Exploring the transition from Maintenance 4.0 towards Maintenance 5.0: A Systematic Literature Review

Zineb AKTEF[1], Anass CHERRAFI[1], Said ELFEZAZI[1] and Dounia SKALLI[2]

[1] EST Safi, Cadi Ayyad University, Marrakech-Safi, Morocco
[2] Faculty of Sciences and Technology, Hassan 1st University, Settat, Morocco
z.aktef.ced@uca.ac.ma, a.cherrafi@uca.ac.ma, s.elfezazi@uca.ac.ma, d.skalli@uhp.ac.ma

Abstract. The swift evolution of the industrial landscape has seen an expedited transformation, compelling manufacturers to embrace the latest developments. While Industry 4.0 introduced new technologies and revolutionized maintenance strategies, a notable gap persisted in addressing the human aspects. This paper presents a comprehensive systematic literature review that delves into the current state of maintenance 4.0 and its intersection with sustainability, aiming to discern the evolving landscape toward maintenance 5.0. The primary objective is to scrutinize the existing paradigm and shed light on the challenges associated with the transition to maintenance 5.0.

Findings indicate a prevalent oversight in existing maintenance strategies, with a notable absence of consideration for the social dimension of sustainability—precisely the catalyst for the emergence of maintenance 5.0. This creates an incomplete view of holistic sustainability. Furthermore, the research outlines its limitations, providing a foundation for future studies within this domain. The paper concludes by discussing prospective study guidelines and offering insights into the theoretical and managerial implications of this evolving approach to industrial maintenance. This research contributes to the discourse on the nexus between technological advancements, sustainability, and the human element in the ever-evolving industrial landscape. It also provides a road map for future research on the ongoing evolution of maintenance practices in the digital age.

Keywords: Maintenance 4.0; Sustainability; Industry4.0; Maintenance 5.0; Industry 5.0; Literature Review.

1 Introduction

In the pursuit of sustaining competitiveness, companies across various industries are increasingly focusing on the concepts and advantages offered by Industry 4.0 [1]. Maintenance, recognized as a critical area for maintaining a competitive edge, is undergoing a transformation through its integration with Industry 4.0, promising to revolutionize conventional maintenance practices [2]. Within this context, Maintenance 4.0 appears as a specialized branch of Industry 4.0. In 2021, a supplementary paradigm to the current Industry 4.0 was presented with the introduction of Industry 5.0 (I5.0), which was propelled by innovation and research to ease the shift toward an industry that is resilient, sustainable, and human-centric [3].

Industry 4.0 used intelligent information processing approaches to make a factory smart, such as communication systems, future-oriented techniques, and more [4]. However, after the Covid-19 pandemic experience, the I5.0 came with a new concept focusing on industry, technology resilience and sustainability. Furthermore, the goal of Industry 5.0 is to make sure that breakthroughs and technologies benefit humanity. [5]. In addition, human factors are always a crucial component to take into account in maintenance operations. [3]. While the main goals of Industry 4.0 are to achieve economic goals by automating repetitive processes and undergoing digital transformation, Industry 5.0 broadens its perspective to encompass resilience, social and ecological goals. Specifically, Industry 5.0 seeks to prioritize the well-being of individuals within manufacturing systems, going beyond a sole emphasis on employment and growth. Industry 5.0 distinguishes itself from the Industry 4.0 concept through its core features, emphasizing human-centricity, sustainability, and resiliency [6].

Maintenance 5.0 has become a new reality for manufacturing organizations more essential to be adopted by organizations. Many publications focused on the challenges of implementing maintenance 4.0 and sustainability integrating only two pillars Environmental and Economical. However, little attention has been given to the social dimension. The biggest barrier is the shift in our society, the dissemination of information about the advantages for the environment and society that come from using new sustainable techniques, and the general public's increased awareness of sustainable practices [7].

This paper aims to explore the state of art on maintenance 5.0. It embarks on a systematic literature review (SLR) centered on Maintenance 5.0, aiming to delineate the current accomplishments and limitations in meeting the demands of Industry 5.0 for maintenance practices. The remainder of the paper is structured into 4 sections : Section 2 gives a theoretical background of the research area, Section 3 presents the research methodology adopted in this paper, Section 4 presents Results and in Section 5 conclusion and discussion are given.

2 Theoretical background

Over the last few decades, numerous studies have explored maintenance approaches, and focus especially on the analytic aspects, for example [8],[9] and [10]. After the 4th revolution of industry, numerous significant modifications in processes and manufacturing systems were introduced, including maintenance strategies [2]. However, the implementation of such approaches have many barriers and challenges [11].

Recently and after the 5th revolution of Industry, I5.0 came with a new concept of maintenance associated with human component [3]. One of the important changes in manufacturing industries after this revolution is maintenance 5.0. Furthermore, it is an idea that emphasizes a more human-centered approach to maintenance, in which hardware, software, and people collaborate to enhance maintenance procedures. Many of the technologies associated with Industry 4.0 are included in Maintenance 5.0, but its focus is on the social side of maintenance since it understands how important it is to achieve sustainable maintenance practices [3].

3 Research methodology

This section explains the study approach used in this work, which is a systematic literature review. According to [12] a literature review process is a essential tool for managing the diversity of knowledge for a particular academic endeavor involving three primary stages: planning the review, executing the review, and reporting and dissemination as illustrated in Figure1.

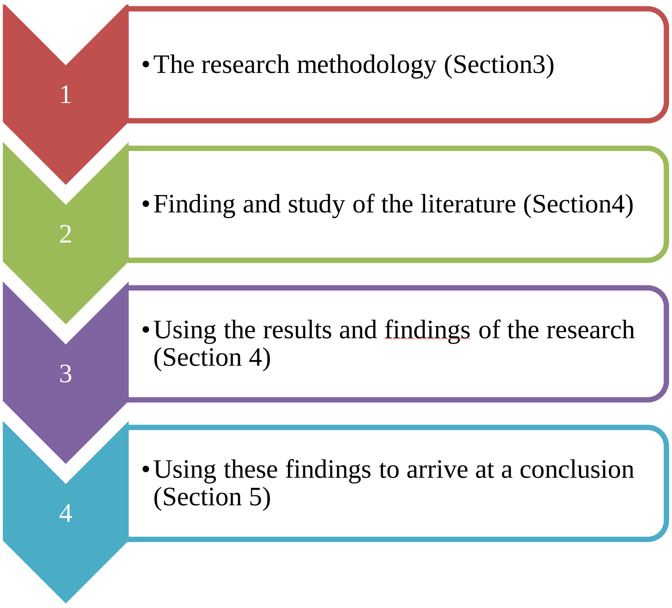

Fig. 1. Research methodology [6]

The exploration of keywords involves examining titles, abstracts, and full-text articles through three databases including Scopus, Web of Science, and Science Direct. The primary objective is to broaden the scope and gather a comprehensive range of articles, even those not explicitly focused on Maintenance 4.0, sustainability, or Maintenance 5.0. In the initial phase, our study specifically targets journal and conference papers identified based on predefined inclusion/exclusion criteria as outlined in Table 1. The chosen timeframe is guided by the emergence of the connection between Maintenance 4.0 and sustainability in 2014 [13].

Our research focuses on a specific string, utilizing the following search criteria: (Maintenance 4.0) AND (Sustainability OR Sustainable), with additional combinations such as Industry 4.0, Maintenance 5.0, Prescriptive Maintenance, and Predictive Maintenance. This strategic approach is designed to ensure a comprehensive retrieval of relevant literature for our study.

Table 1. Research criteria.

Inclusion criteria	Journal Article, Conference Paper. English language Paper published between 2014 and April 2024
Exclusion criteria	Publication in languages other than English Unpublished papers Irrelevant to the topic No full text accessible

4 Results

The total number of papers derived from the three databases search was 867. After removing the duplicates and triplicates, 817 papers remained to be analyzed. After title and abstract screening phase, only 109 papers were identified as relevant. Among them 73 papers were selected after the full text screening.

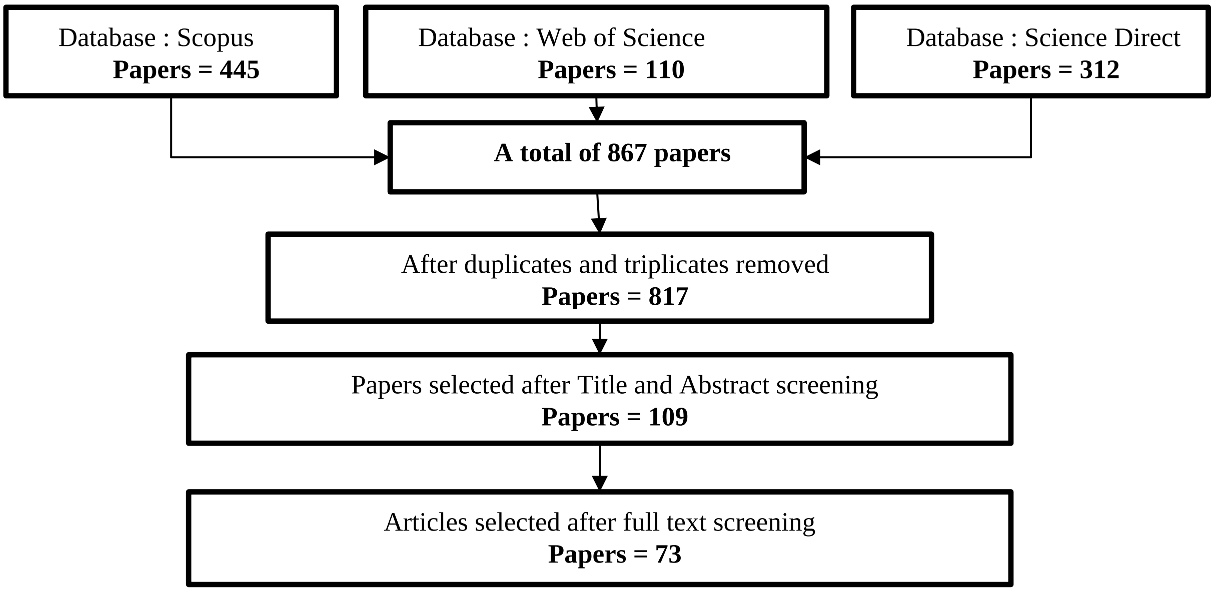

Fig. 2. Results of the literature review.

4.1 Distribution by paper type

This section outlines the findings resulting from our investigation into selected articles. Figure 2 reveals that out of the 73 papers assessed, journal articles constitute a predominant aspect, comprising 55% of the publications. In contrast, conference papers represent 45% of the studied articles.

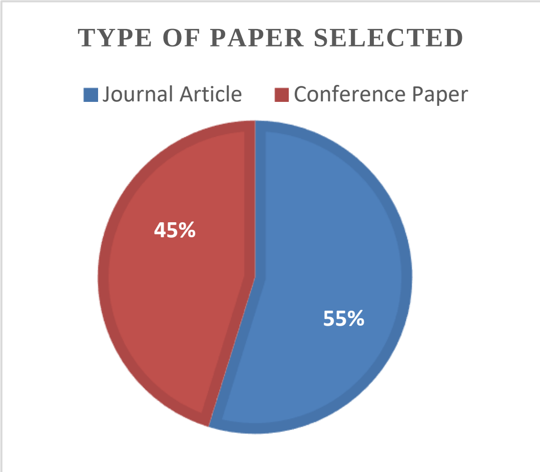

Fig. 3. Type of articles selected

4.2 Annual scientific production

Figure 3 demonstrates the number of articles published annually. According to this graph, it is shown that the number of articles grew steadily after the year 2021, with a peak of 18 papers in 2023. and only 4 % of articles selected were released in the initial three years of our search period. This shows that the time period on our research is well chosen, also it reflects that the research on maintenance 4.0 and sustainability and maintenance 5.0 is earning growing interest and focus.

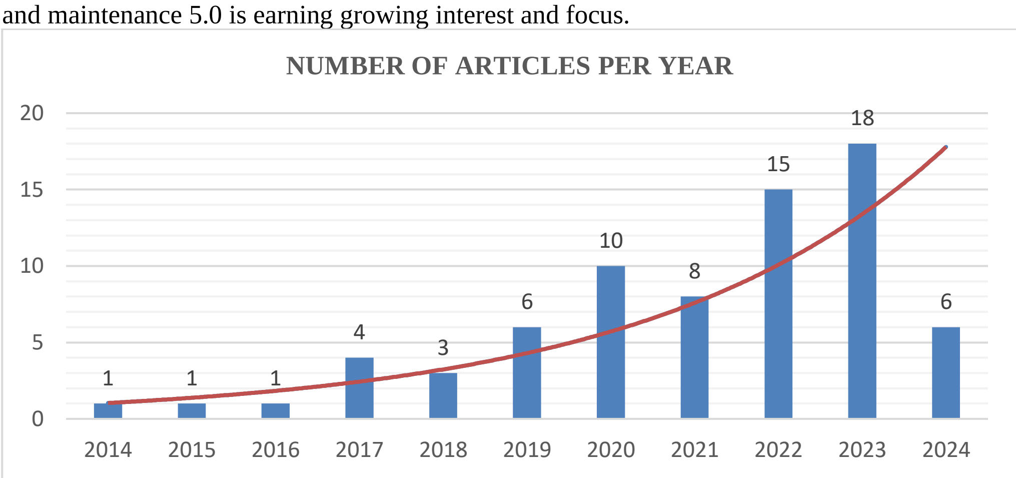

Fig. 4. Publication trend by year

4.3 Geography distribution

The figure 4 illustrates the distribution of published articles across different countries, giving a comprehensive view of the study results. The 73 articles reviewed come from all over the world, 52 countries were involved, with 71% of the research performed in developed countries (i.e Europe, North America and Oceania) and 29% in developing countries (i.e Asia, Africa and South America).

Upon examination it is obvious that Italy has the highest number of published articles, followed by Poland and France. This indicates the implication of these countries on such research area. The varieties in the number of article published per countries might be affected by many factors such as research funding, academic infrastructure.

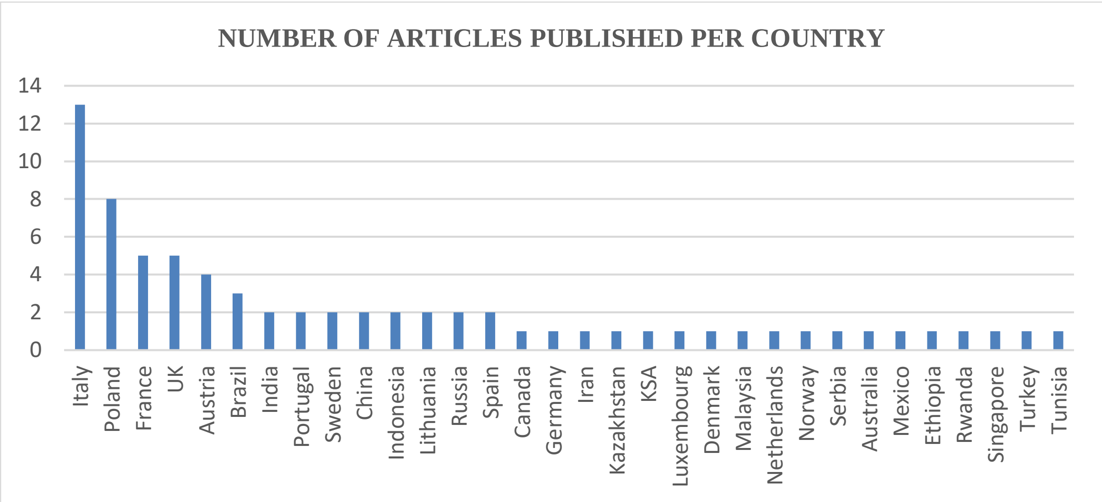

Fig. 5. Number of articles per country

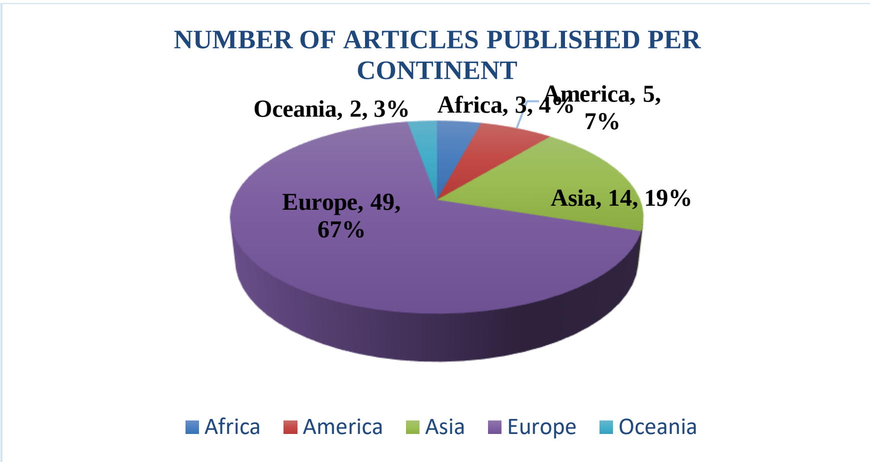

Fig. 6. Number of articles per continent

4.4 Technologies used in I4.0 supporting Maintenance 4.0

The graph below (Figure 6) provides an overview of the distribution of technologies used in I4.0 to support maintenance. There is one largest segment with 20% of articles studied that consider the technology of Artificial Intelligence (AI). According to [14] AI has become a potent tool for creating smart prediction algorithms in a variety of fields. The second largest slice, at 16% signifies the role of Augmented Reality (AR), Machine learning (ML), and Digital Twin (DT). This result shows that AR technology seems to be the most suitable technology for maintenance purposes [15]. Also, it plays a crucial role in predictive maintenance, which can lead to lower costs, higher machine uptime, and more effective maintenance procedures [16]. In addition, The Digital Twin (DT) is widely regarded as the primary instrument to facilitate production and maintenance tasks, and it may significantly aid in the achievement of sustainability objectives. [17].

Also, Machine Learning (ML) which makes it easier to analyze large amounts of data in order to identify trends and generate accurate predictions [18]. It is divided into four groups: supervised learning, unsupervised learning, reinforcement learning, and deep learning [14] that comes here with only 8%, followed by the technology Internet of Things (IoT) which aims to minimize unexpected equipment downtime and enhance reliability [19]. Also, there is another technology that comes with 12%, it is Cyberphysical Systems (CPS) which are a new class of systems that combine physical and computational capabilities to interact with people in a variety of creative ways [6]. Furthermore, we find Big Data with only 6% which provides the opportunity to offer a detailed view of a manufacturing process [20]. These technologies not only help companies become more innovative and competitive, but they also have a sustainable nature that is consistent with Industry 5.0 goals [21].

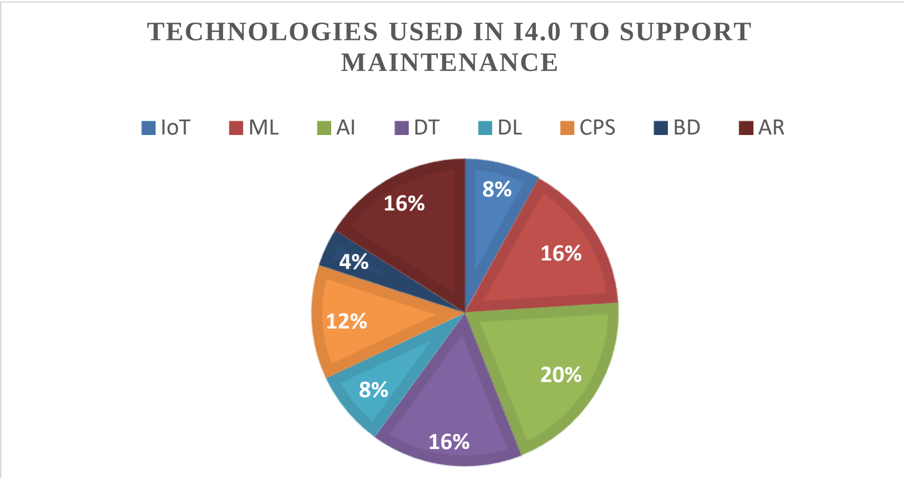

Fig. 7. Technologies used in I4.0 to support maintenance

4.5 Maintenance 5.0 Challenges

Each year, manufacturers consistently adopt new technologies to increase benefits and minimize machines downtime. This is the main reason behind the implementation of Maintenance 4.0. And lately they're having tendency to implement maintenance 5.0.

Even tough adopting maintenance 5.0 is inevitable, it is surrounded by many challenges. One of the significant challenges of maintenance 5.0 is human resource issue. According to [6] workers do not need to be provided by an adequate training, however they should cooperate with robots to do the assigned tasks. The factor that will give rise to another challenge which is designing a hybrid workplaces to apply and advance ethics in a human-machine co-working context [22]. According to [23] designing durable, secure, scalable, and human-centered technologies to alter the industrial sector is the largest challenge that Industry 5.0 presents to engineers.

Moreover, there is an issue of technical integration, for example using the AR technologies will be a gain for maintenance technicians. Although AR tablets play a key role for maintenance, they have limitations in terms of practicality and safety. the reason why wearable AR are preferred [15]. Besides, we find the challenge of data security that caused by IoT, such as data piracy, hacking and data breaching [6]. Revisiting the issue at hand, [24] explains how smart contracts implemented properly with blockchain technology may help do away with the need for third-party registrations or paperwork. Furthermore [25] presents that the most challenge of the intelligent maintenance in the context of cutters and industrial equipment is the need to balance operational life with economic life considerations.

4.6 Research Gaps

Although, different maintenance strategies aim to improve the industry by increasing uptime and avoiding unplanned downtime. The majority of existing strategies suffer from the following limitations: i) Many maintenance strategies do not consider sustainability ii) Most maintenance strategies only consider the two pillars of sustainability (Environmental and economic dimensions) iii) The majority of maintenance strategies only study the effect of sustainability in Maintenance and not the relationship between the dimension of sustainability. Moreover, [3] brought a new term linked to sustainability which is True Sustainability. This term was defined as sustainability that considers all these aspects simultaneously, economic, environmental, and social aspects. Besides, [26] provided a framework for evaluating both the maturity and sustainability of maintenance procedures in production systems.

One of the main issues in implementing sustainable maintenance is the human aspect. Previous research repeatedly show that decision-makers frequently reject to adopt the data-driven, system-generated guidance in their operational protocols [27]. In addition, the maintenance operators need more technologies to help them to diagnose, inspect or training.

5 Conclusion

The primary goal of this paper was to ascertain the state-of-the-art of Maintenance 4.0 and sustainability and comprehend its evolution towards Maintenance 5.0 within the context of Industry 5.0. To achieve this, we meticulously selected and analyzed 73 articles spanning the literature from 2014 to 2024. Despite the inevitability of adopting Maintenance 5.0 in light of the fifth industrial revolution, it is accompanied by numerous challenges.

The connection between Industry 4.0 and sustainability is gaining increasing attention both in terms of geographical and temporal aspects. Specifically, environmental sustainability has emerged as the most extensively researched dimension compared to social and economic aspects. However, as mentioned earlier, the social sustainability component receives disproportionately less attention. The findings underscore the necessity for further research in exploring the intersection between Maintenance 4.0 and open innovation for sustainability, particularly focusing on the social aspect of sustainability.

The lack of literature available on maintenance 5.0 made it challenging to identify the barriers associated with its implementation. Additionally, the technologies introduced by Industry 5.0 are currently in the process of being installed. For further research, there is potential for investigation into the barriers confronting maintenance 5.0, with an aim to identify and implement effective solutions.

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