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Ceramic Industry 4.0:

Paths of Revolution in Traditional Products

ABSTRACT

Industry 4.0 presents new challenges for traditional sectors of the economy, for example, the production of ceramic products. This chapter reveals how traditional ceramic industries can (1) assess, (2) plan, and (3) lead Industry 4.0 adoption. The findings are based on the Portuguese ceramic sector. Three interrelated dimensions of the fourth industrial revolution are studied, namely, (1) digital ecosystems, (2) security and safety, and (3) digital sustainability. Industry 4.0 is not restricted to high-tech products, cannot be addressed by one-size-fits-all solutions, and requires cooperation within business ecosystems. The authors propose a model for Ceramic Industry 4.0 and suggest guidelines for managers involved in global supply chains of traditional products. For theory, this chapter suggests emergent research opportunities for (1) sectorial maturity models, (2) data quality and regulatory compliance, (3) cyber-security and risk management, and (4) an integrated vision of sustainability in the digital era.

Keywords: Ceramic Industry, Sectorial Study, Traditional Products, Digital Ecosystems, Cyber-security, Digital Sustainability

INTRODUCTION

Industry 4.0 is changing traditional sectors of the economy (Brettel & Friederichsen, 2014). The impact of the forth industrial revolution is particularly relevant in small and medium sized enterprises (SMEs) with high levels of manual work. This is the case of ceramic companies that export the majority of their production and must be prepared to compete at a global scale. The ceramic industry from the European Union (EU)-27 accounts for 23 % of global ceramics production. According to the Eurostat, it represented a production value of 28 billion Euros in Europe and over 200.000 direct jobs in 2015.

Ceramic industry could be divided in ten major sub-groups: bricks & tiles, floor & wall tiles, sanitaryware, pottery & tableware, refractories, abrasives, clay pipes, expanded clay, porcelain enamel, and technical ceramics. All these ceramic industry subsectors are energy intensive, namely due to the drying and firing processes, which involve firing temperatures between 800 and 2000 ºC. The manufacture of ceramic products is a complex interaction of raw-materials, technological processes, people, and economic investments. It includes the transport and storage of raw materials, ancillary materials and additives (e.g. deflocculating agent – sodium silicate for preparation of raw materials), preparation of raw materials, shaping, drying, surface treatment, firing, and subsequent treatment (Quinteiro, Almeida, Dias, Araújo, & Arroja, 2014). Complexity of the production process is diverse and also the market requirements are different for each ceramic industry sub-group. Yet, the entire sector is affected by the fourth industrial revolution.

There are new technological opportunities for ceramic production. Recent examples include the use of mobile technologies in maintenance and product traceability (Barata, Cunha, Gonnagar, & Mendes, 2017), additive manufacturing, 3D printing, and simulation platforms (Smit, Kreutzer, Moeller, & Carlberg, 2016). However, Industry 4.0 in mineral non-metal manufacture raises many challenges for managers. We subscribe to the view of Oesterreich and Teuteberg (2016, p.136) about the "*urgent need for the development, understanding and assessment of frameworks, business models, reference models and maturity models for Industry 4.0 implementation with focus on technology, people and processes*". Industry 4.0 assessment models tailored for specific sectors of the economy will be essential. Other challenges include the creation of digital competencies (Prifti, Knigge, Kienegger, & Krcmar, 2017), the development of digital ecosystems (Andersen & Ross, 2016), improvement of work practices, and sustainable development (D. Chen et al., 2015). Moreover, there is an urgent need to identify and deploy pilot cases to guide the major changes towards industry of the future.

This chapter addresses Industry 4.0 in traditional sectors and specificities of mineral non-metal production in Portugal. The next section presents the background of our research. Afterwards, we identify challenges and opportunities in three key dimensions for the ongoing industrial revolution in ceramic, namely, digital ecosystems, safety and security, and digital sustainability. Next, we present the results of a field study and propose strategic recommendations. These developments emerged from a 120 participants' workshop that mobilized the entire industry. The chapter concludes revealing future research directions in the scope of digital transformation of ceramic production.

BACKGROUND

Industry 4.0 is gaining increasing attention by researchers worldwide. A keyword search made in Google Scholar using a combination of the terms "Industry 4.0", "Industrie 4.0", and "Fourth Industrial Revolution" reveals a constant growth in the recent years, especially since 2013. There are several databases available for scientific research (e.g. Scopus, EBSCO, B-on …), but we decided to start with Google Scholar because it presents a broad search result of both academic and practitioners contributions. Figure 1 illustrates this trend.

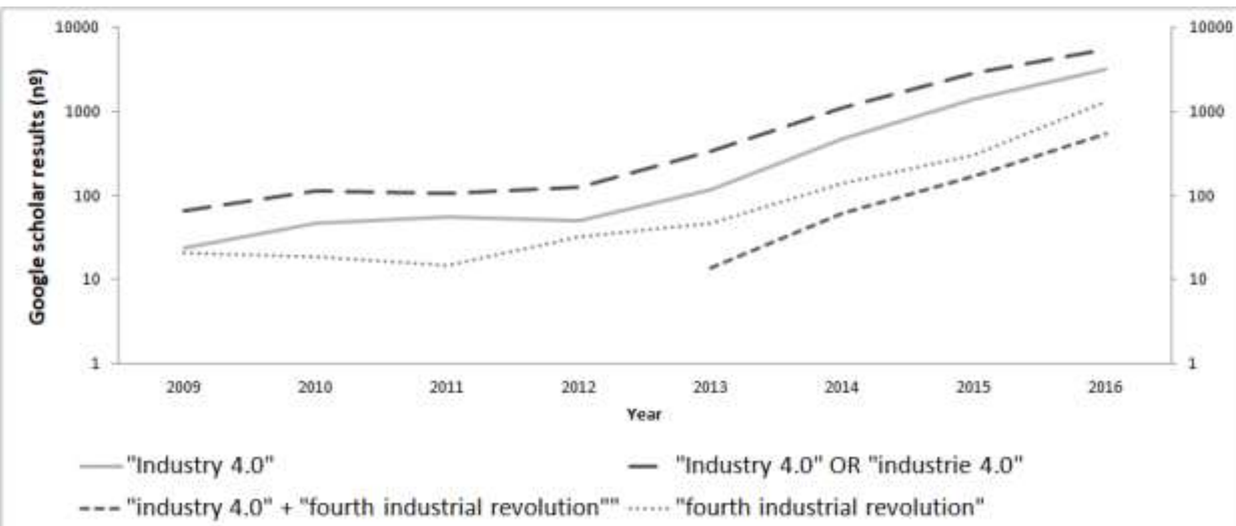

Figure 1. Evolution of Google scholar results about the topic of Industry 4.0

Industry 4.0, *Industrie 4.0*, or *Usine du Futur* are examples of the terms used to identify a priority for Europe: Industry digitalization. The examples include the digital single market (European Commission, 2016c), the mobility of business processes within the entire supply chain and the upgrade for an integrated digital world with profound socio-technical implications. The term Industry 4.0 was initially coined as a reference for high tech policies of the German government. However, digitalization and cyber-physical systems are still in an immature state, especially in traditional sectors of the economy, for example, ceramic and glass manufacturing. Later, the German government include other policies in parallel to Industry 4.0, namely, sustainability, nanotechnology, and internet-based services, requiring an integrated approach by managers. As stated by Prof. Klaus Schwab, "*we are in the midst of the Fourth*

Industrial Revolution, which will affect governments, businesses and economies in very substantial ways. We should not underestimate the change ahead of us" (Schwab, 2015).

In November 2016, Jean-Claude Juncker reinforces the idea that "*digital technologies are going into every aspect of life. All they require is access to high speed internet. We need to be connected, our economy needs it, people need it*" (European Commission, 2016a). In his speech we can identify several important figures, for example, 90% of the professions will soon require digital qualifications, online commerce represents a saving of eleven billion Euros, and there is a priority to support cloud initiatives and the Internet of Things (IoT). Three main goals are identified: (1) improve connectivity, (2) create a better context for business, and (3) promote growth and employment. The European Commission mobilizes fifty thousand million Euros of public and private funding for industry digitalization. Moreover, the agenda aims at the creation of new competencies for the digital era (European Commission, 2016b).

According to Smit et al. (2016), the scenario in each country and each economic sector differs and it is possible to identify specific requirements for Industry 4.0 implementation, as presented in Figure 2.

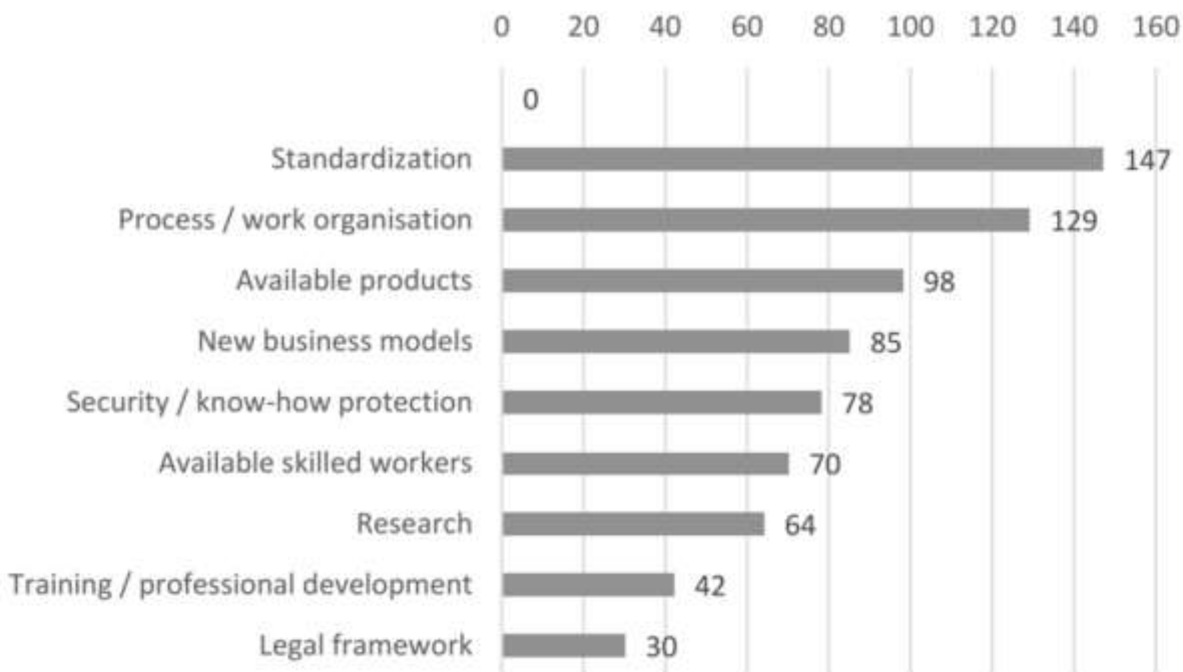

Figure 2. Requirements for Industry 4.0 – Results presented by BITKOM, VDMA and ZVEI in 2013, considering 278 companies (Acatech, 2013; Smit et al., 2016)

The standardization is a top priority, referring to the open systems and platforms needed to connect the different elements of supply chains. Next, it is necessary to redesign business processes (Vidgen & Wang, 2006). It is also necessary to create new business models supported by information systems. Mobile and cloud also poses new challenges for ciber-security. Finally, the study also points to the importance of research investments, social aspects, and a legal framework.

And what happens in the case of traditional products that represent a significant part of the world economy? For example, in construction "*only 19% of engineering and construction companies have advanced data analytics capabilities*" and "*it simply won't be possible for companies to achieve advanced digitization without making a step change in investment, given the continued rapid progress anticipated* *by companies who are already leading*" (PwC, 2016). There are several barriers to consider, as presented in Figure 3.

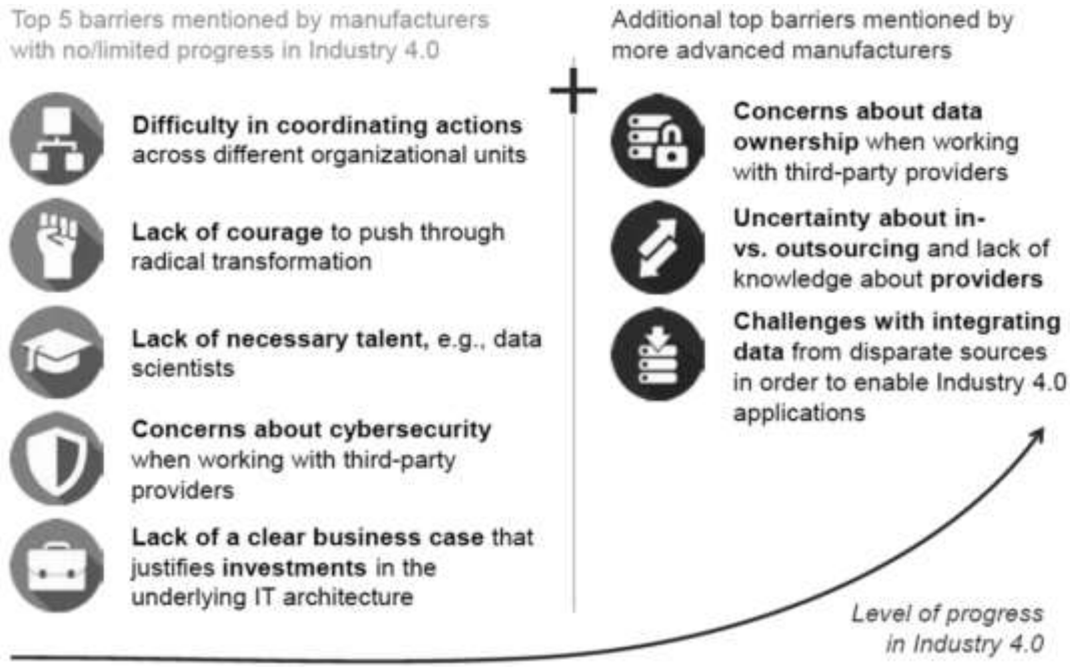

Figure 3. Barriers for industry digitalization – Global Expert Survey 2016 by McKinsey (Bauer et al., 2016)

There are several barriers that managers face to implement Industry 4.0, including organizational aspects, confidentiality, and integration in the supply chain. These barriers are particularly relevant in traditional sector of the economy, mostly supported by small and medium sized companies; more difficulties to cooperate with universities in advanced research; and fewer resources to invest in technological innovation. As a consequence, traditional sectors must joint efforts with industry associations to (1) diagnose their Industry 4.0 maturity level, (2) create a tailored roadmap according to the needs and opportunities of the supply chain, and (3) implement pilot projects to guide their Industry 4.0 efforts. The importance of pilot projects is also highlighted by (Bauer et al., 2016) "*providing the right implementation support both for an initial pilot, and for scaling the efforts across different sites is crucial to succeed*".

The next section presents specific challenges for traditional products that we identified in our contacts with Portuguese ceramic industries.

INDUSTRY 4.0: THE CHALLENGE FOR TRADITIONAL PRODUCTS

This section addresses three key dimensions for Industry 4.0 research in ceramic industry: (1) digital ecosystems, (2) safety and security, and (3) digital sustainability. The first dimension includes technological aspects of Industry 4.0 and specific guidelines for industry digitalization. Next, we approach the social perspective of Industry 4.0, considering the new risks for people but also opportunities to improve work conditions. Lastly, we address the sustainability element that is so crucial to ceramic industries, namely, the environmental and energy elements of Industry 4.0.

Digital Ecosystems

Digitalization is determinant to Industry 4.0 (Smit et al., 2016; Zhou, 2013) and involves social (Degryse, 2016; Prifti et al., 2017), technical (Leyh, Schäffer, Bley, & Forstenhäusler, 2017), and organizational (Weill & Woerner, 2015) challenges. According to Weill and Woerner (2015), companies should use digital technologies to increase their knowledge about the consumers and lead the creation of digital ecosystems involving multiple business partners.

A vision of business ecosystem was initially suggested by Moore (1996) and is inspired in biological ecosystems. In this context, businesses cannot be planned and managed apart from the environment. Organizations evolve trough symbiotic relationships between the business and other elements of the ecosystem, for example, their partners, customers, and suppliers. As a consequence, business innovation requires moving beyond the organizational borders and managers are advised to plan an ecosystem approach to digital success (PwC, 2016). As stated by Bharadwaj, El Sawy, Pavlou, and Venkatraman (2013) in "*a digitally intensive world, firms operate in business ecosystems that are intricately intertwined such that digital business strategy cannot be conceived independently of the business ecosystem, alliances, partnerships, and competitors*".

There are important pillars of industry 4.0, namely, cloud computing, mobile connectivity, social aspects, big data and associated analytics, and innovation accelerators such as robotics, additive manufacturing, or the internet of things (Brettel & Friederichsen, 2014; Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Smit et al., 2016). Big data means that large amounts of digital data can be analysed to assist the business strategies. Cloud computing and mobile devices are essential to create digital platforms that connect people and businesses around the globe. Smart sensors and location-based technologies are generating new digital data in real time that can be used to assist robots operation and support human decisions. 3D printing is now changing prototyping of new products and also the production process in many industries.

There are several contributions that explain how each pillar of industry 4.0 can contribute to digital ecosystems. Big data will be essential for additive manufacturing with ceramics, one of the most common materials for this form of manufacturing (L. Wang & Alexander, 2016). Cloud and mobile can support the development of new MES (manufacturing execution systems) platforms, more accessible and tailored for small and medium sized ceramic companies (REF. removed for referring). Internet of things can assist energy management in ceramics, for example, building ceramics (J. Wang, Huang, Chen, Liu, & Xu, 2016) where the energy contributes for an important part of the final product cost, namely it can represent till 30% of the total cost. Huson and Hoskins (2014) studied 3D printing for concept models and ceramic artworks. Each pillar can contribute for the creation of digital ecosystems (Andersen & Ross, 2016; Weill & Woerner, 2015) in the perspective of (1) the digital infrastructure (e.g. L. Wang & Alexander, 2016) or (2) digital services. Moreover, it is possible to find studies that use a combination of industry 4.0 enablers to propose new solutions for ceramics (e.g. J. Wang, Huang, Chen, Liu, & Xu, 2016).

The list is vast, but technologies are only one part of the equation. According to several authors (Acatech, 2013; Brettel & Friederichsen, 2014; Lasi et al., 2014; Smit et al., 2016), industries must evaluate its maturity, create a comprehensive digital strategy and implement pilot projects to evolve in their Industry 4.0 efforts. The next section addresses possible tools and approaches to evaluate industry 4.0 readiness and prepare a roadmap.

Design-time of Industry 4.0: assessing maturity levels and establishing the strategy

There are several maturity models for Industry 4.0, however, the existing proposals are recent and there is a lack of proposals that completes the procedure model of development for transfer, evaluation, test, and maintenance (Becker, Knackstedt, & Pöppelbuß, 2009). In fact, some models are still under development, for example, FIR (2017), INTRO4.0 (WP5) Eureka project "Introduction strategies of Industry 4.0

methodology and technology for SMEs" to end in 2018 (KIT, 2016), COTEC maturity model for Portuguese industry, or IPH Hannover (IPH, 2017). Table 1 presents a list of academic and practitioners' models that are available to assess Industry 4.0 and establish a digital strategy.

Table 1. Models to assess Industry 4.0 maturity

Industry 4.0 Assessment Model	Model Description	Model Stages
(PwC, 2017)	An online self assessment model for industry 4.0 created by a global consulting company. It suggests to (1) conduct the online self assessment, (2) identify needs for action, and then (3) benchmark against other companies	Includes four stages (I Digital Novice, II Vertical Integrator, III Horizontal Collaborator, and IV Digital Champion) and six dimensions, namely, (1) Business Models, Product & Service Portfolio; (2) Market & Customer Access; (3) Value Chains & Processes; (4) Information Technology (IT) Architecture; (5) Compliance, Legal, Risk, Security & Tax; and (6) Organization & Culture
(Rockwell Automation, 2014)	The Connected Enterprise Maturity Model is a practitioner's model proposed by Rockwell Automation, a leading company in industrial automation. The model offers guidelines to implement advanced networks of operations technology (OT) and information technology (IT)	Five stages (from 1-assessment to 6-collaboration)
(Isaka, Nagayoshi, Yoshikawa, Yamada, & Kakeno, 2016)	A maturity model for production systems developed by Hitachi. It suggests the use of image analysis as a sensing technique	A plant at level 1 uses data for visualization of their site. Level 2 connection, allows product traceability and level 3 analysis, work automation and process optimization. The following stages are 4 measurement, to identify and solve production bottlenecks, 5 prediction, and the most advanced 6 symbiosis, where resources are optimized and production plans coordinated with company stakeholders
(IMPULS, 2017)	Industry 4.0 readiness self assessment commissioned by the IMPULS Foundation of the German Engineering Federation (VDMA). It is a comprehensive model that addresses social, organizational, and technological aspects	There are six readiness levels ranging from 0 – insignificant Industry 4.0 activities to 5 - top performers

Industry 4.0 Assessment Model	Model Description	Model Stages
(Leyh et al., 2017)	The System Integration Maturity Model Industry 4.0 (SIMMI 4.0) considers four dimensions to assess the IT system landscape – vertical integration, horizontal integration, digital product development, and cross-sectional technology criteria	Five stages that start at Stage 1 – Basic digitization level and reaches a maximum of 5 - Optimized full digitization.
(Knoke, Missikoff, & Thoben, 2017)	Collaborative Innovation Capability Maturity for virtual manufacturing enterprises	Five stages aligned with the Capability Maturity Model (Paulk, Curtis, Chrissis, & Weber, 1993)
(Schumacher, Erol, & Sihn, 2016)	Model that includes social, technical, and organizational dimensions to assess Industry 4.0 readiness in manufacturing. These authors considered a total of nine dimensions, each one calculated as a weighted average of different items (62 in total). It is a comprehensive model with radar charts to visualize data and identify improvement priorities	The stage is assessed as a continuous result from 1 to 5.
(Ganzarain & Errasti, 2016)	Focuses on the process of change in diversification strategies. It is necessary to (1) define a vision, (2) establish a roadmap, and (3) implement Industry 4.0 projects ensuring training and risk management	The first stage is 1 – Initial (inexistent industry 4.0 vision) and can reach a maximum of 5 – detailed transformation of business model.

The studies presented in Table 1 highlight the importance of assessment for Industry 4.0. There are also other studies focusing specific technologies, for example, a reference model and roadmap for Internet-of-Things in manufacturing (Soldatos, Gusmeroli, Malo, & Di Orio, 2016), industrial internet (Menon, Kärkkäinen, & Lasrado, 2016), and cyber-physical systems (Westermann, Anacker, Dumitrescu, & Czaja, 2016). Assessing is the first step, then, it is necessary to take actions to go digital, as presented in the next section.

Run-time of Industry 4.0: Pilot projects in the ceramic industry

After evaluating Industry 4.0 readiness, organizations must implement their digital strategy. Nevertheless, there are challenges for SMEs. A study promoted by the European Parliament recognizes that one obstacle to the participation of SMEs in the supply chain of Industry 4.0 is the "*capacity to run pilot projects to test out Industry 4.0 mechanisms and potentially limited access to facilities to test advanced solutions*" (Smit et al., 2016). Other barriers to develop Industry 4.0 projects in SMEs include the lack of awareness about technologies, high investments required, the need for specialized IT staff, and the dependency from big companies (Smit et al., 2016). We also found these evidences in the ceramic industry, requiring significant efforts from governments and associations to put Industry 4.0 in the managers' agenda.

A tailored roadmap for Industry 4.0 implementation must involve the creation of a digital infrastructure, digital business services (Immonen, Ovaska, Kalaoja, & Pakkala, 2016) and digital business processes (Vidgen & Wang, 2006). The need to complement infrastructure investment (e.g. cloud platform, IoT) with new services and processes becomes clear with the LEGO case study presented by Andersen and Ross (2016). While the initial focus was in the creation of new software platforms and infrastructure acquisition, recent advances include the creation of new digital services accessible to customers and business partners. Yet, a roadmap that expands company borders also requires to implement mechanisms of trust, a key element to ensure cooperation between elements of the supply chain (Grzybowska, Kovács, & Lénárt, 2014) and integration, which is an essential aspect for Industry 4.0.

Portuguese ceramic industry already started to implement Industry 4.0 but the context of ceramic production poses particular problems, as presented in Figure 4.

Figure 4. Going digital in traditional manufacturing: the challenge of numerous products

Figure 4 present the moulding phase of the ceramic production (on the left) and a plant area that mixes moulds used in the process (bellow, on the right) and products that are still under development process (on the top-right). This case is specific to the table and ornamental ware ceramic subsector (other production processes such as tiles of technical ceramic have different characteristics) but it can be used to illustrate the (1) multiple product references simultaneously under production, (2) the fragile characteristics of the product (consistency of the ceramic material) in all the stages (e.g. presenting difficulties to use robots), (3) the low cost of each unit, posing difficulties, for example, in the use of traceability devices such as RFID tags, (4) the highly manual process that is mostly supported by paper records in SMEs.

In spite of the difficulties that are evident in traditional products such as ceramic, Industry 4.0 is not restricted to high tech industries. In fact, ceramic industries are emerged in global supply chains and must implement systems that adhere to the digital ecosystem needs. Moreover, the complexity to directly implement Industry 4.0 technologies (e.g. robots, simulation, mobile technologies) demands for new cooperation efforts between the industry, the university, ceramic associations and technological centres.

The result of this cooperation is already visible and new pilot projects are under development. Table 2 presents examples of pilot projects and ideas developed in the Portuguese ceramic industry.

Table 2. Industry 4.0 in the ceramic industry: pilot projects for traditional products

Industry 4.0 Pilot Project	Description
Mobile Manufacturing Execution Systems (mMES)	This project started by CTCV – Technological Center for Ceramics and Glass, aims at the creation of a cloud-based MES for mobile devices. The main purpose of this system is to assist small ceramic industries (that use paper records in almost all the production stages) in digital production records allowing real-time information to the company partners (including suppliers and customers). The use of mobile technologies reduces the financial investment and simplifies the system adoption
Cloud Laboratory Information Management System (cLIMS)	Ceramic products require (internal/external) testing to ensure that product complies with regulations and customer requirements. Although large companies usually have laboratorial data digitalized, small companies continue to use disconnected spreadsheets and paper. Cloud-based LIMS allow to integrate data from external laboratories with the company data, also having specific interfaces for customers and to follow nonconformance actions
Mould digitalization	Moulds are one of the main tools for ceramic production but highly demanding of storage space. Each mould is specific to a product reference and companies consider them a valuable asset to keep. For example, if a customer asks for additional quantities, the ceramic company must use the same mould or create exact replicas. We can find cases of moulds kept for decades that are never needed again. What if we digitalize the moulds and then recreate them when needed using 3D printing devices? The idea is already under development but present difficulties, for example, there are complex moulds with multiple parts that make the “digitalization” – “printing” process costly, requiring algorithms to decide which moulds are economically viable to digitalize – recreate or keep in its materialized form
Digital energy management using simulation, cloud and IoT	Energy management systems are not new. However, most of the existing systems mainly acquire data and raises alerts of energy consumption. Simulation and integration with the production lines will provide additional functionalities to current energy management systems that now include affordable sensors and actuators

Industry 4.0 Pilot Project	Description
Big Data for Marketing and Internationalization	Analysis of Big Data can provide valuable information for designers. The design requirements change across the globe and over time. The potential of Big Data is now being used to assist design trends and market trends (e.g. potential increase of construction in specific countries that justify new local factories or new internalization actions)
Sensing Ceramics	Traditional products such as ceramic tiles can include sensors (e.g. temperature) to assist intelligent houses. It is possible to include new materials in ceramic, for example, sensors and solar systems, as we detail later in this chapter. The incorporation of new elements in ceramic will generate added volumes of digital information
Traceability systems	The use of QR codes in ceramic can assist production control, quality control, and provide digital information to the consumer of traditional products. Recently, a Portuguese ceramic company inserted QR codes in the final product to present specific details that may increase product value (e.g. lot information and quality characteristics, and a video about the production of that specific product reference)
Ceramic Industry 4.0 Maturity model	The creation of a sectorial maturity model for ceramic industry is under development in Portugal, involving universities, companies and the ceramic industry association. The project aims at the development of a tailored model that includes a portfolio of solutions for each ceramic subsector

The examples presented in Table 2 are not exhaustive; its purpose is to illustrate examples of small scale projects that are accessible to traditional industries. Lessons learned include (1) the need to joint efforts between multiple entities, (2) think about digital ecosystems and not merely internal applications of technology or isolated B2B – Business-to-Business channels, (3) explore pilot projects for horizontal/vertical integration, increase trust amongst supply chain elements, and introduce improvements that redesign business processes. It seems very appropriate to quote Michael Hammer in this case: "*don't automate, obliterate*" (Hammer, 1990).

The social and environmental aspects are equally important in ceramic industry 4.0, for example, to ensure the protection of human workers in an increasingly automated production setting and protect the environment. This is the challenge that we address in the next section.

Safety and Security

Industry 4.0 will promote changes on the way occupational safety and health (OSH) is considered nowadays. If some aspects are predictable, like safety aspects related with the increasing of robots in workplaces, others questions arising are more difficult to predict or could be speculative. In the later, it could be mentioned the psychological impact of disruptive changes in work or the decrease of human error as cause of accidents. Additionally, the dissemination of new technologies in manufacture such as additive manufacturing and nanotechnologies, occurring side-by-side with digitalization, are also factors affecting OSH.

In Table 3 some aspects related to Industry 4.0 and their possible impacts on OSH are presented.

Table 3. Industry 4.0 technologies/enablers and their relation to safety

Industry 4.0 Technology/Enabler	Impact on OSH
Robotization	Collaborative robots safety Human training relating to robots Decrease in manual work Hazardous tasks performed by robots
Internet of things	Cyber-security related to safety of cyber-physical systems
Complex embedded software	Hackers or malware as cause of malfunction leading to accidents
Big-data	Increase of capacity to deal with OSH knowledge
Sensors (widespread use)	Workplace environment continuously monitored
Augmented reality	Reduce hazards in maintenance tasks OSH information and warnings in real-time

Digitalization can contribute to increase safety and health in workplaces, reducing heavy tasks, eliminating hazardous operations and creating new prevention opportunities, like sensors or training tools. On the other hand, new risks will appear or existing ones will increase, particularly, those related with the robotization and increasing de-humanization of the work. A third category of impacts are the new challenges to OSH, in this particular, the security-safety relation. In the following items, the possible negative impacts and challenges are discussed.

Security of IT systems and relation with safety

The Smart Factory concept (Lucke, Constantinescu, & Westkämper, 2008) poses challenges related to the safety and security. These factors are considered critical to the success of the manufacturing digitalization and, consequently, of business success, since neither processes nor products should represent a risk to persons (including workers and consumers) or environment (Acatech, 2013). In ceramic industry, process safety is a key element and should not be jeopardized by IT security breaches. It is necessary that IT systems are secure against misuse and unauthorized access to prevent modifications or destruction. Besides industrial piracy or information confidentiality, issues like sabotage or terrorist acts are crucial. Even unintended acts could cause accidents if equipment controls are improperly accessed (Acatech, 2013).

As a result of integration between Information and Communication Technologies (ICT) and Industrial Control Systems (ICS) vulnerability to cyber-attacks is an workplace safety issue (Steijn, Vorm, & Luiijf, 2016). Besides the known possible risk emerging from Industry 4.0 there are also other unknown risks that could emerge (Steijn et al., 2016). From the previously exposed, it is clear that the security-safety relation is more complex with Industry 4.0.

Interaction/integration human-robots in the workplace

Robots are already present in industry, operating in isolated cells, both with physical and/or virtual barriers, usually avoiding the contact with workers. Considering the increase of robots in manufacturing, and most of all the increasing interaction human-robots as one of the main characteristics of Industry 4.0

(Erol, Jäger, Hold, Ott, & Sihn, 2016; Zhou, 2013) the occupational safety aspects are crucial (Fryman & Matthias, 2012). New risks are identifiable while robots will be no longer confined to a location or operating inside a protective cage (segregation paradigm) and collisions between robots and people or other hazardous events could occur (Bicchi, Peshkin, & Colgate, 2008). In a recent study, Dutch researchers identified a set of threats and vulnerabilities related with collaborative robots: change of task, unforeseen situations trust in machines, shared responsibility, regulatory gaps, non-compliance and cyber security (Steijn & Luiijf, 2016). In the same research several control measures are suggested to face the risks arising from the foreseeable interactions.

The basis for safety rules and future regulations are the three laws of robotics[1] defined by Isaac Asimov in 1942 (Magruk, 2016), although those could be adapted or complemented (Steijn & Luiijf, 2016).

Nanotechnologies

In parallel with digitalization of industry it is also expected the increase of the use of nanomaterials. Ceramic industry is already one of the industrial sectors using several nanomaterials (DECHEMA/VCI, 2011) to achieve products with improved proprieties, in particular photo catalytic ceramic tiles and bactericide sanitaryware (J. Chen & Poon, 2009; van Broekhuizen, van Broekhuizen, Cornelissen, & Reijnders, 2011).

Since a nanomaterial is, in general, more hazardous than the bulk form of same chemical compound, special care should be considered during its use. There are numerous studies in nanotoxicology field pointing to possible harmful effects of nanomaterials to human health and environment (Bleeker et al., 2015). Considering the uncertainty related with nanomaterials, it is important to act with specific concerns on OSH. In short, nanotechnology should be side-by-side with nanosafety (Savolainen et al., 2013) and occupational risk management is crucial (Technical Committee ISO/TC 229, 2012).

Information about OSH aspects related to nanotechnology and, in particular, exposure to nanomaterials is available from several international organizations, among others the European Commission and National Institute for Occupational Safety and Health (NIOSH) in the United States of America (European Commission, 2013; NIOSH, 2009).

There are several methods for exposure and risk assessment methods available, both based on qualitative (Vervoort, 2012) and quantitative methodologies (Duarte, Justino, Freitas, Duarte, & Rocha-Santos, 2014), and the tiered approach for exposure assessment should be followed (Environment Directorate OECD, 2015). Recommendations for occupational risk control during nanomaterials handling are also published (Cornelissen, Jongeneelen, van Broekhuizen, & van Broekhuizen, 2011; NIOSH, 2013), being highlighted the hierarchy of controls (Technical Committee ISO/TC 229, 2012) presented in Figure 5.

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[1] - First Law: a robot may not injure a human being or, through inaction, allow a human being to come to harm. Second Law: a robot must obey the orders given it by human beings, except where such orders would conflict with the First Law. Third Law: a robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

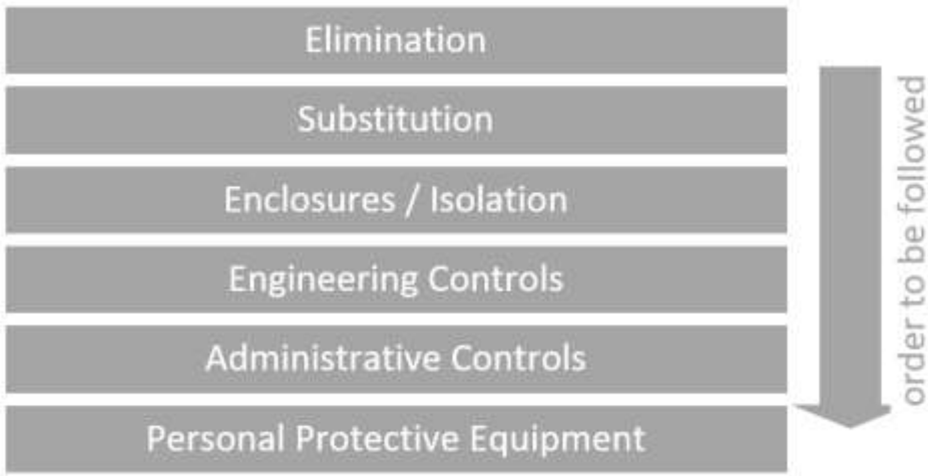

Figure 5. Hierarchy of controls in nanotechnology indicating the order to be followed (adapted from Technical Committee ISO/TC 229, 2012)

Additive manufacturing

The risks related to additive manufacturing depend most of all of the technology used. Emission of particles and/or vapours from the used materials are concerns common to other manufacturing technologies and the risk will depend, not only of the process but most of all, the hazardous nature of the materials. Considering different additive manufacturing technologies (Afshar-Mohajer, Wu, Ladun, Rajon, & Huang, 2015; Wong & Hernandez, 2012) it is possible to identify several risk factors, such as high temperatures, lasers of different types and hazardous chemicals (both in vapour or particulate form). Since the use of additive manufacturing technologies in ceramic industry is already a reality, in particular 3D printing of models and it is expected to increase, special attention should be given to these aspects. In recent research about exposure to both ultra-fine particles (UFP) and volatile organic compounds (VOC's) there were found exposures of concern (Afshar-Mohajer et al., 2015; Yi et al., 2016).

Psychosocial aspects and risks

It is expected that jobs will change and new jobs will emerge with the technological evolution (World Economic Forum, 2016). These changes will raise new challenges related to OSH, not only in consequence of differences in tasks and operations but also the way existing tasks will be performed. In fact, workers will interact with new interfaces and deal with increasing information. It is expected that physical demand of work will drop but psychological stress will increase (Gabriel & Pessl, 2016). The emotional and mental stress may raise with increasing flexibility in work and a diminution of communication and cooperation between employees since interaction between humans and machines will increase (Degryse, 2016; Gabriel & Pessl, 2016). Also, the constant work performance evaluation could be cause for increase of stress (Degryse, 2016). On the other hand employees' work-life balance could improve (Gabriel & Pessl, 2016).

Safety-by-design

Considering that process automation has been an increasing safety factor (Fadier & De la Garza, 2006), it is expected, and it is important, that safety aspects will be considered during design of Industry 4.0 factories. For the last decades, several researchers in the Safety Science field are calling the attention for the need to improve safety in workplaces considering the hazards in the design phase, developing safer equipment's, processes or products (Fadier & De la Garza, 2006; Hale, Kirwan, & Kjellén, 2007). NIOSH, launched a campaign to reduce risks in workplaces called Prevention Through Design (Schulte, Rinehart, Okun, Geraci, & Heidel, 2008) and more recently, several researchers and institutions raised the importance of safety-by-design in the nanotechnologies field (Morose, 2010; Silva, Arezes, & Swuste, 2016). Furthermore, it is relevant to consider the concept Security by Design in development of IT systems (Acatech, 2013), for the reasons already mentioned.

This section highlights the importance of combining technical and social aspects in the paths of the ongoing industrial revolution. The next section reinforces this need, including the sustainability element that affects the entire society.

Digital Sustainability

The implementation of Industry 4.0 implies a digital sustainability strategy, which aims to minimize environmental impacts while improving operational measures and supporting sustainable growth. Cyber-physical systems require the analysis of ceramic production life cycle in order to optimize the economic, social and environmental risks and opportunities, with the purpose of reduce environmental impacts in all the life cycle at the previous design stage. Additionally, it is necessary to improve the operational efficiency of ceramic processes in order to reduce the depletion of natural resources, pollution and associated ecological impacts. On the other hand, it is expected to acquire more accurate and real-time information and data regarding environmental aspects and impacts on ceramic manufacturing.

According to the European Commission, the construction sector is considered the highest energy consumer in EU, accounting for almost 40% of the total energy consumption and contributing almost 36% to the EU's total greenhouse gas (GHG) emissions and produces 15% of the total industrial waste. Among the most commonly used construction materials, cement and ceramic materials are two of the most energy intensive construction materials. Ceramic products are one of the oldest building materials and generate a series of environmental impacts over their life cycle (Almeida, Dias, Demertzi, & Arroja, 2016; Quinteiro et al., 2014). Portugal is a country with a long tradition in ceramics, both in production and consumption, and is ranked as one of the top European manufacturers of ceramic products due to the high quality of raw materials. The Portuguese ceramic industry produces a variety of products adapted to building works, such as bricks, covering materials, flooring tiles, etc. This industry is responsible for a number of environmental aspects like energy consumption (energy intensive), gaseous emissions (CO2, NOx, HF, HCl, heavy metals, particulate matter, etc), liquid emission (suspended solid, chemical oxygen demand, heavy metals) and wastes (broken ware, packaging waste, plaster moulds, sludge, etc).

Assessing the environmental impacts of the different types of ceramic products has become crucial to improving the environmental performance of this sector. Such assessment can be achieved through Life Cycle Assessment (LCA) studies based on ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b) standards, applied to the different stages of a product's life cycle. Ceramic product have significant impacts during the manufacturing process, namely the firing stage of production is one of the most relevant in terms of environmental impacts. But the type of ceramic raw materials, the kiln operation conditions, electricity consumption, raw materials used and type and distance of transport are key elements that justify the variability in impacts like global warming (climate change), ozone layer, abiotic and fossil resources depletion, eutrophication, acidification, and photochemical oxidation (Almeida et al., 2016; Quinteiro et al., 2014).

Cerame-Unie, representing the ceramic industry in Europe, stresses that resource efficiency requires a Life Cycle Assessment (LCA) approach that takes into account all stages of the product, including its durability, lifespan and reduction of resource consumption over the use phase. Although LCA is a recognized instrument to assess environmental impacts in industry including ceramic one, it requires a lot of environmental data, major collected manually, validation of the quality data and it is very time consumer (Almeida, Barata, Dias, & Arroja, 2015).

Industry 4.0 and digital systems provide a new approach in which physical production processes and ICT grow more closely together (Gabriel & Pessl, 2016). Embedded sensors, systems, mobile devices and production facilities are integrated and able to communicate with each other via the internet, in order to monitoring and controlling the ceramic process in a transparent way. The cyber-physical systems represent a further evolution from the existing embedded systems. The same priority can be identified in direct digital manufacturing (D. Chen et al., 2015).

On the other hand, the digital systems and the construction and operation of robots will have new environmental aspects and risks, namely the new materials that may be hazardous and potential emissions to environment (e.g. particles and volatile organic compounds (VOC's)). These aspects must be monitored and controlled.

Table 4 presents examples of possible Digital Sustainability Strategies that can be applied in the ceramic industry to achieve a sustainable development.

Table 4. Examples of digital sustainability strategies applied in ceramic process and products

Digital Sustainability Strategy	**Key Aspects**	**Description**
Ecodesign or design for sustainability	Sustainability Life cycle thinking	Life cycle thinking – aims at the prevention of environmental impacts throughout their life cycle while eco-innovation and new business opportunities are encouraged and potential cost savings arise
Selection of low-impact materials	Digitalization of quarries Incorporation of waste on a circular economy perspective	Digitalization of quarries (clay, feldspar, Kaolin, etc) in order to have precise information on the quantity and quality and the best way to explore the quarry and at same time the environmental recovery
		The use of by-products by the industry or as raw material for other industries allows cost reduction facilitating the supply of raw materials and the elimination of waste deposit. Main constraints pointed out are related to quality control due to the not homogeneous composition – use of sensors and embedded systems Incorporation of industrial waste for the production of ceramic tiles, in a way that the by-product quality and quantity is continuously monitored and interact with production line in order to avoid defects. For example, a ceramic tile can reach up to 80% of recycled material by weight while retaining the strength and versatility (example: InEDIC[2])

[2] http://www.prepare-net.com/project/inedic-innovation-and-ecodesign-ceramic-industry [accessed 18/12/2017]

Digital Sustainability Strategy	**Key Aspects**	**Description**
Reduction of the material use	Reduction in products thickness	There are several examples of tiles with reduced thickness and mechanical performance in buildings. IoT can contribute in this purpose, reducing tile thickness from 12 mm to 4 mm (Light ceramic floor tile by Revigres is one example, with resource efficiency through the all life cycle)
Reduction of the environmental impact in the production phase	IT network systems High efficiency process and resource control Innovations and ceramic materials	The optimization of the industrial production process throughout Industry 4.0 and digital sustainability can lead to a reduction of energy, CO_2 and other combustion pollutant emissions, as detailed information on each point of the ceramic production process, resource (e.g. clay, sand, feldspar) and energy use can be monitored and optimized over the entire value chain
		Controlling consumptions (e.g. electricity, natural gas consumption) as well as emissions (gaseous emission, liquid emission) in main unit process like spray-driers, driers and kilns in a continuously optimized IT network system
Reduction of the environmental impact in the use phase	Eco-innovations for energy performance or multifunctionality	Innovation regarding new bricks with high thermal, mechanical and acoustic performances that improves the energy performance of the building or multifunction products. Example: SolarTiles – Integrated photovoltaic into ceramic products for high efficiency for building coatings (roof and facade claddings) incorporating thin-film photovoltaic cells (COMPETE2020, project 3380)
		New materials like ceramic tiles with phase change materials (PCM) to improve thermal characteristic and energy efficiency in buildings. Project examples include ThermoCer developed by Cinca and CTCV in Portugal (QREN, project number 23143) or Selfclean (QREN 21533) - Ceramic coating with self-cleaning properties, purifying functions, high efficiency and durability, by modifying its surface with nanostructured photocatalytic materials
Transport and logistics	Information systems for the distribution of ceramic products Smart mobility, smart logistics	New information systems for the distribution phase of ceramic products will make “smart mobility” and “smart logistics”

Digital Sustainability Strategy	**Key Aspects**	**Description**
Optimizing the installations of end-of-life systems of ceramic materials	Information systems for installation and dismantling	The installation of ceramic products into buildings (e.g. brick or ceramic tile) or the final disposal of products can be simplified and optimized

The integration of digital sustainability strategies is a key dimension for sustainable ceramic industry and the development of "smart ceramic products", changing to a dynamic process that entails continued improvement, diversification and industrial upgrading, and technological eco-innovation throughout the value chain.

DEVELOPING CERAMIC INDUSTRY 4.0 – STRATEGIC RECOMENDATIONS

A workshop involving 120 participants from ceramic industry was scheduled to February 2nd 2017, three days after the announcement of Industry 4.0 strategy by the Portuguese government. The morning session had presentations from governmental entities, Industry 4.0 experts, and industry associations. The afternoon aimed to evaluate the perception of maturity in specific dimensions of Industry 4.0 (e.g. vertical integration, competencies) and understand priorities for key processes of the industry (e.g. energy management involving IoT and predictive algorithms). A mobile app was created to allow interaction between researchers and the workshop participants, as presented in Figure 6.

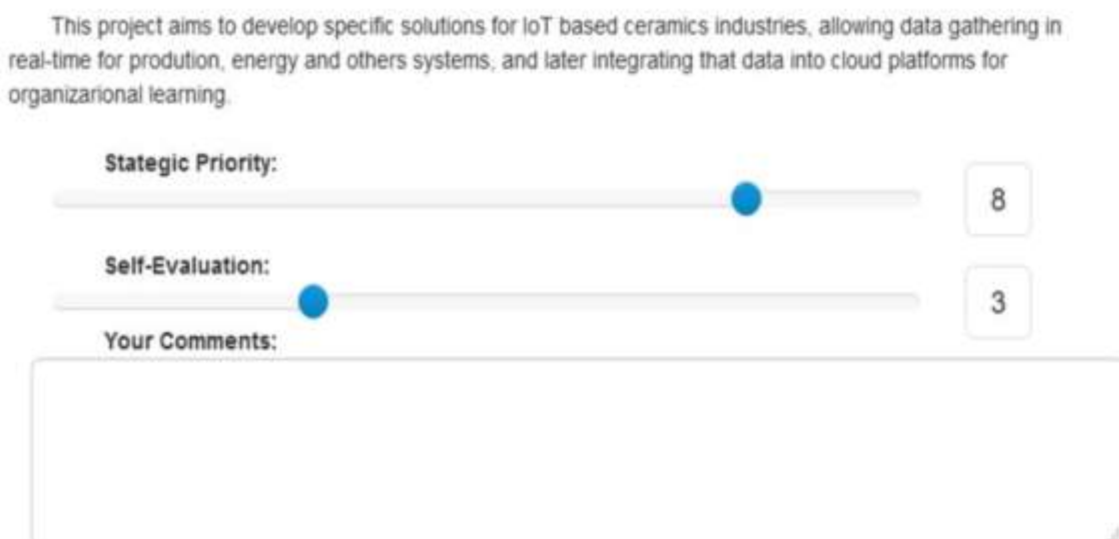

Figure 6. Industry 4.0 Workshop – Mobile app support (extract)

The mobile app included the possibility to evaluate company maturity on the topics presented and to define the strategic priority of the organization, for Industry 4.0. key processes were selected (e.g. energy management, digitalization) and a discussion about possible solutions occurred (e.g. IoT for energy management, Big data for marketing). The results of voting were used for the debate and to define strategies to develop Industry 4.0 in ceramic industry, presented in Figure 7.

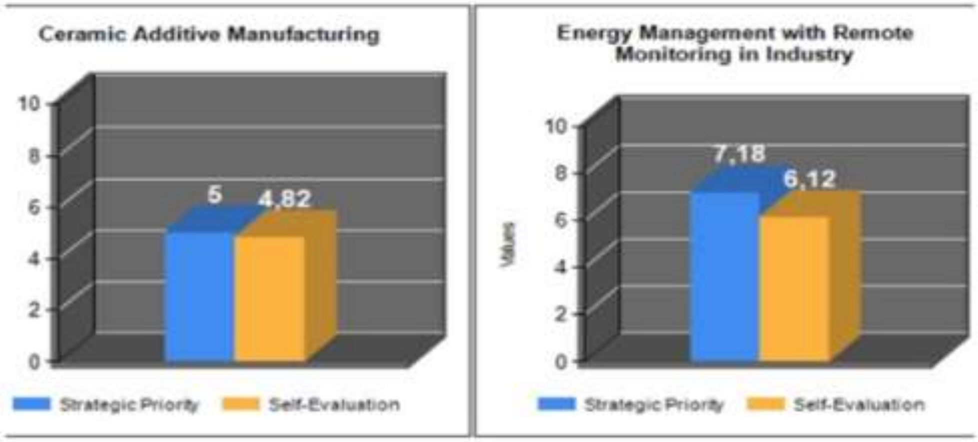

Figure 7. Industry 4.0 Workshop – Strategic priorities for the ceramic industry (extract)

The most disrupting topics of robotization and additive manufacturing were not considered as top strategic priorities for the ceramic industry. The workshop participants were more enthusiastic about the creation of a digital services cloud, energy management solutions, new marketing strategies using Big Data (e.g. design trends for ceramic products). The workshop discussion allowed us to confirm that:

- Not all technological components associated with Industry 4.0 are relevant for their digital strategy;
- A higher maturity stage does not mean that the component has low priority (e.g. the participants considered to be well prepared in terms of energy management, but this topic is so important for ceramic and glass industries that they still consider it a top priority for all Industry 4.0 actions);
- The majority of respondents considered themselves in a positive stage (above 5 in a scale ranging from o to 10) but our field studies shows a less developed scenario;
- To be successfully, Industry 4.0 in traditional sectors of the economy should not have a mere technological focus. It is necessary to consider social and organizational aspects, for example, safety and sustainability that we also addressed in this chapter.

As a result, we defined a strategic model towards Ceramic Industry 4.0. Our purpose with this high-level representation is to (1) highlight the importance of cooperation between different elements of the supply chain in traditional products and (2) include social, organizational, and technological elements in the company roadmap for industry 4.0. We used the model to communicate the results of our workshop with the industry. The model suggests that managers must define a multidisciplinary team and create pilot projects that address five interrelated dimensions (1) the industry context (e.g. relation with stakeholders, horizontal integration), (2) people (e.g. safety, competencies), (3) industrial process (e.g. energy reduction via IoT, digitalization via 3D printing), (4) Industry 4.0 Technologies (e.g. cloud platforms and augmented reality systems), and (5) information/data (e.g. data quality and protection. The model is outlined in Figure 8.

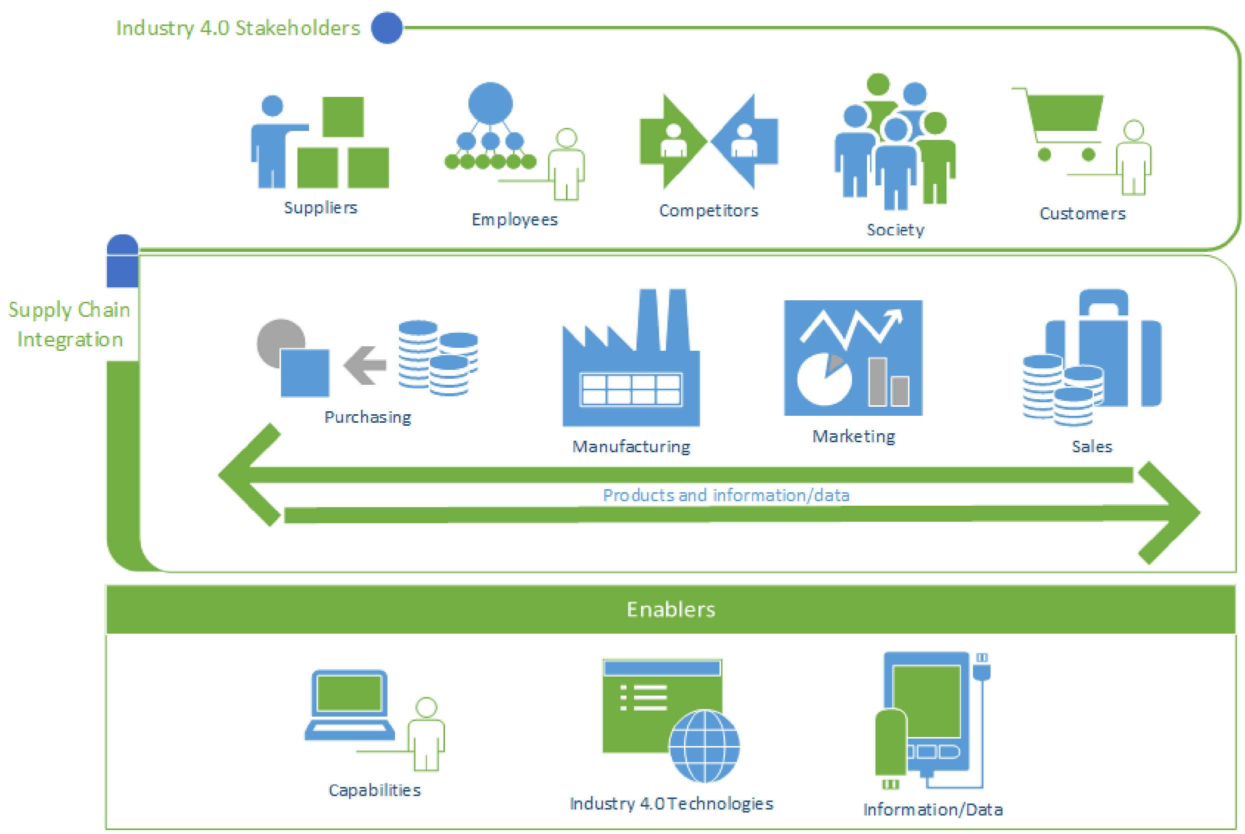

Figure 8. Strategic model for the development of Ceramic Industry 4.0

The model presented in Figure 8 suggests that digitalization involves several (internal/external) stakeholders of the organization. Therefore, managers should involve different experts in their pilot projects, develop internal competencies for Industry 4.0, and cooperate with their customers, suppliers, and research institutions. Industry 4.0 complexity does not recommend "Industry 4.0 ready solutions" offered by single suppliers.

The model also suggests developing pilot projects within the ceramic process supply chain. For example, (1) using IoT to monitor raw material inventory directly by the suppliers, (2) adopting new robots for manufacturing, (3) use Big Data potential to identify trends in global markets (e.g. design trends that are so crucial to create products that adhere to architecture movements), (4) implement augmented reality to support product selection by the end users or cloud platforms to simplify data integration.

Industry 4.0 technologies will generate large amounts of information/data and use a plethora of technologies (e.g. sensors, algorithms, standards) that evolve faster than ever. More data also represent additional responsibilities such as data protection measures and responsible use of resources (e.g. energy reduction). Therefore, academic partnerships with the industry are essential to get access to emerging developments and lead the industrial revolution.

The simplified model offers guidelines for industrial managers. First, it recommends creating knowledge networks with multiple stakeholders. Horizontal and vertical integration is not possible to achieve in isolation from the supply chain partners and regulatory bodies. Second, it highlights the need to address multiple points of the value chain, once again, involving internal and external stakeholders, for example, when drastic changes in the process creates the possibility to decentralize production in multiple small units around the globe. Third, Industry 4.0 enablers are complex and require specialized staff in the organization. Examples include new skills in Industry 4.0 technologies and a professional structure to deal with information/data (e.g. protects data vulnerabilities, comply with regulations, generate value with the data, for example, with data scientists). The non-strict vision of industry 4.0 as a mere technological investment can help managers to avoid what Arvidsson, Holmström, and Lyytinen (2014) named as "*strategic blindness: organizational incapability to realize the strategic intent of implemented, available system capabilities*". Next, we explain the avenues for future research that captured the attention from the managers in the Portuguese ceramic industry.

FUTURE RESEARCH DIRECTIONS

Digital ecosystems can determine the survival of the factories of the future. Current research in this area is changing the landscape of production processes, using decentralization (Brettel & Friederichsen, 2014) and new platforms connecting multiple elements of the supply chain. To compete in global markets, companies must prepare their digital infrastructure and create digital services and processes to comply with the requirements of their customers. There are also challenges that include data quality (essential in integrated systems), data protection and privacy, and regulations that improve interoperability between different systems.

Current maturity models to assess Industry 4.0 are too generic to be useful and most of these tools are still under development. It is necessary to create tailored maturity models for different sectors of the economy (Barata & Cunha, 2017). This evidence emerges when we address specificities of each economic sector; one approach to Industry 4.0 in automotive or aeronautical does not necessarily represent an optimum solution in traditional sectors of the economy. Future research is needed to test the effectiveness of the maturity models in practice, the managers' adherence and the utility of the tools to assist roadmaps implementations - not merely as a diagnosis tool.

There are many challenges and opportunities in the security and safety fields in the ceramic industry. Cooperative robots safety and cyber-security are already identified as relevant issues. Also the additive manufacturing occupational risks and nanotechnologies need special attention from the OSH researchers. The development of sensors to monitor chemical, physical and biological contaminants in workplace environment and to monitor workers biological parameters is another relevant area of future research. The uncertainty related to the role human work in manufacturing industry in the future poses questions in research fields like ergonomics and human factors or psychosocial risks. The new professions arising from the industrial changes will need new OSH paradigms.

The emergence of the Internet of Everything (connected objects and people) will generate vast amounts of data that will help us understand more about the way we interact with each other and improve sustainability in ceramic processes. Moreover, the increasing number of sensors and connected devices puts energy management on the top of researchers' priorities. The challenge to digital sustainability is to identify transformation potential including ways of interact in a manner that promotes the reduction of the energy consumption, gaseous and liquid emission and waste prevention. On the other hand relevant research, education, and political constraints (e.g. limiting energy production up to the precise needs of consumers, forecasts of natural events or disasters, preventive maintenance) regarding the sustainability impacts of Industry 4.0 will have to be developed. If sustainable practices are seen as value added to the ceramic process that will act as drivers to sustainable development and eco-innovation, On the contrary, if they are merely seen as a cost burden or a constraint to business and innovation, they will not be successful. New economic and social models will be developed based on a key principle of sustainability.

CONCLUSION

Industry 4.0 affects all sectors of the economy, yet, traditional manufacturing industries face additional challenges and require specific solutions. This chapter addresses three key dimensions of Industry 4.0 in the context of ceramic production, namely, digital ecosystems, safety and security, and digital sustainability. In each case we include examples that are under development in industry, progressively changing the business strategy, the social, and the technological landscape of ceramic production.

Additionally, strategic recommendations for Ceramic Industry 4.0 are provided. The guidelines emerged from a recent workshop with 120 participants and preliminary results of research projects in ceramic industry.

There are also limitations to our study that must be stated. Industry 4.0 is a vibrant area of research and many other examples could be important for traditional products. The challenges and recommendations are well supported by theory and practice in the Portuguese ceramic industry but each sector of the economy can have specificities to consider. For this reason, it is advised to tailor generic models to the need of each economic sector and also to the need of each company. The strategic model presented in this chapter aims to assist industry managers to evolve in Industry 4.0, ensuring that a comprehensive approach is selected, yet, it is a simplification of the complex reality of Industry 4.0.

This chapter can assist researchers in the identification of new opportunities for the industry of traditional products. Small changes can have a major impact in less developed industries. For managers, this chapter presents a multidimensional perspective of Industry 4.0 challenges in ceramics, real examples that can inspire pilot projects, and strategic recommendations for the vision of Ceramic Industry 4.0.

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KEY TERMS AND DEFINITIONS

Ceramic Industry 4.0: The ongoing initiatives for digital transformation in the Portuguese ceramic sectors of the economy. The roadmap includes social, technical, and organizational changes that are necessary to compete in global supply chains.

Digital Ecosystem: Socio-technical system inspired in natural ecosystems that connects a group of companies/people/things via digital platforms. It requires a digital infrastructure and digital services to interact with external parties of the organization. Similarly to natural ecosystems, sustainability and safety are critical aspects.

Maturity Model: A tool used to assess the current state of an organization in a specific context of analysis. This type of models is also used to communicate best practices and guide organizational improvements.

Digital Sustainability: The opportunities raised by digital transformation to meet the sustainability goals and reduce the carbon footprint.

Life cycle assessment: Assessment of the environmental impacts applied to the different stages of a product's life cycle.

Nanosafety: The different techniques, tools, and approaches related to the safety of nanotechnology. It involves the policies, standards, and research needed to ensure the proper development and use of nanomaterials in the factory of the future.

Safety-by-design: The use of methods in early stages of the product life cycle to minimize hazards and comprehensively improve health and safety.