1]. The changes induced by the adoption of such regenerative models can bring benefits along all these three dimensions, in different ways. From an economical point of view, circular economy can generate sales and profits, investing in infrastructure, paying tax responsibly, creating jobs, etc., while, from an environmental level, sustainability signifies minimizing waste and emissions or hazardous substances, using energy and resources efficiently, using environmental sound materials and protecting biodiversity. Finally, from a social point of view, circular economy can lead to good community relations, respecting human rights, granting good working conditions and ensuring the continuous learning of workers inside the factory. Although there have been great progress in integrating the economic and environmental spheres, difficulties still remain in fully incorporating the social dimension. As a result, economic planning and policies lack the fully acknowledgment of human rights, education and health, and gender diversity [2]. A concrete enhancement of the social sustainability can be made possible by the adoption of new technological solutions and paradigms coming from the fourth industrial revolution, also known as *Industry 4.0* [3][4]. Indeed, this latter promotes the computerization of manufacturing grounding on some design principles, such as interconnection, information transparency, decentralized decisions and technical assistance. Two key enabling technologies underpinning this evolution are Internet-of-Things (IoT) and Cyber-Physical Systems (CPS), which in turn are typically combined with other technologies [5] (e.g. Digital Twin [6], Augmented and Virtual Reality [7], etc.). One of the main strengths of Industry 4.0 is its capability to create intelligent cross-linked modules, holding a great opportunity for realizing sustainable industrial mechanisms on all three dimensions mentioned above. In addition, it can contribute to enhance the interoperability of all the productive hardware and software resources covering the factory life-cycle.

According to [8], there are different opportunities of sustainable manufacturing from Industry 4.0 based on macro and micro perspectives. For example, from a macro perspective view, new evolving business models are highly driven by the use of smart data for offering new services, i.e., selling the functionality and accessibility of products instead of only selling the tangible products will be a leading concept (product servitisation); cross-linking of value creation networks offers new opportunities for realizing closed-loop product life cycles and industrial symbiosis. Closed-loop product life-cycles help in realizing de- and re-manufacturing systems enabling to deliver high quality upgradable and re-usable future products at affordable price to the global market. Industrial symbiosis describes the (cross-company) cooperation of different factories in order to realize a competitive advantage by trading and exchanging products, materials, energy, resources and information [9]. From a micro prospective point of view, the major opportunities for sustainability in Industry 4.0 come from the adoption of new cutting edge technologies of computerized manufacturing. For example, a simplistic scenario may consist in turning the factory into a 4.0 one by retrofitting: machineries can be equipped with a distributed sensors network and actuator systems as well as with related control logics in order to realize a CPS with existing manufacturing equipment so that the new capabilities can contribute to the economic and environmental dimensions of sustainability.

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. Thus, the social challenges of Industry 4.0 struggle for a wider involvement of human factors in the product life-cycle and process simulation or co-simulation. For example, the Human-in-the-loop (HITL) allows the user to change the outcome of an event or process and is extremely effective for the purposes of training because it allows the trainee to immerse themselves in the event or process. This human-centered vision is in line with the European Commission strategy as reported in [10], 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 [11] 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. The human-centered approach has been fostered in the context of Italian Industry 4.0 initiatives too, as their inclusion in the scope of Call "Centri di competenza ad alta specializzazione"[1] (hereinafter mentioned as Competence Centers) launched by the Italian Ministry of the Economic Development can demonstrate. The initiative promotes the establishment of highly specialized competence centers on Industry 4.0 issues, in the form of public-private partnerships. The competence centers will have to carry out guidance and training activities for companies as well as support in the implementation of innovation projects, industrial research and experimental development aimed at the realization of new products, processes or services (or their improvement) through advanced technologies in the field of Industry 4.0, particularly for SMEs.

According to the Competence Centers Call, the overall goal of this study is exploring the potential of the technologies related with Industry 4.0 (Hermann et al. (2016)) to enhance workforce skills and competences. In this paper we extend a previous work where a knowledge-based system for enhancing the workforce skills and competences in the scenario of Industry 4.0 has been proposed [1]. Specifically, this research work presents more improvements w.r.t. the previous one as it adds more considerations in the introductory section about sustainability and Industry 4.0. It widens the related works section by adding new works about the principal topics exploited in this work, i.e., the Teaching Factory, Visual Approach in manufacturing training and Knowledge-based Systems. In addition, this extended version adds details about the knowledge models underpinning the proposed system. 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. Thanks 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" [12]. Secondly, it exploits the *Visual Approach* concept to manufacturing [13]. 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 [14] or by using new Information and Communication Technologies (ICTs) for implementing *gamification* in order to support decentralized decision-making. Finally, the adoption of *Knowledge-based* systems, which use proper formalisms (semantic-based languages or ontologies) [15] in order to represent the knowledge hidden in the product or production process and facilitate the knowledge elicitation promoting the sharing of knowledge and best practices, thus contributing to create a continuous learning workplace and support the human factor within the company [16], [17]. All the above paradigms contribute to realize the envisioned concept of Smart Sustainable 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 article 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, eventually, demonstrates the use of advanced technologies from the Industry 4.0 panorama in order to create a user-centred factory environment. We try to verge the layered framework previously introduced on a real case study aligning the needs encountered with the technological solutions belonging to each layer. The idea of user-centred environment within the factory 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.

Since this work represents a case study research and the proposed case is a *contemporary phenomena in its natural context*, the research methodology and guidelines followed here are in line with those introduced in a well known work in the literature [18]. As far as possible, we have borrowed some of the key definitions, concepts and phases of such methodology from software engineering to Industry 4.0 theoretical and operational context. Although this work is not conceived as a case study research report, we have tried to formalize a case study protocol and follow it when describing, analyzing, evaluating and reporting the case under study.

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 case study aiming at demonstrating the applicability of the conceptual framework introduced in this work. Section 5 introduces the case study protocol, highlighting its phases. Finally, the last section summarizes the main findings evaluating the case study research. Later on future research investigations are outlined.

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[1] http://www.sviluppoeconomico.gov.it/index.php/it/incentivi/impresa/centri-di-competenza

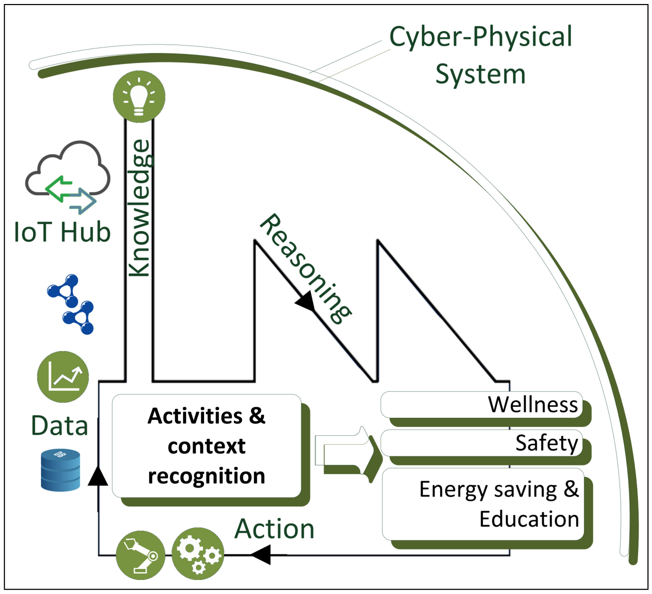

Figure 1. The Smart Sustainable Factory as a Cyber-Physical system

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. In the following subsection, a review of the major Industry 4.0 conceptual models will be outlined, while in the subsequent subsections a brief review of the three characterizing topics underpinning this work will be proposed.

A. Industry 4.0 conceptual models

Lee et al. [3] propose 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 [19]. 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 [20]. Such functionalities intersect with the second axis, which represents the life cycle of facilities and products and is based on IEC 62890 [21]. 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) [22] 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) [23] 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 [24], the authors proposed a system approach to support sustainability of manufacturing from three perspectives:

energy, material, technology.

B. The Teaching Factory

From a theoretically point of view the Teaching Factory originates from previous instructional approaches such as training-on-the-job and hands-on learning, which in turns represent learning methodologies laying on a well-know and principled model: the Bloom's taxonomy [25][26]. This latter is used to classify educational learning objectives into levels of complexity and specificity [27], from knowledge to synthesis through application and analysis, by emphasizing the final objective of the learning process, i.e., developing real competencies in learners rather than just knowledge transfer. Prior to the use of the term Teaching was the expression Learning Factory. Although, they are now used interchangeably, the word "learning" in the term, as opposed to teaching, emphasized the importance of experiential learning, whose effectiveness in retention and application possibilities w.r.t. traditional methods such as lectures, has been broadly proven and discussed in several works [28][29]. The first Learning Factory was developed in 1994 by the Penn State University and it was conceived as an interdisciplinary hands-on senior engineering design projects with strong links and interactions with industry [30]. This early model of learning factories emphasizes the hands-on experience gained by applying knowledge learned at the culmination of engineering education to solve real problems in industry and design/redesign products to satisfy identified needs [31][32]. More recently the use of learning factories has become multifaceted as various manifestations of Learning Factory (at different sizes and involving different scenarios) have appeared, and the term Teaching Factory has taken hold in different application scenarios. As a general rule, the great interest for such paradigm rises from the strong feeling that promoting excellence in manufacturing represents the major drive to generate wellness and wealth in any nation; moreover, it is triggered by the customization-movement of products [33]. These new forms of production control and flexible manufacturing increase the complexity of production systems especially concerning information processing and software engineering, thus requiring modern ways of training to prepare aspiring engineers (or blue collars) for related issues. For this reason, manufacturing education has received great attention from researchers and scholars, so the interest for Learning (or Teaching) Factory have moved from local to European and worldwide organizations, while initiatives and projects aiming at developing educational programs in industry have been fitting in the political agenda of many national and international politicians. To cite few examples, the European Commission with Manufuture and Factories of the Future initiatives has promoted research programs oriented in this way, the CIRP Research European Association has developed a Collaborative Working Group (CWG) on Learning Factories, the German Federal Ministry of Education and Research through the German Academic Exchange Service (DAAD) has founded the Network of Innovative Learning Factories (NIL), and, finally, the Italian Government has come out with the Competence Centers Call already mentioned in the introductory section.

According to numerous works in the literature [34][28][35], the line of investigation related to the teaching factory is twofold: from the one hand, it tries to ameliorate the communication channel and the synergy between academia and industry (Academia-to-Industry), by recognizing the needs of modern industries in the increasing complexity of the market and transferring the research achievements and technologies advances from research groups and universities to industry; from the other side, it strengthens the communication channel between the industry and the education systems (Industry-to-Classroom) by elevating the vocational learning to an effective authentic learning instructional approach thanks to real study cases brought into the classroom. From a learning methodological point of view, almost all works existing in the literature point out that, in order to make modern factories and workers resilient to the changing market conditions and to the complexity of new technologies involved in the production process, it is necessary to "act self-organized in unknown situation". For this reason, traditional teaching methods are no longer sufficient to train competent employee, thus new approaches are needed. Training in realistic manufacturing environments, modernize learning process bringing it closer to the industrial practice, leverage industrial practice through the adoption of new manufacturing knowledge (fostering the sharing and the elicitation of knowledge), improve young (future) engineers competences [30]. The accent on realistic manufacturing environments is also put by the CIRP Learning Factory group (mentioned above), which has analyzed different definition attached to the expressions above by collecting the features characterizing each of them. This led the the working group to individuate two sense of Learning (or Teaching) Factory that it is worth to recognize here, depending on the degree of contextualization: the narrow and the broad sense. The learning factory in the narrow sense provides a real value chain for a physical product in which participants can perform, evaluate, and reflect their own actions in an on-site learning approach. Whilst, the Teaching Factory in a broad sense may emphasizes the use of Virtual Reality (or Mixed-Reality) representations of factory facilities (value added chain) and promote the learning process through e-enhanced learning tools, which connect trainees remotely (through the network communication infrastructure). The CIRP CWG has also proposed a morphological (multidimensional) model serving as an orientation in the design of a new learning factory as well as a classification tool for existing learning factories (50 single features in seven dimensions were identified).

In industry, most notably large automotive companies have recognized the enormous potential of learning factories.

From a technological perspective, the Teaching Factory is supported by different e-enhanced learning tools, from the traditional Learning Management System like Moodle [36] to recent Virtual Classroom Environments [37], Mixed Reality simulation and gamification [7]. Furthermore, the realization of a fully-synchronized Digital Twin supports the concrete implementation of the Learning (or Teaching) Factory. Indeed, due to the strict synchronization and the closed loop between the real and the digital factory, the DT enhances the collaboration between stakeholders, strongly supporting the human knowledge toolkit, i.e., conceptualization, comparison and collaboration [38], and thus contributing to the realization of the teaching factory.

C. *Visual Approach to Manufacturing*

According to [39], mixed reality is the merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time. In recent years, the scope of its use has been increasingly widening by embracing entertainment and interactive arts, education as well as engineering and medical applications [40]. In the field of manufacturing engineering and production process, mixed reality systems are widely used to implement an efficient and effective visual approach which try to transfer the right information at the right person at the right time [41]. In addition, in the context of instructional settings, MR systems have been used for implementing Virtual Learning Environment (VLE) concerned with issues of learning, training and entertainment. In this regard, [42] analyzes the state-of-art research of VLE based on virtual reality and augmented reality, providing several examples for the purpose of education and simulation. These applications show that VLE can be means of enhancing, motivating and stimulating learners understanding of certain events, especially those for which the traditional notion of instructional learning have proven inappropriate or difficult. This advantages are valuable also in the context of the Teaching Factory where learners are knowledge workers or blue-collars called to continuously strive for excellence and training within modern industrial scenario. Beyond the Mixed Reality notion, the interaction between computers and environments becomes actually environmental understanding or perception. In this regard, the perception Windows API developed by Microsoft[2] reveal environmental information, which are added to the Mixed Reality system. Environmental input captures elements such as a person's position in the world (e.g., head tracking), surfaces and boundaries (e.g., spatial mapping and spatial understanding), environmental lighting, environmental sound, object recognition and location, thus augmenting the user experience to a highest level of involvement improving retention all acquired skills and knowledge. In [43] is described the teaching factory solution called Agro, providing expedient exercises by hands-on training as well as in depth technology training. The central part of this learning arrangement is the intelligent conveyor belt system in combination with different stations arranged in so-called factory zones. Each zone offers various education possibilities (the possibility to improve competences in a particular field), e.g., Zone A (Process Automation) may contribute to instruct trainee in controlling typical process variables such as temperature, level, pressure, flow rate, etc.; whilst, Zone C (Production automation) offers the following possibilities (not limited to): detection, differentiation, separation and mounting of a product, or, programming controllers, adjusting sensors.

D. *Knowledge-based system*

Knowledge-based manufacturing (KBM) is the application of knowledge-based systems technology to the domain of manufacturing design and production. The design process is inherently a knowledge-intensive activity, so a great deal of the emphasis for KBE is on the use of knowledge-based technology to support computer-aided design (CAD). However, knowledge-based techniques (e.g. knowledge management) can be applied to the entire product lifecycle. KBM is essentially engineering on the basis of knowledge models, i.e., a knowledge model uses knowledge representation to represent the artifacts of the design process (as well as the process itself) rather than or in addition to conventional programming and database techniques. In this regard, one of the most spread technology for knowledge representation, widely used in different domain, no less in manufacturing engineering is *ontology*. The latter 'is a formal, explicit specification of a shared conceptualization [44], where a conceptualization represents a common view of how to represent a domain of interest. Various research studies have exploited the great expressivity of ontologies to integrate information related to different abstraction levels within a manufacturing context. For instance, [45] presented the Manufacturings Semantics Ontology (MASON), an upper ontology developed upon the three major concepts of entities, operations, and resources; the authors also illustrated its two applications to implement an automatic cost estimation and a multi-agent framework for manufacturing simulation. Another example of general-purpose ontology for the manufacturing domain is represented by ADACOR (A Collaborative Production Automation and Control Architecture) [46], which is focused on the shop floor level and is based on the main pillars of decentralised systems, supervisor entities and self-organisation. Moreover, [15] designed the manufacturing system engineering (MSE) ontology, which provides a common understanding of manufacturing related terms to enhance the reuse of knowledge resources within global extended manufacturing teams. More recently, Terkaj, Pedrielli and Sacco [47] dealt with heterogeneity of the digital tools supporting the factory life-cycle phases, by introducing the Virtual Factory Data Model (VFDM), which aims at formalising and integrating the handled concepts of building, product, process and production resource. The basic idea behind VFDM is similar to the one behind the work by Panetto, Dassisti and Tursi (2012) [48], where the product ontology ONTO-PDM is proposed to provide a semantic layer to business, design and manufacturing product-related information. Chungoora et al. [49] proposed an approach based on ontology, which is combined with the model-driven architecture (MDA) in order to enhance interoperability between domain of design and manufacturing. Negri et al. [50] presented an ontology to model production systems and support interoperability in a service-based control architecture. Bruno et al. [51] proposed a semantic platform for managing product lifecycle information, based on a modular ontology for PLM. Finally, the use of knowledge-based models for enabling context-awareness in the context of Smart Home, which can be borrowed in the Smart Factory scenario too, has already been explored and experimented by the authors in [52].

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) categorize 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.

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[2] https://docs.microsoft.com/en-us/uwp/api/windows.perception

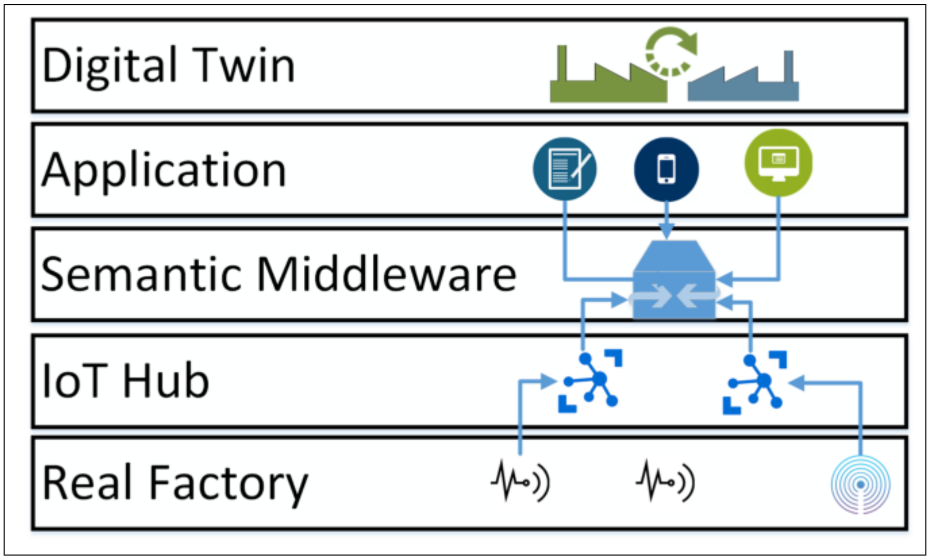

Figure 2. Conceptual framework for the Social User-centered Manufacturing in Industry 4.0

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 [7][53].

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. Homogenizing the representation languages for data models leads to several advantages: the reuse of already validated and standardized model, make it easy and fast the design of new products based on available knowledge bases providing the features and configuration options of the product being design, the possibility to pass such formal models as input of reasoning tools, which apply first-order logic based rules in order to entail new knowledge from the asserted knowledge base. *IoT Hub* follows the new manufacturing paradigm of the *Cloud Manufacturing*, which is 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 [54]. Indeed, with the rise of Big Data and Big Data Analytics technologies [55][56], 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.

The *Semantic Middleware* layer at the centre of the framework represents a sort of *gateway* which plays the role of systematic integrator of semantically annotated data [57][58], 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: (i) implementing the proper approach to transparently access data from multiple clients, by taking into consideration security, reliability, redundancy and trustability issues; (ii) 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 [59]. 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 and is one of the technological solution adopted in the demonstration scenario. Finally, the Smart Tools include all Business Intelligent tools and Analytics [56] used

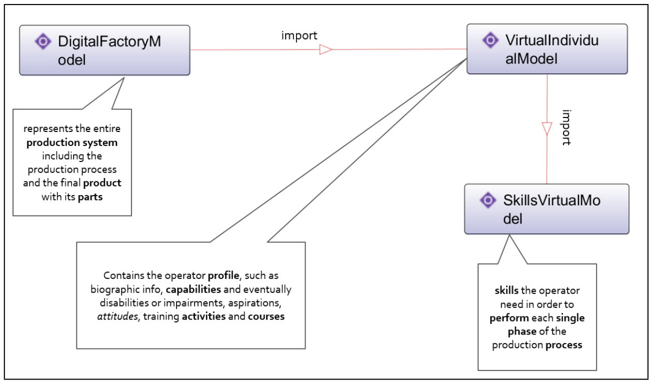

Figure 3. The knowledge model importing schema

to analyze data and get insights 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 [55] [60]. CAD is one part of the whole Digital Product Development (DPD) activity within the Product Lifecycle Management (PLM) processes, and as such is used together with other tools, which are either integrated modules or stand-alone products, such as: Computer-aided engineering (CAE) and Finite element analysis (FEA), Computer-aided manufacturing (CAM) including instructions to Computer Numerical Control (CNC) machines, Document management and revision control using Product Data Management (PDM).

The highest level of the framework is the *Digital Twin* level. It resembles the Cognition level of the 5C architecture [3], i.e., at this stage proper presentation of the acquired knowledge throughout the lower levels must be provided. Additionally, 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 relies on three representational models, which formally describe the meta-models of the digital replica of the factory: the *Digital Factory Model*, the *Virtual Individual Model*, and the *Skills Virtual Model*.

IV. KNOWLEDGE MODELS

A detailed description of the knowledge models at the basis of the system proposed in this work will be provided in the current section as extension of the already mentioned previous work by authors. In Figure 3 the importing schema of the ontologies related to the three representational models is depicted. All models have been written using OWL (Ontology Web Language) and present a Description Logic (DL) expressivity equal to *AL* (Attributive Language). This latter involves: atomic negation (negation of concept that do not appear on the left hand side of the axioms), concept intersections, universal restrictions and limited existensial quantification. For further details about Description Logics and their expressivity a good reference is [61], while for a formal definition of ontology and all its specifications the work of Staab et al. is a comprehensive one [62]. Ontologies in figure have been realized within Protégé (v. 5.2.0) ontology editor [63], which allows, thanks to numerous plugins, to represent even graphically all the axiomatized classes and related properties, thus easing the design and realization of ontologies. All images referenced in this section have been realized using OntoGraf plugin [3], which is able to represent, using the most spread graph layout, a graph where nodes represent classes and edges represent object properties linking classes with each other. The entire ontology at the basis of the system has been conceived as a modular one and implemented using the *import* clause in order to link the core module to the side modules (Figure 3 depicts this mechanism). Furthermore, by acknowledging a common best practice in ontology design, each module has not been conceived and designed from scratch but existing ontologies with common overlaps with our application or knowledge domain have been taken into account also for just inspiring a direction to move in developing our ontology [64].

The three ontological models underpinning the knowledge layer of the proposed system are: the Digital Factory Model, the Virtual Individual Model and Skills Virtual Model. Each of these models will be described in the following subsections.

A. The Digital Factory Model

This model is the core of the whole representational model underpinning the proposed knowledge-based system. It contains concepts and logical relations representing the entire production system involved inside the company (from the shop floor to the manager desk) including production process, final products (with all their specific parts), by-products (meant as secondary product made in the manufacture or synthesis of something else), services, components, raw materials, and so forth. It borrows some concepts and idea from the Virtual Factory Data Model introduced in [16]. The top level classes contained in this module are:

- *Component*, an high-level abstraction class used to represent a part or element of a larger whole, especially a part of a machine or vehicle or a product;
- *Manufacturing Production*, a class meaning a process of converting raw material into finished products by using various processes, machines and energy. Production is a process of converting inputs into outputs;
- *Product*, an high-level abstraction class representing an article or substance that is manufactured or refined for sale. It is also conceived as a product anything that can be offered to a market and that might satisfy a want or need;
- *Production Process* is a class representing a process of combining various material inputs and immaterial inputs (plans, know-how) in order to make something for consumption (the output). It is the act of creating output, a good or service which has value and contributes to the utility of individuals;
- *Production stage*, any phase of a production process meant as a step to be accomplished in order to obtain a final product;

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[3] https://protegewiki.stanford.edu/wiki/OntoGraf

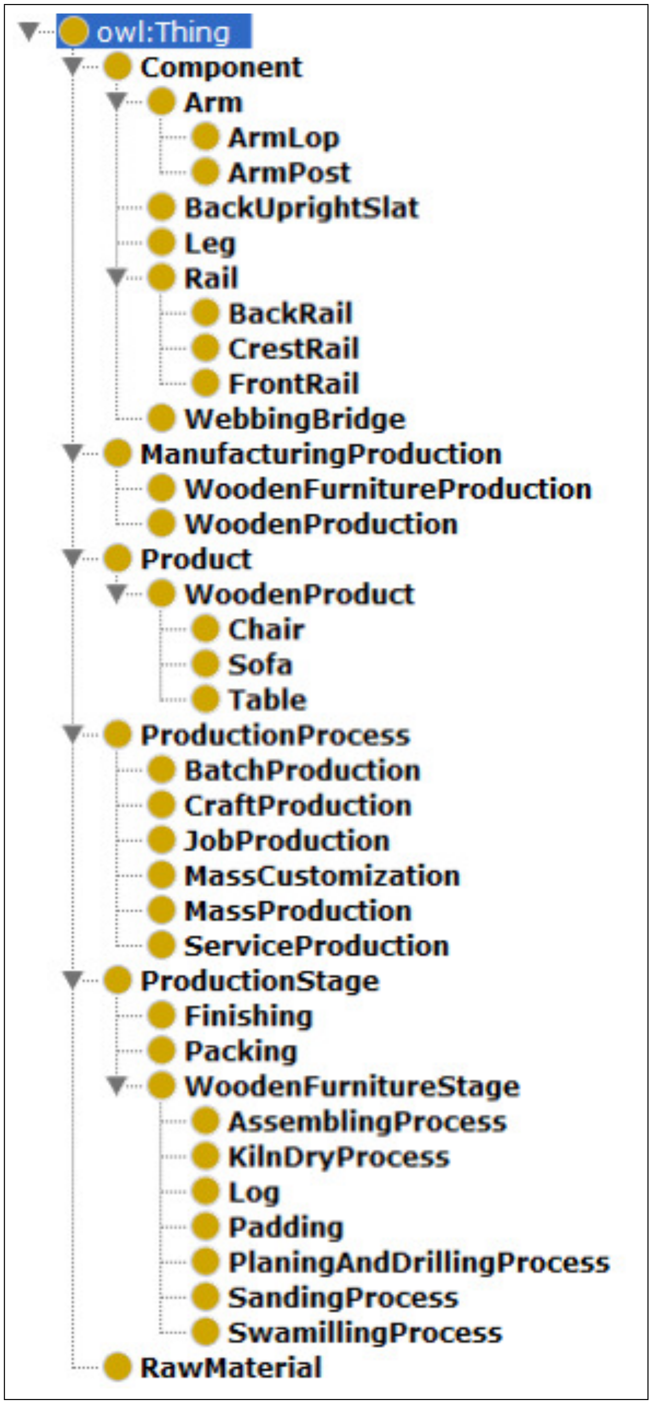

Figure 4. Digital Factory Model classes hierarchy OntoGraph export

- *Raw Material*, a class representing a basic material that is used to produce goods, finished products, energy, or intermediate materials which are feedstock for future finished products.

Figure 4 depicts the classes hierarchy of the Digital Factory Model using Protégé ontology editor, while the box in Figure 5 shows some axioms generating the classes hierarchy in Description Logics.

Arm ⊑ Component
ArmLop ⊑ Arm
ArmPost ⊑ Arm
AssemblingProcess ⊑ WoodenFurnitureStage
BackRail ⊑ Rail
BackUprightSlat ⊑ Component
BatchProduction ⊑ ProductionProcess
Chair ⊑ WoodenProduct
Component:
Courses: CraftProduction ⊑ ProductionProcess
CrestRail ⊑ Rail
Finishing ⊑ ProductionStage
FrontRail ⊑ Rail
JobProduction ⊑ ProductionProcess
KilnDryProcess ⊑ WoodenFurnitureStage
Leg ⊑ Component
Log ⊑ WoodenFurnitureStage
MassCustomization ⊑ ProductionProcess
MassProduction ⊑ ProductionProcess
Packing ⊑ ProductionStage
Padding ⊑ WoodenFurnitureStage
PlaningAndDrillingProcess ⊑ WoodenFurnitureStage
Rail ⊑ Component
SandingProcess ⊑ WoodenFurnitureStage
ServiceProduction ⊑ ProductionProcess
Sofa ⊑ WoodenProduct
SwamillingProcess
SwamillingProcess ⊑ WoodenFurnitureStage
Table ⊑ WoodenProduct
WebbingBridge ⊑ Component
WoodenFurnitureProduction ⊑ ManufacturingProduction
WoodenFurnitureStage ⊑ ProductionStage
WoodenProduct ⊑ Product
WoodenProduction ⊑ ManufacturingProduction

Figure 5. Digital Factory Model classes hierarchy excerpt

B. *Virtual Individual Model*

The Virtual Individual Model 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 module imports the Skills Virtual Model described later on in this section. The Virtual Individual Model is based on the Virtual Individual Model provided within the Pegaso project [65] and provides a formally multi-faceted description of the operator within the factory. The top level classes of this ontology are:

- *User*, which subsumes its direct subclass *Worker*. This one is used to profile a worker inside the company with all biographic info belonging to him/her (gender, age, language and so on). This class has object relation with fillers in classes belonging to the Skills Virtual Model, such has: *attendedCourse*, *attendedTrainingActivity* and *requiresSkill*;
- *Training Activity*, any formative activity a worker accomplishes in order to get trained for carrying out a specific production process phase (or step).
- *Courses*, a wider formative activity designed for workers making them able to use a particular technology. With respect to Training Activity a course includes many formative units and present interdisciplinary links to similar courses or related technologies courses.

In the box in Figure 6 some axioms generating the classes

BenchCarpenter ⊑ Woodworker
CNCMachinesOperator ⊑ Operator
CabinetMaker ⊑ Woodworker
ComputerControlledMachinery ⊑ Courses
Engineer ⊑ Worker
FurnitureFinisher ⊑ Woodworker
OfficeWorker ⊑ Worker
Operator ⊑ Worker
Technician ⊑ Worker
WoodSawingMachineSetter ⊑ Woodworker
Woodworker ⊑ Operator
Worker ⊑ User

Figure 6. Virtual Individual Model classes hierarchy excerpt

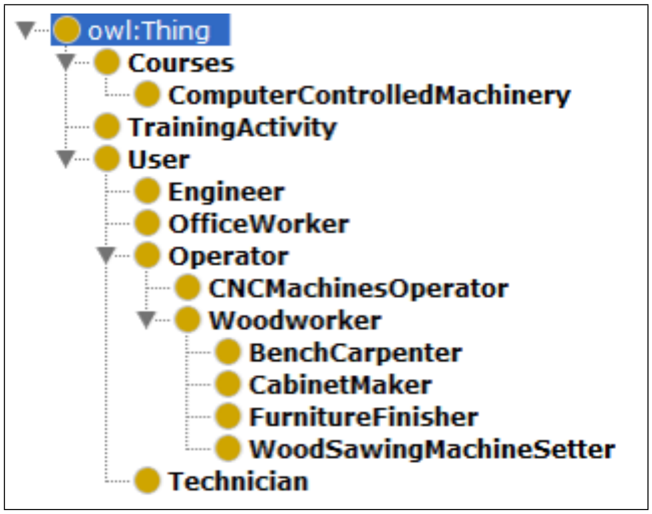

Figure 7. Virtual Individual Model classes OntoGraph export

hierarchy of the Virtual Individual Model are shown using the operators of Description Logics, while Figure 7 depicts the same classes hierarchy using the Protégé ontology editor.

C. Skills Virtual Model

The Skill Virtual Model provides a formal representation of the skills the operator need in order to perform each single phase of the production proces. It includes the knowledge of product and its parts, processes, competencies and operator capabilities. This model is imported from the previous one that in turn is imported from the first one. One of the existing model that have inspired this ontological model is the technical report entitled: *Skills for Key Enabling Technologies in Europe by the European Commission* [10]. The top level classes of this ontology are:

- *Competence*, a class embodying the concept of ability to do something successfully or efficiently within the workplace, specifically concerning a profession, e.g., programmer, manager, seller, etc.;
- *Skill* a class embodying the concept of ability to do something successfully or efficiently specifically concerning a practice in a production processing.

In the box in Figure 8 some axioms generating the classes hierarchy of the Skills Virtual Model are shown using the operators of Description Logics, while Figure 9 depicts the same classes hierarchy using the Protégé ontology editor.

Assembling ⊑ WoodworkingSkill
CutAndShape ⊑ WoodworkingSkill
DrillPresses ⊑ WoodwoorkingMachineSkill
EquipmentSetting ⊑ WoodworkingSkill
MillingMachines ⊑ WoodwoorkingMachineSkill
PickingUsingAREquipment ⊑ SelectivePicking
ProjectSpecificationVerification ⊑ WoodworkingSkill
SelectivePicking ⊑ WoodworkingSkill
UsageOfLathes ⊑ WoodwoorkingMachineSkill
UsageOfRouters ⊑ WoodwoorkingMachineSkill
UsageOfSaws ⊑ WoodwoorkingMachineSkill
UsageOfShapers ⊑ WoodwoorkingMachineSkill
WoodFasteningMachines ⊑ WoodwoorkingMachineSkill
WoodworkingMachineSkill ⊑ WoodworkingSkill
WoodworkingSkill ⊑ Skill

Figure 8. Skills Virtual Model classes hierarchy excerpt

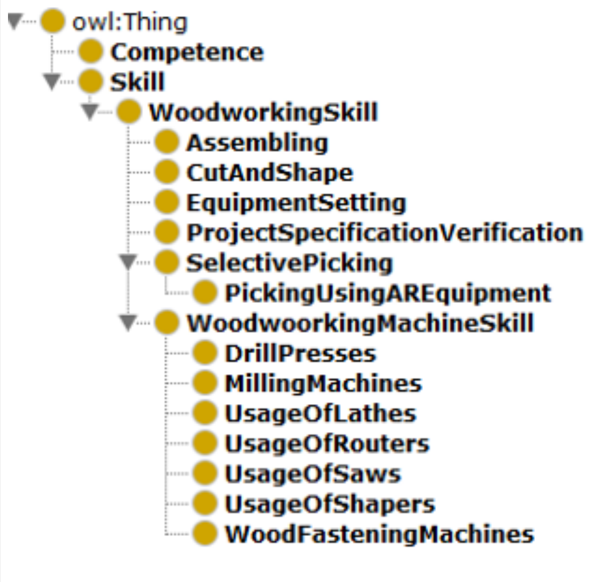

Figure 9. Skills Virtual Model classes OntoGraph export

D. The merged model

By merging the three models described above, the whole modularized knowledge layer for the proposed system is obtained. From such integration some interesting logical links between classes coming from the module parts derive, as shown in Figure 10 reporting the main object relations characterizing the whole ontology and described in DL language in the box in Figure 11.

The main *Object Relations* are the following ones:

- *attendedCourse*, which has *User* as broader domain class and *Course* as filler class. It establishing a logical link between the worker ontological individuals (with all its features) and the course individuals with all information strictly related to courses;
- *attendedTrainingActivity*, which has *User* as broader domain class and *TrainingActivity* as filler class. It establishing a logical link between the worker ontological individuals (with all its features) and the training activity specific to a particular production process step;
- *hasSkill*, which has *User* as broader domain class and *Skill* as filler class. It establishing a logical link

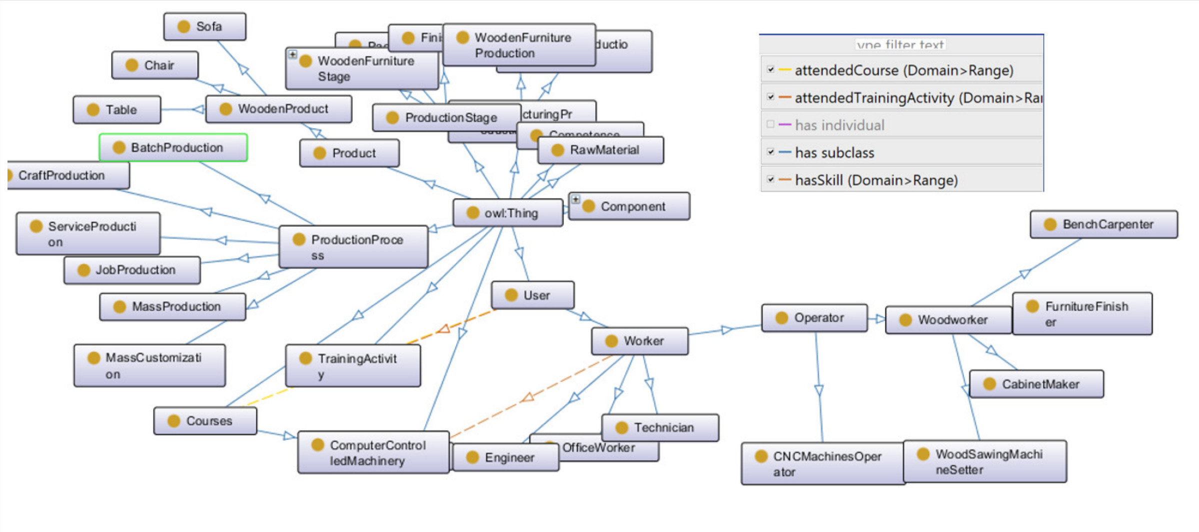

Figure 10. The main object relations characterizing the whole ontology

between the worker ontological individuals (with all its features) and the skills collected in the knowledge base, which assume relevance within the company due to its core business;

- *requireSkill*, which has *ProductionStage* as domain class and *Skill* as filler class. It establishing a logical link between the specific work step needed to carry out a processing and the skills collected in the knowledge base, which assume relevance in doing such specifi work activity.

$\exists$ attendedCourse Thing $\sqsubseteq$ User
$\top \sqsubseteq \forall$ attendedCourse Courses
attendedTrainingActivity
$\exists$ attendedTrainingActivity Thing $\sqsubseteq$ User
$\top \sqsubseteq \forall$ attendedTrainingActivity TrainingActivity
hasSkill
$\exists$ hasSkill Thing $\sqsubseteq$ Worker
$\top \sqsubseteq \forall$ hasSkill Skill
requiresSkill
$\exists$ requiresSkill Thing $\sqsubseteq$ WoodenFurnitureStage
$\top \sqsubseteq \forall$ requiresSkill WoodworkingSkill

Figure 11. Major object relations DL excerpt

V. CASE STUDY RESEARCH METHODOLOGY

In this section the process steps for conducting the proposed case study will be described, according to the guidelines suggested in [18]. Also in this work, we put the proposed case study in the context of other research methodologies and refer to general definitions of the term case study according to established works in the literature [66][67][68]. All dimensions resulting from the cited works emerge in this one, being this (1) an empirical method aimed at investigating contemporary phenomena in their context, (2) a research strategy that uses multiple sources of evidences, (3) a case where the boundary between the phenomenon and its context may be unclear, finally, (4) it is characterized by information gathering from few entities (people, groups, organizations) and lack of experiment control. This research is also in line with the "observational methods" proposed by [69]. Our case study is used for explanatory purposes, according the Robson classification [66], as it involves testing existing theories in confirmatory studies. It can be considered an *interpretive* case study, according to [70], as it attempts to understand phenomena through the participants' interpretation of the case study context. In figure 12, the study case research methodology followed here is summarized according to the steps mentioned in [18]. The main steps of the procedure are depicted in the green arrows and are as follows:

1) Case study design and planning;
2) Data collection and preparation;
3) Analysis of Data;
4) Reporting;
5) Reviewing.

Each phase will be detailed in the subsequent subsections and it is worth to mention here that the whole procedure is subject to continuous review by other researcher or stakeholders and the evaluation of each phase, also in this work, has been carried out through specific checklists at the end of each phase.

A. *Case study design and planning*

Acknowledging the general *mantra* that planning is crucial for every project (also in case study research like this), we have applied the minimal set of elements that a plan for case study should contain according to [66]: (1) Define what to achieve, the *Objective*; (2) characterize what is studied (*Case*); (3) review the frame of references about the objective, i.e., the *Theory*; (4) what to know about the case under study (*Research questions*); (5) the strategy for collecting data or evidence about the case and, finally, individuate a strategy for analyzing data (where to seek data).

Being this a case study exploratory and descriptive in nature, the Objective of the case study is more generally formulated and less precise than in fixed research design. According to the description of the case study described in section VI and what stated in the introduction, the case aims at demonstrates the use of advanced technologies from the

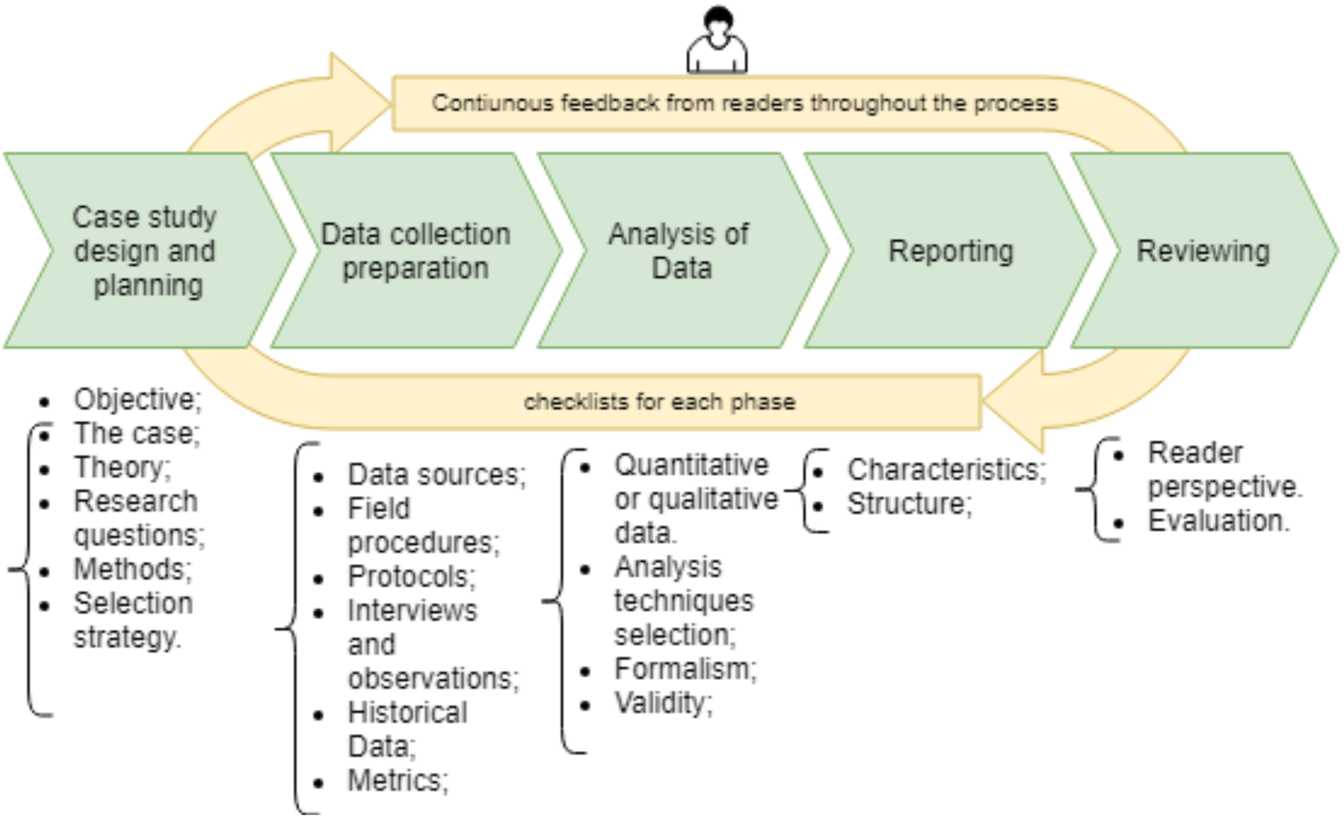

Figure 12. Case study methodology overview

Industry 4.0 panorama in order to create a user-centred factory environment, thus, we formulate the objective (Obj) as the question in the box below:

Obj: Are the advanced technologies from Industry 4.0 able to promote a user-centred factory environment in modern factories?

The case study is described in section VI too and is conceived as an holistic study according to [67], where two different scopes are addressed: (1) the ability of the system to support the worker in each phase of the production process, (2) the ability of the system to improve the level of comfort and wellness of the workers at a shop floor. The frame of reference, i.e. the theory, followed in this case study research has been defined in the direction of making the context of the case study research clear and is focused on Industry 4.0 literature In particular the conceptual models existing in the literature and advanced technologies have been reviewed and collected in order to fulfill the frame of reference for this case study research. The frame of references is described in Section 2, where a review of the main conceptual models for Industry 4.0 is shown, for example, the ”5C architecture for Cyber-Physical Systems, the Reference Architectural Model Industrie (RAMI) 4.0, and ”The Open Platform Communications Unified Architecture (OPC UA)” to cite a few. Furthermore, the references section shows the three inspiring paradigms from Industry 4.0, with a review of the enabling technologies for each of them: the Teaching Factory, the Visual Approach to Manufacturing (with AR/VR technologies) and the knowledge-based manufacturing systems.

The research Questions (RQs) for this case study research have been individuated in order to state what is needed to know in order to fulfill the objective of the study. The research questions specialize the objective breaking it into more detailed questions. Here three question have been reported:

RQ1: Does the proposed system enhance workforce skills and competences by promoting a continuous learning environment within the company?
RQ2: Does the proposed system augment the social sustainability within the company by promoting good community relations, respecting human rights and granting good working conditions?
RQ3: Does the productivity increase thanks to the good workers' condition the system is able to guarantee within the company?

In order to answer to the research questions, it is needed to collect evidences and data from the shop floor whose level of formalism and nature will be detailed in the subsequent sections.

B. Data collection and preparation

There are several different sources of information that can be used in a case study. In this one, we have used different degree of data collection techniques, according to [71]. Also, we have taken into account viewpoint of different roles inside the company, e.g., workers, managers and engineers, this way making the conclusion stronger than a conclusion based on a single source. Specifically, first degree data collection used involve real time data or information acquisition through for example interviews and observations at a shop floor, while, second degree collection data consists in the usage of software tools made available for the workers within the proposed system and automatically monitored. Finally, a third degree of collection techniques is used for example when historical data from previous production processes have been analyzed in order to compare the data of the new results with standard production methodologies outcomes (in terms of failure, production pieces for time units, and so forth). The first degree data collection is based on *Interviews*. In this work different types of interviews have been used according to the recipient of the interview itself. A fully-structured interviews, similar to a questionnaire-based survey, is used for workers engaged in the shop floor in production processes supported by the new system under study, while *open questions* have been addressed to managers and engineers. In the first case, the aim of the interviews was to seek to find relations between constructs and describe or explicate the case, while in the second case, the aim is to know how individuals (managers and engineers) qualitative experience the phenomenon. An interview session is divided into a number of phases. First the researcher presents the objectives of the interview and the case study, and explains how the data from the interview will be used. Then a set of introductory questions are asked about the background etc. of the subject. After the introduction comes the main interview questions, which take up the largest part of the interview. In order to get feedback and avoid misunderstandings, the major findings are summarized by the researcher towards the end of the interview. In general, in this case study interview sessions are structured according to the *funnel model* that begins with open questions and moves towards more specific ones.

C. Analysis of data

Since this case study research is a flexible research method, qualitative data analysis methods are used. According to [18], the basic objective of the analysis is to derive conclusions from the data, keeping a clear *chain of evidence*. This means that a reader should be able to follow the derivation of results and conclusions from the collected data. In order to achieve this, we have implemented a systematic analysis techniques where analysis has been carried out in parallel with the data collection. As soon as new insights come out during the analysis of collected data, new data must often be collected and instrumentation such as interview questionnaires are updated. In fact, according to Figure 12, each phase is subject to a continuous process of reviewing according to feedback received from readers and other researchers. The need for multiple researchers point of view comes form the attempt to reduce as much as possible any bias by individual researcher. This case study uses the *Hypothesis confirmation* techniques rather than the *Hypothesis generation* [72], as the study is explanatory and aims to confirm that a hypothesis is really true. The hypothesis are in line with the research questions previously stated. Firstly, hypotheses are generated and then they are confirmed in a procedures based on a series of steps. For instance, transcribed interviews from managers are initially analyzed by one of the researchers and properly codified in order to assign to each interviewee's point of view, a point in favor or not to the corresponding hypothesis being confirmed, then, the results from multiple interviewees are collected in order to summarize findings. Structured interview are less complicate in analysis due their structured nature. Here positive answers to a questionnaire coded for specific hypothesis to confirm are collected in order to obtain a confirmation or not based on the majority of collected answers.

D. Reporting

The report communicates the findings of the study, but is also the main source of information for judging the quality of the study. This article in not conceived as a fully reporting of the case study research upon which is based. For such scope, future activities have been planned in order to fully accomplish this task. This section just describes broadly the research methodology used in order to present our case study. This study may have different audiences, such as peer researchers, policy makers, research sponsors, and industry practitioners and is preliminary to further detailed reports.

E. Reviweing and validation

A set of checklists (Chk) for each phase have been listed in order to help reviewer and other stakeholder in order to validate the methodology and the correctness of the case study. A short list of some of them are shown as follows:

Chk1: What is the case and its units of analysis?
Chk2: Are clear objectives, preliminary research questions, hypotheses (if any) defined in advance?
Chk3:Is the theoretical basisrelation to existing literature or other casesdefined?
Chk4: Are the planned methods and measurements sufficient to fulfill the objective of the study?
Chk5:Is data collected according to the case study protocol?
Chk6: Is the analysis methodology defined, including roles and review procedures?
Chk7: Are there clear conclusions from the analysis, including recommendations for practice/further research?
Chk8: Are the case and its units of analysis adequately presented?
Chk9: Are the objective, the research questions and corresponding answers reported?
Chk10: Does the report contain conclusions, implications for practice and future research?

VI. 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*

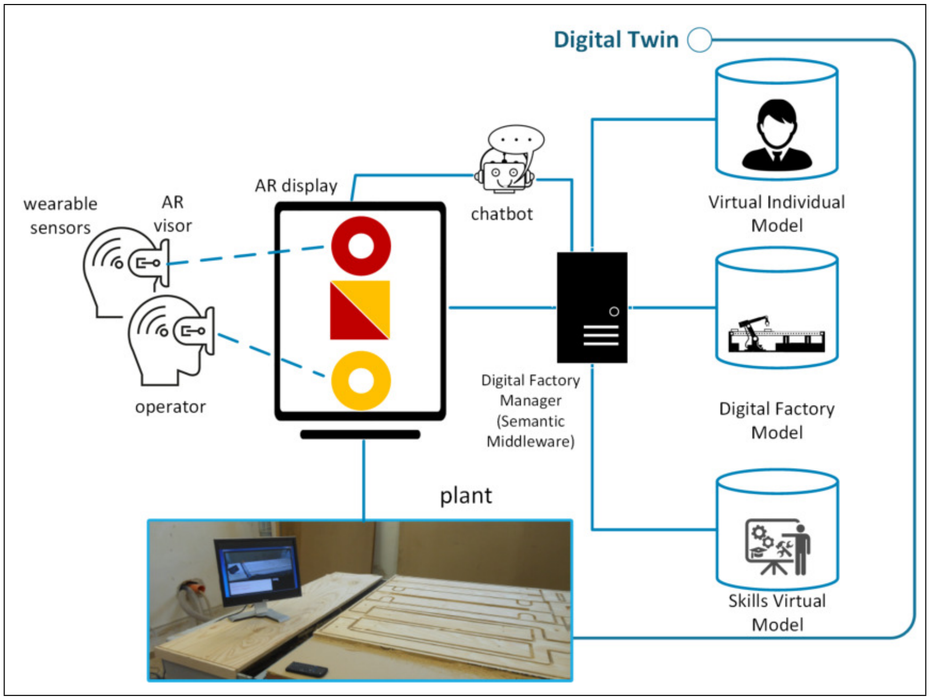

Figure 13. Case study conceptual overview

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 13, 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 [73], belonging to the Semantic Web technologies panorama [74]. The latter are used for formally representing the knowledge about the whole factory and the involved actors through the semantic model presented in the previous section.

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 [57]. 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 [59]; 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 closed-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 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 plan 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.

VII. 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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