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AN OVERVIEW ON THE USE OF AI/ML IN MANUFACTURING MSMES: SOLVED ISSUES, LIMITS AND CHALLENGES

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Abstract

Artificial Intelligence (AI) and Machine Learning (ML) represent popular topics of Industry 4.0. The use of these techniques, which are evolving rapidly in both academia and practice, can bring many benefits to production systems, such as enabling resilience and improving sustainable growth. However, given the effort needed in the implementation of AI/ML such as in terms of data quality and employee skills, the potential of AI/ML has not yet fully materialized in the context of manufacturing Micro, Small, and Medium Enterprises (MSMEs), which could improve their core processes or innovate product level to stay competitive, taking advantage of these technologies. This research work, methodologically based on a scoping literature review, presents an investigation of which are the existing applications of AI/ML in manufacturing MSMEs and discusses the limitations and challenges of these technologies. Moreover, the main emerging topics of research and future trends are summarized.

Keywords: *Artificial Intelligence; Machine Learning; Micro, Small, and Medium Enterprises; Data Analytics*

BACKGROUND AND MOTIVATION

To remain competitive, continuous improvement and optimization of processes are the key requirements of manufacturing companies. Owing to the increasing digitalization and the integration of smart devices and machines in production systems, a large amount of data is available and needs to be stored, processed, and analysed.

Several Artificial Intelligence (AI) methods have been applied in the manufacturing context including Machine Learning (ML), Deep Learning (DL), and many others to solve tasks of different nature. Typical use cases range from demand-side management to condition monitoring, predictive maintenance, quality, production planning, production control, and supply chain management [1–3]. In manufacturing systems, AI and ML can enable time and cost savings, increased quality and waste reduction, and facilitate manufacturing development in smart, flexible, and eco-friendly production ecosystems [4].

For these reasons, technologies related to Artificial Intelligence and Machine Learning, one of the most promising AI technologies, are increasingly used to extract from data knowledgeable value which can bring lots of benefits to manufacturing systems [2]. AI represents a broad field of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence [5], whose main objective is the creation of human-like behaviour in machines for perception, reasoning, and action. Broadly speaking, systems that incorporate AI possess analytical capabilities that emulate human cognition. Instead, ML represents the most promising subfield of AI, defined by Iqbal (2022) as a «set of methods that can automatically detect patterns in data, and then use the uncovered patterns to predict future data, or to perform other kinds of decision making under uncertainty» [5]. It enables computer systems to recognize correlations from data, thereby making human-like decisions without defined rules and it is based on the generalization of knowledge from data and can be realized with different methods such as classification, clustering, regression, and anomaly detection [2]. The successful implementation of ML models depends on suitable algorithms and large amounts of high-quality datasets. In general, three categories of ML can be distinguished based on how the models learn from the data: supervised, unsupervised, and reinforcement learning techniques.

In recent years, the scientific interest in AI and ML has increased from a “data science” point of view and due to the unprecedented performance, that can result from their implementation, these techniques have been integrated with other technologies such as Digital Twin [6] or Additive Manufacturing [7]. Nowadays AI and ML represent such cross-cutting approaches to problem-solving that they can be applied in totally different fields regardless of the specific application area and/or business characteristics. AI-based tools and services can support decision-making processes, reducing the dependence on employees’ experience, improving time-

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consuming activities that generally are performed by workers, and/or outperforming the classical analytical approaches to problems.

However, although AI and ML as parts of analytics solutions are becoming popular as methods to meet the requirements of rapidly evolving, dynamic manufacturing environments, the use of these solutions for manufacturing Micro, Small, and Medium Enterprises (MSMEs) has not yet been fully explored. These enterprises are struggling to understand the real impact of this new technology on their business management. To keep up with this evolution and achieve the competitive advantages it can provide, companies need to invest in technology and innovation. This represents a particular challenge for MSMEs, which form the backbone of the Indian economy. After the announcement of the package in May, the Ministry of Micro, Small, and Medium Enterprises made an upward revision in the definition of MSME based on feedback received from different stakeholders. The new definition and criteria came into effect on 1st July 2020.

Table 1. Definition of micro, small and medium-sized enterprises

Sr. No	Type of Enterprise	Investment	Turnover
1.	Micro Enterprise	Not more than Rs.1 Crore	Not more than Rs.5 Crore
2.	Small Enterprise	Not more than Rs.10 Crore	Not more than Rs.50 Crore
3.	Medium Enterprise	Not more than Rs.50 Crore	Not more than Rs.250 Crore

Manufacturing SMEs, which were strongly affected by the pandemic in terms of value added (-9,8%) [8], need to improve their core processes to survive. Among the various technologies that can bring advantages to MSMEs, it is crucial to provide the best conditions for implementing and realizing the value of AI and ML applications. Providing AI solutions for low-cost automation, simulation, Internet of Things (IoT), and data analytics can create new opportunities for manufacturing MSMEs that can make use of a wide range of software products that are easily accessible to try and test how AI applications could be helpful (e.g., Google Tensor Flow) [9].

To the best of the authors' knowledge, a review of the most recent scientific studies on the use of AI and ML in the context of MSMEs is not present in the literature. Most of the authors focused on the general topic of Industry 4.0 in MSMEs [10], or on a specific application of AI/ML in MSMEs manufacturing systems [11], whereas the main limitations and challenges were obtained through surveys and questionnaires. For this reason, this research work aims to provide an overview of the literature on the existing applications of AI/ML in manufacturing MSMEs focusing on the business issues that aim to solve, and above all, their main limitations and challenges. The objective of this research work is to understand the steps that have been taken, as well as what gaps still exist in the literature for the successful practical application of these technologies in MSMEs.

The remainder of this paper is organized as follows. Section 2 describes the research methodology and Section 3 presents the main results of the quantitative and qualitative analyses of the literature. Finally, section 4 provides the main conclusions of the study and possible future research directions.

RESEARCH METHODOLOGY

To fill the gap already defined, the existing scientific literature was examined using a scoping review approach that summarizes complex and heterogeneous topics, to identify research gaps and set the scene for a future research agenda [12]. A literature analysis was conducted to answer the following research questions (RQs):

- RQ1: Which types of problems can be solved by implementing of AI/ML in manufacturing MSMEs?
- RQ2: What are the main limitations and challenges associated with the use of AI/ML techniques in manufacturing MSMEs?

The first group of keywords referred to MSMEs, the second to the technologies investigated (AI and ML), and the third to the manufacturing sector. The search string, that is, the combinations of keywords from the groups obtained using the Boolean 'AND' operator between each group, and the 'OR' operator within each group, was used to cover the titles, keywords, and abstracts of papers in the database. Regarding other restriction criteria, the search was limited to articles written in English, belonging to the time horizon of the last 20 years, and whose document type was conference proceedings, articles, or reviews. Moreover, all the subject areas unrelated to production were excluded. After the search, a selection screening was performed in two stages. The first stage involved the reading of the titles and abstracts of each paper, and papers were included or excluded according

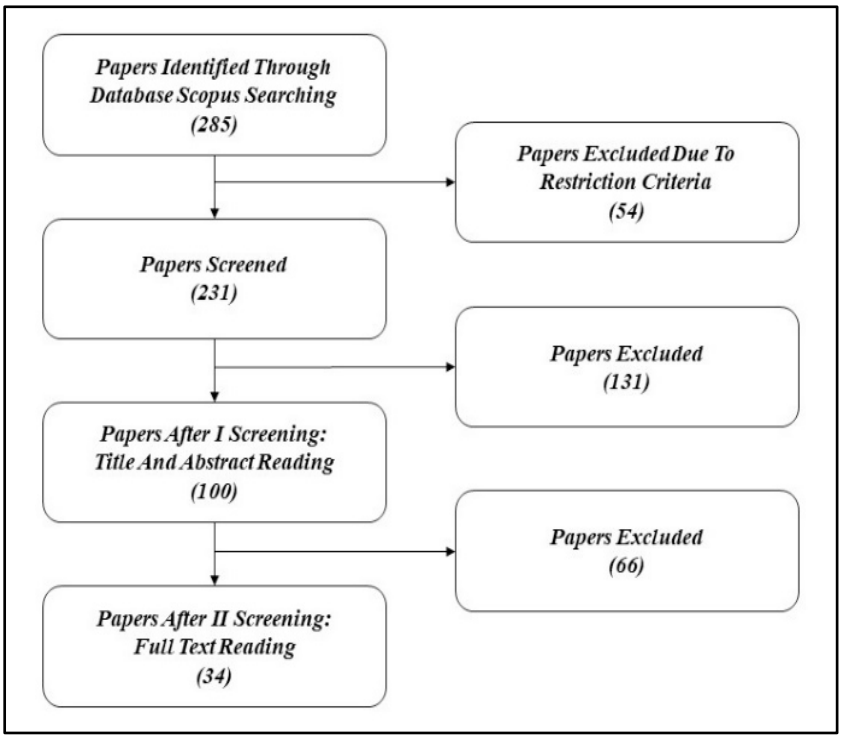
to the following exclusion criteria: no text available; papers not related to all three groups of keywords; papers not related to the manufacturing environment; papers in which AI/ML were not the focus; papers in which the focus was the algorithm and not the application or case studies. The second screening involved the reading of the full text of the papers selected and the identification of the most relevant articles based on the same exclusion criteria described above. Finally, relevant information on the papers resulting from the second screening was collected. The carried-out analysis was focused on:

- Main characteristics of papers: over the classical information related to the authors, year of publication, and type of document, the articles were classified according to their innovative contributions (i.e., reviews, surveys, development of a framework, development of a model/method, development of a service/tool, case study).
- Application of AI/ML in MSMEs: enterprises category involved in the study (Micro, Small, and/or Medium sized enterprises), the field of application (e.g., maintenance, quality, etc.), the specific type of problem to solve, and the country (if mentioned).
- Reported limitations and challenges: all the issues, problems, and possible challenges reported in the papers were collected to understand what limits the application of AI/ML in MSMEs and what the challenges to be faced.

2. Quantitative and qualitative results

The number of articles that resulted from the Scopus search, after exclusion based on the defined restriction criteria, was 231. The first screening stage allowed us to exclude 131 articles that were not in line with the objectives of this research work. Finally, only 34 articles were selected according to the exclusion criteria described in Section 2. The screening stages and the results obtained are reported in Fig. 1.

Figure-1: Scooping Literature Review: Screening and Result



The selected studies covered a time horizon ranging from 2014 to 2022. The number of papers over the years (Fig. 2) shows an evident growth above all in recent years which demonstrates the increasing interest of researchers in this topic. 29 out of 34 papers were published in the last three years (2020-2022). No significant differences were found in terms of document type. Half of the papers (17) were presented at international conferences and were mainly published in Procedia CIRP (3 papers), Procedia Computer Science (2 papers), and IFAC-Papers Online (2 papers). The remaining papers were published in peer-reviewed journals such as Applied Sciences (Switzerland) (3 papers), Annals of Operations Research (2 papers), and Technological Forecasting and Social Change (2 papers).

Regarding innovative contributions (Fig. 2), most of the selected papers dealt with the development of a method or model based on AI/ML for MSMEs [13–20], the development of a framework e.g. for measuring the AI/ML readiness of enterprises, promoting the adoption of AI/ML in MSMEs or facilitating the decision-making process for tasks that make use of AI/ML [4,11,21–26], the development of a service/tool [27–34] and surveys based on

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interviews or questionnaires submitted to MSMEs samples [35–42]. Lastly, only one study proposed a real case study [43] and one paper focused on a literature review on the use of AI and IoT within SMEs [44]. More interesting is how articles related to different innovative contributions have been distributed over the years (Fig. 2). In 2021, along with a small increase in studies focused on the development of methods or models and a decrease in studies focused on the development of services or tools, the number of studies based on surveys and the development of frameworks has significantly increased. This trend highlights that scientific attention is now more focused on the application of AI/ML in MSMEs and how to benefit from the already developed solutions.

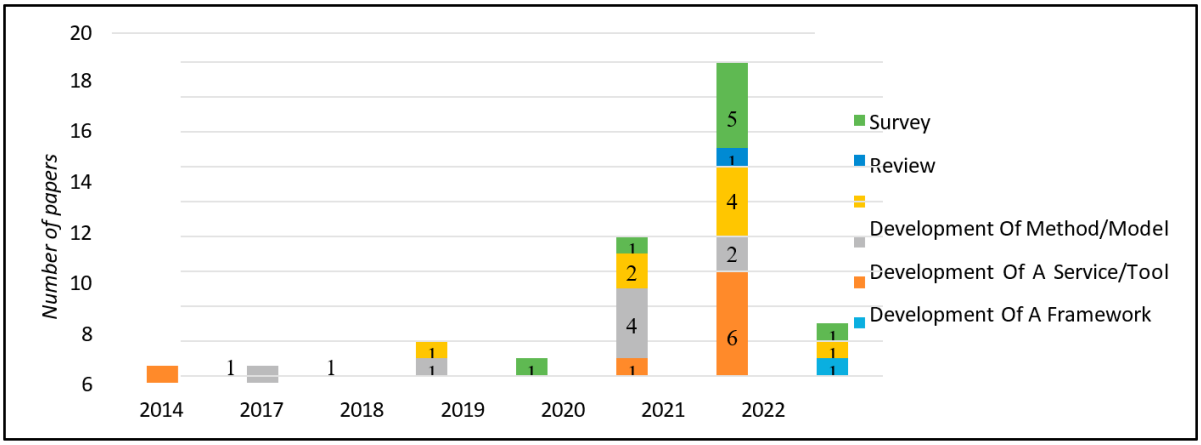

Fig. 2. Articles distribution over the years and innovative contributions.

To answer the RQ1, the main characteristics of the studies in terms of enterprises category involved, the field of application and the specific type of problem to solve, type of industry involved, and country have been collected. Most of the selected papers focused on applications for Small and Medium Enterprises (32 out of 34 papers). The remaining two papers dealt with, respectively, medium [15] and micro-sized enterprises [36]. It is interesting to note that micro-enterprises have no needs to use "complicated" systems based on AI/ML for the improvement of core processes. They have been included in the analysis only to evaluate whether something different from what was expected by the authors came out from the literature analysis. Another fundamental aspect to highlight is that not all the studies selected were conducted in INDIA. Therefore, the definition of MSMEs can differ from country to country. The countries most analyzed in the selected studies were India [4, 11, 30, 40], Germany [18, 39, 43], China [34–36], and the United Kingdom [23, 38].

The results related to the application domains are reported in Fig. 3

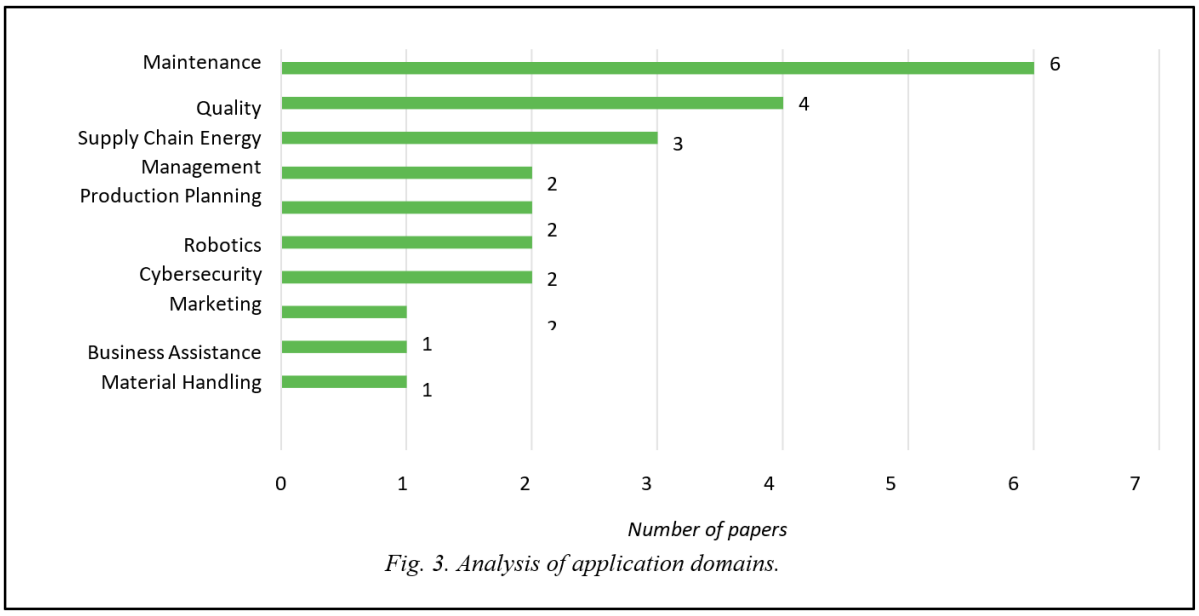

Fig. 3. Analysis of application domains.

As reported in Fig. 3, most papers focused on the use of AI and ML for maintenance (6 papers) and quality (4 papers), which represent the most studied problems probably because of their relevance and quicker return on investment. In the field of maintenance, most of the studies proposed solutions based on these technologies for predictive maintenance [11,18,22,24,31], mainly aimed to minimize the uncertainty in diagnosing the machine

failure and maximize the availability of equipment predicting the Remaining Useful Life of the machine and its components. Thanks to the real-time data provided by Industrial Internet of Things (IIoT) sensor networks, AI can help prevent machine failures and reduce maintenance costs [28]. No trend was identified in terms of AI/ML models used in the studies due to the multiple applications in the same domain. For example, in the prediction framework developed by Velmurugan et al. (2021) [11], the Linear Regression technique was used to evaluate the accuracy of failure rate variations and the K-Mean approach to identify the optimal nearest responsible maintenance and service center, whereas, in the study by Omri et al. (2021) [24], Artificial Neural Network was used. To avoid the need for specialists in the execution of the prognostics model in terms of machine learning algorithm selection, the prognostics solution proposed by Jain et al. (2020) [31] integrated automated machine learning via Auto-WEKA, an off-the-shelf open-source technology.

Focusing on the quality field, most quality checks in SMEs are manually performed by workers, and this process can be vulnerable to human errors. Due to the costs of these processes and their effects, many studies have focused on the automation of defect detection that can be achieved by applying AI/ML techniques to the data, also in this case, provided by IIoT [14,15,19,29]. All the studies of this application domain were based on neural networks. A Convolutional Neural Networks model was used for image detection achieving high accuracy in the studies by Ha and Jeong (2021) [14] and Hansen et al. (2020) [29], whereas Sariyer et al. (2021) [15] preferred a Multilayer Perceptron neural network for product quality level classification and re-work quantity prediction. Lastly, in the study by Becker et al. (2020) [19], to detect errors during the printing process, a Long Short-Term Memory neural network model was used to learn the different sound classes from recorded audio.

Regarding the class defined “Supply Chain” (3 papers), only one study focused on AI adoption to increase the operational efficiency in terms of resilience, integration, and transparency of the supply chain involved in food processing [40]. Moreover, warehouse operations are also vital in the context of supply chain management and can benefit from AI/ML techniques: a demand-forecasting model based on Long-Short-Term Memory for inventory management has been proposed to predict the inventory data of a firm by Kim et al. (2022) [13], whereas a system has been configured for the improvement of storage assignment and order picking by Choy et al. (2017) [34].

Furthermore, in the context of production control, two studies focused on AI/ML for energy management. Nowadays, many SMEs are interested in implementing measures to reduce energy consumption and improve energy management, because energy efficiency represents a way to save money and resources. AI/ML can be used to predict the energy demand of CNC machining operations based on real production data [16]. Instead, the research work by Grigoras et Neagu (2020) [25] presents a decision support platform, based on AI and data mining, which has been developed to increase energy efficiency for SMEs.

In the context of production planning, two research works dealt with the prevision of lead time through ML for SMEs highlighting the need for accurate prediction as the fuel of manual and simulation-based production planning. Lead time prediction, which is quite challenging above all in the case of systems characterized by high product variance and the variation of order parameters (such as in Make To Order systems), should be addressed before any kind of optimization in terms of scheduling [17,43].

AI/ML can also be used for robotics and cybersecurity applications. In robotics, AI/ML can be applied to overcome different issues. The main focus of the research work by Francalanza et al. (2018) [20] was the generative design, i.e., an artificial intelligence approach, for the development of customizable robotic manipulators to use in SMEs, whereas an ML framework has been developed by Roitberg et al. (2014) [26] for human activity recognition, fundamental in the cooperation between humans and robots. Regarding cybersecurity, ML-based solutions are investigated in two studies [27,38]. ML is a very effective technique since security-related data can be analysed predictively to defend against potential attacks at an early stage.

Lastly, advancements provided by AI/ML can also be obtained in other fields such as:

- Marketing: one problem to be solved through data analytics is customer churn prediction. A combination of RFM analysis (classical marketing approach for customer scoring and segmentation based on recency, frequency, and monetary total of their transactions) and ML algorithms has been proposed by Aleksandrova (2018) for this particular problem [33].
- Business assistance: given the dependence on the decision-making processes for the profitability of the enterprises, AI technologies can be integrated into the process of business decision-making through the introduction of an assistant, such as an “advisor” able to help the entrepreneur both at the stage of creating or managing the enterprise [32].
- Material handling: an AI approach has been identified to reduce accidents, improve system efficiency, and optimize parameters such as the time of handling components and speed of Automated Guided Vehicles (AGVs) [30].

Overall, only for 24 articles, it has been possible to identify a clear connection to a single application domain. For the remaining 10 papers (mainly surveys or studies based on the development of a framework), no specific application domain has been found because their approach mainly focused on the implementation of these technologies from a general point of view.

2.2. Limitations and challenges

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Investing in digital solutions is a key requirement for manufacturing MSMEs if they want to survive, grow, and remain competitive in highly dynamic markets. In this context, the implementation of AI/ML solutions can improve processes and it could become crucial for the evolving role of sustainability which is strongly entwined with digitalization and its evolution [37]. However, the real feasibility of AI/ML solutions and their implementation is hindered by some limitations that have been carefully analysed to address RQ2. The main limitations found in the literature are listed in Table 3.

Limitation	Description
Data problems	Data quality, quantity, and availability are the most highlighted limitations to the use of AI/ML techniques. Companies do not have enough data to feed AI/ML solutions and there is a need to structure and automate data collection before any kind of more complicated solution [13–15,17,21–24,39–43]. The collection of data and the availability of datasets for validating the models are dependent on the type of application. For example, for predictive maintenance lots of public datasets are available whereas for other kinds of applications domain there is a lack [17]. Moreover, related to data, some studies reveal that transparency and security concerns, and cybersecurity are considered critical [23,39,41,44].
Lack of knowledge/skill	MSMEs are affected by the lack of high levels of AI/ML and IT knowledge [18,21,23,34–36,39,41,42,44]. For this reason, even if the use of new solutions AI/ML seems to be beneficial, they could not utilize them. Further problems are linked to employee ages [35], insufficient training [35,42], and lack of experience [18].
Lack of budget	Compared to larger companies, SMEs have a small budget to invest in technology [18,23,35,39,41,42]. Moreover, they have the perception that the cost of these solutions is very high even if this is not always true. There is a lack of methods and tools to estimate the cost/advantage ratio of AI/ML applications [21].
Complexity of solutions	AI/ML-based solutions are too complicated for the context of MSMEs [4,21,35,41]. Even though solutions have become more accessible in the last years (easy-to-use solutions such as machine learning tools provided by Microsoft Azure), AI/ML solutions are perceived as complicated since no sufficient knowledge and resources can be included in these kinds of projects.
Lack of management	Managers should understand the feasibility and benefits of adopting AI solutions [21,35,41] and if needed. However, they generally do not have a clear strategy in place to collect data and use AI. MSMEs struggle much more than larger companies with the entry barriers described and their intelligent transformation should be a gradual process established little by little to avoid negative outcomes [35].

Furthermore, other limitations, even if less reported, have been highlighted. Surely, all the tools or methods based on the use of data are dependent on the level of digitalization of the enterprises [39,44]. For example, old equipment can represent a real limitation for the collection of data useful for applying AI/ML techniques [39]. Only 19 out of 34 papers provided interesting considerations of limitations and the most useful were those methodologically based on carried-out surveys (6 papers). Moreover, the analysis of the literature allowed us to identify the challenges of the use of AI/ML in manufacturing MSMEs as described below.

5. There is a lack of constrained end-to-end solutions that can be easily implemented. MSMEs companies require simple solutions that can be deployed and used quickly [21,23,43,44]. It is also necessary to guarantee better integration of these solutions into their existing heterogeneous landscapes [43]. While large businesses are systematically moving to AI/ML applications, smaller companies risk being left behind. Research can contribute to further facilitating access to these technologies by appropriate frameworks that reduce the need for technical knowledge and are adapted to the requirements of SMEs [41].
6. A very challenging point is the difficulty in identifying meaningful AI/ML-based solutions according to a specific problem [39,41]. How to choose the best solutions, and if they are useful, is very complicated for MSMEs which rarely need these advanced solutions which require extensive data preparation, laborious parameter tuning, and a comprehensive understanding of the underlying problem [23].
7. Human-related issues have been raised. The lack of involvement by employees [39] or too little acceptance amongst users [41] can significantly affect the results that can be obtained from the implementation of new technologies such as AI/ML. For this reason, a real challenge is to establish how to involve employees in

the introduction and the use of these technologies. Significant emphasis needs to be put on human factors, including training and communication involving AI/ML techniques [42] and the reduction of the skill set required to switch to these technologies [36,40]. It is also interesting to note that the integration of manufacturing and AI can provide lots of employment opportunities. On one hand, new jobs such as AI engineers and technicians are required, but on the other hand, routine-intensive occupations, and manual and repetitive jobs are vulnerable to automation. The prevalent perception seems to be that the replacement of human workers with machines is at high levels: this can make the employee suffer from job losses, layoffs, re-employment, and the necessity of retraining for new jobs [36].

8. The digital revolution increasingly calls SMEs to pursue technological innovation such as the implementation of AI and adherence to environmental sustainability goals [37]. Given the high number of application domains of AI/ML technologies, it would be interesting to evaluate how manufacturing can benefit from data-driven approaches and what aspects of sustainability, over the environmental ones, can be affected.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Today AI and ML are seen as strategic components to achieve competitive advantages and there is a large potential for applying these techniques in the manufacturing context. To keep up with the evolution provided by these technologies, companies need to invest in innovation, and this is particularly challenging for MSMEs, which tend to have limited access to these technologies and struggle more to innovate in comparison to larger enterprises.

This research work, methodologically based on a scoping literature review, presents an initial comprehensive overview of the use of AI and ML in manufacturing MSMEs highlighting the limitations and challenges of these applications. The main results of the carried-out analysis are reported below.

- There has been an increasing scientific interest in this topic, as confirmed by the number of selected publications in the last three years.
- The analysis reveals that micro-enterprises are not interested in using these types of applications.
- The main fields of application of AI/ML for MSMEs are maintenance and quality, whereas other application domains are less investigated. For each field, the most explored issues that can be faced by using AI/ML have been identified.
- The main limitations to the implementation and correct use of AI/ML-based solutions in MSMEs are data
- problems (in terms of availability, quality, and quantity), lack of knowledge and skill in the field, lack of financial resources to use for the investment, the general complexity of the actual solutions proposed and the lack of management involvement and strategy. Less investigated is the lack of digitalization.
- The main challenges identified are the simplification of AI/ML solutions and adaptation to the MSMEs requirements, the correct identification of AI/ML solutions for the specific application domain, and the achievement of a higher level of employees' involvement in the introduction of these new technologies and finally, the identification of the correlations with sustainability.

However, this study presents some limitations. The search strategy could be improved in different ways such as by using multiple scientific databases and defining a better set of keywords to use for the search. Moreover, the topic of MSMEs should be investigated not only through scientific literature but also through other sources such as white papers, consulting companies' reports, and business reports.

Regarding future research directions, to obtain a more precise picture, the individual types of applications for which AI/ML have not been thoroughly investigated should be explored. Focusing on a particular application domain could allow the researchers to better focus on the type of AI/ML techniques implemented. It would also be useful to systematically address the connection to other technologies even in the case of MSMEs. AI/ML can support other kinds of technologies such as Digital Twin, Human-Robot Collaboration, and several others.

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