# Chapter 2

## Key enabling technologies, methodologies, frameworks, tools and techniques of smart and sustainable systems

*Leonel Patrício[1], Paulo Ávila[3,4], Leonilde Varela[1,2], Fernando Romero[1,2], Goran Punik[1,2], Hélio Castro[3,4], Luís Fonseca[3,5]*

[1]Universidade do Minho, Department of Production and Systems Engineering, 4800-058 Guimarães, Portugal

[2]ALGORITMI Research Centre, Universidade do Minho, 4800-058 Guimarães, Portugal

[3]School of Engineering (ISEP) - Polytechnic of Porto, 4200-465, Porto, Portugal

[4]INESC TEC, 4200-465, Porto, Portugal

[5]INEGI, 4200-465, Porto, Portugal

E-mail: leonelfilipepatricio@gmail.com, psa@isep.ipp.pt, leonilde@dps.uminho.pt, fromero@dps.uminho.pt, putnikgd@dps.uminho.pt, hcc@isep.ipp.pt, LMF@isep.ipp.pt

**Abstract**

For manufacturing systems, Industry 4.0 is currently considered a big challenge, being closely related to intelligent manufacturing or production, alongside with a more or less widened set of technologies, methodologies, frameworks, tools and techniques. I4.0 encompasses a diversity of approaches to enable the progress of production systems, resulting in shortened production times, production efficiencies, product quality, customization, and flexibility performance. Due to the general awareness about the importance of enabling intelligent manufacturing alongside with sustainable production, sustainability is gaining a refreshed importance. Due to the importance of the theme, there is a need for an updated review on the main enabling approaches of I4.0 for sustainable manufacturing systems. For this purpose, a literature review was conducted attending the research question: Is there an increased attention being given to sustainability issues nowadays in the Industry 4.0? Through this work it was possible to verify which are the main I4.0 pillars and sustainability pillars considered in Academia, which are: for I4.0 the Integration of Horizontal and Vertical Systems (94%) and Additive manufacturing and 3D printing (56%); for sustainability the economic dimension (95%) is the main one, with a large difference from other factors.

**Keywords:** Industry 4.0; Sustainability; Key enabling approaches and tools of I4.0; Industry 4.0, smart factory, and sustainability.

## 1. Introduction

Industry 4.0 is a German project that combines manufacturing with high-level information technology and digitization (Adolph, et al., 2016). It is a revolution in manufacturing and brings innovative perspectives on how manufacturing can participate in new technologies, methodologies, frameworks, tools and techniques, in short, approaches, to achieve maximum production effectiveness and efficiency, alongside with automation and integration levels, with minimum or optimized use of resources. The effect of this new paradigm derives from the evolution of intelligent or smart factories, by refining this concept and further improving and exploring it at higher levels of digitalization and high standard technologies. One central concern and objective of the application of the I4.0 paradigm consists on reaching extremely effective and efficient use of resources, means, products, materials, and tools to enable a very fast dynamism, flexibility, and (re)configurability capabilities, to enable customized production, and a full integration of all stakeholders and "things" in an organization, from suppliers to customers and all associated business partners, in a large network of partners, which may be organized in different ways, for instance, in virtual organizations or enterprises, distributed or extended manufacturing systems or collaborative networks, to enable a more effective and prompt adaptation to the current highly demanding requisites associated to a dynamically and fast changing globally distributed market, alongside with manufacturing and management goals (; (Kagermann, et al., 2013; Deloitte, 2014; Smit, et al., 2016; Wittenberg, 2016; Putnik, & Ferreira, 2019).

In recent years, intelligent or smart manufacturing has received a great interest in academia and industry, because it gives competitive advantage to manufacturing organizations, making this type of industry more effective, and efficient through the use of advanced ICT (Kagermann, et al., 2013; Deloitte, 2014; Smit, et al., 2016; Wittenberg, 2016; Putnik, & Ferreira, 2019). Moreover, in the current Industry 4.0 (I4.0), companies and underlying manufacturing and management approaches, technologies and systems have further to be sustainable (Varela, et al., 2019). In I4.0 the duality of flexibility and productivity is a recurring challenge for organizations, which seek to reduce costs, and a greater offer of customized products. The flexibility of manufacturing systems can be understood as the ability to produce a wide variety of products, being considered one of the most important requirements for new applications, for instance in robotics (Esmaeilian, et al. 2016). Moreover, for reaching this flexibility it is further fundamental to put available manufacturing systems with high level of reconfigurability and reliability (Samala, et al., 2021a,b; Putnik, et al., 2021).

Manufacturers faced the impulses of product specification, with the need to increase resource efficiency and reduce product projection times. These stimuli are related to digitization, use of information technologies and the connection of products, resources and production processes, which are leveraged by the internet of things (IoT) (Scheuermann, et al., 2015; Rennung, et al., 2016). Moreover, the previous requisites should further be fulfilled along with economic, social and environmental sustainability ones (Varela, et al., 2019), as expressed in Fig. 1, by (Morrar & Husam, 2017).

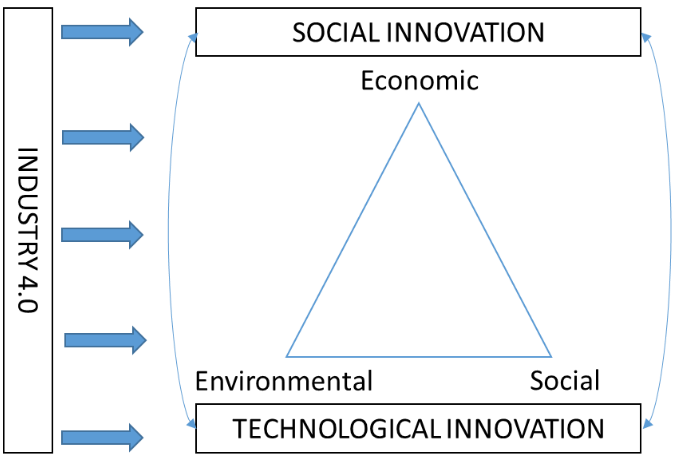


**Figure 1.** Sustainable structure applicable to Industry 4 (Morrar, and Husam, 2017).

The issue of sustainability is becoming very important at the manufacturing level, particularly for industries with intensive practices of resources and energy. Sustainable development is instituting changes in the way manufacturing systems are designed and implemented. Sustainability emerges as one of the topics in the international governance market and they are interconnected (Putnik & Ávila, 2016). Almeida, et al. (2015) say that it is common to ignore the interdependence of the sustainability pillars for short periods of time, but history has shown that before long, mankind is reminded of it through some types of alarms or crisis.

Researchers have identified the relationships and contributions of Industry 4.0 to sustainability as an emergent and dynamic research subject (Fonseca, Amaral & Oliveira, 2021; Ghobakhloo, 2020). The successful adoption of Industry 4.0 can positively impact sustainability by improving knowledge sharing, collaborative work, production efficiency and productivity (Jena, Mishra & Moharana, 2020; Machado, Winroth & Ribeiro da Silva, 2020). Moreover, I4.0 can support novel business models and contribute to cost reduction and customer experience enhancement (Machado, Winroth & Ribeiro da Silva, 2020; Fonseca, Amaral & Oliveira, 2021) and improve communication and information flows (Linder, 2019). Research results also posit that combining Industry 4.0 technologies with development practises (e.g., Lean, contributes to improved employee morale, reduced lead time, enhanced product quality, customized products, and waste reduction (Bogle, 2017; Kamble, Gunasekaran & Dhone, 2020). Nevertheless, Industry 4.0 can also have some potential negative influence on sustainability due to cybersecurity risks, labour-saving technologies causing job losses and labour market disruption, and increased production and consumption rates leading to over resource consumption (Beir, et al., 2020, Nara, et al., 2021).

This work identifies the main enabling technologies, approaches, methodologies, methods, techniques, models, tools and platforms for intelligent or smart and sustainable manufacturing systems in Industry 4.0, founded on organised works review, including, conceptual articles about I4.0, approaches, technologies, and platforms for a sustainable I4.0. The review will be conducted with the following central research question in mind:

*Is there an increased attention being given to sustainability issues nowadays in the Industry 4.0 oriented smart manufacturing and management context?*

To achieve the objective of this work, the rest of this document is organized as follows. Section 2 presents the research methodology, mentioning the source of information used for conducting the literature search process and subsequent extraction of the most important contributions found in the focused domain of this study. Section 3 presents a brief description of the most relevant publications reached through this study and its analysis. Finally, some conclusions and future work are presented in Section 4.

## 2. Methodology

Carrying out a careful literature review is very important to come up with some important insights regarding the state of the art about some specific, and more or less widened, research topic or domain, and its evolution in time. In this work a works review was done in instruction to evaluate and analyse existing contributions about sustainable and intelligent manufacturing in companies. Saunders, et al. (2016) established an organized review process, based on an iterative cycle for defining appropriate keywords to a specific theme, by searching important literature and carrying out a corresponding analysis. In this work a similar methodology was used. In order to deepen the knowledge about the main technologies, methods, techniques, approaches, methodologies, models, tools and platforms for intelligent and sustainable manufacturing systems in Industry 4.0, and based on distributed manufacturing environments or collaborative networks, a study was carried out, based on the information reached through scientific publications searched and analysed.

Therefore, in this research work several steps were taken, according to the methodology previously described and the main groups of keywords shown in Fig. 1. According to that methodology, the search, selection and analysis of the various articles, directly related to the theme of this literature review, is summarized in three main stages, as about: "identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners" (Fink, 1998). There was a need to carry out these steps in order to clarify how this work was carried out, regarding the research theme, and further evolve and classify the articles, besides its geographic distribution identification, their main characteristics and methods, methodologies, technology, approaches, models, techniques, tools and/or platforms used. For the development of this research work, it was thus necessary to start to establish the search string and selecting the academic database for carrying out the search process.

The B-ON data base was chosen for carrying out this research work. This library enables admission to an extensive range of academic publications in international scientific journals and conferences, indexed in most well-known indexation systems, e.g., Web of Science and Scopus. The B-ON is an extensive databases including thousands of peer-reviewed journals and publications in a widened set of fields and arising from different scientific areas. These publications include peer-reviewed articles from several well-known publishers and editors, such as Elsevier, Springer, MDPI and IEEE, among others, that were considered in this study and further analysed, published until the first trimester of 2021. For this research a search string was defined by including a set of considered key terms, referring to the theme of this work. It is important to notice that for each term used there are several synonyms that can be mentioned and were also used in the search process underlying this work. Table 1 shows the search terms and respective synonyms used in the search process.

**Table 1.** Groups of key words considered for searching the literature.

| Group KW1 | Group KW2 | Group KW3 |
|---|---|---|
| (Approach or technology or method or model or methodology or tool or framework or platform or system or architecture) | (Smart manufacturing or Industry 4.0, or Industrie 4.0 or I4.0 or Intelligent manufacturing) | (Sustainability or sustainable or eco-efficient) |

The search string used in the work for getting articles from the B-ON online library database was based on the key terms and the respective synonyms indicated in Table 1:

**String =** (Group KW1) **AND** (Group KW2) **AND** (Group KW3)

**String** = *(Approach or technology or method or model or methodology or tool or framework or platform or system or architecture) AND (Smart manufacturing or Industry 4.0, or Industrie 4.0 or I4.0 or Intelligent manufacturing or distributed manufacturing or collaborative networks or collaboration) AND (Sustainability or sustainable or eco-efficient)*

The string is composed by the main keywords intended to be considered, and that are further used to organize the information in 3 groups: (Title, Abstract; Subject Terms). In order to get the articles more closely related to the theme of this work, the articles were filtered according to their relevance to the theme under study. Duplicate and not considered key articles, and articles with incomplete bibliographic data, were removed. In addition, parameters that were used for the filters applied were related to the following issues: peer reviewed and full text available. Initially, the research results reached a total of 717 publications. After applying the search filters, the total set of articles did decrease to 249 articles, and among these the ones that were considered to be more closely or directly related to the research underlying this work were verified. Therefore, the number of articles analysed dropped to a total of just 20 articles. In Table 2 it is possible to see the filters applied in the search results, as well as the number of articles obtained throughout the search process.

**Table 2.** Filters applied to the search process.

| | Articles |
|---|---|
| Initial result: | 717 |
| 1 - Restrict to: Peer Reviewed | 383 |
| 2 -Type of fonts: Academic Journals; Conference Materials; Books | 382 |
| 3 - From: 2010 to 2021 | 380 |
| 4 - Language: English | 372 |

| | |
|---|---|
| 5 - Editor (addleton academic publishers; elsevier b.v.; mdpi ag; elsevier ltd; mdpi; ieee; mdpi publishing; elsevier sci ltd; taylor & francis ltd; elsevier; elsevier science) | 334 |
| 5 - Restrict to: Full Text | 249 |
| Final result: | **249** |

Figure 2 represents a flow diagram of the literature search carried out, and respective screening of the topic used in this research work. To analyse the main data of the articles found, it was necessary to carry out two types of characterization. In the first categorization phase, the year of publication and the type of article (research, review, conference, book chapter, journal paper, and editorial) were classified. In the second type of analysis, the publications found were characterized as being theoretical or conceptual contributions, literature reviews or case studies.

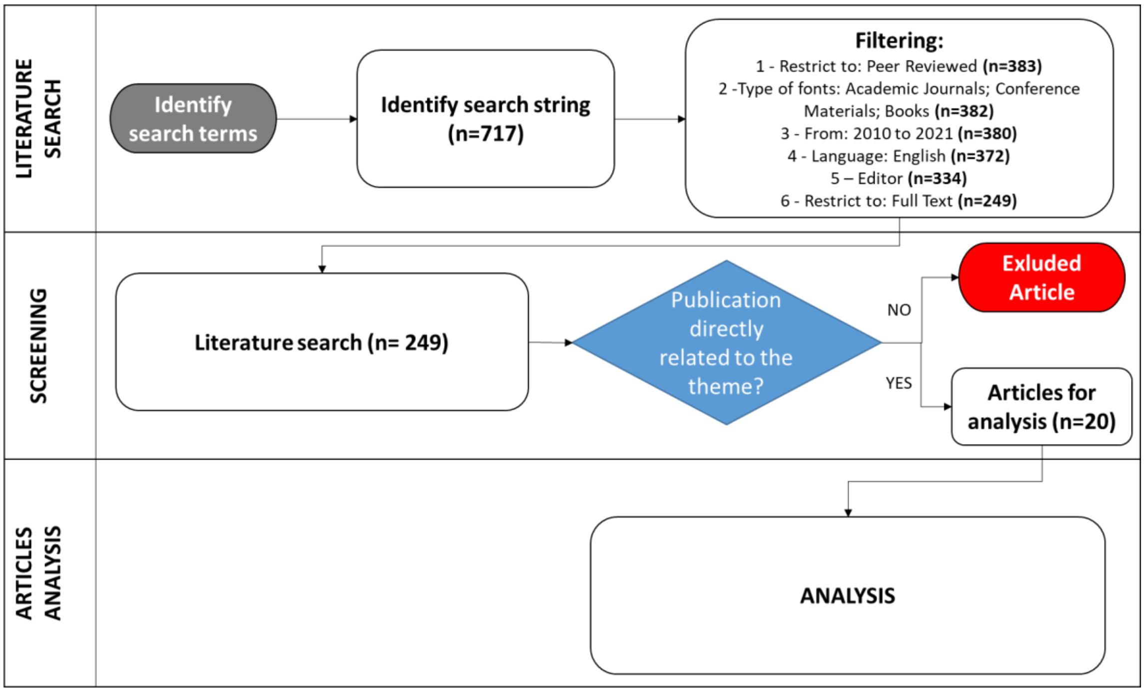


**Figure 2.** Flow diagram of literature search and respective screening (Neves, et al., 2020).

## 3. Article Synthesis and Analysis

In order to deepen the knowledge on enabling technologies, approaches, methodologies, structures, tools and techniques of intelligent and sustainable manufacturing systems for I4 .0, a study based on scientific articles was necessary to investigate the comprehensive information on this topic. Throughout this chapter, we will review different contributions from the most relevant papers that address this topic, which falls in the context of I4.0, and the underlying smart manufacturing concept, along with sustainability issues.

Regarding the I4.0, the main pillars that were considered, and for which contributions were found, are related to: Big Data and Data Analytics, Simulation, Horizontal and Vertical Integration, [Industrial]Internet of Things, Autonomous Robots, the cloud, Cyber Physical [Production] Systems, and Security, Augmented Reality, and Additive Manufacturing (Kagermann, et al., 2013; Deloitte, 2014; Smit, et al., 2016; Putnik, & Ferreira, 2019). The collection of articles found and analysed, as previously mentioned, was made using the database of the online library B-ON. According to the selection parameters described previously, 19 articles were selected for further analysis, as it is shown in Table 3.

**Table 3.** Synthesis of information retrieved from most relevant articles analysed.

| Authors | Title | KW | Journal |
|---|---|---|---|
| **Man, J. and Strandhagen, J. (2017)** | An Industry 4.0 research agenda for sustainable business models | Sustainability; Business Model; Industry 4.0; Research Agenda | Procedia CIRP |
| **Giret, A. et al. (2017)** | A holonic multi-agent methodology to design sustainable intelligent manufacturing control systems | Sustainability; Multi-Agent Systems; Holonic Control; Manufacturing; Design Method; | Journal Of Cleaner Production |
| **Yazdi, P. et al. (2018)** | An Empirical Investigation of the Relationship between Overall Equipment Efficiency (OEE) and Manufacturing Sustainability in Industry 4.0 with Time Study Approach | Small And Medium Enterprises; OEE; OECD; Manufacturing Sustainability; Time Study; Industry 4.0; Material Handling Systems; Agent-Based Control Architecture | Sustainability |
| **Thomas, A. Et al. (2018)** | Smart Systems Implementation in UK Food Manufacturing Companies: A Sustainability Perspective | Food Manufacturing; Digital Hub; Sustainability Profile; Smart Systems; Survey | Sustainability |
| **Varela, M.L.R, et al. (2019)** | Evaluation of the Relation between Lean Manufacturing, Industry 4.0, and Sustainability | Lean Manufacturing; Industry 4.0; sustainability; economic; | Sustainability |

| | | | |
|---|---|---|---|
| | | environmental; and social; structure equations modeling | |
| **Scavarda, A. Et al. (2019)** | An Analysis of the Corporate Social Responsibility and the Industry 4.0 with Focus on the Youth Generation: A Sustainable Human Resource Management Framework | Sustainable Human Resources; Industry 4.0; Corporate Social Responsibility; Conceptual Framework; Youth Generation | Sustainability |
| **Hidayatno, A. et al. (2019)** | Industry 4.0 Technology Implementation Impact to Industrial Sustainable Energy in Indonesia: A Model Conceptualization | Industry 4.0; Sustainable Energy; Making Indonesia 4.0; Technology Adoption; Model Conceptualization | Energy Procedia |
| **Ren, S. et al. (2019)** | A comprehensive review of big data analytics throughout product lifecycle to support sustainable smart manufacturing: A framework, challenges and future research directions | Big Data Analytics; Smart Manufacturing; Servitization; Sustainable Production; Conceptual Framework; Product Lifecycle | Journal Of Cleaner Production |
| **Ghadimia, P.et al. (2019)** | Intelligent sustainable supplier selection using multi-agent technology: Theory and application for Industry 4.0 supply chains | Sustainable supplier selection; Industry 4.0; Multi-agent systems; Cyber-physical systems; Industry 4.0 supply chain | Computers & Industrial Engineering |
| **Lee, Wo et al. (2019)** | Development of na Intelligent Tool Condition Monitoring System to Identify Manufacturing Tradeoffs and Optimal Machining Conditions | Smart and Sustainable Manufacturing; Artificial Intelligence; Evolutionary Strategies; Tool Condition | Procedia Manufacturing |
| **Fatimah, Y. et al. (2020)** | Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development | Industry 4.0; Internet Of Thing (Iot); Maturity Model; Smart Waste Management; | Journal Of Cleaner Production |

| | | | |
|---|---|---|---|
| | goals: A case study of Indonesia | Sustainability; Sustainable Circular Economy; Sustainable Development Goals (SDG's) | |
| **Bai, C. et al. (2020)** | Industry 4.0 technologies assessment: A sustainability perspective | Industry 4.0; Technology; Sustainability; Hesitant Fuzzy Set; Cumulative Prospect Theory; VIKOR | International Journal Of Production Economics |
| **Yadava, G. et al. (2020)** | A framework to achieve sustainability in manufacturing organisationsof developing economies using industry 4.0 technologies' enablers | Developing Nations; Empirical Study; Industry 4.0; Manufacturing Supply Chain; New Technologies; Robust Best Worst Method (RBWM); Sustainability | Computers In Industry |
| **Villara, L. et al. (2020)** | Fostering economic growth, social inclusion & sustainability in Industry 4.0: a systemic approach | Sustainable Development; Social Inclusion Approach; Soft Systems Methodology; Industry 4.0; Smes Strategy; Manufacturing Sector | Procedia Manufacturing |
| **García-Muiña, F. et al. (2020)** | Sustainability Transition in Industry 4.0 and Smart Manufacturing with the Triple-Layered Business Model Canvas | Industry 4.0; Sustainability; Manufacturing; Business Model Canvas | Sustainability |
| **Ahmad, S. et al. (2020)** | Towards Sustainable Textile and Apparel Industry: Exploring the Role of Business Intelligence Systems in the Era of Industry 4.0 | Business Intelligence Systems Adoption; Industry 4.0; Sustainability; Textile Industry; Apparel Industry | Sustainability |

| | | | |
|---|---|---|---|
| **Yadav, G. et al. (2020)** | A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case | Sustainable Supply Chain; Challenges; Industry 4.0; Circular Economy; Solution Measures; Best Worst Method; ELECTRE | Journal Of Cleaner Production |
| **Nara, E. et al. (2021)** | Expected impact of industry 4.0 technologies on sustainable development: A study in the context of Brazil's plastic industry | Cloud Computing Search Subject For Cloud Computing , Industry, Internet Of Things, Models, Plastics, Robots, Sustainable Development, Brazil | Sustainable Production And Consumption |
| **Enyoghasi, C. and Badurdeen, F. (2021)** | Industry 4.0 for sustainable manufacturing: Opportunities at the product, process, and system levels | Industry 4.0; Sustainable Products; Sustainable Processes; Sustainable Systems | Resources, Conservation And Recycling Volume |
| **Costa, J., Ávila, P., Bastos, J., Pinto Ferreira, L. (2021)** | A new simple, flexible and low-cost machine monitoring system | Industry 4.0; Machine Monitoring; Beacon, Bluetooth BLE; Remote Monitoring; Low Cost; SME's; b-Remote | Dyna Ingenieria e Industria |

Man, J. and Strandhagen, J. (2017) present an article that discusses possible sustainable business landscapes and proposes a research agenda on how Industry 4.0 can be used to produce sustainable business models, where opportunities for sustainable contributions exist when designing products for longevity. Sustainability means not only being more efficient, but also using less raw material and recycling more products. This changes the value proposition, supply chain, customer association, and financial validation of a business model. This work addressed the following I4.0 pillars: 3, 5 and 8. Giret, A., et al. (2017) proposes a work focused on a method that helps researchers to design sustainable intelligent manufacturing systems. The approach centres on identifying the producing elements and hence the style and integration of sustainability-oriented mechanisms within the system specification, providing specific development tools with integrated support for proprietary resources. It is carried out through a set of case studies, investigation in which the projected technique can be gauged. This work addressed the following I4.0 pillars: 3 and 9.

Yazdi, P. et al. (2018) present a paper with the objective of designing and analysing the implementation of an intelligent and sustainable materials handling system for materials distribution using an agent-based algorithm as a control architecture. The study focused on recognizing and analysing effective factors in the sustainability of improved processes, using a simple model. For this, through expert opinions, the effective factors on the sustainability of process improvement activities are determined. This work addressed the following I4.0 pillars: 3 and 9. Thomas, et al., (2018) present an investigation aiming to explore the applicability of intelligent systems in food manufacturing companies in the United Kingdom and to identify the main priority areas and improvement levers for the implementation of such systems. A survey is carried out including a questionnaire, follow-up interviews and visits to 32 food manufacturing companies in the UK. The questionnaire and interviews are guided by a unique measurement instrument that the authors developed with a focus on SS (Smart Systems) technologies and systems. This work presents an original contribution, as it is one of the few academic studies to explore the implementation of SS in industry and provide a new perspective on the main motivators and inhibitors of its implementation. The results suggest that the current turmoil in the sector may be bringing food companies closer to adopting such systems; therefore, this is a good time to define and develop the optimal SS implementation strategy. This work addressed the following I4.0 pillars: 3 and 8.

In (Varela, et al., 2017) a review on Lean Manufacturing (LM), Industry 4.0 (I4.0), and the three pillars of Sustainability is put forward, with the main goal of the explanation of the meaning of these three main subjects underlying the work (LM, I4.0, and Sustainability). Moreover, the authors focus on a proposed structural equation model, based on two exogenous constructs (LM and I4.0) and the three endogenous constructs (EcS, EnS, and SoS), each construct composed by three manifest variables, and with six hypotheses, for quantitatively measuring the effects of LM and I4.0, in the Sustainability pillars. Additionally, so as to statistically validate such hypotheses, a collection of 252 valid questionnaires from industrial firms of Iberia (Portugal and Spain) were analysed. The validation of the projected model was obtained through the appliance of the corroborative correlational analysis and also the corresponding values of the adjustment quality given a liableness and validity with a decent fitness. in addition, a correlation between luminous flux unit and I4.0 was conjointly confirmed. As a worldwide conclusion, the results obtained through the study administrated enabled to state that exists a relation between I4.0 and property, and a not confirmed relation between luminous flux unit and property. These conclusions will contribute as a crucial call support for the commercial firms and its stakeholders, even as a result of not all the results square measure in line with different opinions and studies. Moreover, this can mean that companies have now a stronger knowledge base to further decide about the implementation of LM and I4.0, and their implications in Sustainability.

Hidayatno, A. et al. (2019) present research that aims to discover the systemic impact of the development and implementation of technology from Industry 4.0 for the transition of sustainable energy in developing countries, which eventually needs a valid model conceptualization that acts as a standard for future research. The United Nations Industrial Development Organization has defined the relevance of Industry 4.0 and sustainability in the global sustainable development goals 7 and 9, that digital industrial development will support the growth of the Sustainable energy industry. Therefore, the implication will certainly affect all countries with different meanings, including one of the emerging industry countries, Indonesia. In response to this, Indonesia is currently mapping out the way to enter Industry 4.0 era, making Indonesia 4.0. This work addressed the following I4.0 pillars: 3.

Ren, S. et al. (2019) present a study combining the main technologies of smart manufacturing and the idea of ubiquitous servitization. A comprehensive overview of big data in intelligent manufacturing was undertaken and a conceptual framework proposed from a product lifecycle perspective. As one of the most important technologies for intelligent manufacturing, big data analytics can reveal insights, such as relationships between lifecycle decisions and process parameters, helping industry leaders make more informed business decisions in management environments. This work addressed the following I4.0 pillars: 1, 3 and 9. Ghadimia, P.et al. (2019) presents a study called a Multi-Agent that is a systems approach (MASs) proposed to address the process of evaluating and selecting sustainable suppliers to provide an appropriate communication channel, structured information exchange and visibility between suppliers and manufacturers. In addition, the application of MASs in this process, and its natural applicability as one of the technologies that allow the move to the 4.0 supply chain industry, are investigated in detail. It turns out that what is proposed in this approach can help decision makers within manufacturing companies to make quick decisions with less human interaction. The merit of the developed MAS is demonstrated through a real-world implementation by a medical device manufacturer. Finally, the limitations and advantages of the proposed approach are presented in conjunction with some observations for future work. Advances in information and communication systems offer immense opportunities for supply chain intelligence and autonomy by establishing stepping stones for Industry 4.0 supply chains (SCs). However, this process has not yet been carried out in the SCs of Industry 4.0, where interconnection, in real time transparency of information, technical assistance and decentralization of members of a physical system (members of the supply chain) are considered the main design principles. This work addressed the following I4.0 pillars: 3 and 9.

Lee, Wo et al. (2019) present a work with a tool condition monitoring of an intelligent system that they present in a research work aimed at identifying manufacturing trade-offs related to sustainability and an ideal set of machining conditions monitoring the status of the machine-tool. In addition, they use a multi-objective optimization based on an evolutionary algorithm that is used to find the ideal operating conditions. Through the result of the increased use of sensors and networked machines in manufacturing operations, artificial intelligence techniques play a fundamental role in deriving significant value from the big data infrastructure. These techniques can inform decision-making and can enable the implementation of more sustainable practices in the manufacturing industry. In machining processes, a considerable amount of waste (scrap) is generated as a result of failure to monitor a tool condition. This work addressed the following I4.0 pillars: 1, 2, 3, 5, 8 and 9.

Scavarda, et al., (2019) developed a research that was developed between 1 March 2019 to 2 September 2019, through a bibliographic review involving human resources and deadlines related to the concept of sustainability, industry 4.0, corporate social responsibility and young generation. Its public target is the young generation of the world. Two proposals were created after reviewing the literature and collecting data, which allowed the elaboration of “an analysis of corporate social responsibility and industry 4.0 with a focus on the young generation: a sustainable management of human resources structure." The authors of this research contribute with theoretical and practical educational purposes to insert the young citizen in society. This contribution also involves the work of companies in planning and preparing their team for the development of activities in the communities in their neighbourhood, which will allow the creation of new proposals to be presented, so that nations can incorporate their young people in the transition labour market and have a sustainable vision for future generations. This work addressed the following I4.0 pillars: 3.

García-Muiña, et al., (2020) present a paper with the objective of analysing the introduction of sustainability in the corporate value proposal, through the evolution from a traditional to a sustainable business model. The business model innovation is investigated in the case of a producer of ceramic tiles in the district of Sassuolo, Italy. The company has introduced several sustainability practices over the years and, through investments in Industry 4.0 technologies, is able to carry out impact assessments of its production process. The tool applied to the business model transition will be the Business Model Canvas by Triple-Layered, by Joyce and Paquin. The results illustrate the new company's sustainable value proposal, considering all three pillars of sustainability: environment, economy and society. Despite the limitations resulting from the individual case study, the results can be easily adapted to other ceramic tile companies in the sector. In addition, the authors' research can inspire other manufacturing companies to develop a sustainable business model project. This work explores the still limited literature on the application of sustainable business model methods in operational scenarios. This work addressed the following I4.0 pillars: 3 and 9.

Ahmad, et al., (2020) present a study on one of the determinants of the adoption of Business Intelligence Systems (BIS) with an eye to understand how BIS can solve sustainability issues in a company with industry 4.0 technologies. The methodology they use is a qualitative research approach that is applied with 14 semi-structured detailed interviews with 12 of the world's leading T&A companies. The snowball and purposeful sampling strategy is used to select participants. The qualitative content analysis technique is used to analyse the interview data. The results revealed several topics, such as sustainability problems in T&A companies, improved value creation processes with leading Business Intelligence (BI) solutions and difficulties in adopting BIS. Major improvements are seen in apparel retailing because apparel companies are more likely to adopt Industry 4.0 technologies with advanced technologies for business intelligence (BI) solutions. The results prove the fundamental role of economic sustainability in the adoption of BIS and Industry 4.0 technologies in T&A companies. This work addressed the following I4.0 pillars: 1, 3 and 8.

Fatimah, Y. et al. (2020) present a work whose objectives are to investigate the fundamental issues and opportunities and develop a sustainable and intelligent waste management system in Indonesia, using technologies from industry 4.0. The system should provide a multidimensional approach, determine the maturity level of the waste management system in a technical method and seek the objective of designing a new strategy to minimize the problems of waste management. In this work they present a comprehensive systematic review of the literature, intensive discussions in focus groups and direct observation in Indonesian cities were the approaches used to develop waste management business processes and their system design. The waste business processes consist of mixed collection, classification, transportation, varied treatment and chain disposal. The proposed waste management system project features circular economy processes that can separate municipal waste, identify waste characteristics and determine sustainable waste treatment technologies through the use of the Internet of Things (IoT) as an integrator. This study contributed to the objectives of sustainable development (SDGs), such as Good health and well-being (SDG 3); Drinking water and sanitation (SDG 6); Decent work and economic growth (SDG 8); Responsible Consumption and Production (SDG 12) and Climate Action (SDG 13). The study proposes a new smart and sustainable waste management project, which can achieve satisfactory economic, social and environmental performance in waste management. This work addressed the following I4.0 pillars: 3 and 4.

Bai, et al. (2020) present a structure of measures for sustainability based on the United Nations Sustainable Development Goals; incorporating various economic aspects, environmental and social attributes. They also develop a hybrid decision method of multiple situations integrating a hesitant fuzzy set, cumulative prospecting theory and VIKOR. This method can effectively evaluate Industry 4.0 technologies based on their sustainable performance and application. They apply the method using the secondary case information from a report by the World Economic Forum. The results show that mobile technology has the greatest impact on sustainability across all industries, and nanotechnology, mobile technology, simulation and drones have the greatest impact on sustainability in the automotive, electronics, food and beverage and textiles, apparel and footwear, respectively. The recommendation of this paper is to take advantage of the Industry 4.0 adoption technology to improve the impact of sustainability, being needed that each technology has to be carefully assessed in the context of each sustainability dimension. Investment in such technologies should consider appropriate priority investment and promotion. This work addressed the following I4.0 pillars: 2 and 3.

Yadav, et al. (2020) present a study with the objective of developing a framework to improve the adoption of sustainability in manufacturing organizations in developing nations using technologies from Industry 4.0. Initially, facilitators who strongly influence the adoption of sustainability are identified through a literature review. In addition, they present a large-scale research which is conducted to reach Industry 4.0 enabling technologies to be included in the structure. Based on empirical analysis, a framework is developed and tested in an Indian manufacturing case organization. Finally, Robust Best Worst Method (RBWM) is used to identify the intensity of influence of each capacitor included in the structure. The results of the study reveal that managerial, economic and environmental facilitators have a strong contribution to the adoption of sustainability. The results of the present study will be beneficial for researchers, professionals and policy makers. This work addressed the following I4.0 pillars: 1, 4, 5 and 9.

Villara, et al. (2020) present an investigation that proposes a soft systems methodology to deal with the context of sustainable complexity and inclusive industrial development phenomena. Its holistic nature provides useful insights that plan how I4.0 and social inclusion fit into the Mexican context. The theoretical proposal is based on the state of the art of social inclusion in the sector 4.0 and a survey for an I4.0 initiative accessible through a stakeholder system network communication approach. The inclusive strategy is an effort to align root systems for sustainable development with stakeholders for Mexican SMEs in the manufacturing sector. This work addressed the following I4.0 pillars: 3 and 9.

Yadav, et al. (2020) present a study that aims to develop a structure to overcome the challenges of SSCM through solution measures based on industry 4.0 and the circular economy. This study identifies a unique set of 28 SSCM challenges and 22 solution measures. In addition, an automotive case organization is used to test the applicability of the framework developed through the hybrid Best Worst Method (BWM) - Elimination and Choice Expressing Reality (ELECTRE) approach. Entries for the BWM-ELECTRE approach are obtained by building a panel of experts within the case organization. Initial entries are taken for BWM comparisons to calculate the weight of SSCM challenges; whereas, a further comparison of challenges and solution measures is also obtained for the ELECTRE approach to calculate the final classification of the solution measures to overcome the SSCM challenges. The results of the case reveal that managerial and organizational challenges and economic challenges emerge as the most critical for the adoption of SSCM. The results of the present study will be beneficial for researchers working in the SSCM 4.0 industry and in the domain of the circular economy; Whereas, practitioners can use prioritized solution measures to formulate effective strategies to overcome SSCM adoption failures. This work addressed the following I4.0 pillars: 3 and 9.

Enyoghasi and Badurdeen (2021) present an investigation with a comparative analysis examining individual technologies in Industry 4.0 and their potential impact on sustainable manufacturing. A structure based on clusters of sustainability metrics for products, processes and systems is applied to examine these impacts. The results reveal that the literature is still limited in identifying opportunities to improve sustainability at different levels using technologies from Industry 4.0. The impact on many criteria related to product, process or sustainability at the system level due to Industry 4.0 technologies has not yet been examined. Comparative analysis, and other literature, are used to provide additional guidance for future research and opportunities on leveraging Industry 4.0 technologies for more sustainable manufacturing. The implications for the industry through providing a framework for identifying potential solutions to improve sustainable manufacturing performance using industry 4.0 technologies are also discussed. This work addressed the following I4.0 pillars: 3 and 9.

Nara, et al. (2021) developed a study investigating the impacts of Industry 4.0 technologies using the Triple Bottom Line perspective for sustainable development. They present a sustainability-oriented model for assessing the influence of Industry 4.0 technologies on sustainable metrics. The model analyses the impact of Industry 4.0 technologies on several key performance indicators related to sustainable development. The model was tested in the plastics industry, which has a high potential for technological 4.0 Industry aggregation in emerging economies. A diffuse multi-criteria TOPSIS method was used to classify Industry 4.0 technologies, identifying those with the strongest and weakest impacts on sustainable development. As a result, it was suggested that the internet of things, cyber-physical systems, sensors and the implementation of big data are engines for sustainable development. It also shown that these technologies are associated with substantial positive impacts on economic metrics. However, there was much less positive influence on environmental and social metrics, suggesting an imbalance in the perspective of the Triple Bottom Line for the plastics industry. In addition, negative impacts of robots on job creation and low influence of cloud computing technologies and systems integration for sustainable development were found. Based on these findings, this work contributed to the decision-making process by helping managers, process engineers and stakeholders to understand and estimate the expected impacts of Industry 4.0 technologies on economic, environmental and social aspects for sustainable development. This work addressed the following I4.0 pillars: 1, 3, 4, 6 and 7.

Costa, J., Ávila, P., Bastos, J., Pinto Ferreira, L. (2021) present the proposal of a system for remote monitoring of equipment in real time that meets the requirements of low cost, simplicity, and flexibility. The system monitors the equipment in a simple and agile way, regardless of its sophistication, installation constraints and company resources. A prototype of a system was developed and tested in both laboratory conditions and in a productive environment. The proposed architecture of the system comprises a sensor that transmits the machine’s signal wirelessly to a gateway which is responsible for collecting all surrounding signals and send it to the cloud. During the testing and assessment of the tools, the results validated the developed prototype. As a main result, the proposed solution offers to the industrial market a new low-cost monitoring system based in mature and tested technology laid upon flexible and scalable solutions.

The articles previously presented were analysed based on the nine main pillars of I4.0 (see Table 4) and for the three pillars of sustainability (see Table 5). In both tables, for each of the works were identified which pillar(s) are addressed, and subsequently it was quantified the total percentage of the papers that cover each pillar and the percentage of the pillars that are covered by each paper.

**Table 4.** Pillars of I4.0 addressed by the articles selected in the research.

| Research papers \ Pillars of I4.0 | | Big Data and Data Analytics | Simulation | Horizontal and Vertical Integration | Industrial Internet of Things | Autonomous Robots | The Cloud | Cyber Physical Systems/Security | Augmented Reality | Additive Manufacturing | **% Pillars p/ article** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | Giret, A. et al. | | | x | | | | | | x | 22 |
| | Man, J. and Strandhagen, J. | | | x | | x | | | x | | 33 |
| 2018 | Yazdi, P. et al. | | | x | | | | | | x | 22 |
| | Thomas, A. et al. | | | x | | | | | x | | 22 |
| 2019 | Varela, L. et al. | x | x | | | x | | | | | 33 |
| | Hidayatno, A. et al. | | | x | | | | | | | **11** |
| | Ren, S. et al. | x | | x | | | | | | x | 33 |
| | Ghadimia, P.et al. | | | x | | | | | | x | 22 |
| | Lee, Wo et al. | x | x | x | | x | | | x | x | **67** |
| | Scavarda, A. et al. | | | x | | | | | | | **11** |
| 2020 | García-Muiña, F. et al. | | | x | | | | | | x | 22 |
| | Ahmad, S. et al. | x | | x | | | | | x | | 33 |
| | Fatimah, Y. et al. | | | x | x | | | | | | 22 |
| | Bai, C. et al. | | x | x | | | | | | | 22 |
| | Yadava, G. et al. | x | | | x | x | | | | x | 44 |
| | Villara, L. et al. | | | x | | | | | | x | 22 |
| | Yadav, G. et al. | | | x | | | | | | x | 22 |
| 2021 | Enyoghasi, C. and Badurdeen, F. | | | x | | | | | | x | 22 |
| | Nara, E. et al. | x | | x | x | | x | x | | | 56 |
| | Costa, J. et al. | | | | x | | | | | | **11** |
| **% Articles p/ pillar** | | 28 | 11 | **94** | 22 | 17 | **6** | **6** | 22 | 56 | |

**Table 5.** Pillars of sustainability addressed by the articles selected in the research.

| Research papers \ Pillars of Sustainability | | Environmental | Social | Economic | % Pillars p/ article |
|---|---|---|---|---|---|
| 2017 | Giret, A. et al. | | | x | 33 |
| | Man, J. and Strandhagen, J. | x | | x | 67 |
| 2018 | Yazdi, P. et al. | | | x | 33 |
| | Thomas, A. et al. | | | x | 33 |
| 2019 | Varela, L. et al. | x | x | x | **100** |
| | Hidayatno, A. et al. | x | | x | 67 |
| | Ren, S. et al. | | | x | 33 |
| | Ghadimia, P.et al. | | x | x | 67 |
| | Lee, Wo et al. | | | x | 33 |
| | Scavarda, A. et al. | | x | | 33 |
| 2020 | García-Muiña, F. et al. | x | x | x | **100** |
| | Ahmad, S. et al. | | | x | 33 |
| | Fatimah, Y. et al. | x | x | x | **100** |
| | Bai, C. et al. | x | x | x | **100** |
| | Yadava, G. et al. | x | | x | 67 |
| | Villara, L. et al. | | x | x | 67 |
| | Yadav, G. et al. | | | x | 33 |
| 2021 | Enyoghasi, C. and Badurdeen, F. | | | x | 33 |
| | Nara, E. et al. | x | x | x | **100** |
| | Costa, J., et al. | | | x | 33 |
| **% Articles p/ pillar** | | 37 | 37 | **95** | |

Analysing the previous tables, it is possible verify the following:

- The I4.0 pillars more addressed are: Horizontal and Vertical System Integration; Additive Manufacturing and 3D Printing;
- The I4.0 pillars less addressed are: The Cloud; and the Cyber Security;
- None of the papers covers all the pillars of I4.0;
- The Sustainability pillar most addressed is the economic, by 95% of the papers, and with a large difference compared to the other pillars;
- There are only five papers (25%) that cover the 3 pillars of sustainability.

## 4. Conclusion

This work enabled the identification of the main approaches of intelligent or smart and sustainable manufacturing systems, and supply chains or networks in the scope of I4.0, based on a systematic review of the literature. The main objective of this work was to pay particular attention to sustainability issues, as this is considered a central and of upmost concern nowadays, in a I4.0 context, and underlying the smart factory concept. Through this work it was also possible to verify which are the main I4.0 pillars and sustainability pillars considered more frequently in research, which are: for I4.0 the Integration of Horizontal and Vertical Systems (94%) and Additive manufacturing and 3D printing (56%); for sustainability the economic dimension (95%) with a large difference compared to the other pillars.

Attending the central research question exposed in section one "*Is there an increased attention being given to sustainability issues nowadays in the Industry 4.0?*" the results suggest that there is not yet so much attention to the pillars of environmental and social sustainability, which are fundamental dimensions of sustainability. Considering that, there is space to increase the research of I4.0 with the aim of achieve a better compromise between industrial development and sustainability.


## Acknowledgements

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.


## References


Adolph, Lars, et al., (2016). German Standardization Roadmap: Industry 4.0. Version2. DIN, Berlin.

Agustinho, A. (2014). Sustentabilidade Empresarial: uma análise das consequências na estrutura de custos. Dissertação de Mestrado de Gestão. Lisboa, ISG - Instituto Superior de Gestão.

Almeida, A., Bastos, J., Francisco, R., Azevedo, A., Ávila, P. (2016) Sustainability Assessment Framework for Proactive Supply Chain Management, International

Journal of Industrial and Systems Engineering, Vol. 24, Nº2, p.198-222, Inderscience Publishers.

Beier, G.; Ullrich, A.; Niehoff, S.; Reißig, M.; Habich, M. (2020) Industry 4.0: How it is defined from a sociotechnical perspective and how much sustainability it includes A literature review. J. Clean. Prod., 229, 120856.

Bilge, P., Badurdeen, F., Seliger, G., Jawahir, I.S. (2016) A novel manufacturing architecture for sustainable value creation. CIRP Ann. - Manuf. Technol. 65, 455-458.

Bogle, I.D.L. (2017) A perspective on smart process manufacturing research challenges for process systems engineers. Engineering.

Bogue, R., (2014) Sustainable manufacturing: a critical discipline for the twenty-first century. Assemb. Autom. 34, 117-122.

Bonizella, B., Sagar, A. (2004) Nongovernmental organizations (NGOs) and energy. Encycl. Energy 4, 301-314.

Cassettari, L., Bendato, I., Mosca, M., Mosca, R. (2017) Energy Resources Intelligent Management using on line real-time simulation: a decision support tool for sustainable manufacturing. Appl. Energy 190, 841-851.

Chan, F., Li, N., Chung, S.H., Saadat, M. (2017) Management of sustainable manufacturing systems-a review on mathematical problems. Int. J. Prod. Res. 55, 1148-1163.

Costa, J., Ávila, P., Bastos, J., Pinto Ferreira, L. (2021). A new simple, flexible and low-cost machine monitoring system, Dyna, Dyna-Acelerado (0).

Davis J, Edgar T, Porter J, Bernaden J, Sarli M. (2012) Smart manufacturing, manufacturing intelligence and demand-dynamic performance. Comput Chem Eng., 47, 145–56.

Deloitte. (2014). Industry 4.0 - Challenges and solutions for the digital transformation and use of exponential technologies.

Esfahbodi, A., Zhang, Y., Watson, G., Zhang, T. (2016) Governance pressures and performance outcomes of sustainable supply chain management - an empirical analysis of UK manufacturing industry. J. Clean. Prod. 1-13.

Esmaeilian, B., Behdad, S. abd Wang, B. (2016) The evolution and future of manufacturing: A review. Journal of Manufacturing Systems 39:79-100.

Feeney AB, Frechette SP, Srinivasan V. (2015) A portrait of an ISO STEP tolerancing standard as an enabler of smart manufacturing systems. J Comput Inf Sci Eng., 15(2):021001.

Festo Group (2017) Qualification for Industry 4.0. Denkendorf: Festo Didactic SE.

Fiksel, J.; Low, J.; Thomas, J. (2004) Linking sustainability to shareholder value, Environmental Managers Journal.

Fink, A. (1998) Book Reviews: Conducting Research Literature Reviews: From Paper to the Internet. Sage Publications.

Fonseca, L.; Amaral, A.; Oliveira, J. (2021) Quality 4.0: The EFQM 2020 Model and Industry 4.0 Relationships and Implications. Sustainability, 13, 3107.

Garetti, M., Taisch, M. (2012) Sustainable manufacturing: trends and research challenges. Prod. Plann. Contr. 23, 83-104.

Ghobakhloo, M. (2020) Industry 4.0, digitization, and opportunities for sustainability. J. Clean. Prod., 252, 119869.

Golini, R., Gualandris, J. (2018) An empirical examination of the relationship between globalization, integration and sustainable innovation within manufacturing networks. Int. J. Oper. Prod. Manag.

Herrmann, C., Schmidt, C., Kurle, D., Blume, S., Thiede, S. (2014) Sustainability in manufacturing and factories of the future. Int. J. Precis. Eng. Manuf. Green Technol. 1, 283-292.

Jena, M.C.; Mishra, S.K.; Moharana, H.S. (2020) Application of Industry 4.0 to enhance sustainable manufacturing. Environ. Prog. Sustain. Energy, 39, 13360.

Jordan, J.A. Jr, & Michel, F.J. (2000) Next Generation Manufacturing: Methods and Techniques. John Wiley & Sons, Chichester.

Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013) Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group. Forschungsunion.

Kamble, S.; Gunasekaran, A.; Dhone, N.C. (2020) Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies. Int. J. Prod. Res., 58, 1319–1337.

Kusiak A. (1990) Intelligent manufacturing systems. Old Tappan: Prentice Hall Press.

Lee J, Bagheri B, Kao HA. (2015) A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manuf Lett, 3, 18–23.

Li B, Hou B, Yu W, Lu X, Yang C. (2017) Applications of artificial intelligence in intelligent manufacturing: A review. Front Inform Tech El, 18(1):86–96.

Linder, C. (2019) Customer orientation and operations: The role of manufacturing capabilities in small- and medium-sized enterprises. Int. J. Prod. Econ., 216, 105–117.

Machado, C.G.; Winroth, M.P.; Ribeiro da Silva, E.H.D. (2020) Sustainable manufacturing in Industry 4.0: An emerging research agenda. Int. J. Prod. Res., 58, 1462–1484.

Malviya, R.K., Kant, R. (2015) Green supply chain management (GSCM): a structured literature review and research implications. Benchmark Int. J., 22, 1360-1394.

McFarlane D, Sarma S, Chirn JL, Wong CY, Ashton K. (2003) Auto ID systems and intelligent manufacturing control. Eng Appl Artif Intel., 16(4):365–76.

Morrar, R., Arman, H. and Mousa, S. (2017) The Fourth Industrial Revolution (Industry 4.0): A Social Innovation Perspective. Technology Innovation Management Review.

Nara, E.O.B.; Becker da Costa, M.; Baierle, I.C.; Schaefer, J.L.; Benitez, G.B.; Lima do Santos, L.M.A.; Benitez, L.B. (2021) Expected impact of industry 4.0 technologies on sustainable development: A study in the context of Brazil’s plastic industry. Sustain. Prod. Consum., 25, 102–122.

Neves, A., Godina, R., Azevedo, S. and Matias, J. (2020). A Comprehensive Review of Industrial Symbiosis. Journal of Cleaner Production. 247(20):119113 DOI: 10.1016/j.jclepro.2019.119113

Barbosa J, Leitão P, Adam E, Trentesaux D. (2015) Dynamic self-organization in holonic multi-agent manufacturing systems: The ADACOR evolution. Comput. Ind., 66:99–111.

Ocampo, L.A., Clark, E.E. (2015) A sustainable manufacturing strategy framework: the convergence of two fields. Asian Acad. Manag. J. 20, 29-57.

Oztemel E. (2010) Intelligent manufacturing systems. In: Benyoucef L, Grabot B, editors Artificial intelligence techniques for networked manufacturing enterprises management, 1–41, Springer.

Putnik, G., Ávila, P. (2016) Governance and Sustainability (Special Issue Editorial), International Journal of Industrial and Systems Engineering, Vol. 24, Nº2, p.137-143, Inderscience Publishers.

Putnik, G.D., Ferreira, L.G.M. (2019) Industry 4.0: Models, tools and cyber-physical systems for manufacturing (Editorial). FME Transactions, 47(4), 659-662.

Putnik. G.D., Pabba, S.K., Manupati, V. K., Varela, M.L.R., Ferreira, F. (2021) semi-Double-loop machine learning based CPS approach for predictive maintenance in manufacturing system based on machine status indications, CIRP Annals - Manufacturing Technology, 70(1), 365-368.

Rennung, F., Luminosu, C. and Draghici, A. (2016) Service Provision in the Framework of Industry 4.0. Procedia - Social and Behavioral Sciences 221:372-377.

Samala, T., Manupati, V. K., Nikhilesh, B.B.S., Varela, M.L.R., Putnik, G.D. (2021) Job adjustment strategy for predictive maintenance in semi-fully flexible systems based on machine health status, Sustainability, 13(9), 5295.

Sarkis, J. (2001) Manufacturing's role in corporate environmental sustainability: concerns for the new millennium. Int. J. Oper. Prod. Manag. 21, 666-686.

Saunders, M., Lewis, P., Thornhill, A. (2016) Research Methods for Business Students.Pearson Education Limited, Pearson Education UK.

Scheuermann, C., Verclas, S. and Bruegge, B. (2015) Agile factory-an example of an industry 4.0 manufacturing process. 2015 IEEE 3rd International Conference on Cyber-Physical Systems, Networks, and Applications.

Seuring, S., (2013) A review of modeling approaches for sustainable supply chain management. Decis. Support Syst. 54, 1513-1520.

Smit, J., Kreutzer, S., Moeller, C., & Carlberg, M. (2016) Industry 4.0.

Song, Z., Moon, Y. (2016) Assessing sustainability benefits of cyber manufacturing systems. Int. J. Adv. Manuf. Technol. 90, 1365e1382.

Thirupathi Samala, Vijaya Kumar Manupati, Maria Leonilde R. Varela, and Goran Putnik (2021) Investigation of Degradation and Upgradation Models for Flexible Unit Systems: A Systematic Literature Review. Future Internet, MDPI, 13(3), 57.

Thobe, K., Wiesner, S. and Wuest, T. (2017) "Industrie 4.0" and Smart Manufacturing – A Review of Research Issues and Application Examples, International Journal of Automation Technology.

Tranfield, D., Denyer, D., Smart, P. (2003) Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br.J. Manage. 14 (3), 207–222.

Varela, L., Araújo, A., Ávila, P., Castro, H., & Putnik, G. (2019) Evaluation of the relation between lean manufacturing, Industry 4.0, and sustainability. Sustainability, 11(5), MDPI, 1439.

Wan J, Tang S, Li D, Wang S, Liu C, Abbas H, et al. (2017) A manufacturing big data solution for active preventive maintenance. IEEE Trans Ind Inform. 13(4):2039–47.

Wang S, Wan J, Zhang D, Li D, Zhang C. (2016) Towards smart factory for Industry 4.0: A self-organized multi-agent system with big data based feedback and coordination. Comput Netw, 101:158–68.

Wang SY, Wan J, Li D, Zhang C. (2016) Implementing smart factory of Industrie 4.0: An outlook. Int J Distrib Sens N, 2016:3159805.

Wittenberg, C. (2016) Human-CPS interaction – requirements and human-machine interaction methods for the Industry 4.0. IFAC-Papersonline 49–19, 420–425.

Xia, X., Govindan, K., Zhu, Q. (2015) Analyzing internal barriers for automotive parts remanufacturers in China using grey-DEMATEL approach. J. Clean. Prod. 87, 811-825.