Industry 4.0 in Medium-Sized Enterprises

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Industry 4.0 (I4.0) is a broad term increasingly used across industries to refer to organisational, social and economic changes that result from the intensive use of digital technologies. It generally implies the adoption of a series of practices that rely heavily on the Internet and other technologies to share and analyse data, most notably, the Internet of Things (IoT), cloud computing and artificial intelligence (AI). I4.0 data-driven processes are touted to enhance productivity and expand supply and value chains in new product development. In manufacturing, I4.0 practices include collecting and sharing data using sensors in interconnected devices and using digital technologies for processing and analysing data to take new actions.

industry 4.0 design advanced manufacturing IoT

1. Implementation of I4.0 Solutions in SMEs

Industry 4.0 practices and solutions essentially involve the optimisation and digitalisation of computer technologies that were implemented toward the end of the 3rd industrial revolution. Digitalisation aims to allow interconnectivity, automation, machine learning, and real-time data collection as techniques to improve product, supply and consumer life cycles. As noted by Matt et al. [1], large companies have rapidly embraced digitalisation and are working intensively on introducing the required technologies. Conversely, they describe that small and medium-sized enterprises (SMEs) face significant hurdles in digitalisation by possessing neither the readily available human nor financial resources [1][2]. In many developed countries, SMEs form the backbone of the economy; they account for the largest share of the gross domestic product and are also significant employers [3][4]. Thus, new concepts, examples and applications of digitalisation in SMEs have to be explicitly provided to pave the way for a successful implementation of I4.0 and increased economic impact. Matt, Modrák and Zsifkovits [1] describe how-over the past 10-year development of I4.0-the primary I4.0 mechanism that SMEs have successfully been able to implement has been to optimise manufacturing processes via a frugal combination of cyber and physical worlds to improve manufacturing outcomes.

Withing the I4.0 landscape, digitalisation is supported by vertical data integration, cloud computing, IoT, big data analysis, advanced automation and robotics, simulation, cyber security, virtual and augmented reality and artificial intelligence [5][6]. With a multitude of options available and limited resources, it is paramount that guidelines and frameworks are developed to help SMEs approach digitalisation [7]. Furthermore, to achieve a tangible impact on the transformation of manufacturing, such frameworks must consider the main challenges SMEs face. For example, a report by the World Economic Forum identified that technology vendors focus on offering services and developing solutions for large manufacturers as such sales are likely to offer more significant returns [4]. As a result, there is a limited offer of data capture and analysis solutions tailored for SMEs, which suggests a need for creativity and resourcefulness to not only adopt these new technologies but also integrate them into business activities that translate the benefit to sales, partnerships, or other returns on investment. Moreover, the OECD found that many SMEs lack managerial awareness of IoT solutions and the value of data-driven decision-making, are incapable of assessing risks in the digital space, and lack specialists with the required technical expertise to manage data collection [3]. With a limited understanding of the benefits of adopting data capture and analysis practices, SMEs fail to perceive a clear return on investment.

Although barriers exist to SMEs' digitalisation, opportunities and enablers for the required transformation exist. After an extensive analysis of manufacturing SMEs in Italy, Ricci et al. [8] found that openness to collaborate with external stakeholders is crucial to digitalisation because external stakeholders can assist companies in recognising and adopting new technologies. Furthermore, as noted by Cotrino, Sebastián and González-Gaya [7], IoT cost has reduced dramatically over the last few years, and the number of available technologies has multiplied. Similarly, cloud computing is a well-established technology with low cost, and virtual reality (VR) is flexible and can now be readily implemented in many production processes [7]. For example, there are support models with case studies implementing VR technologies to design assembly systems [9] and assistive technologies to improve productivity [10].

Furthermore, SMEs have historically demonstrated an ability to innovate and implement novel solutions via their simple organisational structures and small size. This characteristic typically allows them to react faster to market, technological and environmental changes [4]. Therefore, research should focus on developing flexible approaches for reducing digitalisation's financial risk. Veneri and Capasso [11] predict that the IoT era will undergo continuous shifts and evolution. Given this expected rapid change, The researchers believe that to reduce financial risks, SMEs should leverage IoT by continuously improving infrastructure, skills and technologies instead of incurring one-time, large-scale transformations.

Although the aforementioned challenges and enablers are common in SMEs, companies might face different hurdles depending on their existing technologies, production processes and people [12]. Thus, another essential aspect of approaching digitalisation is understanding how to assess I4.0 readiness and maturity. Using I4.0 maturity models allows companies to conduct a self-assessment of areas they need to tackle to position themselves better to implement I4.0 technologies [13]. Amaral and Peças [12] thoroughly review different frameworks to assess manufacturing I4.0 maturity and propose a method that explicitly targets SMEs. Thus, there is a great benefit for SMEs to explore these tools when defining digitalisation strategies, which should focus on adopting technologies to strengthen competitive advantages and improve internal weaknesses [14].

Moreover, existing works that focus on processes to assist digitalisation of manufacturing companies have taken different approaches and leave room for further exploration. On the one hand, Stoldt et al. [15] have proposed a framework to approach digitalisation that focuses on detecting and addressing production inefficiencies to improve productivity. However, their framework focuses on technical aspects and ignores critical human factors that affect how technologies are used. For example, as previously explained, the lack of talent to operate and maintain complex systems is a significant barrier to SMEs' digitalisation. Similarly, Abdulnour et al. [16] present an approach for SMEs to adopt technologies to increase productivity using simulation and mathematical models. Still, many SMEs lack the expertise required to adopt such solutions. On the other hand, Sampayo and Peças [17] propose a comprehensive framework for designing and developing cyber-physical systems, but its design is not explicitly intended for the needs of SMEs. Nevertheless, although not much attention has been given to usability factors, these frameworks have an aspect that is crucial for de-risking SMEs digitalisation, using strategic planning to recognise opportunities and prototyping to reduce risk. This is supported by Ramadan et al. [14], showing that the successful implementation of I4.0 practices is tied to internal organisational forces and strategy.

2. The Role of Designers in I4.0

I4.0 research usually focuses on manufacturing and supply chain processes, but little attention has been paid to how the products are designed within this new manufacturing paradigm [18]. However, as Kuys, Koch and Renda [18] explain, manufacturing and supply chain fundamentally exist to support the creation of products purchased and used by an end customer. Thus, it is critical to understand how designers adapt to the technologies that I4.0 encompasses. García Ferrari [19] states that designers must adjust to the amalgamation of the physical, biological and digital spheres that digitalisation brings. As he explains, the interconnectivity through the Internet and other technologies will enable the creation of different products and services; thus, although designers face challenges, there are also opportunities to transform the design practice.

Most literature regarding the transformation of design remains explorative. For example, Franzato [20] states that digitalisation is changing how products are produced and consumed and argues that with new tools and practices, such as open designs on the Internet, design is becoming a creative network where everyone can contribute. The changes in how products are made and consumed, and the changes in the disciplines involved in such processes, also suggest that design roles could vary depending on which area of I4.0 design interacts with. On the one hand, collaborative robotics and additive manufacturing for making products are relevant areas of increased importance in digitalisation [21]. On the other hand, the computerisation of objects in the IoT also brings opportunities for designers [21].

What Cross [22] discussed more than four decades ago still applies:

“Design is changing; its products and processes are changing, so too is the role demanded of the designer”.

For example, years after Cross' statement, the accessibility to computers enabled 3D modelling and tactile-screen technologies allowed digital sketching. These design tools are now embedded in design education and practice and are considered standards [23]. The same may occur now; new technologies change manufacturing and supply chains, so the tools and role of design will likely change. However, designers' exact roles in I4.0 are still undefined as the digitalisation of manufacturing is still in its infancy.

Although much is unknown, a recent study by Kuys, Koch and Renda [18] that surveyed 190 product/industrial design practitioners worldwide suggests tools and activities that may become general practice in design in the I4.0 era. For example, they said, VR and augmented reality facilitate designers' and users' interaction with objects in the digital space, merging it with the physical. This could speed up the design process and facilitate 3D modelling. Furthermore, topology optimisation tools, which use software to refine designs for additive manufacturing, could become widespread [18]. These technologies and the accessibility to 3D printing equipment at low prices may allow designers to manufacture products themselves and reach the end customers directly [18], thus, changing the traditional relationship of designers with engineering and manufacturing facilities. The elimination of traditional stakeholders usually involved in commercialising a product towards a new paradigm of blended design and technological processes could lead to a market transformation. However, this new designer-customer process may only represent a portion of the market and apply to certain products. Is there room for designers to bring value to large-scale manufacturing processes within the factory of the future? It is believed that there is an opportunity to exploit designers' creativity, user-centredness and visualisation skills in this context. Furthermore, design processes can bring value to the manufacturing transformation. Design thinking processes, for example, rely on re-phrasing problems, prototyping and visualisation techniques to rapidly evaluate solutions for innovation, having human needs as the foundation of the approach [24]. Such flexibility to solve complex problems could be leveraged when analysing how to adopt new technologies, using prototypes and evaluation tools that consider the benefits digitalisation will bring to all stakeholders.

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