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Enterprise Integration and Interoperability in the Footwear Industry: Challenges for Collaborative Digital Manufacturing Networks in Society 5.0

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Abstract. The footwear manufacturing industry requires high specialization of the operations for the realization of shoe collections, which necessitates a high collaboration among relevant enterprises (e.g., shoe maker, suppliers, sub-contracted companies). This work aims to analyze challenges to ensure interoperability, digital transformation and enterprise integration for the Footwear Digital Manufacturing Networks (FDMNs) towards a collaborative and interoperable Society 5.0. The advances in digital technologies facilitate the emergence of the FDMNs and have the ability to invigorate this manufacturing sector. However, ensuring interoperability and digital transformation is rather challenging. A framework is advanced to address areas where future research and development work can bring significant value in the context of Society 5.0.

Keywords: Footwear Digital Manufacturing Networks, Footwear Industry, Interoperability, Enterprise Integration, Digital Transformation, Society 5.0.

1 Introduction

Industrial environments are complex ecosystems, where diverse stakeholders interact and cooperate [1]. The digital collaboration among the enterprises in the footwear manufacturing sector is particularly challenging due to its distinctiveness, and specific technical and business prerequisites [2]. The footwear manufacturing industry distinguishes by a make-to-order manufacturing practice, dynamic season-directed product demand, and the production cycles are rather short; due to the high specialization of the operations involved towards the realization of the final products (e.g., cutting, stitching, finishing, assembly), different companies jointly collaborate to execute specific activities [3].

The up-stream segment in the footwear manufacturing industry comprises the activities primarily executed by three types of companies: the shoe maker (SM) (e.g., the company that creates the finished shoe), Sub-contracted Companies (SCs), and Supply Companies (SPCs); the SCs are enterprises hired by the SM to manufacture pieces of a shoe or the whole shoe, and the SPCs deliver raw and/ or specific shoe components, such as: uppers, heels, or metallic accessories [3]. Interoperability and enterprise integration must be ensured to support the digital collaborations among the

different companies in this industry, and to make sure that the data exchanged is interpreted in the same way by the communicating enterprises.

Interoperability commonly concerns the capability of two or more components or systems to transmit/ interchange information and consume it [4]. The absence of interoperability obstructs the enactment of collaborative manufacturing business processes [5]. With the emergence of Industry 4.0 and digital technologies (e.g., Internet of Things (IoT), cloud computing, cyber-physical systems), digital production networks [6] (also called in the literature digital manufacturing networks [7]) emerged. Within the scope of this article, a Footwear Digital Manufacturing Network (FDMN) is a form of collaborative organization (see: [8],[9],[10],[11]) that specifically targets the footwear industry, and comprises heterogeneous and geographically distributed enterprises which put together their physical and digital resources and competences to attain a specific goal (e.g., manufacture a shoe collection) in the context of Society 5.0. Aligned with [12], the FDMNs are intended to operate without human interfaces, independently controlling and adapting their activities, e.g., considering external variations. This concept is also aligned with the vision of Society 5.0 reflecting interconnected systems enacted within the society, merging the physical space and the cyber spaces [13].

Ensuring interoperability in this sector, and, generally, in the fashion industry, is very difficult [2][14]. The increasing digitalization in manufacturing has further lead to the acknowledgement of concerns for ensuring interoperability in this sector and implementation of Industry 4.0 [1]. Several initiatives exist to address enterprise integration and interoperability in this industry, such as R&D projects, frameworks, standards. However, a recent investigation of interoperability approaches in the up-stream segment footwear manufacturing industry is missing, although very important, and a discussion of challenges towards a collaborative and interoperable Society 5.0 is lacking. This work addresses this gap.

This work aims to analyze challenges for interoperability, enterprise integration and digital transformation in the FDMNs towards the realization of a collaborative and interoperable Society 5.0. The advances in digital technologies facilitate the emergence of the FDMNs and have the potential to reinvigorate this rather traditional manufacturing sector. Areas where future research and development work can bring significant value in the context of Society 5.0 are illustrated, including tackling concerns regarding ethics, data privacy, individualized assessment metrics (e.g., that could be combined with biometrical metrics). Challenging areas that need to be further addressed concern: analytics and artificial intelligence in the IoT-enabled FDMNs; evaluating the efect of digital transformation; social (footwear) manufacturing; digital twins and artificial intelligence; education/ adequate trained workforce; privacy, trust and ethics.

Due to the extent and diversity of research on enterprise integration and interoperability, researchers, developers, and practitioners would benefit from such a focused analysis on interoperability advances, as well as challenges and enablers for digital transformation in the footwear up-stream segment, and discussion of areas of improvement in this field towards the realization of the collaborative and interoperable Society 5.0. This work contributes to the current literature on interoperability and enterprise integration in the footwear up-stream segment by adding on prior work: (1) it provides an analysis of prior studies tackling interoperability and enterprise

integration, and (2) based on the findings of this analysis, a framework is advanced to synthesize the themes that require practitioner's and scholarly attention to advance the current body of knowledge towards the realization of the collaborative and interoperable Society 5.0. This contribution is constructed by addressing research questions, such as: **(RQ1)** Which are prominent initiatives aimed at ensuring interoperability and enterprise integration in the footwear manufacturing industry up-stream segment? **(RQ2)** Which are enablers for digital transformation in this industry, in the context of FDMNs? **(RQ3)** Which are the emergent challenges that the literature posits concerning interoperability and enterprise integration in this sector? **(RQ4)** Which are the directions for future research and development work that may benefit attaining digital transformation and interoperability in this industry, in Society 5.0?

The remainder of this article is structured as follows. Background information about the footwear manufacturing sector up-stream segment and the FDMNs is introduced next. Section 3 presents the research approach and related work. An analysis of challenges and enablers for digital transformation is presented in Section 4, and the proposed framework synthesizing areas to be further addressed. The last section contains concluding remarks.

2 Background

As the footwear manufacturing industry has a season-driven product request with short design and product phases, the SMs often center on executing high-quality high-fashion shoes in rather little amounts, sometimes with an increase in the number of models offered, completed in a make-to-order mode [3]. The diverse activities are often executed by different SCs, e.g., because of the specific craft required for completing each shoe component [15]. The main roles of the companies operating within the up-stream segment of the footwear industry are: buyer, seller, and delivery recipient.

This industry is highly fragmented and the realization of the final products requires strong collaborations among these companies [16], which compel adequate Information and Communication Technology (ICT) infrastructures to manage the information and digital production flows, and integrate the different companies in this sector [15]. Thus, it is a strong need to ensure interoperability and enterprise integration in collaborative forms of organization, such as the FDMNs, which are made up of SMs, SCs and SPCs.

The FDMNs, referred in this article in the context of Society 5.0, reflect a collection of enterprises in the footwear industry (e.g., SMs, SCs, SPCs) that join their resources (e.g., manufacturing equipment, software systems, devices, sensors, data) for a specific period of time to attain a specific goal (e.g., manufacture a footwear collection, deliver a digital service), aiming to act with no or minimal human involvement. The FDMNs produce, exchange, collect, archive and share data, and execute complex data and process analytics to accomplish the goal(s) set, acquire an increased revenue, increase the operational efficiency (e.g., of the whole network, and of each individual company), and bring improved customer experience. Aligned with the vision of Society 5.0 in [13], the resulting data, products, and services are relevant for the society.

Specific for the FDMNs is the focus to address interoperability and enterprise integration requirements in the footwear industry, although similarities exist with other forms of collaboration (e.g., virtual enterprises, collaborative networked organization, production networks). The FDMNs make use of the digital technologies in the footwear industry, and focus on the delivery of digital services, and participation in the interconnected ecosystem, in the interoperable and interconnected Society 5.0. Similar to previous forms of collaboration, the main phases of a FDMN are: set-up, operation, and dissolution. However, the FDMN concept, as defined in this article, emphasizes the digital nature of the intra- and inter-organizational collaborative business activities executed among the networked enterprises in the footwear industry, and the role of digital technologies, interoperability and enterprise integration, in the context of Society 5.0 and recent developments in Industry 4.0. Additionally, interoperability, enterprise integration, and digital technologies are regarded as enablers towards the execution of the collaborative manufacturing activities, supporting the realization of the goals(s) set by the FDMN, by each enterprise, and Society 5.0.

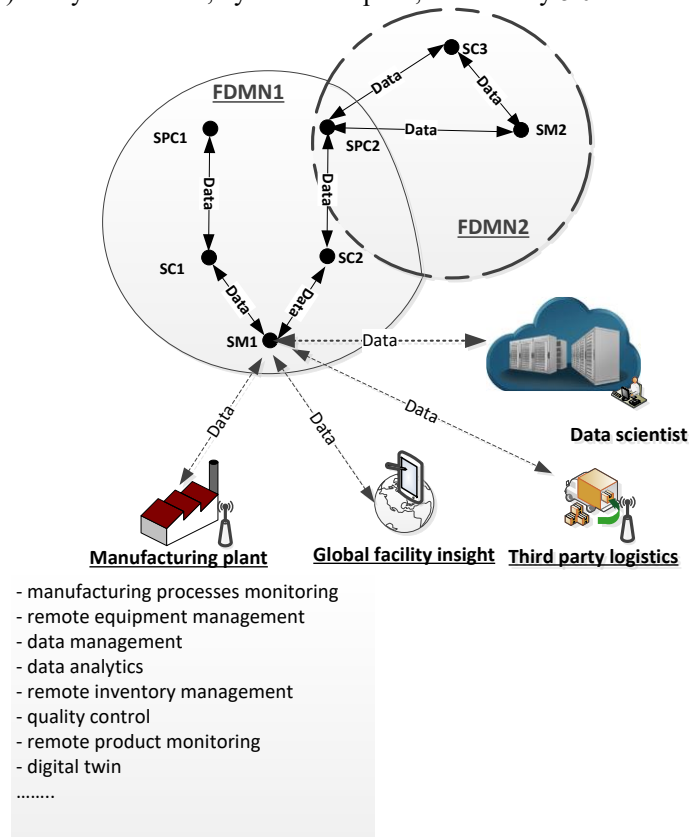


Fig. 1. FDMNs operation – an example

Fig. 1 illustrates the operation of two FDMNs and the data flows. The enterprises exchange data and execute cross-organizational business processes (e.g., order management) towards the realization of a shoe collection. One enterprise (SPC₂ in this

example) participates simultaneously in more than one FDMNs. The SM stores the operational and other relevant data (e.g., data from the manufacturing plant, third-party logistics collected using different information systems and IoT technologies) on a private cloud, and performs data analytics and process mining, e.g., to support and optimize decision making, identify or diagnose production bottlenecks, monitor the execution of the inter-enterprise business processes.

Fig. 2 portrays a simple instantiation of a shoe manufacturing business scenario during the FDMN operation. The SM performs the actual manufacturing of the shoe, using as input shoe components from the SC and data collected from the manufacturing operations (physical layer, e.g., data from manufacturing equipment, hardware, communication interfaces), FDMN connectivity layer, service layer (e.g., data analytics, process mining), application layer (e.g., digital workflow monitoring, data visualization). The data collected by the SM during the FDMN operation phase, from the manufacturing plant and third party logistics (as illustrated in Fig. 1) is stored, cleaned and analyzed, e.g., to identify bottlenecks in the production. During the FDMN operation, the SM, SC and SPC exchange business documents, such as: Submit Order and Accept Order as part of the order management inter-enterprise business process, and Dispatch Advice.

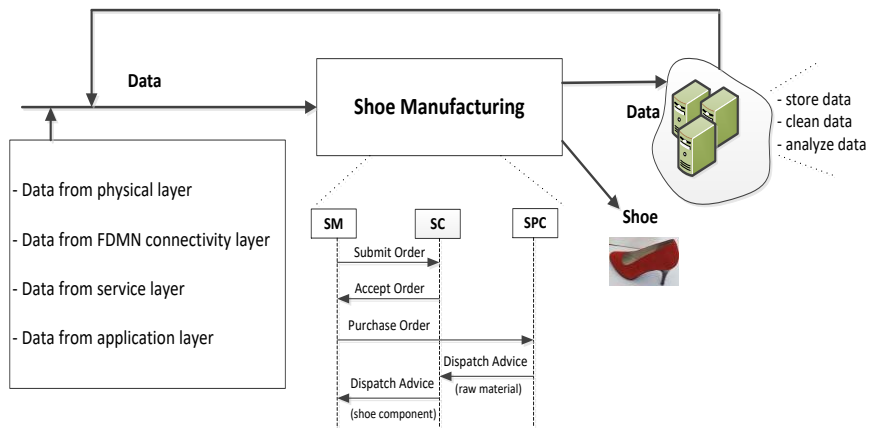


Fig. 2. An instantiation of a shoe collection manufacturing business scenario during a FDMN operation phase

These examples illustrate the need for interoperability and enterprise integration in the context of the FDMNs and Society 5.0.

3 Research Method and Analysis of Related Work

With the goal to determine and analyze prominent interoperability and enterprise integration approaches in the up-stream segment of the footwear manufacturing industry, a literature review has been carried out considering the PRISMA guidelines [17]. The literature search included an analysis of works published between January 2005 and December 2021. The following digital libraries were searched: ACM, Springer, IEEE, Science Direct/ Elsevier as they constitute major databases in this area. The following keywords were identified: “interoperability”, “enterprise integration”, “footwear manufacturing industry”, “footwear industry”, “footwear sector”, “infrastructure”, “ICT infrastructure”, “interoperability framework”, “e-business”, “digital manufacturing”, “digital manufacturing network”, “collaborative network”, “collaborative networked organization”, “IoT”, “Industry 4.0”. Boolean operators such as OR, AND, NOT have been used to determine works that combine more than one of these topics. Examples of queries include: (“interoperability” AND “footwear industry” AND “digital manufacturing”); (“interoperability” AND “footwear industry” and “IoT”). The list of articles retrieved was very large. Thus, a more elaborated search was performed and different inclusion/ exclusion criteria were set. Firstly, the works written in a language different than English were excluded, as well as the works for which full access has not been granted. Secondly, by reading the title and abstract, the works clearly out of scope were eliminating. The available technical reports (e.g., of R&D projects) and web-sites were also inspected.

The numerous works focusing on ensuring interoperability and enterprise integration in the footwear manufacturing industry reveal the importance of these topics in this sector. The case studies completed either at national level or at a regional level echo the relations among the different enterprises in the footwear manufacturing industry and the need to ensure enterprise integration and interoperability, such as: [18] in Brazil, [2] in the North of Portugal. The R&D projects completed in the past two decades targeting enterprise integration and interoperability in the up-stream segment of the footwear sector include: EFNET-European Network the European Footwear Network for Electronic Trading (cordis.europa.eu/project/id/FP4_28442), with the goal to build a communication infrastructure for information distribution in this sector, SHOENET (cordis.europa.eu/project/id/IST-2001-35393) with the goal to endorse solutions by implementing information systems and novel tools to expand the innovative capabilities of the SMEs in this sector, MODA-ML (www.moda-ml.org), Cec-made-shoe (www.cec-made-shoe.com) with the objective to accomplish seamless interoperability, eBIZ of the eBIZ-TFC project (www.ebiz-tfc.eu), which represents an action for e-business harmonization within the European footwear and textile clothing industry.

While EFNET1 identified national e-commerce initiatives in operational use, EFNET2 tackled data exchanges in the reselling phase contemplating the ebXML (ebxml.org) specifications. EFNET3 focused on the exchange of business data, targeting the first circle of the chain [2]. However, EFNET3 did not register significant implementation [19]. The-XML based Shoe Markup Language (ShoeML) – which represents a framework of XML schemas structured considering the design data storage and exchange needs – has been utilized to collect footwear design data relevant for the EFNET2, EFNET3 schemas [3]. The SHOENET project developed a messaging

platform that allows the integration of existing applications or information systems from distinct SMEs in the footwear value chain and the secure exchange of business documents, guaranteeing trackable operations completed; and a collection of 17 XML-established business documents for the footwear industry [3]. The Cec-made-shoe project builds on previous footwear interoperability initiatives, utilizing the SHOENET messaging platform and 17 XML-established business documents; the operational platform deals with business processes involved in different shoe value chain phases, e.g., from the shoe collaborative design to the final shoe delivery [3]. The eBIZ Reference Architecture 4.0 [20] deals with technical, semantic and business aspects of interoperability. However, sparse pilots were completed in this industry to demonstrate their use in digital transformation. Main obstacles in implementing eBIZ 4. (such as: high effort, lack of knowledge) are analyzed in [20].

The use and adoption of standards by the SMEs in the textile-clothing and footwear industry in Europe is analyzed in [21]. The Shoe Process INTERoperability Standard (SPRINTS) – which represents an XML-based language to describe a data exchange protocol between systems and machines in the footwear production domain is presented in [19]. However, the focal point is on CAD communication. A framework and implementation example to ensure interoperability in a collaborative networked environment are advanced in [10] and [22]; the proposed approach relies on the concept of business enabler system, which delivers different services as SaaS (such as: messaging service, performance assessment). However, this solution did not have a broad acceptance.

Standards used for exchanging data or e-documents in the apparel, footwear, and fashion sector include [23]: GS1 EANCOM (www.gs1.org/standards/eانcom – which represents a sub-set of the UN/EDIFACT standard) and GS1 XML, PRANKE (pranke.com), eBIZ, Ryutsu Business Message Standards (the Japanese equivalent of a supply and demand chain, www.gs1.jp.org/2018/service-and-solution/2_4.html), Universal Business Language (UBL, ubm.xml.org).

Some EU-funded projects focused on distributed control systems for optimizing the transfer of materials from one machine to another machine [24], or on the application of established international standards (such as IEC-61499) to footwear plants automation [25], or personalized shoes. The focal point of the EURO-SHOE project (www.euro-shoe.net) has been the manufacturing of individualized shoes at a reasonable price, akin to mass manufacturing. The aspect of the shoe as well as its adaptation to the real shape of the foot were targeted, having in view of comfortable footwear, easily alterable to anatomical imperfections [19].

There are recent works that reflect the use of digital technologies in selecting specific footwear; for example in [34] is presented the application of artificial neural networks in selecting shoe lasts for citizens with mild diabetes [34]. Endeavors for implementing Industry 4.0 or industrial IoT concepts in the footwear industry are reported in [26], [27]. Several technology enablers in traditional manufacturing industries (such as the footwear manufacturing, clothes or furniture sectors) are discussed in [1]; the authors emphasize the limited capacity to invest in digital production technologies of the enterprises in the traditional industry sectors, which hinders them to take broad advantage of Industry 4.0. Five categories of enablers and challenges to be furthered addressed to attain digital transformation in the footwear manufacturing industry are

presented in [28]: networking, digital data and insights, automation, customer-centric manufacturing, digital access.

The analysis of related work revealed that a recent comprehensive analysis of challenges and directions for further R&D work that may benefit attaining interoperability, enterprise integration, and digital transformation in this industry, within the context of Society 5.0 is not available although highly relevant.

4 Analysis, Challenges, and Framework

The above referred initiatives identified (except for EFNET) have a messaging interoperability layer, which enables the exchange of e-documents in the footwear manufacturing sector. However, only supplying a messaging layer is not enough to ensure wide scale interoperability in the FDMNs, as other interoperability dimensions need to also be addressed, such as: the execution and monitoring of operational business processes, the workflow of the documents interchanged, semantic interoperability. By making available a common set of e-documents, the Shoenet approach addresses semantic interoperability, but it does not address the choreography of the e-business documents interchanged. The Cec-made-shoe approach was completed considering the results of previous initiatives, and tackles this gap. However, the solution deployed as the operational ICT messaging infrastructure is proprietary, obstructing interoperability [22]. The eBIZ Reference Architecture 4.0 [20] represents the most developed approach towards attaining interoperability in this sector, addressing technical, semantic and business interoperability challenges. However, scarce pilots exist to depict its role in digital transformation.

There are R&D projects that although did not primarily focus on interoperability in the footwear manufacturing industry they tackled interoperability challenges in this sector, such as: myShopNet (www.myshopnet.eu) which develops a software platform that supports a user to create a complete e-commerce solution within 24 hours for the commercialization of customizable goods involving specific modules for footwear, shirts, and high-end fashion, CORENET (cordis.europa.eu/project/id/260169), which addresses customer necessities targeting a wide range of European inhabitants, including aged, obese, disabled or diabetic persons.

The Reference Architecture Model for Industrie 4.0 (RAMI 4.0) was designed to address interoperability for Industry 4.0, which surfaced from the industrial revolution in Germany, with a solid background built on the modeling of industrial norms and standards of the Deutsche Industrie Norm specification [29][30]. However, scarce solutions exist in the footwear sector that show the adoption of cyber-physical systems for Industry 4.0, although the benefits of their adoption in manufacturing is widely acknowledged, e.g., [31][32]. The use of the RAMI 4.0 in the footwear industry is discussed in [26]; the authors emphasize the challenges to implement it (e.g., the need to retrofit existing equipment, communication requirements), and advance a methodology aimed to support SMEs in implementing smart machines.

The use of the digital technologies is the selection of specific footwear (for example the application of artificial neural networks in picking shoe lasts for persons with mild diabetes) is described in [34]. However, the adoption of digital technologies in this

sector is limited because the SMES in the traditional industries have narrow capabilities to invest in digital production technologies which impedes them to fully benefit of Industry 4.0 advantages [1]. Towards attaining seamless interoperability, enterprise integration and digital transformation in this sector, three challenges are discussed in [28]: analytics in IoT manufacturing, analyzing the effect of digital transformation, social manufacturing.

Summarizing the findings, the following challenges were identified in the literature towards attaining digital transformation in this sector:

- *Restricted ability to spend on digital production technologies* [1]. As most enterprises in the footwear industries are small and medium sized, and the costs associated with digitalization in this sector are high, it is challenging for the enterprises in this sector to make the required investments;
- *Analytics in IoT Manufacturing* [35]. The amount of data required to be archived and managed (e.g., from the physical layer, connectivity layer, service layer, as illustrated in Fig. 2) is increasing with the digital transformation. New applications or software tools need to be designed and implemented to support large scale data/ information management and analytics [35]. Additionally, data in the production processes could be erroneous or noisy (for example: caused by broken equipment or sensors, and cleaning large volumes of data to support accurate analytics is a challenging task. Analytics in the footwear manufacturing and data cleaning are relevant at the enterprise level (e.g., as portrayed in Fig. 2, for the SM), and at the FDMN level (as illustrated in Fig. 1).
- *Analyzing the effect of the digital transformation*. It is important to develop new models to assess the economic impact of digital transformation in this sector, and implement adequate software tools; this allows the quantification and analysis of the benefits and creates advantages over the competitors [1].
- *Social manufacturing* represents a new paradigm for increasing customization accuracy and efficiency, making use of crowdsourcing and big data [36]. Recent advancements in 3D printing and 3D manufacturing enable shoe customization. Nevertheless, it would be relevant to also consider biomedical information for individualized footwear (such as: internal tension) [1], behavior analysis and dynamic netizens [36]. Although some advances exist in this area, for example in the design of orthopedic shoes, it is challenging to automatically construct footwear from a digital foot model, and enterprises continue to concentrate on low-level individualization [1]. Aggregating such data may also rise privacy concerns.
- *Difficulty to implement RAMI 4.0* [26], e.g., it is challenging to retrofit existing equipment, the need to address communication requirements

The visions of Society 5.0 and Industry 4.0 attempt to integrate information between different industries [13]. This requires attaining digital transformation, and addressing societal challenges (e.g., to reconcile individual and societal interests) and technical challenges, e.g., building a technological framework to support the operation of an information integration architecture and data platform that allows to integrate data and information between different sectors, which will supply a knowledge database that links the information from distinct sectors, allowing cross-sector collaboration [37].

Tasks to be tackled towards realizing Society 5.0 include [37]: establishing industry-academia partnerships and developing an adequate collaboration model, develop big data analytics and information integration architecture, digitalization of the different dimensions of life. Towards attaining digitalization in manufacturing, and implementing Industry 4.0, several challenges should be tackled [33], such as: education; interoperability; digital twins, simulation and artificial intelligence; high performance computing platforms, human-machine cooperation; cybersecurity, trust, and privacy; business, society, and ethical issues. Accordingly, adding intelligence in Industry 4.0 or manufacturing (e.g., to support decision making) is an important challenge to be further addressed and integrating simulation in digital twins might be a solution [33].

In the context of footwear manufacturing, especially the topics of education (and providing adequate workforce, with both manufacturing knowledge and computing skills) is very challenging, e.g., due to the high investments that need to be made in continuously training employees, and acquiring adequate software/ technology for digitalization considering the limited resources of the enterprises in this industry. As a technology-enabled data intensive society, Society 5.0 requires highly qualified workforce which surpasses the education necessities of Industry 4.0; the engineering education of Society 5.0 requires not only the knowledge and skills of development of applied technology, but it should also embed the dimensions of ethics and humanism [38].

As the footwear manufacturing industry is expected to be fueled by IoT and artificial intelligence, privacy, ethics and trust issues need to be addressed, e.g., concerning ethical implications of automatic decision making, and their implications on individual citizens and society [39]. While trusting that the artificial intelligence algorithms will make appropriate decisions, it is important to address aspects such as: cultural considerations, ethical frameworks, legal and regulatory compliance, transparency, explainability [40]. As it is expected that by 2023 the digital twin technology will grow by 38% annually [41], it is important that IoT technologies in manufacturing are integrated to allow feeding data into the digital twins [33].

Fig. 3 synthesizes the areas that require attention in the context of the FDMNs to advance the current body of knowledge towards the realization of the collaborative human-centric Society 5.0.

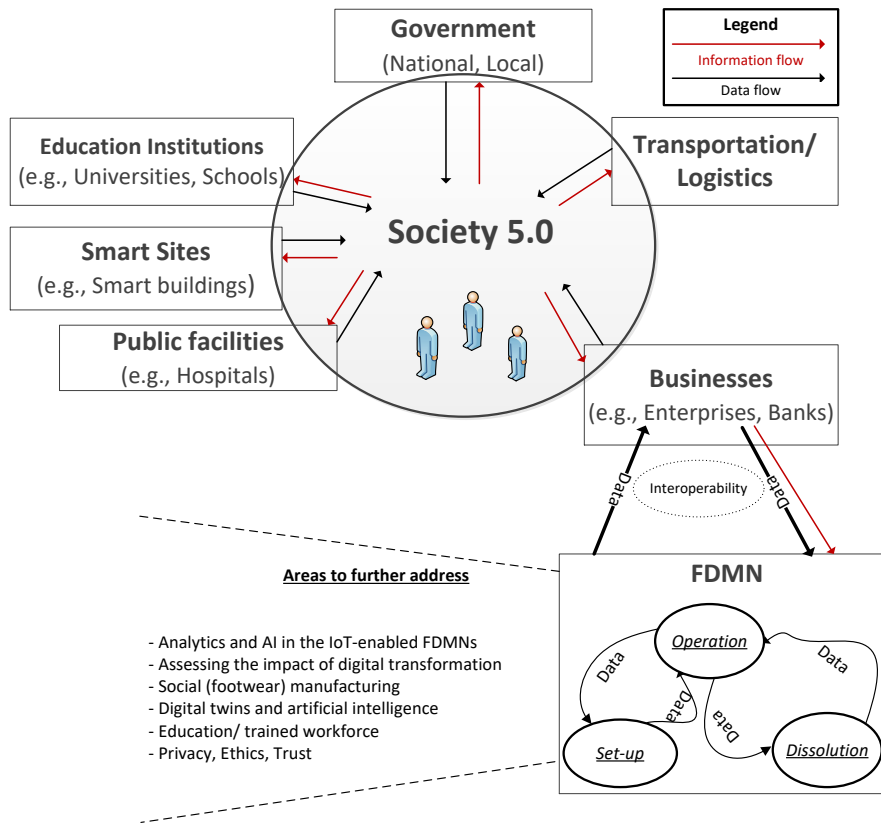


Fig. 3. Areas to further address in footwear manufacturing in the context of Society 5.0

5 Conclusions and Future Work

Ensuring interoperability and enterprise integration is essential for the set-up and operation of the FDMNs. The most relevant interoperability approaches targeting the up-stream segment of the footwear manufacturing industry include R&D projects, frameworks, architectures, and standards. The digital technologies could reinvigorate this rather traditional sector. However, the lack of resources to invest in adequate technologies [1], and the difficulty to implement Industry 4.0 approaches, such as RAMI 4.0 (e.g., due to the difficulty to retrofit existing equipment, communication needs) [27] represent main obstacles towards digitalization.

Towards realizing the vision of a collaborative and interoperable human-centric Society 5.0, several aspects need to be further addressed in the area of footwear manufacturing, such as: analytics and artificial intelligence; assessing the impact of

digital transformation; social (footwear) manufacturing; education/ adequate trained workforce; privacy, trust and ethics.

As Society 5.0 promotes the digitalization of all facets of life and intensive cross-sector collaboration, attaining cross-sector interoperability represent a big challenge. Future R&D work needs to concentrate on the development of interoperability standards and frameworks to address this challenge, and on analyzing the impact of digital transformation in this sector and in Society 5.0. For example, the gains, costs and risks of the digital transformation could be assessed and analyzed at individual level, organization/ enterprise level, industry sector, and societal impact.

References

1. Jimeno- Jimeno- Morenilla A., Azariadis P., Molina-Carmona R., Kyratzi S.: Technology enablers for the implementation of Industry 4.0 to traditional manufacturing sectors: A review. *Computers in Industry* 125, 1003390 (2021).
2. Ribeiro S.V., Santos V.R., Pereira C.S.: Collaborative networks in the Portuguese footwear sector and the cluster of Felgueiras, *KMIS*, 197--204 (2017).
3. Chituc C.-M., Toscano C., Azevedo A.: Interoperability in collaborative networks: independent and industry-specific initiatives – the case of the footwear industry. *Computers in Industry* 59(7), 741--757 (2008).
4. IEEE: IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries, Institute of Electrical and Electronics Engineering, NY (1990).
5. Jardim-Goncalves R., Grilo A., Popplewell K.: Novel strategies for global manufacturing systems interoperability, *Journal of Intelligent Manufacturing*, pp. 1--9 (2016).
6. Pereira A.C., Romero F., 2017. A review of the meaning and implications of the Industry 4.0 concept. *Procedia Manufacturing* 13, 1206-1214 (2017).
7. Dakhnovicg A.D. et al.: Applying routing to guarantee secure collaboration of segments in digital manufacturing networks. *Aut. Control and Computer Science* 52(8) 1127-1133 (2016).
8. Camarinha-Matos L. M.: New Collaborative Organizations and their Research Needs. In: Camarinha-Matos, L.M., Afsarmanesh, H. (eds.) *Processes and Foundations for Virtual Organizations. PRO-VE 2003. IFIP vol. 134*. Springer, Boston, MA, 3--14 (2003). https://doi.org/10.1007/978-0-387-35704-1_1
9. Chituc C.-M., Toscano C., Azevedo A.: E-business and collaborative networks: A service-oriented ICT platform for the footwear industry, *IEEE INDIN*, 591--596 (2007a).
10. Chituc C.-M., Toscano C. et al.: Towards seamless interoperability in collaborative networks. In: Camarinha-Matos L.M. et al. (eds.) *Establishing the Foundation of Collaborative Networks. PRO-VE 2007. IFIP vol. 243*, Springer, Boston, MA 445--452 (2007b).
11. Camarinha-Matos L.M.: Collaborative Networked Organizations: Status and trends in manufacturing, *Annual Reviews in Control* 33(2), 199--208 (2009).
12. Erol S. et al.: Tangible Industry 4.0: a scenario-based approach to learning for the future of production. *Procedia CIRP* 53, 13--18 (2016).
13. Deguchi A., Hirari C. et al: What is Society 5.0? In: *Society 5.0 A people-centric super-smart society*. Hitachi-UTokyo Laboratory, Springer Open, Chapter 1, 1--24, (2020).
14. Bindi B. et al. 2019. eBusiness standards and IoT technologies adoption in the fashion industry: Preliminary results of an empirical research. In: Rindaldi R., Bandinelli R. (eds.) *Business models and ICT technologies for the fashion supply chain.IT4Fashion 2017. LNEE 525* Springer, 139--150 (2019).

15. Fani V., Bindi B. and Bandinelli R.: Balancing assembly line in the footwear industry using simulation: A case study, *Communications of the ECMS* 34(1), Proc. ECMS, M. Steglich et al. (eds.) (2020).
16. Shamsuzzoha, A. et al.: Dynamic and collaborative business networks in the fashion industry. *International Journal of Computer Integrated Manufacturing* 26(1/2), 125--139 (2013).
17. Moher D. et al.: Preferred reporting items for systematic review and meta-analyses: The PRISMA statement. *PLOS Medicine* 6(7): e1000097 (2009).
18. Fani, V., et al.: Supply chain structures in the Brazilian footwear industry: outcomes of a case study research. In: XX Summer School "Francesco Turco", 37--42 (2015).
19. Danese, G., et al.: A novel standard for footwear industrial machineries. *IEEE Trans. Ind. Inf.* 7(4), 713--722 (2011).
20. Bindi, B., et al.: Barriers and drivers of eBIZ adoption in the fashion supply chain: preliminary Results, *ICIEA*, 555--559 (2018).
21. De Sabbata P. et al.: Standards creation and adoption for SMEs networks: The experience of the European textile-clothing and footwear industry. In: H. Panetto et al (eds.) *Interoperability for Enterprise Software and Applications*. John Wiley & Sons, Inc.: 41- 52 (2010).
22. Chituc C.M. Azevedo, A., Toscano, C.: A framework proposal for seamless interoperability in a collaborative networked environment. *Computers in Industry* 60, 317--338 (2009).
23. GS1: Implementation of GS1 EDI standards in 2018, Detailed Report, 24 April 2019. www.gs1.org/sites/default/files/docs/EDI/edi_implementation_2018_public.pdf (2019)
24. E. Carpanzano et al.: Development of manufacturing automation systems through object-oriented concepts and international standards, *IEEE INDIN*, 607--611 (2004).
25. M. Colla et al.: Applying the IEC-61499 model to the shoe manufacturing sector. *IEEE ETFA*, 1301--1308 (2006).
26. Hernández E., Senna P., Silva D., Rebelo R., Barros A.C., Toscano C.: Implementing RAMI4.0 in Production - A Multi-case Study. In: Almeida H., Vasco J. (eds) *Progress in Digital and Physical Manufacturing. ProDPM 2019. Lecture Notes in Mechanical Engineering*. Springer, Cham: 49--56 (2020).
27. Cunha B., Hernández E., Rebelo R., Sousa C., Ferreira F. (2021) An IIoT Solution for SME's. In: Gonçalves J.A., Braz-César M., Coelho J.P. (eds) *CONTROLO 2020. CONTROLO 2020. Lecture Notes in Electrical Engineering*, vol 695. Springer, Cham, 313--321 (2021).
28. Chituc C.M.: Interoperability in the Footwear Manufacturing Networks and Enablers for Digital Transformation. In: Cherfi S., Perini A., Nurcan S. (eds.) *Research Challenges in Information Science. RCIS 2021. Lecture Notes in Business Information Processing*, vol. 415. Springer, Cham, 581--587 (2021).
29. DIN Deutsches Institut für Normung e.V.: *DIN SPEC 91345:2016-04: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)* (2016).
30. Wermann J., Colombo A.W. et al.: Using an interdisciplinary demonstration platform for teaching Industry 4.0. *Procedia Manufacturing* 31, 302--308 (2019).
31. Wang L., Törngren M., Onori M.: Current status and advancement of cyber-physical systems in manufacturing. *J. Manuf. Syst.* 37 (Part 2), 517--527 (2015).
32. Pivoto D.G.S. et al.: Cyber-physical systems architectures for industrial internet of things applications in Industry 4.0: A literature Review. *J. Manuf. Sys.* 58 (Part A) 176--192 (2021).
33. Leitao P., Pires F., Karnouskos S., Colombo A.W.: Quo Vadis Industry 4.0? Position, Trends, and Challenges. *IEEE Open Journal of Industrial Electronics Society* vol. 1, 298--310 (2020).
34. Wang, C.-C., et al.: Artificial neural networks in the selection of shoe lasts for people with mild diabetes. *Med. Eng. Phys.* 64, 37--45 (2019)
35. Dai H.-N. et al.: Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies, *Enterprise Information Systems* 14 (9-10) (2020).
36. Shang X. et al.: Moving from mass customization to social manufacturing: a footwear industry case study. *Int. J. of Computer Integrated Manufacturing* 32(2), 194--2015 (2019).

37. Deguchi A., Karasawa K.; Issues and Outlook. In: Society 5.0 A people-centric super-smart society. Hitachi-UTokyo Laboratory, Springer Open, Chapter 8, 155--173, (2020).
38. Lantada A.D.: Engineering Education 5.0. Continuously Evolving Engineering Education. International Journal of Engineering Education 36(6), 1814--1832 (2020).
39. Hurlburt G.: Toward applied cyberethics, Computer 51(9), 80--84 (2018).
40. Karnouskos S.: Self-driving car acceptance and the role of ethics, IEEE Transactions on Engineering Management 67(2), 252--265 (2020).
41. Panetta K.: Top 10 Strategic Technology Trends for 2018" (2017). Available at: www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2018