smart cities

Review

Striving for a Safer and More Ergonomic Workplace: Acceptability and Human Factors Related to the Adoption of AR/VR Glasses in Industry 4.0

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Abstract: The word *smart* is very popular these days, as a result of nearly everything being digital today. Background information: In this digital world, everything is interconnected by smart devices. The driving force behind this is today's Industry 4.0 environment, which is affected by many factors, including the ergonomic and safe design of new technology, ensuring the safety of factory operators, whilst increasing productivity and profits. The authors answer the following research questions: Are AR/VR systems or devices proposed for industrial use capable of meeting the needs of the industry (including sustainability)? Are these AR/VR devices designed to ensure easy use and efficient training of factory operators? Do the proposals of the reviewed research papers place sufficient emphasis on creating ergonomic workplaces? These publications were categorized into three subcategories based on the used key technology, research or application area, and their main purposes. Conclusion: Virtual reality, augmented reality, and IoT are becoming increasingly more suitable for industrial use, despite facing scrutiny and criticism.

Keywords: augmented reality; Industry 4.0; smart glasses; virtual reality

1. Introduction

Technology in almost every field of life has developed rapidly during the past few decades, mainly following the birth of Information Technology (IT). Over the past decade, manufacturing companies have faced a variety of challenges, primarily in response to the fluctuating demand for goods and changing needs. This cannot be solely attributed to the rapid development of IT. Instead, this is more of a result of the changing needs of customers and suppliers. These demands include the use of innovative technological support in the form of Augmented Reality (AR) and Virtual Reality (VR). AR/VR systems are applicable in a multitude of areas, including labor force training, designing new factories and assembly lines, simulating hazardous situations, providing information in a new way, measuring human factors, etc. Therefore, the purpose of this paper is to provide a qualitative literature review of the state-of-the-art technology in this research field, with a primary focus on the safety of workers, the most valuable asset a company can have. Our purpose is to review the literature in a way that facilitates the adoption of AR/VR technology in the industry, whilst also improving the working conditions of factory operators and improving productivity.

New smart technologies, including Augmented Reality, Internet of Things, and Virtual Reality, all play a vital role in the Industry 4.0. This term, referring to the subset of the fourth industrial revolution concerning industry, is often used in the development of manufacturing and line production. The era of the First Industrial Revolution saw the mechanization of manufacturing by steam and hydropower, whereas the Second Industrial Revolution was characterized by the introduction of mass production and assembly lines powered by electricity. The third saw the further automation of production by additional electrical and electronic devices, and we can now witness how cyber-physical production systems merge the virtual world and reality. The Industry 4.0 environment is scrutinized by Alcácer and Cruz Machado [1], describing the so-called enabling technologies and systems over the manufacturing environment. They analyzed the following key technologies of Industry 4.0 in great detail: The Industrial Internet of Things, cloud computing, big data, simulations, AR, and autonomous robots.

The Internet of Things is a computing concept that describes the idea of connecting everyday objects to the Internet, thus allowing it to identify itself among other devices without requiring human interaction with a computer. Ashton [2] formulated the definition of IoT, creating its first and most widely recognized definition. As a network, it not only connects people, it also interconnects them with their surrounding objects and devices. Focusing on industrial applications, physical and digital systems are connected within the factory in Industry 4.0. The focal design principles are the following: Interconnection, collaboration, security, and data analytics [3].

Virtual Reality (VR) is a form of inclusive digital media that generates three-dimensional, virtual imagery and interactive environment that is perceived or processed by the user to a great extent as they perceive the real world. To enable these users to interact with this simulated environment and experience it, VR glasses are worn in order to use VR applications. Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) have become a multidisciplinary research field over the last decades. Each of the three mentioned 'realities' are located on a "reality-scale", which is demonstrated in Figure 1. Augmented Reality expands upon our reality. MR is between VR and AR, and it allows augmented objects to be interacted with [4].

Figure 1. The types of realities, from real to virtual [4].

We agree with the Health and Safety Executive's (HSE) [5] definition of human factors: "Human factors refer to environmental, organizational, and job factors, and human and individual characteristics, which influence behavior at work in a way which can affect health and safety". Grant [6] defines the three pillars of the concept of sustainability: Economic (profits), environmental (planet), and social (people). These pillars shape the concept of sustainability, the role of which is to avoid compromising the future while meeting the needs of the present. We wish to examine how these factors are addressed in the research papers we review, keeping our credo in mind: Safety is of paramount importance. Our greatest concern was that many papers discuss new developments and technological advancements, yet seldom do they discuss human factors and ergonomic design strategies, which also affect productivity and the well-being of workers. The adoptability of new technology, and the burden of learning how to use a new system also may not be the primary focus of papers. Other aspects are to be considered, as some may feel that their jobs may be threatened by the emergence of new technological advancements.

The challenges these new devices pose to both the employers and employees should not be neglected. This paper focuses on research discussing the ergonomic design and sustainability of these new devices. We intend to add a new perspective to the field, emphasizing the importance of safety (resulting in efficiency and increased productivity). Adding this perspective could forward the discussion in the field, improving the technology adopted.

This manuscript is structured as the following: In Section 2, the materials and methods are presented. Section 3 deals with the results, while Section 4 discusses them. In the last section, the conclusions are summarized.

2. Materials and Methods

In order to find the best results for our research questions, a literature review has been employed as our research methodology. The strategy for preparing the literature review implies the search for all significant publications based on selected criteria. Our systematic review defines a structured process for identifying and analyzing publications. This systematic review is based on clearly formulated research questions (RQ), identifies relevant publications to evaluate, and evaluates the quality of these publications based on explicit criteria. Therefore, it includes the following steps: Identify RQs, identify relevant publications, assess the quality of the publications, summarize the findings, and interpret the findings. We express the hope that other researchers or managers of industry will be able to use the results of this paper.

The research questions are as follows:

- **RQ1**: Are AR/VR systems or devices proposed for industrial use capable of meeting the needs of the industry (including sustainability)?
- **RQ2**: Are these AR/VR devices designed to ensure easy use and efficient training of factory operators?
- **RQ3**: Do the proposals of the reviewed research papers place sufficient emphasis on creating ergonomic workplaces?
- We have formulated the following hypothesis: **VR and AR devices and applications may not yet be suitable for implementations in the industry** (still requiring further development and substantial testing).

The literature research took place between February and June 2019, querying Web of Science, Science Direct, and Scopus databases. These databases provide the opportunity to browse verified sources containing a significant number of entries and have a high impact-factor (a criterion for Ph.D. student publications). A list of 383 records was identified since 1988. However, to ensure that no outdated sources are used, our literature review focused on the last two, three years. A search interval was set for studies published between January 2017 and June 2019. Altogether, 198 records were identified. Duplicates, resulting from some entries appearing in multiple databases, were then removed. This reduced the search results to 158 specific records.

Abstracts of the resulting 158 records were then screened for contents relevant to our research goals. Elimination of 71 records then occurred due to not being in English, or not having Open Access or Free Downloading rights (only free research papers were fully accessible). Thirty-one records were deemed inappropriate due to being non-industrial studies. Next, two different researchers conducted a full-text article review of the remaining 56 records. Forty records were eliminated for not containing any usable answers to our research questions. The resulting 16 records that have met all eligibility criteria are evaluated in this literature review.

We have also completed the search of the MDPI Publisher Applied Sciences and Sensors journals. The reason we have opted for searching on MDPI was the abundance of articles meeting very high standards (hence their reliability). A total of 156 articles were found there since 2017. After reading their titles and their abstracts, eight articles were deemed relevant. Sixteen records being from the first search and eight records from the second, 24 publications had been selected as a starting point for further in-depth analysis. The number of selected publications is shown in Table 1. Figure 2 shows the flowchart of the selection methodology based on the PRISMA flowchart [7]. The selection criteria were based on a three-step model presented by Kitchenham [8]. These three steps are planning the review, conducting the review, and reporting the review. Since it is an effective method we have become well accustomed to, we decided to employ this model in our research paper. After formulating the strategy, a rigorous search was conducted in the bibliographic databases, using the pre-selected keywords. The review is reported in Sections 3 and 4.

Table 1. Years and number of appropriate publications.

Publication Year	Number of Publications in the Web of Science, Science Direct, and Scopus Database	Number of Publications in the Sensors, Applied Sciences, and Symmetry Journals
2019	4	2
2018	9	5
2017	3	1

The document "Summary Table of analyzed publications" was created as a result (Table A1 in the Appendix A).

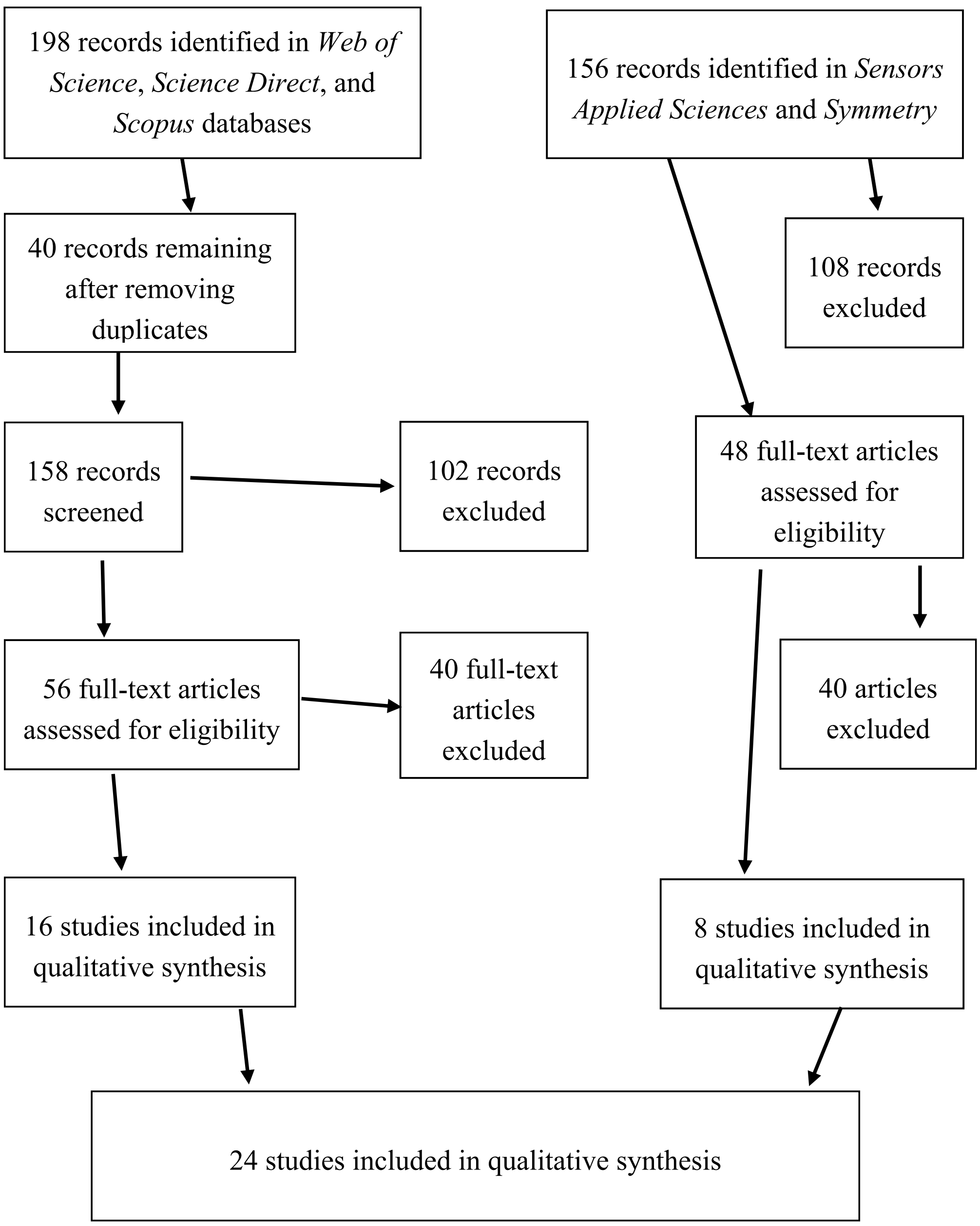

Figure 2. Choosing the analyzed papers based on PRISMA [7] flow-chart.

3. Results

This section consists of three subsections, with the first discussing how AR/VR Smart Glasses may be applied. The second subsection discusses the industrial environment. In the third subsection, usability and sustainability are discussed.

Industry 4.0 and supply chains face several major challenges, which are feedback cycles, dynamics in production, and logistics systems. An international team (Dolgui et al.) [9] reviewed the control theory of engineering and management problems of supply chains. Their analysis is based on the basics of control and system theory for supply chains and operational management, however, certain features and properties do not allow direct application of control theory methods.

The market for wearable products is rapidly growing, with smartwatches, smart glasses, clothing, headbands, wristbands, jewelry being common examples of such wearable products. The market is increasing in various sectors of Industry 4.0 products, including medical services, entertainment, gaming, lifestyle accessories. Wearable Technologies will be in almost every field of our life in the near future.

3.1. Adoption and Challenges of AR/VR Glasses

In order to assess the consumers' reactions to VR glasses, including the degree of acceptance, Herz et al. [10] did research involving 611 consumers from Germany. Items assessed within this research focus on the consumers' response to VR specific factors, effects of the use of this technology, and also intend to highlight anything unusual or surprising in these responses. Many technology acceptance models focus on the benefits of the use of a product, thus neglecting user feedback and criticism of any potential risk. Including this feedback is essential, as with any new technology, scepticism among the consumers arises. They may not be convinced that the potential risks of using the technology (privacy breaches, adverse effects on health, or psychological well-being) are outweighed by its benefits.

An appealing aspect of the use of VR technology is how a user can experience being in a virtual world, as opposed to smartphones, which lack this core feature. The results discussed in this paper (Herz, 2019) [10] are rather surprising: Virtual presence and virtual embodiment (being the capability of feeling situated in another environment and the feeling of having a body different to our own, respectively) seem to be positive factors of using virtual reality. However, experiencing only one of these features did not improve the attitude of the users towards VR at all. Only the coexistence of these two features resulted in a significant improvement in user attitude. Another surprising discovery of the paper is the priorities of consumers when considering the purchase and use of such technologies. Herz et al. [10] found that consumers show a moderately positive attitude towards VR glasses. When questioned about certain aspects of the use of this technology, the consumers showed a positive attitude if hedonic benefits could be associated with the product. Other priorities were comfort, utilitarian benefits, and the risks associated with data privacy. On the other hand, consumers did not express concerns regarding the risks of their health, physical, or psychological well-being.

To demonstrate how well-applicable VR glasses can be in various tasks, Bogaerts et al. [11] scrutinized the process of designing camera networks. This placement problem consists of finding an optimal location for a certain number of cameras, in order to maximize the coverage of surveillance cameras in an area of interest. By developing a VR Human Interface, the authors of the paper intended to enable humans to manually design a network of cameras and compare their efficiency to existing automated processes using elaborate algorithms.

As a measure to avoid the traditional steps of an automated planning scheme, this User Interface (UI) was intended to enable humans to design the camera network plan, without the loss of quality. The simple concept was to place the user in the scene of interest equipped with the VR glasses to assess the coverage of the cameras. The user adjusts the position of these cameras, and the environment points are visualized as a cloud, indicating the lack of coverage. As further adjustments are made, the user can effectively reduce these areas and improve overall camera coverage. Their experiments compared the performance of user-generated and computer-generated plans (with each experiment using the same constraints). Novices, given no prior training, were recruited to carry out the VR assisted camera network planning. Bogaerts [11] describes this as an unconventional practice, whilst keeping users away from the design process through automation as being "the traditional recipe in the camera network design literature", stating that the motivation for this approach is how the task proves to be difficult for users. The human-generated design provided better coverage in the experiments, and the employment of VR and visualization augment user capabilities during the process of planning, thus allowing even non-experts to design the arrangements of cameras in areas of interest. This may also solve another urgent issue in the rapidly expanding Industry 4.0: The constant undersupply of trained experts for the insatiable demand posed by the industry.

The authors of the paper emphasized the importance of the results, which "transcend the camera network design literature". These results can be applied to any other process, merely requiring smaller modifications. Moreover, the results were not presented as evidence of humans being superior to computer-generated solutions. Instead, Bogaerts et al. [11] suggested that the quality of automated algorithms may be enhanced by humans, should the problem become more challenging.

In order to determine which pair of smart glasses are most suitable for adoption in a smart factory, Syberfeldt et al. [12] reviewed 12 smart glasses. Before reviewing the glasses, a set of essential parameters were defined, which help determine the most suitable product. As Augmented Reality Glasses are becoming vital in the transformation of the industry, the support of shop-floor operators in smart factories has become a paramount objective of the process of Industry 4.0. The author of the paper states that their main goal is to facilitate the acceleration of the adoption of AR glasses, and by reviewing the currently available products, wish to determine one, whose properties suit the purpose the most.

The parameters taken into consideration were the ones that potentially affect the working conditions of the operators: Battery power, mass, handling. The battery power was defined to last for an eight-hour shift, the mass was not to exceed 100 g, and the glasses were to be voice-operated (hands-free). Syberfeldt et al. [12] found the Epson Moverio BT-300 to be the most usable device of the 12 reviewed products, possessing the most favorable parameters. As a conclusion, however, it was stated that the adoption process is impeded by the limitations of these devices, with the author stating that the glasses cannot be worn for an extended period of time (due to their weight), and people wearing ordinary glasses find it nearly impossible to wear smart glasses.

Another paper discussing the development of smart glasses also aims to maintain the health and well-being of employees, while using technological innovations as well. Terhoeven et al. [13] developed a new pair of smart glasses within the collaborative research project Glass@Service, with an approach to strive for an ergonomic design. This is essential, as several risk factors have been pointed out regarding the extended use of smart glasses, such as the mental and physical strain these glasses place on the users. To provide a more accurate insight into these issues, acceptance, usability, and the influence on mental strain were analyzed. The author of the paper conducted a survey involving 59 employees before implementing the technology. The results indicate that the employees had high expectations and were critical of the implementation of smart glasses. The workers found it difficult to adopt and use these new glasses. It is imperative that designers of AR/VR architectures first perform a needs assessment survey before designing new systems, lest the design proves to be ineffective or difficult to use, causing additional problems instead of solving one.

In mobile AR/VR systems, improving the user experience is crucial to sustain the use of the product itself. Fang et al. [14] described the basis of this as a real-time six-Degree of Freedom (DoF) motion tracking. This may encounter setbacks as a result of latency, completely spoiling the usability and Quality of Service (QoS) of the application. The author of the paper proposed real-time motion tracking based on visual-inertial sensors. With the combination of inertial sensor input and camera images, the real-time determination of the user's location can be achieved.

The constituents of the process are jitter filtering, moderation filtering, and latency filtering. These depend on the user's position and motion and improve the efficacy of the process. When the mobile device is stationary, the jitter-filtering takes place, whilst the moderation-filter and the latency-filter act during motion (with the latter involved in rapid motion). Fang et al. [14] pointed out that visual marker-based solutions heavily rely on being able to detect these markers, which may fail to do so in adverse conditions. The proposed system would eliminate this hindering factor, as it is not affected by blurring and consequential loss of tracking. A monocular visual-inertial system was proposed, with the follow-up experiments validating the method.

Fernández-Caramés et al. [15] examined the application of AR to enhance the "next generation of automated and computerized factories", as being the key technology of Industry 4.0. The paper discussed its use in the shipbuilding industry as Navantia, a leading company of the industry, studied how this new technology could be adopted and applied in their model: "Shipyard 4.0". This involved the development of their proprietary industrial AR architecture, based on the fog computing paradigm and cloudlets.

The objective was to formulate a system capable of handling physically distributed devices, which could reduce network traffic and computational loads whilst keeping low-latency and QoS in mind. Regular smartphones could be used, but an industrial environment ideally utilizes devices resistant to dirt, moisture, and impact. The use of helmets (Head-Mounted Display (HMD)) would be ideal, except for their prohibitive cost. An experiment carried out by the author of the paper was to determine the performance and efficiency of the proposed architecture. This was done by analyzing network traffic with WireShark. Fernández-Caramés et al. [15] found that fog gateways responded quicker when a single Industrial AR (IAR) device was used. However, when additional devices are also operated, this advantage of fog computing diminishes, and cloudlets respond faster. The author concluded that IAR devices are very much useful in this form of application. Nevertheless, optimization is still necessary.

In order to amend the manufacturing environment, Mengoni et al. [16] proposed a novel Spatial AR (SAR)-based system. To support manual work, and to complement the current AR systems in use, the authors have developed a system which could be utilized in smart factories. The objectives of the design were to support the process of training operators (by facilitating the learning process), and to improve the operators' posture during work. This is a major breakthrough in the design of assistive technology, as ergonomics may not have always been prioritized in the past.

The risks associated with an unhealthy posture and dangerous actions made by operators are direct consequences of low attention focused on human factors. These may result in lower performance, higher production time, increased absence from work, and Musculoskeletal Disorders. By focusing attention on these human factors, the efficiency of a factory may be increased, and the manufacturing process may become more economical as a result. As new ergonomic standards are developed, the author states that workplaces should be designed or modified accordingly to adhere to these guidelines. Another major benefit of installing such systems is how operators benefit from them when being coordinated to new workstations. As assembly lines consist of many workstations, operators could be readily trained to master them and, in addition, the facilitation of their activities can be improved using this technology.

Mengoni et al. [16] state that while AR is widely used, most employ multimedia devices, such as smartphones, HMDs, and screens. The use of an SAR-based system enables the operators to exclusively focus on the workstation, and not be distracted by having to constantly peek at the screen situated beside the workstation (and not directly on it). A projected image, however, does not hinder progress, and can project instructions. The system consists of two modules: The Ergonomic Module monitors posture and projects an alert when the operator's posture has been of concern. The Assembly Support Module provides instructions to the worker by projecting it on the surface of the workstation. This arrangement allows the operators to work without wearing any devices causing discomfort.

An experiment had been carried out with the participation of 30 subjects. The results of the experiment carried out to compare this system to conventional screens proved that the participants perform better when instructions are projected. Thus, assembly tasks can be more effectively supported by SAR-based systems.

The training of operators is of great importance to ensure a factory can function. The effective training of engineering students also plays an important role in any industry. Mourtzis et al. [17] proposed an effective method to introduce young engineers to the manufacturing and design processes of the industry. By applying advanced visualization techniques, the engineers could envision the product design, thus grasping a better understanding of the process. A simulation of actual products provides a realistic overview of the design process, and the final results are easily visualized. Here, designers may interact with the product and can instantly see which components need to be modified.

The "Teaching factory paradigm" incorporates a method of dividing the participants of the experiment into smaller teams. As a result, the engineering students become accustomed to working as a team, and function as members of this team. This collaboration occurs between the engineering students and experienced engineers, who supervise the process. The objective of the experiment was to design a remote-controlled car using this system. Mourtzis et al. [17] claim that the results indicated a noticeable improvement in the results of the participants, with errors reduced by 12%, and production assembly time becoming 10% quicker.

3.2. Industrial Environment

AR assistance in manufacturing is the inevitable future for factories willing to modernize production as part of the Industry 4.0 process. Since it is becoming an everyday tool for operators, Danielsson et al. [18] have examined the attitude of the operators towards the adoption of AR as part of their job in manufacturing. Thirty-five interviewees were interviewed in a Volvo factory, to collect data regarding their views on working with AR. After analyzing the data gathered during these interviews, the authors of the paper have found that a largely positive attitude towards this technology was observed, thus serving as an encouragement to adopt AR. Danielsson et al. [18] also suggested the use of an AR-interface when assembling engines.

The investment in AR by companies is considered to be lucrative as it can significantly decrease their maintenance service fees. This is easily achieved by performing remote maintenance, with the use of off-shelf mobile devices and AR technology. Masoni et al. [19] discuss this as a way a skilled operator or technician is enabled to perform repairs and maintenance tasks remotely: "The maintenance expert should be able to see and hear through the operator's eye and ears and then operate through his hands". The method is defined as the unskilled workers capturing images with their devices, which are then sent to the skilled technician for analysis. The skilled technician then gives instructions on what repairs must be made based on the received images or videos.

Unfortunately, technological limitations adversely affect the development of this proposed method. The authors discuss the problems encountered during the use of off-shelf phones, with the camera being its greatest flaw. Commercially available smartphones are not all fitted with cameras capable of capturing the motion of a rapidly moving part (of a machine). Assuming a 30 Hz frame transmission rate, this severely limits the visual inspection of a machine. Masoni et al. [19] also emphasize the language barrier between the two operators, as the cultural diversity of any company's workforce is nearly guaranteed. Manufacturing plants situated in remote or underdeveloped areas may only have low-bandwidth internet available, posing further difficulties.

To address the lack of interaction between humans and machines, Zhang et al. [20] have created a smart manufacturing interaction interface by using AR technology. The authors' hypothesis was that interaction and the complexity of instructions given to machines can be increased by communication via an AR-based interface. Machines within Distributed Numerical Control systems are connected to a Machine Control Unit (MCU). A set of instructions is given by the MCU, allowing it to control the machine tools. Current systems require the manual input of data, which results in commands too simple to perform certain tasks.

To test the hypothesis, the authors of the paper developed a prototype system consisting of AR tablet devices. The three constituents of the system are the following: A 3D sensing module, an in-situ design module, and a Wi-Fi-based communication module. The testing of the system proved to be successful, verifying the hypothesis.

For the industry to readily adopt AR and apply it to its production lines, certain requirements must be fulfilled. Quandt et al. [21] collected and formulated these certain requirements, including examples of the requirements in two case studies. The three main categories were requirements during development and integration, during setup, and during operation. The two case studies were wind energy and a welding simulator.

The requirements during development and integration have a financial or legal aspect. The cost-effectiveness is a matter of justifying the investment expenses of adopting AR. Regulations also affect requirements. If the technology used brings about the unavoidable surveillance of the workers, then additional regulations do apply. These are requirements of data security. During the design process, the consideration of other (more general) applicable regulations is paramount, including work-safety and specifications of hygiene. Setup also includes cost-related requirements, which are essential to running a factory efficiently: The setup time of the new technology should be minimal. This also includes minimal maintenance and calibration.

Requirements for operation included the real and virtual objects to be in precise alignment and real-time capability. Another crucial requirement that must be taken into consideration is the ergonomics of the implemented technology. This is to ensure the safety of the operators, and additionally, help them avoid discomfort, which can significantly distract them (possibly leading to defective products or accidents).

Ruppert et al. [22] have also dealt with this area of the industry. In order to accommodate the increasing variability in production, the transformation of the human-in-the-loop physical production systems is taking place. The authors of the paper have proposed a system to handle this enormous variability: An activity-time and performance measurement system based on software sensors. This consists of fixture sensors and an indoor positioning system designed to ensure real–time connection between the varying product quality and the performance of the operator. A benchmark problem is used to demonstrate how applicable the proposed methodology is. Redundancy is the benefit of having multiple sensors. The proposed constrained estimation algorithm provides reliable results, thus confirming its efficiency.

As the population grows, current estimates predict an additional three billion more middle-class consumers by 2030. An unprecedented rise in demand, which can only be supplied with goods from a sustainable system of production and design. Yang et al. [23] discuss the conventional linear model, which the authors summarized as a "take-make-consume-dispose" model. However, these previously mentioned factors are challenging this unsustainable model, eventually abandoning it in favor of the circular economy model. This model ensures that the products manufactured are regenerative and restorative by design, allowing them to be renewed after disposal. The concepts of Industry 4.0 could effectively address these issues, and the potential of remanufacturing could be unlocked. This remanufacturing process has been exemplified in two case studies, demonstrating their efficiency and reliability.

3.3. Usability and Sustainability

When considering the investment in VR glasses as part of the transformation process of Industry 4.0, not only are the technological capabilities considered, but the user experience is also important. To assist the evaluation of these VR glasses, Yu et al. [24] have developed questionnaires to not only evaluate the user experience of various products but also to seek any relationship between the user experience variables. Regarding the types of VR glasses evaluated, the focus was on mobile glasses instead of conventional VR headsets, as the former may be readily used following the installation of the VR application on the user's smartphone. The authors have recruited 30 participants who have volunteered to take part in the series of questionnaires and tests. To simulate the actual market of these devices, men made up 66% of the participants, whose age group was between 20 and 30 years of age. During the evaluation of the VR glasses, four dimensions were being assessed: Hardware, the mobile application, motion sickness (induced by the use of the device), and interaction operation performance. The results show that motion sickness can be significantly reduced with higher perceived user experience quality.

Real-time communication between systems and humans is a basic paradigm of Industry 4.0. However, should process optimization ever be done, human interactions must be recorded and understood sufficiently in order to effectively design the optimization process. The research conducted by Peruzzini et al. [25] had two objectives: Investigate the technology available to determine what could assist the monitoring of user experience, and by scrutinizing the application of Industry 4.0 concepts, ensure the well-being and safety of the workers. As the methods used to evaluate the workers' mental and physical workloads are determined, the collected data could be used to improve the design of the working environment. Peruzzini et al. [25] defined the three purposes of the survey: Avoiding machine downtime (process delay) by improving the process control, ensuring the safety of the workers by preventing excessive mental and physical workloads, and improving the quality of process planning, using the workers' actions as feedback. The smart factory architecture, which integrates human factor monitoring, requires constant access to a set of parameters to be monitored.

Industry 4.0 paradigms emphasize the importance of integrating all objects within a smart factory and humans into cyber-physical systems (CPSs). This elaborate task is achieved by placing sensors on wearable items that facilitate the process of human activity recognition (HAR). Zheng et al. [26] discussed this process by describing it as an analytical pipeline, where the processing of input data occurs. The most significant part is data pre-processing, the constituents of which are data segmentation and data transformation. The authors' study discusses the analysis of the deep learning model performance, and the impact data segmentation methods have. Four transformation methods are enumerated. The experiment carried out by the authors was to recognize a set of human activities (HAR) by using the data provided by multiple sensors worn by the subjects. Apart from the multichannel method offering the best performance, the proposed method has also outperformed most of the other machine-learning techniques: The recognition accuracy of 97.2% was achieved for the following eight human activities: Climbing stairs (upwards), climbing stairs (downwards), jumping, lying, jogging, standing, sitting, and walking.

Han and Kim [27] have proposed gaze-based hand interaction, which was intended to improve user immersion in a VR application. An analysis of efficiency was performed using a questionnaire based on an experimental environment, which was presented in 3D. In this environment, interactive content is produced, resulting in a high degree of immersion in a mobile VR environment. The proposition has been verified, as 45.24% of respondents had confirmed that the hand interaction provided high immersion. Also, respondents had not reported any significant amount of VR sickness or discomfort during the use of these VR mobile applications.

The availability of information regarding the appropriate and effective use of workplace head-worn displays (HWDs) is limited, especially the available options for the types of HWDs and UI designs. Kim et al. [28] have done research on how HWD types and designs of UI affect usability, visual discomfort, and job performance. Perceived workload, being another significant aspect, was also observed during order picking and part assembly tasks within a warehouse job simulation. Binocular and monocular HWD types, along with the four UIs were separately tested to assess their effects on job performance. Results indicated that UI designs had a greater impact on the previously described criteria, whereas HWD types did not have an observable effect.

The use of IoT has proven to be beneficial in many cases and studies, however, the inherent risks of the use of these technologies are not to be neglected. A major issue and risk associated with the use of IoT is the violation of privacy and data protection. Yildirim and Ali-Eldin [29] have presented a study in which the analysis of influencing factors has been performed, which determine the employees' decision to use wearable devices at work. The first component of the study is a literature review of studies dealing with the acceptance and adoption of new technology, and how they are perceived by the workers (risk and trust). The second component is a survey of 76 employees of an IT firm, who have submitted their answers to a questionnaire. The prediction of factors influencing the users' willingness to use these devices was performed with the Adaptive Neuro-Fuzzy Influence modeling. Results indicate that the application of the Adaptive Neuro-Fuzzy Inference System improves the predictability of user attitude towards the use of IoT devices, and the strongest motivation for using wearable IoT devices is their perceived usefulness.

Gregori et al. [30] have also discussed the significance and necessity of integrating the workers in a digitalized smart factory. Their proposition is an Internet of Things (IoT) infrastructure, which is intended to improve the well-being of the workers and productivity in general. This is achieved by acquiring human-related data via sensors and wearable devices interconnected by the factory wireless network and then transmitted to the processing unit of the factory for evaluation. The objective of this proposition is to improve production by identifying impeding factors. Bottlenecks, resulting in severe losses of profit, are predominantly a result of human actions, hence the primary focus on human performance. Another objective is reducing absenteeism among workers, which is often a result of occupation-related disease (induced by incorrect posture, negligence, etc.). This system proves to be beneficial to both the company and the workers, and improves the definition of the humans' role in Industry 4.0.

The possible future of VR is another research field that is closely related to smart factories and the adoption of Industry 4.0 paradigms: Next-generation VR devices could help contribute to the enhancement of user experience with the addition of several features, designing these future devices to allow a multi-user VR environment, and wireless connections achieved by using popular networking devices (resulting in low operating costs). The constraints and limitations encountered are a product of the inherent design of wireless networks: Packet delay. Ahn et al. [31] proposed a wireless multiuser VR communication architecture, which employs multiple WLAN standards, and is capable of handling substantial network traffic. By enhancing delay performance, high frame rate VR services have become possible to implement. The proposition is feasible in any factory, as it operates on unmodified, commercially available WLAN chipsets.

4. Discussion

Opportunities for an environment promoting collaboration between universities and industry professionals are offered by Industry 4.0. This allows the shaping of the future of manufacturing, whilst considering (and integrating) the concepts and paradigms of Industry 4.0. Despite this decade experiencing this process of transformation, various fields still require significant development [32]. The research papers we have discussed answer our research questions in great detail, allowing us to make accurate conclusions.

Requirement-related issues and sustainability were addressed in **RQ1**. A comprehensive description of the general requirements of the industry was provided by Quandt et al. [21]. Ergonomics were emphasised, as it is essential in ensuring safety, reducing discomfort (thus reducing distraction). An additional advantage is the possible increase in productivity, being an incentive to adopt these new technologies. However, limitations are also noted: Currently available hardware may not be fit for all tasks and stages of industrial production, and hardware manufacturers play a key role in facilitating (or hindering) the widespread adoption of AR/VR technology. Other concepts of Industry 4.0 are related to sustainability, to which Yang et al. [23] proposed a feasible production system for the future: The circular economy model. We express hope for its imminent widespread implementation, as this model provides an alternative to the disposal of billions of products, many of which could have been effectively and efficiently recycled or refurbished. The proposed model fulfills the requirements of the industry, as it offers a production model of nearly 100% recyclable, reusable products.

Other research papers have demonstrated the effective application of AR/VR technology, indicating how it is becoming increasingly suitable for use in the industry. The camera-layout designing interface by Bogaerts et al. [11] improves automated layout designs by complementing the algorithm with manually designed layouts. As user-generated layouts are not necessarily better, it is indicated that users can add important knowledge, as they have a better understanding of the problem. This proves that the future of designing may be complemented by AR/VR. Fernández-Caramés et al. [15] discussed the use of AR technology in assisting shipyard workers, noting the difficulties the workers face, as the safety helmets were not designed to be worn simultaneously with smart glasses. Changes should be made to safety wear in the future to accommodate AR devices, as current design flaws are impeding the adoption of new technology.

A major issue of the future is the lack of trained workforce, which is needed to meet the needs of the expanding global market. Mourtzis et al. [17] developed advanced visualization techniques to assist the training of engineers, addressing the issue of staff shortages in factories. The proposed interface is indicative of the versatility of AR/VR, as engineers can be assisted with this technology, too. This has resulted in more effective training and has contributed to the accelerated development of engineers. The system Masoni et al. [19] designed has enabled skilled technicians to remotely perform maintenance tasks by communicating with unskilled operators via a smart device. This could provide a solution to the lack of trained technicians, however, limitations were noted: A grave issue is the hardware built into these devices. Smartphone cameras (with a 30 Hz framerate) are not suitable for all purposes, as they cannot effectively capture rapidly moving objects. This limitation, along with language and cultural barriers, impedes effective communication and cooperation, requiring more suitable hardware to be manufactured in the future.

RQ2, which is concerned with the acceptability of AR/VR technology, shows how acceptability and the acceptance of these devices are affected, providing a better understanding of what motivates users in their decisions. Herz et al. [10] found that users have surprising priorities for VR devices, with hedonic properties valued the most. This provides a challenge for future VR designers, as this is an additional factor they must take into consideration. Han and Kim [27] discussed the importance of immersion (demonstrated by their research on the acceptance of gaze-based hand interactions on mobile devices). This supports the hedonic values discussed in the previous paper. Terhoeven et al. [13] designed smart glasses with an ergonomic design being paramount. This, however, was not fully accepted by the users, who experienced difficulties operating and wearing the devices. In addition to these challenges, the users also had great expectations and were reported to be highly critical of the glasses. A needs analysis prior to designing new devices could provide invaluable assistance in designing ergonomic, smart glasses, which could be accepted by its users. A certain degree of reluctance to accept new technology may be observed (Danielsson et al. [18]), but users had a mostly positive attitude towards (AR) devices. We believe that a possible remedy to this reluctance could be the effective familiarisation of users with the advantages of new AR technology. The research paper of Yildirim and Ali-Eldin [29] indicates that certain aspects (culture, external factors) must be taken into consideration before implementing a change or adoption of a new device. As a general note, it is indicated that an increasing amount of attention has been shifted to the needs and priorities of the potential users, which can eventually increase acceptance among the workers using the AR/VR devices.

RQ3 is related to creating an ergonomic workplace. Syberfeldt et al. [12] reviewed 12 smart glasses, of which the Epson Moverio BT-300 proved to be the most favorable. However, the limitations of any pair of smart glasses are the difficulties some people face at their workplaces merely owing to their disabilities or physical challenges, which need to be addressed and remedied in the future. Manufacturers of smart glasses exclude visually challenged people by not designing their products to be worn by people wearing glasses. This does not adhere to the increasing inclusiveness of modern workplaces, reducing the chances of employment for these people. Other factors, such as battery life, weight, and handling issues, make these smart glasses unfit for use in a standard eight-hour shift. Manufacturers must provide solutions to these limitations in order to have smart glasses adopted in the future, such as increasing battery life or using lighter materials for the frame.

Human factors have been scrutinized, revealing that human behavior has a significant impact on the health and safety of workers. The Spatial AR system Mengoni et al. [16] proposed focuses on the safety of workers and prevents dangerous actions or an unhealthy posture, promoting safety whilst assisting the training of new employees on workstations at an ergonomic workplace. The UI of a device may also affect UX: Yu et al. [24] sought correlations between UX variables by surveying the simulated market (66% males and 33% females between the age of 20 and 30). Impeding factors, such as motion sickness, are reduced by an improved UI design. The research conducted by Kim et al. [28] also supports this finding as they analyzed the usability and comfort of HWDs. Both studies revealed that UI design has a major impact on UX, rather than the device itself. Human behavior has also been monitored by using wearable devices. Peruzzini et al. [25] recorded human interaction with multiple sensors, including wearables, in order to monitor UX. The purpose was to evaluate the physical and mental workload. The wearable devices did not affect the workers' ergonomics, which indicates their fitness for use in smart factories. Gregori et al. [30] also used sensors and wearable devices to acquire data of the workers who were interconnected with the digitalized smart factory. Flaws in an ergonomic design may cause bottlenecks, along with human actions, causing injuries, absenteeism, or defective products. The acquired data are then used to identify bottlenecks and ensure safety.

We express the hope that further studies will be conducted in this field, which could advance the understanding we have of human factors, and that this research paper will be able to provide the necessary content to facilitate research planning. We can clearly verify our hypothesis, as most of the proposed systems discussed in this research paper may not be readily available or suitable for use. Nevertheless, we anticipate their swift development and adoption in the near future.

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Appendix A

Table A1. Summary Table of analyzed publications.

Research or Application Area	Publi-Cation	Key Technologies	Main Purpose
literature review, reference model of I4.0, key technologies of I4.0, smart factory of I4.0	(Alcácer, 2019) [1]	Industrial Internet of Things, cloud computing, big data, AR	The Industry 4.0 environment is examined in this paper, describing the so-called enabling technologies and systems over the manufacturing environment.
systematic review, smart factory, industrial operator support	(Syberfeldt, 2017) [12]	AR smart glasses	Of the 12 selected smart glasses reviewed, the most suitable and usable was determined based on the analysis of 18 parameters, including battery power, mass, ergonomic factors, etc. Despite the results indicating that the Epson Moverio BT 300 [33] was the most suitable, the authors claimed that improvements were still required before implementation could take place in smart factories.

Table A1. *Cont.*

Research or Application Area	Publi-Cation	Key Technologies	Main Purpose
media, fashion, technology	(Hertz, 2019) [10]	VR glasses	The acceptance and user reactions are assessed in this study by surveying consumers. Deductions and patterns are actively sought to determine whether trends and specific consumer preferences can be observed.
industrial use, technology acceptance, usability, user expectations	(Terheoven, 2018) [13]	AR smart glasses	Tasks were coordinated to employees to determine how suitable smart glasses were, with ergonomic factors taken into consideration. Fifty-nine employees were surveyed, observing the influence of these devices on mental strain and job quality.
manufacturing environment, future smart factories, ergonomic assessment, musculoskeletal disorders evaluation	(Mengoni, 2018) [16]	spatial AR	This study proposed the use of a spatial AR-based system, which is intended to support manual work in two ways: Firstly, to support the workers in the training phase of their job, and to help workers improve their posture by alerting them when incorrect postures are detected. This is to avoid musculoskeletal disorders, thus reducing absence from work and significantly improving operator well-being.
industrial environment, engine assembly, human–robot collaboration	(Danielsson, 2018) [18]	AR	This study presents the results of surveys, where employees were questioned about their attitude towards AR technology. The employees had a positive view on adopting AR.
remote maintenance industry 4.0	Masoni, 2017) [19]	AR	To improve the maintenance services of factories and industrial plants, an AR-based system is discussed, which could allow unskilled operators to repair machines with the remote guidance of a skilled operator.
education, teaching factory, product design	(Mourtzis, 2018) [17]	AR	To ensure the effective introduction of young engineers to the designing process of a factory, AR is used to visualize the product, providing the opportunity to interact. This helps engineers not only to perceive the final result but also to inspect it and find design flaws.

Table A1. *Cont.*

Research or Application Area	Publi-Cation	Key Technologies	Main Purpose
computer-aided design, smart manufacturing, industry 4.0, adaptive manufacturing	(Zhang, 2018) [20]	AR, 3D printing	Smart factories require interconnectivity in order to function properly, a feature many factories lack today. To provide the platform for human-machine interactions, an AR tablet device has been used in a prototype system, which intends to provide an interface for communication with machines and workstations.
supply chain, industry 4.0 scheduling,	(Dolgui, 2018) [9]	-	Analyzing the fundamentals of control and systems theory to supply chains and operations management.
User experience evaluation, Interactive operation, Motion sickness	(Yu, 2019) [24]	VR glasses	The authors of the paper developed questionnaires to evaluate the user experience of various mobile VR glasses (which can be readily used after installing the VR application on the smartphone).
User experience; Human Factors, Industry 4.0, Production system design, Human Interaction	(Peruzzini, 2017) [25]	Eye tracking system (Tobii) biosensors	As great emphasis is placed on the well-being and safety of workers, the monitoring of human interactions is crucial to assess their physical and mental workload. This integrated monitoring of human factors allows for the amendment of future factory designs.
Maintenance, Training simulation, Industrial application	(Quandt, 2018) [21]	AR, simulators	Two case studies are discussed in this study, which are used to formulate requirements towards AR technology for industrial applications. Cost efficiency and a short setup time were two significant requirements (among many others), providing the future designers of AR technology lucid guidelines to adhere to.
Industry 4.0, social sustainability	(Gregori, 2018) [30]	IoT	This paper discusses the integration of workers within the digitalized factory. An IoT infrastructure is proposed, which improves the well-being and productivity of the workers by acquiring human-related data. This is used to identify bottlenecks and prevent occupation-related diseases, having human performance in focus.

Table A1. *Cont.*

Research or Application Area	Publi-Cation	Key Technologies	Main Purpose
Behavior intention, Privacy, Trust	(Yildirim, 2018) [29]	IoT, Adaptive Neuro-Fuzzy Inference systems, Wearable devices Partial Least Square Modelling	Despite being usable in many fields of industry, the use of IoT bears many inherent risks, including the violation of privacy. This study analyses the factors which influence the employees" decision to use wearable devices at work. Results indicate that the strongest motivation for using wearable IoT devices is their perceived usefulness.
User interface, Performance	(Kim, 2019) [28]	AR, head-worn display	This paper investigated how the types of HWDs and UI designs affected job performance.
Camera network design, Camera placement, Human factors	(Bogaerts, 2019) [11]	VR, Submodular function maximization	To facilitate the designing process of a camera network, a VR Human interface was developed, enabling humans to design the network layout. The results indicate that the layouts designed by humans were more intuitive and efficient than the automated designs, which also require human interaction, thus proving to be less effective.
Real-time motion tracking, Adaptive filter, Visual-inertial fusion, Pose estimation	(Fang, 2017) [14]	Mobile AR/VR,	Mobile AR/VR applications require an uninterrupted stream from the built-in camera to provide the user-experience the users expect. Latency often limits the use of these applications, and this study has proposed a new method of motion tracking by using visual-inertial sensors, providing better adaptability. Experiments have validated the proposed method.
recursive estimation, performance monitoring, early warning systems	(Ruppert, 2018) [22]	indoor positioning system, paced conveyor	To cope with the increasing variability of production, the paper has proposed a system based on various sensors which are used to measure performance and ensure the handling of varying product complexity.

Table A1. *Cont.*

Research or Application Area	Publi-Cation	Key Technologies	Main Purpose
deep learning, data preprocessing, Human Activity Recognition (HAR), Industry 4.0	(Zheng, 2018) [26]	Internet of things (IoT)	Human activity recognition is vital in the processes of a smart factory. The detection of human activities is improved in this paper, as different methods are discussed, along with their efficiency. The multichannel method proved to be the most efficient, outperforming other machine learning techniques with a 97.2% recognition rate in the experiments conducted.
Industry 4.0, industrial operator support, fog computing, cloudlet	(Fernández-Caramés, 2018) [15]	Internet of things (IoT), AR, Microsoft HoloLens	In Navantia's "Shipyard 4.0", a new AR architecture is presented, which relies on the use of cloudlets and fog computing to assist operators wearing smart glasses. The presented method proved to be exceptionally efficient when handling larger file sizes, as opposed to fog computing alone, which proved to handle small payloads (<128 kB) efficiently.
orthogonal frequency-division multiple access (OFDMA), multiuser	(Ahn, 2018) [31]	VR, wireless LAN, wireless VR	To enhance the user experience of VR devices, a wireless multiuser VR communication architecture is proposed with the employment of multiple WLAN standards. This proves to be easily implemented, as commercial WLAN chipsets can be used.
remanufacturing, sustainable manufacturing, Industry 4.0, smart factory	(Yang, 2018) [23]	intelligent machining	This study addresses the conventional "take-make-consume-dispose" model of manufacturing, providing a feasible alternative. A new model (circular economy model) is proposed, which prescribes the design of products to be inherently regenerative and restorative by design. Two case studies were used to exemplify this proposed remanufacturing process.
mobile virtual reality, hand interface, interaction, immersion, VR sickness	(Han, 2017) [27]	VR, leap motion	To improve user immersion in VR applications, a gaze-based hand interaction is proposed in this paper. The results indicated that 45.24% of respondents testing the method reported a high degree of immersion, and VR sickness was not reported by the participants of the experiments.

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