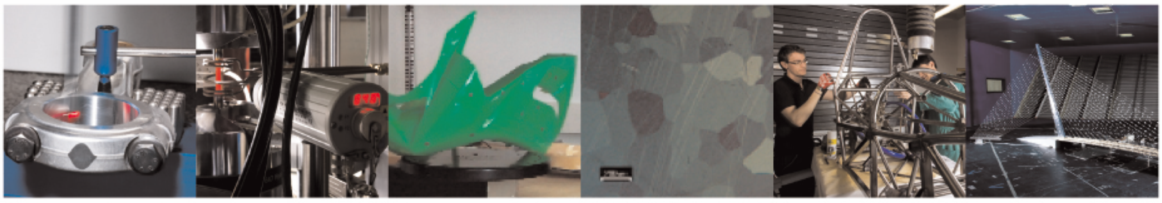

Exploring the Intersection of Metaverse, Digital Twins, and AI in Training and Maintenance

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Exploring the Intersection of Metaverse, Digital Twins, and AI in Training and Maintenance

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As technology advances, we are surrounded by more complex products that can be challenging to use and troubleshoot. We often turn to online resources and the help of others to learn how to use a product's features or fix malfunctions. This is a common issue in both everyday life and industry. The key to being able to use a product or fix malfunctions is having access to accurate information and instructions and gaining the necessary skills to perform the tasks correctly. This paper offers an overview of how Artificial Intelligence, Digital Twins, and the Metaverse - currently popular technologies - can enhance the process of acquiring knowledge, know-how, and skills, with a focus on industrial maintenance. However, the concepts discussed may also apply to the maintenance of consumer products.

1 INTRODUCTION

The problem of having to repair something that does not work properly is a problem that we face every day as end users of products in the B2C (Business to Consumer) market, but it is also a relevant problem in the B2B (Business to Business) market. Manufacturers of production systems, transport systems, and large equipment, in general, must guarantee their buyers a quick, effective, and efficient repair and maintenance service. At an industrial level, product downtime affects production and transport costs and impacts the sustainability parameters of the overall process [1]. Efficient service and maintenance can be a deciding factor for a buyer when choosing a supplier. However, the shortage of skilled professionals to perform maintenance operations can pose a challenge for companies in ensuring efficient and valuable service.

For years, there have been questions about whether digital transformation can help make maintenance services faster, more efficient, and even less expensive. Additionally, we can explore the availability of digital tools that enable the development of workers' new skills, retraining and upgrading of the workers' abilities, with the provision of easy access to the required information.

In both literature and industrial practice, there are numerous examples of the use of digital technologies to support assistance processes, both in the form of support to the maintenance process and of support to the training process, which constitutes a step before maintenance that is used to generate and transfer knowledge and to create skills.

The examples of stand-alone maintenance support environments or remote maintenance services have multiplied in recent years. Many are using Virtual and Augmented Reality technologies, recently addressed as eXtended Reality technology (VR, AR, and XR) [2, 3, 4]. Scholars researching these technologies and their applications have recently demonstrated a growing interest in the Metaverse, also in relation to applications in industry.

In addition, two other technologies are increasing their popularity in industry. One concerns Digital Twins, which are virtual representations of a physical system used for simulation and analysis of their performance, behavior, and maintenance needs. The second technology is Artificial Intelligence (AI), which is increasingly used as a tool for transforming data into easily accessible information with the aim of improving efficiency and enhancing decision-making capabilities.

We believe all these technologies will significantly impact the industrial sector. In this paper, we intend to analyze the state of the art of these technologies and what their combination can bring in terms of benefits to the service of maintenance and repair of industrial products.

2 MAINTENANCE: TASKS AND NEEDS

When a problem occurs in ordinary maintenance and repair situations, the first action is analyzing the problem and making a diagnosis. Today, many machines are equipped with sensors and software that can analyze their own performance and suggest the cause of the problem. This can help identify specific maintenance operations that may be needed and guide the operator through the repair process. In cases where a machine is not equipped with sensors, manuals can provide guidance on what to check to determine the cause of the problem. Alternatively, a common approach is reaching out to a maintenance service to have suggestions on how to detect the cause of the failure. In some cases, a problem may arise that does not have established maintenance and repair procedures, known as extraordinary maintenance, which can lead to more complex maintenance requirements. Collecting and analyzing data is a crucial step in this process, whether for standard or extraordinary maintenance. New digital technologies can assist in the data collection and analysis process, making it easier to identify problems and find solutions.

Once the problem is identified, the operators must use their expertise, abilities, and equipment to resolve it. Some important related considerations concern ensuring the safety of the operators during the maintenance and completing the task quickly to minimize disruption to production and financial losses for the company. A common practice in industry is for operators to consult instruction manuals when lacking knowledge about the procedures required to perform maintenance. Unfortunately, manuals are often reported to be information-deficient or out-of-date. An effective alternative is the support of more experienced fellow operators who can help carry out the maintenance operations. However, this is not always possible or may cause delays. Therefore, the issue here is quickly finding all the clearly explained instructions to perform the required maintenance. Moreover, during maintenance, it is useful to receive feedback on the accuracy of the procedure and the actions being taken. This means that the operator needs assurance that the maintenance tasks are being performed correctly and that the repair was successful.

Based on the above analysis, Fig. 1 provides an overview of the tasks typically performed in a maintenance operation and the related operators' needs, mainly consisting of tools to support the activities. New technologies, which include Artificial Intelligence, Digital Twins, and the Metaverse, can be used effectively, alone or integrated, to develop these tools. In the following section, we will discuss the maintenance enabled by these technologies in the context of the challenges of Industry 4.0 and 5.0, based on the scientific literature and authors' experience in the sector gained over the years.

3 CHALLENGES OF MAINTENANCE IN INDUSTRY 4.0 AND 5.0

While the third industrial revolution was led by innovation in manufacturing processes and systems, the advancement of the fourth industrial revolution was driven by digitally interconnected pervasive industry and manufacturing systems.

Industry 4.0 (I4.0), also known as the fourth industrial revolution, is a term used to describe the trend of automation and data exchange in manufacturing technologies, including, among others, developments in robotics, cyber-physical systems, the Internet of Things (IoT), and Artificial Intelligence (AI), to create "smart factories" that can operate with increased efficiency, accuracy, and speed [5, 6]. I4.0 represents a shift towards more intelligent, interconnected systems that are able to analyze data and make decisions on their own. Therefore, the goal of I4.0 is to create a more connected, efficient, and flexible manufacturing process that can adapt to changing market conditions and customer demands.

While on the one hand, I4.0 brings innovations and benefits to industries that are expected to be revolutionary, on the other hand, it increases the complexity of processes and systems and their management. Indeed, a digital transformation is not truly successful until human resources have a full understanding and mastery of the new technologies.

One of the aspects recognized as the most complex of the I4.0 revolution concerns the maintenance of new robotic and automation systems and cyber-physical systems, which require skills that current technicians often do not have. Several types of maintenance processes are used in industry, including planned maintenance, where extensive repairs or maintenance tasks that are scheduled in advance are performed, corrective maintenance, which is performed when equipment breaks down or fails, and preventive maintenance, which involves regularly scheduled inspections, tests, and tasks that are performed on equipment to help prevent breakdowns and ensure that the equipment is operating at its best. I4.0 introduces an additional type of maintenance, predictive maintenance, that uses sensors and IoT technology to collect data on the condition of equipment, which is then analyzed and

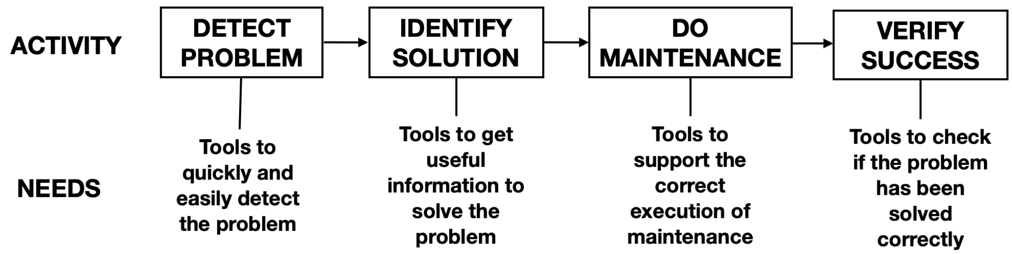

Fig. 1. The tasks necessary to carry out maintenance and operators' needs.

elaborated through AI algorithms to predict when maintenance will be needed and to identify potential problems before they occur.

Industry 4.0 is not a new trend in the industrial sector that has recently emerged. The world of research, industries as well as institutions like the European Commission also started talking about Industry 5.0 (I5.0) a few years ago.

Recent events such as the Covid-19 pandemic and climate crisis have prompted a shift in focus in industry from productivity to the effects on workers and the environment. Additionally, the ability of the industrial sector to withstand disruptions is now considered a crucial aspect. Therefore, the new industrial revolution I5.0 places emphasis on the impact of industry on both workers and the environment, with a focus on human-centricity and the importance of skilling, re-skilling, and up-skilling for workers' health and well-being, and also on the resilience of the industrial world. Therefore, Industry 5.0 goes beyond Industry 4.0 by improving production for profit and focuses on three elements: human-centricity, sustainability, and resilience [7]. From this perspective, maintenance should also be approached with a focus on the operators, positioning them as the central element of the digital factory.

4 EXPLORING THE POSSIBILITIES OF NEW TECHNOLOGY

This Section examines the potential impact of three technologies on industrial maintenance: Artificial Intelligence, Digital Twins, and the Metaverse.

4.1 Artificial Intelligence

Although AI dates back to the fifties [8, 9], the remarkable computational capabilities achieved nowadays, together with the increasing availability of data suitably structured to be easily interpreted by algorithms, have increased the popularity of AI in recent years. Such data can be either of human origin or generated by the algorithms themselves [10], and the continuous production of data easily interpretable by AI is one factor contributing to making these algorithms increasingly performing [11]. The recent spread of tools such as OpenAI's ChatGPT [1] popularized the true potential of AI to a broader audience, prompting numerous companies that possessed similar algorithms to release their solutions as soon as possible (see Google Bard [2]). From all this emerges a very interesting picture of the availability of a series of technologies called GenerativeAI which, if properly used, can be a very powerful tool in the hands of creative people. On the one hand, this rapid diffusion of high-performance technologies provokes a historical debate on whether these tools are really considered "intelligence", on the other hand, it leads to the question of what the real benefits of these technologies can be.

A recent survey analyzes which technical aspects in the metaverse AI algorithms allow for improving the user experience with virtual environments and which application areas can benefit from them [12]. AI is a valid tool for searching for patterns and meanings in the amount of data produced in a context where more and more sensors produce digital outputs. But it is also so if we think of the need to act as an interpreter between different languages, that is, the machine that produces data and the operator who must interpret them, and in turn, the operator who uses human language and wants to dialogue with the machine through a system with an improved overall experience. Sometimes, however, the lack of understanding of how data is processed and analyzed risks generating scepticism in using such algorithms, and in this sense, techniques known as ExplainableAI [13] allow us to overcome this limit.

AI is undoubtedly one of the technologies on which the attention of the industrial world and people, in general, is concentrated.

In the industrial maintenance sector, AI technology can have a significant impact on several aspects, including:

[1]https://openai.com
[2]https://ai.google

- Prediction of any problems that a machine may have, and suggestion of when it is necessary to intervene (predictive maintenance) based on AI analysis of data that the machines produce.
- Ability to locate and quickly access important information contained in already available technical manuals.
- Creation of new technical documentation or instructions for non-expert operators based on the analysis of best-practice maintenance procedures of skilled maintainers.
- Improvement of operators' safety and well-being thanks to the analysis of data collected during their activities.
- Designing user interfaces using a language tailored to the operator's specific needs for knowledge transfer.

AI technology brings with it some problems that need to be considered: the accuracy of the original data used for training the AI models and the reliability of the algorithms that extract useful information from these data. In fact, AI-based applications that give users inaccurate information could lead users to distrust and abandon the use of such technologies. Therefore, it would be beneficial to make the process of data analysis by algorithms transparent, commonly known as the explainability of Artificial Intelligence [13], as we mentioned above.

When utilizing AI technologies to analyze user data, it is important to consider both data privacy and security. Additionally, ethical concerns should be addressed, as AI algorithms can perpetuate and even amplify biases present in the data used to train them, potentially resulting in discriminatory outcomes (see [11] for an overview).

4.2 Digital Twins

Although Digital Twins have been highly familiar since 2002 [14], only as recently as 2017, they have become one of the top strategic technology trends. The definition of digital twin provided by Glaessgen and Stargel in [15] is widely accepted, although it may differ in its specific interpretation across various applications among the numerous definitions of digital twin available. *"A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin."*

Liu et al. conducted a comprehensive and in-depth literature review to analyze digital twins from the perspective of concepts, technologies, and industrial applications [16]. As reported in [17], the primary fields for implementing digital twins are manufacturing, mechanical, and civil engineering.

In their extensive literature review, Negri et al. [18] explored two main questions: firstly, how the digital twin is defined in scientific literature, and secondly, what role it plays in the context of Industry 4.0. The study revealed that the digital twin can be utilized for three main purposes, namely: assessing the health of a physical object to plan maintenance activities, overseeing the entire lifecycle of the object, and enhancing decision-making by employing engineering and numerical analysis.

A Digital Twin can be used as a real-time virtual representation of a real-world physical system that serves as its indistinguishable digital counterpart for practical purposes, such as analyzing and predicting the system's behavior, optimizing its performance, or controlling it remotely. At its optimum, any information that could be obtained from inspecting a physically manufactured product can be obtained from its Digital Twin [19]. A Digital Twin can combine IoT, AI, and software analytics to create simulations that predict how a product or process will perform. By collecting data from physical IoT devices and using it to update and refine the digital twin model, it becomes possible to gain a deeper understanding of the physical devices' performance and behavior and use this information to optimize their operation or take control actions.

Digital Twins can be used in conjunction with advanced AI algorithms to perform predictive maintenance. Digital Twins can become intelligent and active when AI algorithms are used to analyze data to predict when maintenance is needed before any physical signs of failure occur. This can help prevent downtime and minimize the need for costly repairs. Used for predictive maintenance, the Digital Twins allow a holistic view of the health and performance of pieces of equipment. Operators can immediately detect anomalies and deviations in their operations and be alerted about spare parts' maintenance and replenishment. Digital Twins can also be used to simulate the effects of different maintenance strategies, such as replacing a part or adjusting a setting, to determine which approach will be most effective.

Researchers commonly reported that using Digital Twins offers various benefits, such as enhance efficiency [20], decrease operational costs [21], promote more sustainable processes [22], and allow for predictive maintenance [23].

4.3 Metaverse

The emergence of COVID-19 and Facebook's transition to Meta have highlighted the potential of a 3D internet, and organizations are now embracing the idea of using virtual shared spaces.

According to Matthew Ball, *"The Metaverse is a massively scaled and interoperable network of real-time rendered 3D virtual worlds which can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence, and with continuity of data, such as identity, history, entitlements, objects, communications, and payments."* [24].

The term metaverse derives from a science fiction novel from the 90s [25], where the author imagined a universe parallel to the real one, in which users interacted with each other and lived alternative experiences to reality. Each user had his own avatar, with more or less sophisticated features. Some avatars also included facial features that allowed parts of the emotional reaction to being shown. This parallel universe was endowed with rules that established its functioning. This term has become very popular these days, and the idea of metaverse surprisingly does not differ much from the concept imagined by the science fiction writer.

Metaverse is often used to describe a collective virtual shared space created by the convergence of virtually enhanced physical reality and physically persistent virtual space, including the sum of all virtual worlds, augmented reality, and the internet. Therefore, the metaverse can be considered a digitally created mirror of the physical world, where all the things we can do in real life can also be done in that virtual world. The virtual environment serves as a metaphor for the real world without physical or economic barriers.

We can summarise the main distinguished features of the metaverse as follows:

- shared and collaborative space: many users can simultaneously be present in the metaverse, interacting with each other and the virtual environment.
- immersive: realistic graphics and audio, haptic feedback, and other features make it feel like a real place.
- persistent: it is a constantly evolving space, with changes and updates happening in real time, even when users are not present.
- interactive: users can interact with the virtual environment and each other using various input devices such as VR headsets and controllers.

The infrastructure of the metaverse platform must also be capable of facilitating identity management, which involves linking a user's real-life identity with their virtual identity, as well as supporting the creators' economy, which may include various revenue streams such as advertising, sponsorships, subscriptions, and direct sales of digital assets.

According to Gartner, 25% of individuals will spend an hour daily on the metaverse for various activities by 2026 [26]. Currently, there are around 150 virtual worlds that could qualify as metaverse, where millions of users interact through their avatars. Some examples of platforms for metaverse projects are The Sandbox [3], Decentraland [4], and Roblox [5], which are established and popular. Roughly half of all existing metaverse platforms allow free application development. Gaming and social networks are among the top applications of the metaverse. Additionally, there are numerous other fields where metaverse could be used, such as e-commerce, education, training, entertainment, marketing, and collaboration. Although numerous companies across various industries such as railways, automotive, industrial plants, and banking have developed metaverse use cases, the majority of these applications are VR-based and do not possess the distinguishing features of a true metaverse. It is expected that these use cases will take several years to become widespread.

5 THE MAINTENANCE JOB OF THE FUTURE

In the last years, one of the most requested jobs to manage I4.0-based industries is that of maintenance engineers and (yet maintenance) technicians [27, 28]. This necessity poses two challenges. One concerns the training of internal personnel or to be hired to acquire the necessary skills to manage and maintain I4.0 new, highly complex systems. Integrating novel I4.0 technologies into factories introduces the need for new technical skills, which are not only manual skills but also digital skills, where workers must be able to operate advanced machine tools and robots to program complex CNC programs and read and interpret data from sensors. The second challenge concerns the development of practical tools to support the maintenance activities of the new systems, which exploit the potential of new digital technologies.

Concerning the first challenge, Virtual Reality (VR) technology started being used to create immersive, interactive learning environments for training purposes [2, 29]. Operators use a VR headset and its controllers to enter a simulated environment where they can interact with virtual machines and tools and perform tasks as if on a real shop floor. VR training has been used to provide hands-on training for various skills, such as machinery operations. Several research works have demonstrated that VR training can be particularly effective for teaching complex or dangerous skills, as it allows operators to

[3] https://www.sandbox.game/
[4] https://decentraland.org
[5] https://www.roblox.com

practice and make experiences and mistakes in safe and controlled environments [30].

One of the key benefits of VR training is that it can provide a level of realism and immersion that is not possible with other forms of training. By creating a simulated environment that closely mirrors the real world, VR training can help operators develop the skills and confidence they need to perform complex tasks in real-world settings. For example, research has demonstrated that VR training can be particularly effective for tasks that involve spatial reasoning, hand-eye coordination, and situational awareness, such as piloting aircraft [31] or performing surgery [32].

As regards the second challenge, we imagine a modernized operator enhanced with the most modern digital technologies [33] and resilient [34], which is described in the following section.

5.1 The modernized operator

In the paradigm of Industry 4.0, human beings must be considered the focal point of technologies, activities, and information. We observe a shift from more manual skills towards more digital skills of the manufacturing shop floor workers. Consequently, industries must introduce new ways of working for operators, which make the most of the potential of digital factory technologies (see Figure 2). The new ways of working aim at helping to improve the efficiency and effectiveness of maintenance and support operations, allowing the workers to operate in complete safety, allowing for the automation of routine tasks, and the rapid identification and resolution of issues. Consequently, they contribute to preventing equipment failures and improving the speed of repairs and therefore help to reduce costs and downtime and increase the overall operational efficiency of the factory. The use of digital technologies to support operators in various industries, such as manufacturing and transportation, has been increasing in recent years. However, a holistic and integrated view of their use is lacking. Therefore these technologies may be implemented in a fragmented way without considering their full potential impact or integration with other systems.

5.2 How technology can support operators

In addition to AI and Digital Twins, various other digital technologies can aid operators in their tasks within the digital factory.

Diagnostic interfaces Diagnostic interfaces allow operators to access and analyze data from industrial machinery and can be used to identify and troubleshoot problems with the machinery, monitor its performance, and optimize its operation.

Physical assets alerts Physical asset alerts are used to send notifications or warning messages when a problem or issue is detected with a physical asset, such as a piece of machinery so that maintenance operators can address the problem promptly. Various factors can trigger these alerts, including equipment failure, maintenance issues, and performance problems.

Remote assistance Digital technology can be used to provide remote maintenance and support services rather than requiring an on-site visit by a technician in cases where the local operator is unable to resolve the problem. Remote assistance can be used for a wide range of purposes, including providing technical support and troubleshooting, training and instruction, and conducting remote maintenance or repair tasks. Remote assistance can be performed using Augmented Reality applications, where a remote expert can guide the local operator with graphics and instructions leading to the solution of the problem [35, 36, 37].

Wearable biosensors Biosensors can measure various physiological and biochemical parameters in humans, such as heart rate, blood pressure, temperature, and respiratory rate. These parameters can be related to operators' performances. For example, they can monitor technicians' heart rates and activity levels as they work. This information can be used to assess their physical exertion and fatigue levels [38]. Sensors can also be used to measure productivity and efficiency, for example, by tracking the time technicians spend on tasks, the number of tasks they complete, and the quality of their work. This information could be used to identify areas where technicians may need additional training or support. Biosensors can also be used to detect the emotional state of operators on the shop floor. For example, facial expression recognition, voice analysis, and biometric data (heart rate, skin conductance, and temperature) detect emotions such as happiness, sadness, and anger [39, 40].

Safety sensors Many different types of sensors can be used in manufacturing to measure various environmental parameters, such as temperature, pressure, humidity, etc. Some sensors are particularly important for the safety of the workers and can be used to detect potentially hazardous conditions or situations and to alert operators to take appropriate action to avoid injury. Examples of safety sensors are proximity, temperature, noise, and gas

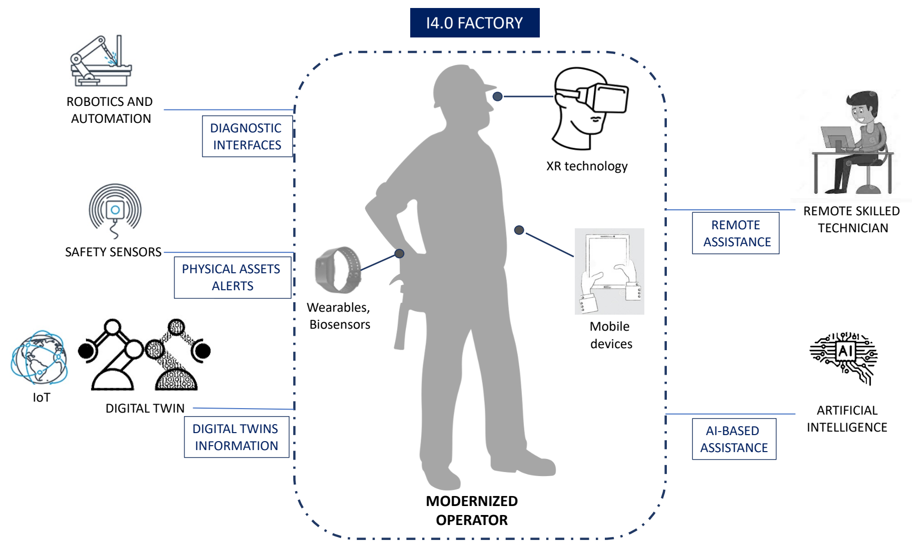

Fig. 2. New ways of working of I4.0 operators.

sensors. Alert signals can be sent to operators through various modalities, including text, visual or sound messages, and tactile signals [41].

XR technology eXtended Reality (XR) technology, which encompasses virtual (VR), augmented (AR), and mixed reality (MR), can be utilized in several ways to enhance maintenance. AR and MR can be used to overlay digital information on physical equipment, providing technicians with real-time data and insights into the status of equipment. Literature reports many AR applications for this purpose [42]. AR can also be used to implement remote assistance applications to facilitate two-way collaboration between field workers and remote technicians [35]. Multisensory technology can enhance the sense of presence in XR applications [43] and realism. The more senses that are engaged in an XR experience, the more convincing and immersive the experience becomes: haptic feedback is used to simulate touch and provide users with a sense of physical interaction with the virtual environment [44]; audio is particularly important [45] and spatial audio can be used to create a more realistic auditory environment; smells delivered through olfactory displays [46, 47] can be used to simulate smells associated with the virtual shopfloor, such as a strong odor of chemicals or solvents in a chemical plant.

6 SCENARIOS OF MAINTENANCE IN THE METAVERSE

As depicted in Fig. 3, in the near future, it will be possible to utilize the Metaverse as the ideal setting for training and maintenance operations.

Digital Twins can be seen as building blocks of the Metaverse, where they act as a real-time virtual copy of a physical item, which can be physical assets (products or buildings), people (employees, operators), and business processes. In the context of the Metaverse, Digital Twins can be used to model and simulate the behavior of virtual objects and systems, such as virtual environments, virtual machines, and virtual robotic systems, and allow operators to indirectly interact with the real objects and systems through the direct interaction with their twins. Digital Twins can be used to simulate the behavior of virtual systems in the Metaverse to test and optimize their design or to train machine learning models that can be deployed in the virtual world. In this way, Digital Twins can play a key role in the development and operation of the Metaverse by providing a means to model, analyze, and control virtual objects and systems within this virtual shared space.

Below, we present some potential scenarios where an operator conducts maintenance within the Metaverse.

Scenario 1. Maintenance training can be conducted within the Metaverse. The virtual factory, machines, and tools are accessible to the operators via a headset, allowing them to fully immerse themselves in the training experience. The virtual environment can be tailored to the operators' specific needs and preferences, providing a customized training experience. A real instructor can be summoned into the metaverse. In the virtual space, the instructor can demonstrate procedures or techniques in a way that is more immersive and interactive than traditional classroom or online instruction. By collaborating

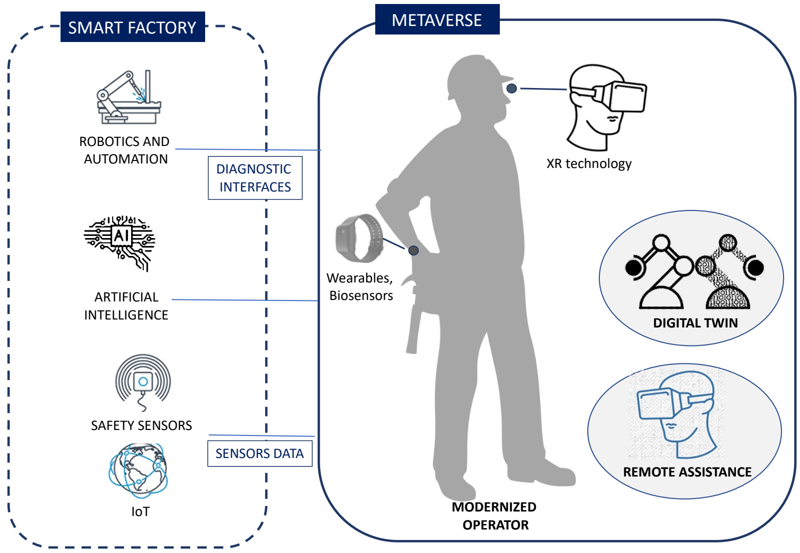

Fig. 3. A proposed perspective on how the Metaverse, Digital Twins, and AI could enhance training and maintenance procedures.

with the operator in the virtual space, the instructor could provide real-time feedback and guidance as the operator practices the skill. The operator can perform these exercises in a safe environment at any time and place. Moreover, as the training is conducted on virtual machines rather than real ones, there is no risk of damage to equipment or personnel. The exercises can be repeated until the operator feels confident in their proficiency. While the technology for summoning real instructors into virtual spaces is not yet fully developed, it is certainly an exciting possibility for the future of training.

Scenario 2. In the event of a machine malfunction, the operator can perform an assisted maintenance procedure by working on the Digital Twin of the machine in question. The Digital Twin can pinpoint the issue through diagnostic analysis and AI models. The operator can practice the maintenance procedure multiple times and test different maintenance strategies until the problem is resolved, and eventually replicate the steps in the actual environment. If necessary, a virtual expert can provide virtually on-site assistance by demonstrating the maintenance procedure to solve the problem. Utilizing wearable sensors, the operator's performance, fatigue, and stress can be monitored. These insights can then be used to adapt the virtual environment, such as adjusting lighting or playing calming music, to enhance the operator's experience and productivity.

Scenario 3. An operator equipped with a headset or AR device is standing in front of a malfunctioning machine. To provide remote maintenance support, an AI-generated hologram of an expert technician appears in AR beside the equipment. An AI-generated hologram is a computer-generated 3D image or projection of a person that is created using artificial intelligence algorithms. This type of hologram can be interactive, responding to voice or touch commands, and can be used for a variety of applications, such as virtual assistants, virtual coaches, and remote support [48]. The virtual avatar functions as a mentor, providing spoken responses to any inquiries the user may have regarding the machinery and malfunctions and guiding the operator through diverse procedures to practice. As the avatar responds, relevant visual details are superimposed onto the machinery in AR, enhancing the operator's understanding of the issue. This lifelike holographic trainer creates a more engaging and natural communication experience, particularly for remote support. By offering personalized real-time information, operators can engage with the problem in a more meaningful way.

7 DISCUSSION AND CONCLUSION

The problem of efficient and effective maintenance and repair service is a crucial one for companies in both B2C and B2B markets. Product downtime can significantly impact production and transport costs, as well as sustainability parameters. The shortage of skilled professionals to perform maintenance operations can pose a challenge for companies in ensuring efficient and valuable service.

Digital transformation and the I4.0 paradigm have the potential to revolutionize the maintenance and repair service, with a wide range of digital tools available to support assistance processes. Artificial Intelligence, Digital Twins, and Metaverse are among the most promising technologies that have been gaining popularity in recent years. The combination of these technologies can bring benefits to both training and maintenance processes, providing easy access to information and developing new skills.

In Industry 5.0, the focus is on a human-centric approach, where the design, development, and implementation of technologies take into account human factors and the needs of the workforce. This approach aims to create an environment that enables the easy adoption and utilization of new technologies by the workforce, leading to safer and more inclusive workplaces, as well as improved job satisfaction and well-being for workers. This benefits not only the workers but also companies by increasing efficiency, productivity, and overall success.

The concepts discussed in the paper can also be applicable to the maintenance of consumer products. In US and Europe, a principle called the Right to Repair has recently been introduced [49]. Using new technologies to provide ordinary people with clear and understandable instructions for fixing household appliances and similar products, would certainly meet this principle.

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