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AR-AI Tools as a Response to High Employee Turnover and Shortages in Manufacturing during Regular, Pandemic, and War Times

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Abstract: The world faces the continuously increasing issue of a lack of skilled employees, staff migration, and turnover. It is strengthened by unexpected situations such as wars, pandemics, and other civilization crises. Solutions are sought and researched in various branches of industry and academia, including engineering, social sciences, management, and political and computer sciences. From the viewpoint of this paper, this is a side topic of Industry 4.0 and, more specifically, sustainability in working environments, and the issue is related to production employees who perform manual operations. Some of the tasks cannot be carried out under robotization or automation; therefore, novel human-work support tools are expected. This paper presents such highly demanded support tools related to augmented reality (AR) and artificial intelligence (AI). First, a panoramic literature review is given. Secondly, the authors explain the main objective of the presented contribution. Then the authors' achievements are described—the R&D focus on such solutions and the introduction of the developed tools that are based on AR and AI. Benefits connected to the AR-AI technology applications are presented in terms of both time savings with the tool usage and job simplification, enabling inexperienced, unskilled, or less skilled employees to perform the work in the selected manual production processes.

Keywords: Industry 4.0; augmented reality; AR glasses; artificial intelligence; assembly; production; migration; refugee; war; Ukraine

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1. Introduction

Industry 4.0 in a complex way is most often understood as the digitalization of the production environment. As a term, it was coined by Prof. Wolfgang Wahlster in Germany [1,2]. There has been a paradigm shift from mass production to mass customization, resulting from increasingly rapid changes in consumer tastes, rapid changes in demand, and the emergence of new competitors [3–6]. To survive and succeed in such competitive conditions, manufacturers should manage product varieties effectively [7]. Smart manufacturing aims to improve energy efficiency, productivity, and production quality while minimizing product life cycles and reducing environmental damage [8–10].

Regardless of the implementation of the idea of Industry 4.0, in any industry where significant automation of production or logistics processes or operations has been introduced, manual activities based on human labor are invariably important [11–13]. For these reasons, in addition to robotization and automation, researchers should always consider human needs in their work. As noted by researchers at the German Development Center for Artificial Intelligence (German: Deutsches Forschungszentrum für Künstliche Intelligenz, DFKI), an important research area in the field of Industry 4.0 is to find a user-interface that is as convenient and intuitive to use as possible to ensure optimal human–machine interaction [14]. That is why new concepts, techniques, and tools are emerging to support management, production, and logistics processes, as well as to support shop floor workers [15,16].

A sustainable approach to business operations requires the addition of appropriate resources, including qualified staff. However, what should be done during civilization crises that humanity periodically faces? Industry 4.0 is also a response to the ever-growing problem of a shortage of skilled employees in many countries worldwide. The Russian army's invasion on Ukraine, and many Ukrainians unexpected movements towards and from their country, show an additional large scale of unpredictability in the labor markets. Certainly, the authors are aware that this is not the only migration crisis of its kind in the world (e.g., Mexican migration to the United States of America, as recently discussed in [17]). Yet, it was a strong trigger for this paper's development; hence, references to the ongoing Russo–Ukrainian war can be expected. From the business point of view, such people's migrations are linked to the exodus of workers from factories, and consequently, it is a trigger for finding remedies. Not much earlier, the labor market experienced turbulence connected to staff shortages due to the spread of COVID-19 and quarantines, or the also noticeable previous European migrant crisis in 2015, when employment of the coming people from Syria was one of the serious points to be solved (it was estimated that Turkey dealt with 3 million Syrian refugees [18]). Such turns of events stand in line with the challenge observed for years—namely, finding qualified employees with nonexpendable qualifications to meet the proper skills requirements in a workplace. These situations trigger the creation of innovative tools or complete workplaces, as presented in this paper. An intuitive support tool could aid in such critical situations and enable new, unskilled people to work. Entering a new job in a new place is challenging for everyone, even the native inhabitants of a place. The level of challenges increases for refugees, with additional factors, such as language barrier, unfamiliarity with customs, the lack of recognition of the home country's educational degrees and work experience, and outright discrimination—as researched in Austria [19]. Acknowledgements can be found that state that refugees in Germany are highly motivated, but they need special support because of "initial disadvantages" [20,21]. Such a support can be ensured owing to sophisticated technologies, e.g., augmented reality (AR) and artificial intelligence (AI).

It is worth mentioning that the theoretical and sociological contributions of the presented topic should be of no less interest than practical ones. The authors point to examples of the theoretical in the literature review section, but concentrate on the latter one. Broader theoretical and sociological contributions are suggested to researchers whose specializations allow them to consider an extensive theoretical-like perspective of AR-AI technologies and their interactions with human migrations and the search for new jobs opportunities, representatives of cognitive neuroscience, experimental psychology, the philosophical perspective, etc.

1.1. Research Questions and Paper Structure

The overall and very brief situation for study presented above is only a starting point for the remaining parts of the paper. The turbulent period in the eastern regions of Europe, started by Russia's military offense in 2022, became the motivation for the authors to identify solutions that could support entrepreneurs losing experienced employees and make it easier for them to recruit and train new employees with a lack of skills in particular fields. However, these skills can be developed in an accelerated way with the application of the tools presented in the article. The paper is devoted to aiding the management of selected manufacturing processes using the developed "AR-AI" support tools, which are based on AR, advanced image recognition, and AI. Manual processes, performed by humans, which cannot be robotized, are in focus. Considering production based on the idea of Industry 4.0, which is characterized by high variability, short series, and high employee turnover, effective tools are required to provide convenient access to information and fast support to unskilled workers without restricting their moves.

As a result of this presented situation, three research questions can be proposed:

- RQ1: Can the AR-AI tool be used to enable unskilled workers to perform production operations?
- RQ2: How can the outflow of professionals from workplaces and the inflow of candidates trained in other areas be addressed?
- RQ3: To what extent are AR-AI tools ready for application in the uncertain business conditions listed, such as war, epidemic, or human migration due to other reasons?

This paper is also characterized by the following objectives: to identify some of the main challenges and threats currently facing the labor market in Central Europe, and to identify potential tools that can be applied to support the mitigation of these challenges and threats (including a proposal of solutions combining the problems outlined and the tools proposed further in this paper).

The paper starts with an introduction of the current geopolitical situation in Eastern Europe, which has become one of many consequences of the latest shortage of employees in the European labor market. Potential ways of dealing with the situation are suggested as well (AR-AI technologies). As far as the paper's topic is concerned, the geopolitical situation is presented in detail in Section 1.2 (this section underlines the significance of the authors' motivation for this paper), whereas Section 1.3 considers a brief literature review of AR-AI applications in general to highlight the relevance of AR-AI technologies. The methodology applied for this paper's research is presented in Section 2. The authors present characteristics of manual processes and the AR-AI support tools in Section 3, which is a suggestive form of appeal to companies that are facing the problem of losing staff and training new employees with little or no experience. Specific AR-AI solutions are discussed in Section 4, and the paper is summed up in Section 5.

1.2. The Employee Shortage in the Labor Market—The State-of-the-Art

The Russian army's invasion in Ukraine shows the large scale of unpredictability in the labor markets of neighboring countries (e.g., Poland). Official reports from the Polish Central Statistical Office and the Polish Ministry of Family and Social Policy describe the large number of Ukrainians working in industry and logistics—over 1 million (the number was estimated based on information provided by the Ministry that about 2.1 million Ukrainians currently work in Poland, with 20.1% of them working in industry and 30.4% in transport and logistics; given after [22]). On the other hand, one can find information that places a significant number of them returning to their country to fight [22,23]—22,000 in the first three days of war [24]. This number increased to 66,200 people a week later [25]. On the other hand, reports show nearly 2 million Ukrainian refugees coming to Poland in the first days of war. According to the United Nations, Poland had taken in 2,514,504 refugees as of 6 April 2022 [26] (this reference is updated every few days), and the numbers are still increasing. Such a significant migration of people (including staff migration) cannot occur without consequences for companies and the domestic economy. One of the topics that the Polish government has raised is finding employment for these refugees. Special acts have already been passed by the Polish government guaranteeing Ukrainians the status of legally staying and the possibility of working in Poland [27]. After about two months of war, entrepreneurs reported employment of over 60,000 refugees from Ukraine [28]. This is only a fraction of the total number of refugees, which is usual, and similarities can be found in different examples. For many refugees, a certain country is often not the destination one, such as, e.g., Tijuana (Mexico), for whom numerous Haitian, Ukrainian, and Honduran refugees that city is not the end destination [29] but who wish to cross to the USA, generating the problem of a floating population and high turnover of personnel in the companies that hire them. Ukrainian refugees have chosen the city of Tijuana, on the border between Mexico and the USA, since border crossings are less crowded there and the authorities of Mexico do not require visas from Ukrainians (a tourist card is enough to enter [30]). Of all refugees, 30% claimed that they will stay for longer and work in Tijuana [19,28]. The authors do not discuss any opinion on this situation—this information is solely of an informative character and can become a matter of independent research.

The Russian army's invasion is undoubtedly shocking in 2022, yet a similar problem occurred in 2015, when Europe faced the biggest migrant crisis in history [31].

War-caused issues are one aspect of the problem, but they only intensified the issues in the labor market that were already present. Leading economic organizations report the ever-growing issue of a shortage of skilled employees in many countries worldwide. It is classified as one of the greatest threats to future economic development [32,33]. The shortage of employees has been noticeable since 2010. In mid-2016 this issue was pointed out as the highest risk to future economic development and has been in first place ever since, apart from the temporary drop during the first year of the COVID-19 pandemic. The data are presented in Figure 1. The presented current status of the challenges of the shortage of skilled employees and the corresponding state of companies suggests the need for novel solutions that can support less qualified employees to undertake employment.

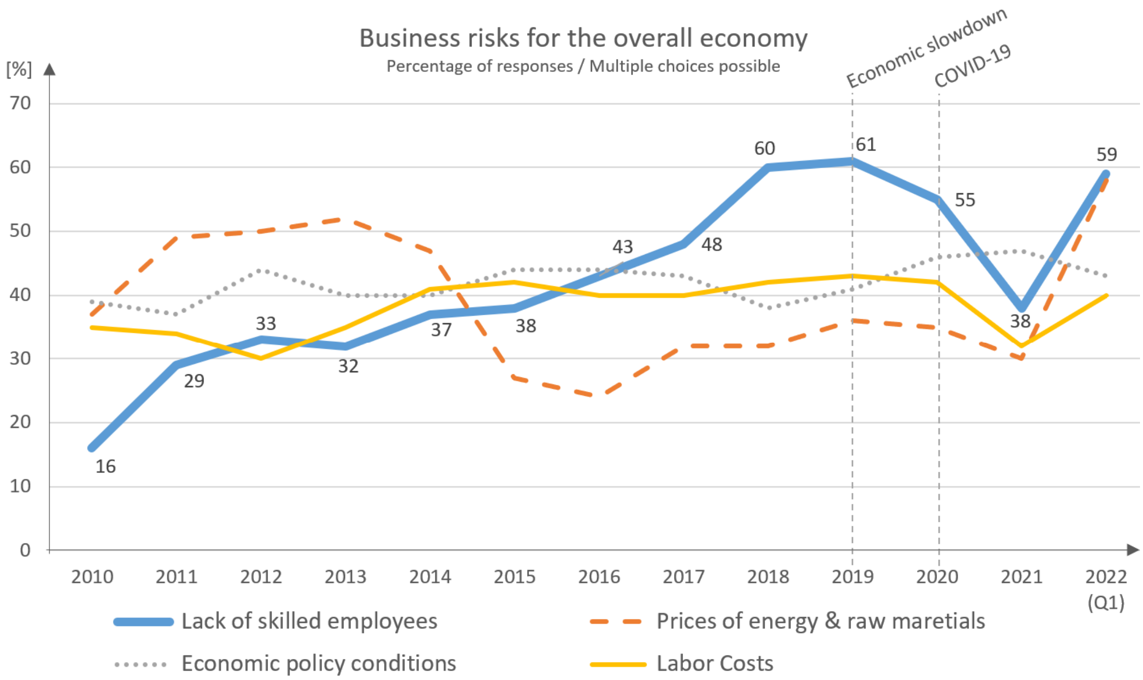

Figure 1. Business risks for the overall economy. Source: own work based on [34].

1.3. Literature Review

Applications based on AR and AI technologies supporting manual production processes, coping with staff shortages, and new staff training (or new skills) led the authors of this paper to develop a panoramic review as a comprehensive and thematically extensive presentation of the matter. The interest was to analyze publications connected to novel and inexperienced employee apprenticeship and support in manual operations, mostly within manufacturing processes, yet not limited to them solely. According to [35], till 2030, AR will play a significant role in the majority of industries, including military [36], medical and healthcare [37], navigation, gaming and entertainment, manufacturing, and especially—from the viewpoint of the current paper—education, training, and remote assistance (providing training in a safe environment).

There are plenty of reviews of the scientific contributions of AR-AI technology applications, some of them quoted below. Therefore, this paper focuses on presenting the most current solutions (screening with the phrase "AR training in manufacturing research"). They are presented by year of publication.

Gonzalez-Franco et al. [38] implemented a mixed reality (MR) setup with see-through cameras attached to a head-mounted display to analyze a manufacturing procedure of aircraft door maintenance. MR training and the conventional face-to-face training were considered and compared. The differences between them were not significant. On the other hand, it was observed that MR setups can achieve high performance in the context of collaborative training.

Ferrati et al. [39] presented research on AR technology with a focus on error rates and the average assembly times during the industrial process of cherry picking. Their AR system consisted of a HoloLens with software built in Unity and Vuforia. It is worth mentioning that the testers who were working in this research experienced no discomfort or headache and it was stated as well that the training delivered through the AR tool had improved outcomes compared to the ones provided the traditional way. The results of the training process indicated that requests for help from additional trainers decreased, that learning time was improved by 22% and that time spent picking was reduced by 26%. Sorko and Brunnhofer [40] also stated that set-up times and processing times can be shortened with the application of the AR technology. On top of that, they mentioned that paths during various industrial operations can be shortened, which is reflected in the aforementioned time reduction and consequently less employee tiredness. Moreover, their research led the authors to the statement that employees can be individually trained in a protected training environment with less training staff effort and reduced error rates.

Osborne and Mavers [41] presented an AR literature review showing both advantages (e.g., hands free to conduct tasks, full transparency of the real world, increase in task efficiency) and disadvantages (e.g., delays in obtaining information, issues when wearing corrective glasses). They noted that training and complex assemblies can be simplified, so a new employee can accomplish a process task without extensive experience.

Büttner et al. [42] investigated the use of a projection-based AR assistive system in a training scenario. Three training configurations were analyzed: the AR assistive system, a paper manual, and personal training. The personal training results were the most efficient. The AR system, however, satisfied the challenge of a trainee mislearning content, but it was not faster than the training done by a human. Despite such results, the authors agreed that AR technology can be successfully applied as trainer-less tools for training employees in manufacturing.

Most of the research on training processes with AR applications versus the traditional approach has been finalized with a survey related to the content and effectiveness of the instructional outcomes [39–41]. The authors of the mentioned research agreed that AR technologies can be applied for training both skilled employees and those requiring new skills.

It is also worth pointing out research papers with a literature review connected to AR technology. Bottani and Vignali [43] reviewed the literature connected to AR published between 2006 and early 2017 to identify the main areas and sectors of AR application. Without a doubt, that literature review should be updated (even the authors themselves pointed out in the future research section that the review needs to be continued in greater detail to consider industrial sectors where AR systems could be successfully deployed), but the authors specified industrial sectors, the representatives of which had pointed out the benefits of AR technologies. Among these sectors were laboratories, manufacturing, machine tools, architecture, engineering, construction and operations (AECO), and automotive. The authors of [43] noted that at the time of publication, the AR applications were often little more than experimental prototypes. Quandt and Fraitag [44] reviewed publications connected to users' acceptance of AR technologies, released between 2011 and 2020, in the following areas of application: maintenance, training in the work environment, assembly, and order picking. In the case of training, they mentioned Fraga-Lamas et al. [45], who focused on providing step-by-step instructions on a specific piece of equipment or machine, which depended on the employees' level of knowledge, or passing knowledge from experienced employees to less experienced ones with implementation of the AR technology.

An evaluation of the AR solutions in manufacturing was also conducted by Zigart and Schlund [46]. Meanwhile, Doolani et al. [47] considered the topic from a broader perspective and reviewed research papers connected to manufacturing training with the application of extended reality (XR; including AR as well as VR—virtual reality). The authors planned a clear progress in the application of such advance technologies and specified their domains. Kaplan et al. [48] specified the key benefits of using XR-based training, stressing the ease of implementation in difficult environments (e.g., the disaster training presented in [49]). On the other hand, it was also noted that the XR-based training poses a threat to traditional training. Werrlich et al. [50] pointed to an important result, from the perspective of the current paper: the employees trained with the AR systems performed better in short- and long-term training than in the case of traditional trainings. What is also very interesting, as far as the review of [47] is concerned, is that the authors specified which phases of manufacturing can be supported/trained with AR technology: the learning phase (with tasks such as sorting, picking, keeping, assembling, installation), the tangent phase (with tasks such as using rare tools/machinery, hand tools, power tools), and the end phase (with tasks such as an inspection and cleaning routine, including processing, shoveling, sweeping, and cleaning work areas).

At AR technology conferences, including the most respected ones, such as the International Symposium on Mixed and Augmented Reality (ISMAR) conferences, it can be noticed that in the first period of intensive AR development (review of the first decade of the ISMAR conference, 1998–2008 [51]), the biggest contribution to this field was devoted to the software and hardware parts of the AR technology itself (tracking, interaction, calibration, display), as the fundamentals of AR had a long way to go to achieve maturity [51]. In a review of AR trends in the second decade of the ISMAR conferences (2008–2018), described in [52], there was a significant increase in research on applications and evaluation (an increase from 5% to 16%), which was the second result after research on tracking techniques (19%).

It is worth presenting a summary of the above contributions to state a certain research gap. Numerous researchers considered staff training with the application of AR, MR, or XR in their publications and projects: training with AR and MR technologies in [38], training with AR glasses [39], and training with XR technologies [47,49]. Some of the researchers proved that the training could demand less training staff effort and ensure reduced error rates [40]. Other advantages of staff training with AR technologies were mentioned in [41,42], together with an investigation of the disadvantages of such potential. Almost none of the contributions considered AR technology application from the viewpoint of human migrations and consequently searching for new job opportunities by people with no or few qualifications. However, to prove that it is possible to transfer knowledge and abilities of more experienced personnel to those less so with the application of AR technologies, the publication by [45] can be mentioned. Any significant similarity to the current contribution was not found in review papers such as, e.g., [43,44,51,52]. As a result of a panoramic review of the literature, so far, no usage of AR and AI tools as potential solutions to face the exodus of employees because of war, epidemic, or human migration due to other reasons has been noticed or considered. Therefore, this issue is treated as a research gap. As this panoramic review of the literature shows, growth in interest in the subject continues. Therefore, it is worth presenting some of the most recent research, given in the next section. The solutions presented provide significant support to potential employees, whose qualifications are different from the expected in their new potential workplace. Thus, these solutions can provide significant support to employers who have lost or must manage employees as a result of, for example, an ongoing war, epidemic, or human migration due to other reasons.

2. Materials and Methods

The authors carried out expository, descriptive, and experimental research [53]. The first part consisted of a literature and official data review. Its purpose was to outline the situation and, at the same time, to explain why the authors chose to present the material given in this paper. The current situation concerns both the state of technology (given in Section 3) and, above all, the situation in the labor market (given in Section 2). At the same time, the authors suggest potential solutions for employers facing the necessity to train newly come and inexperienced employees to perform novel tasks and operations in manufacturing and logistics. Therefore, the second part of the research was based on observations and an in-depth case study of three selected production processes. The experimental part measured the benefits of the application of AR-AI tools in these processes. This part is described in the next section. The overall methodology is given in Figure 2.

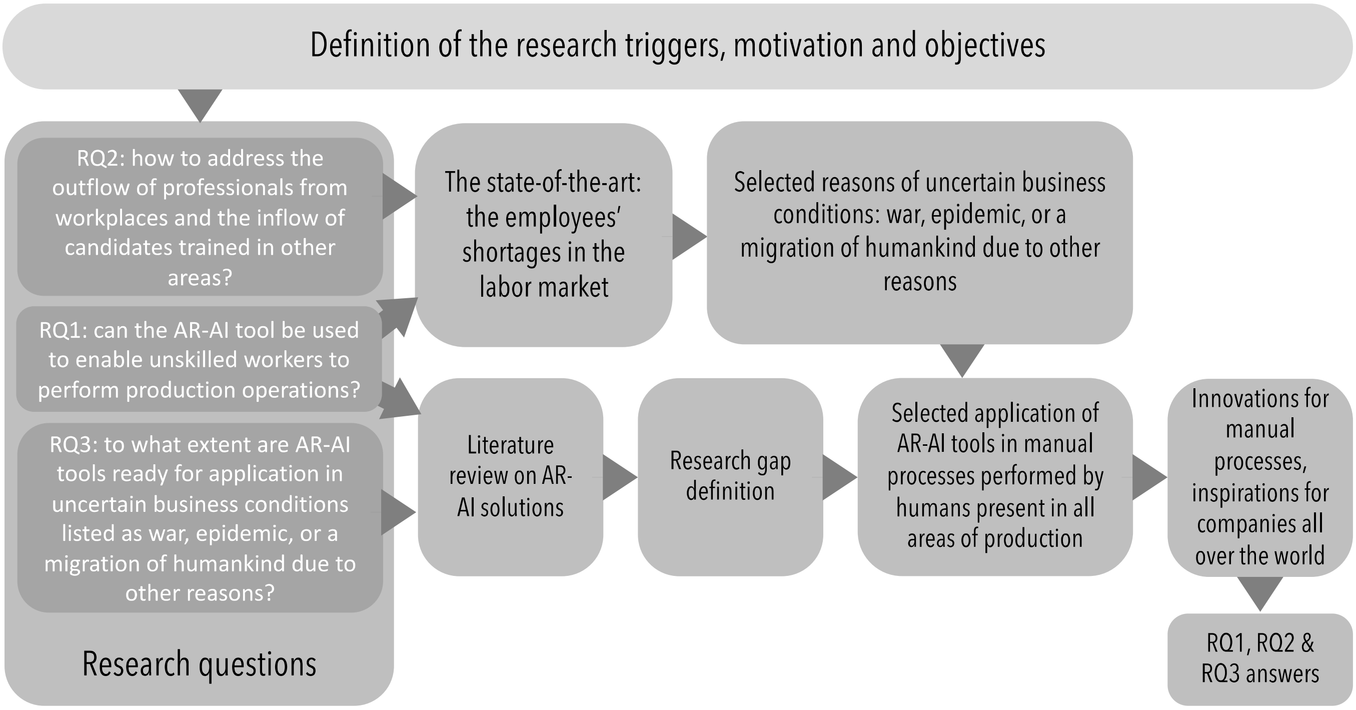

Figure 2. The methodology applied in the research.

3. Results

Researchers from the Oxford University and Graz University of Technology noted that detailed studies on the impact of AR applications on key process performance indicators are scarce [54]. This is due to the fact that until recently, most of the AR devices were wired, early-stage laboratory prototypes focused on technology development and the creation of potential applications, rather than devices ready for testing and application under demanding conditions in a manufacturing environment [55,56]. In this section, the authors present solutions that are ready to be implemented in actual manufacturing processes.

Manual processes performed by humans are present in all areas of production. These include technological processes such as assembly, auxiliary processes such as maintenance, and control processes such as quality checks. Figure 3 presents a simplified diagram of the manufacturing process, highlighting in red the paper's main area of interest.

The latest technological advances in various fields, including AI, raise the question of what can be added to the possibility of operator–machine interaction and how [57]. The authors of the publication outlined the architectural framework and possibilities for future interaction between the workstation/machine and the operator. One of the devices that can significantly affect the performance and quality of the human–machine interaction interface are glasses using AR technology [58–60]. The newest AR glasses provide the user with the necessary information in a specific place and time, whereas the control, creation of information, notes, or reports is done using simple gestures or speech [61].

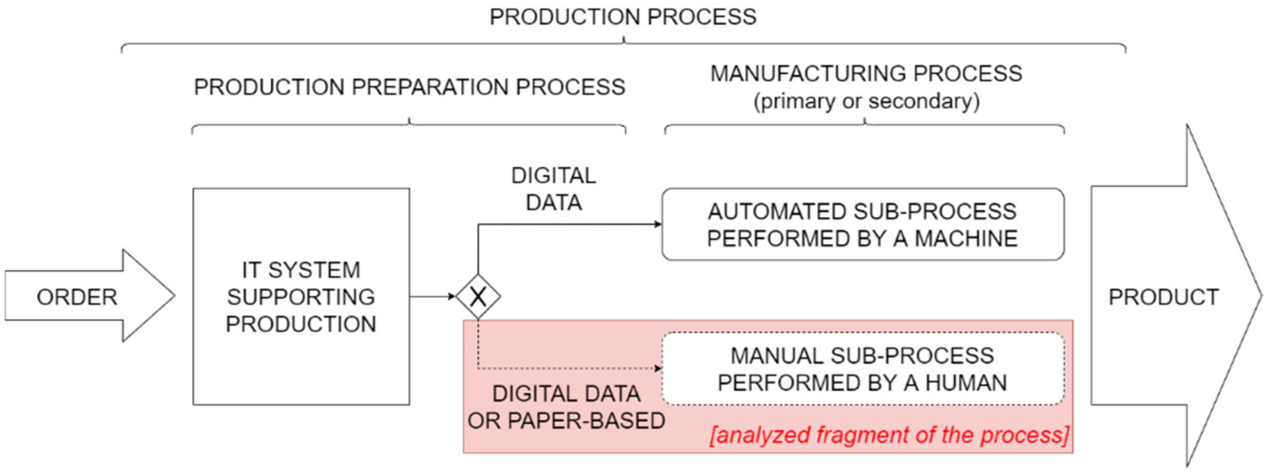

Figure 3. A simplified diagram of the production process with the focus area marked in red.

In the literature, one can find a number of publications devoted to the R&D of AR in different areas of production, such as assistance in the initial training of students and new employees [62,63], logistics [64], robotics and machine construction [65,66], maintenance, inspection, service and repair [67–69], and assembly [12,60,70]. However, these are mainly descriptions of concepts, and there are only a few examples of and research on the implementation of AR-based tools in production processes [71].

AR tools can be based on mobile devices like AR glasses or tablets, but also stationary workplaces, including spatial AR systems (spatial augmented reality, SAR). SAR systems with a permanently attached projector are sometimes referred to as mixed reality (MR) [12]. Examples of SAR are AR fitting rooms in clothing stores [72]. In the industrial environment, these are, for example, white dummies onto which an image of a product is overlayed by a projector—e.g., a car dashboard [73] or the interactive workstations on a production line, guiding a user within the production. Examples are illustrated in Figure 4.

Figure 4. Examples of SAR—stationary AR. **Left**: DTPoland intelligent station (source: the current authors' workplace); **right**: Bosch Rexroth ActiveAssist workstation [74].

The current paper's authors have been focusing on the processes of manual assembly, maintenance, machine changeover, inventory, and quality control for years. In the case of the assembly of, e.g., wires in a control cabinet, the individual operations are not complicated—it is the number of them that causes complications. In maintenance, on the other hand, it is the high complexity of modern machines that causes difficulties for the staff performing regular inspections. AR support tools can make the work easier, allowing the time of execution of certain tasks to be shortened. Moreover, such tools, as far as the system is capable, can control the correctness of the activities conducted and reduce the number of errors.

The authors developed the AR-AI tool to support manual processes. On the one hand, it was created for managers responsible for process management, and on the other, for the production workers—the tool users. The prototype uses AR glasses. It provides AI-based automatic access to relevant structured information, located in a specific location of the 3D space, while not restricting the worker's movements. Real-time operation is provided. The outline of the proposed concept is shown in Figure 5.

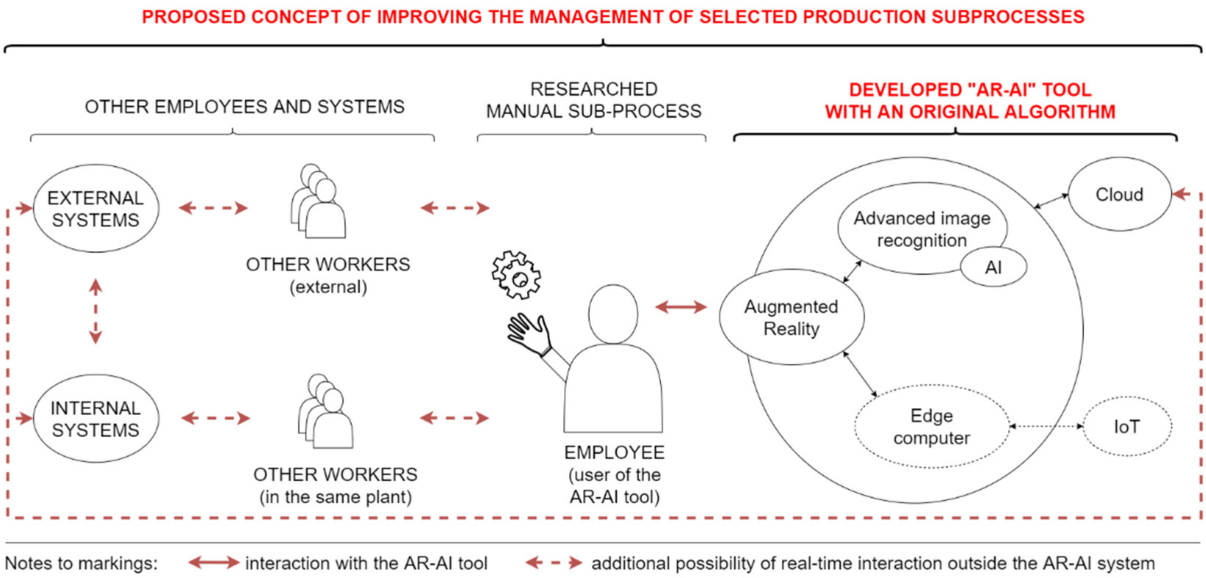

Figure 5. The proposed concept of improving the management of selected processes using the AR-AI prototype, which supports the production worker.

The main components used for the described solution are:

- AR device;
- Proprietary software based on AI (including the creation of a labeled dataset, data augmentation, machine learning, PyTorch library, and convolutional neural networks—CNN) and advanced image recognition (including OpenCV library, template matching, edge detection);
- Cloud computing;
- Optional edge computers and Internet of Things (IoT) devices.

The use of AI allows for precise recognition of the surroundings and objects, and as a result, automatic access to appropriate, structured information located in a specific place in the 3D space. The optional devices are intended to guarantee the real-time operations in some of the processes that have such a requirement. The concept of the AR-AI tool, including digital data management, is shown in Figure 6, which shows the flow of information between smart glasses (Figure 7), software in the cloud, and optional components.

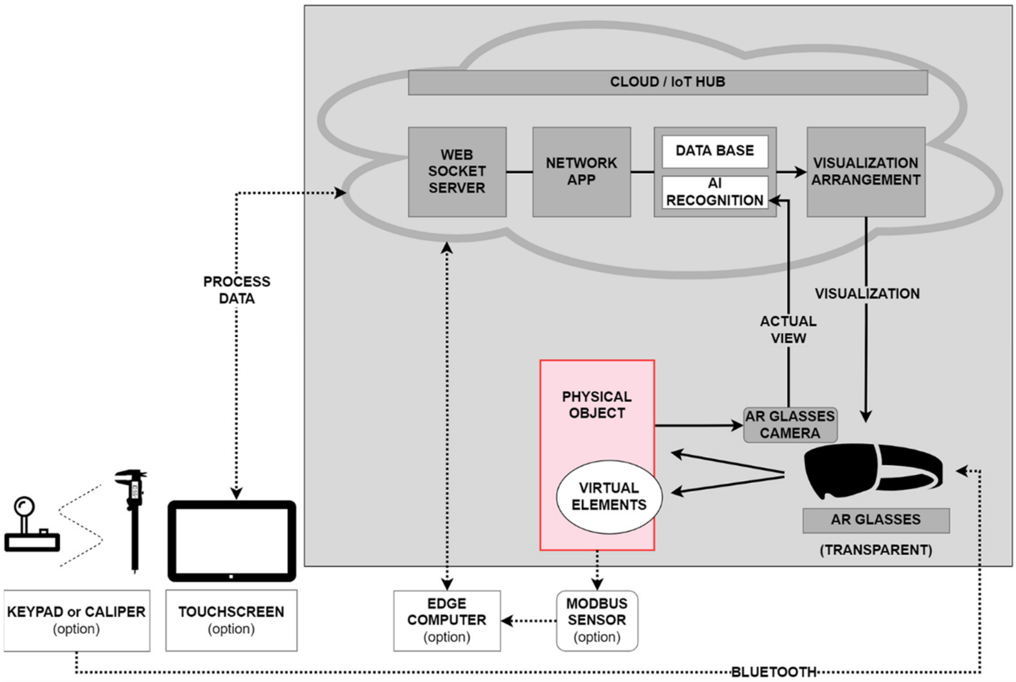

Figure 6. The main diagram with the concept of the AR-AI tool supporting the production worker. The main components are proprietary software, AR glasses, cloud and other optional elements, and a physical object means, e.g., a control cabinet, a controlled machine, or a manufactured product.

The history of AR dates to the 1960s, yet its successful industrial applications have only been known of for a few years [75]. AR technology applied for a variety of tasks presents tremendous opportunities for industry in terms of time reduction and thus cost reduction [76]. Many of the newest technologies are in their early stages, yet at the same time they are already approaching a tipping point in their development, as they add value and complement each other by combining technologies in the physical, digital, and biological worlds [77].

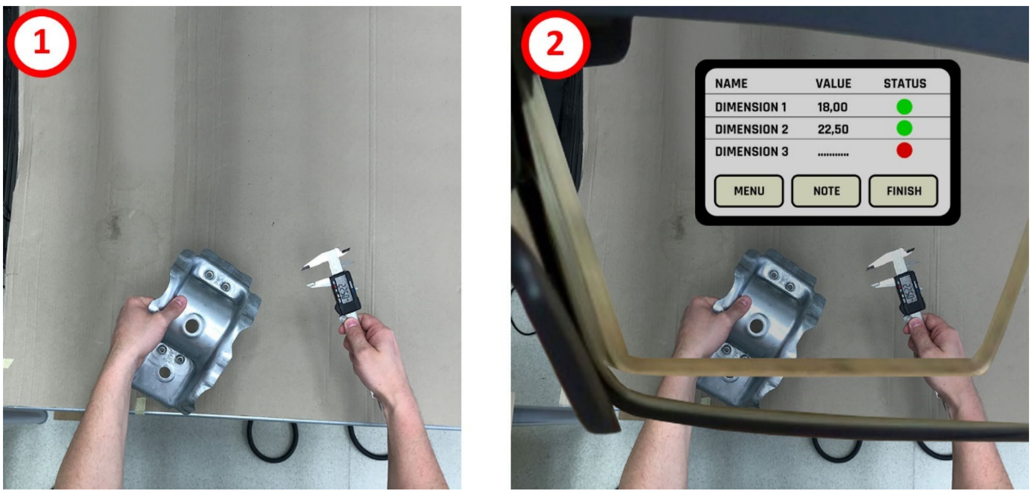

Figure 7. Comparison of the existing quality control process with the one organized with the AR-AI tool: (**1**) the image seen without the AR-AI tool (in the left hand an element for quality control is held, and in the right one, a caliper); (**2**) the image as seen through the AR-AI tool glasses, with an additional virtual screen (previously published in [78]).

4. Discussion

The authors performed the initial research on the three selected production processes: wire assembly, inspection of a production line, and quality control of a manufactured product. These processes and the corresponding AR-AI tools were described in separate papers [60,61,69,78]; nevertheless, it is worth emphasizing that the results given below are revealed in this scope for the first time, but are preliminary and will be further verified and validated.

The first process concerned the assembly of wires in the control cabinet, with the median number of 300 wires in one complete cabinet [60]. The research on six testers resulted in a serious improvement in the process—the assembly time saved was on average 2:15 (hh:mm) thanks to the AR-AI support tools (including AR glasses and the AR Smart Wiring 4.0 system). The average required assembly time with the AR-AI tool was reduced by 40%. That means a savings of one working shift (8 h) for every 3.5 assembled cabinets, which is a strongly significant result.

It should be noted that the speed of the testers' adaptation to the assembly system, both with and without AR glasses, was different. A similar observation, although in the case of a different production process, was described by Sanna et al. [79]. However, correlations were observed among group of testers with similar characteristics. The shortest duration of experiments was among relatively young testers (born 1983–1989) with certain experience in the industry, including positions directly related to the assembly of control cabinets. The slowest courses of experiments were done by older testers (born 1966–1969) with no previous experience in the industry. Younger testers (born in 1989) with no experience in the industry saved the greatest amount of time in minutes. This result can be associated with the younger age, whose representatives often show natural skills in using the latest technologies (this is connected to rapid adaptation in a work environment as well). For this young, unexperienced group, the results of experiments without the AR-AI tool, associated with the need to interpret the 3D electrics schematics on the touchscreen, were clearly worse than for the group with industrial experience.

The second process was the inspection of the production line, typically lasting 45 min as a task that is traditionally done manually. The average time saved by five testers, with the use of the AR prototype was 17:05 (mm:ss)—the required inspection time with the AR-AI tool was reduced by 37%. The research into this solution continues and is yielding increasingly satisfactory results. Of the five testers, two had a background in the process and three represented the unskilled group.

The third process was the quality control of the manufactured product, performed directly in a workplace. The introduction of the AR-AI tool allowed the process to be reconfigured. With the appropriate AR-AI tool, instead of operators going to the control place for the check, the control employee headed to the operators' workplaces. This resulted in a complete reduction of the downtime observed in the original process, within which the operators left their manufacturing places and moved to the control spot to conduct the quality control process. For a single operator working for one shift (8 h assumed), the total production downtime was simulated to equal on average of 45 min. Elimination of this time provided a savings of 10% in the case of regular operators' time.

It is worth highlighting the fact that both experienced employees and people without a particular understanding of the elementary activities and manual operations participated in the tests of the processes mentioned above. This attests to the implementation maturity and application potential of the presented solutions in enterprises willing to employ people with non-technical preparation to perform technical and engineering tasks.

5. Conclusions

The developed AR-AI tools were presented together with a summary of the initially researched results. Different testers with various personal characteristics were examined. Age and experience were the variables. The variance of results within the mentioned processes depended, among others, on the individual characteristics of the testers, the production organization in the respective plant, and the existing IT infrastructure. Despite that, all results confirmed the clear benefit of the developed AR-AI tools and the validity of the concept of automatically displaying the right information in front of the user's eyes at an exact location (e.g., at the assembly point or above the inspected machine). With the use of the AR-AI tools, it is possible to save users'/operators'/employees' time and reduce the duration of selected manufacturing processes by an average of 29%. The assembly of wires in control cabinets can be reduced by 40%, production line inspection by 37%, and quality control by 10%. It was verified that the AR-AI prototypes enabled unskilled employees to perform the work in the selected manual production processes. It is very important, as the annual business survey of the German Chamber of Commerce and Industry (Deutscher Industrie- und Handelskammertag DIHK) [33], including the report "The greatest threats to economic development" [34], pointed out that the lack of qualified employees is one of the greatest threats to future economic development, based on the observations from 2010 until current times and events. The lack of enough skilled employees is one of the greatest threats as well [80–82]. This problem is growing year by year, despite the economic slowdown noticed in 2019 and the uncertainty connected to COVID-19 in 2020–2022 (and still ongoing).

It is worth answering the set of research questions. First, can the AR-AI tool be used to enable unskilled workers to perform production operations (RQ1)? The studies showed a positive effect of the AR-AI tools on unskilled workers in selected production processes, which may be the answer to this constantly growing challenge of the temporary or long-term shortage of employees. A properly constructed support tool based on AR, advanced image recognition, and AI simplified the selected production operations, thus shortening the time to perform these operations and enabling them to be done by unqualified or less-qualified people. In some cases, during the research, a regular person was ready to do the job even without preparatory training. These AR-AI tools increasing the abilities of unskilled employees in selected production processes can be partially treated as an answer to RQ2. The maturity and application potential of the presented AR-AI solutions was successfully confirmed by the testers performing technical and engineering tasks. Certainly, such research should be continued, and the authors hope that considerations of this kind shall be undertaken by their successors, and in doing so, by themselves (especially that certain processes mentioned above were not given in the contributions published so far and will be soon subjected to detailed analysis).

In 2022, the number of mobile AR users is expected to reach over 1.07 billion all over the world, and it is foreordained to increase to 1.73 billion by 2024 [83]. Part of these users are expected to use AR technology in everyday working environments. AR glasses alone are expected to achieve sales of 960,000 units in 2022 (more than doubled from 2021), and increasing to 3.9 million or more by 2024 [84]. A huge impact on e-learning and training programs has occurred, especially in industrial applications, as the references given in this paper suggest. This is also confirmed by independent reports, such as, for example [85] quoting from [86]: "around 14 million employees in the US are going to use smart AR glasses on a regular basis for their on-job tasks and training by 2025" [86].

Knowing that, AR-AI tools could also support such critical situations as the one caused by Russia's invasion of Ukraine. Reports say that nearly 2 million Ukrainian refugees came to Poland in the first three weeks of the war [26], and on the other hand, many Ukrainians working in Poland left to fight in their country [25]. Such a migration of people is not without significance for the domestic economy and the daily operation of companies. Therefore, the Polish government simplified the law, granting Ukrainians the possibility of working in Poland. It is supposed that some of them (even those not qualified enough) will seek jobs in industry. Since the industry is seeking employees, AR-AI tools can strongly support in creating a match, allowing unskilled/less skilled people to instantly start new work, as AR-AI technology integrates digital data directly, live, and in a real time with the physical work environment [87]. What is important is that AR-AI support tools are gender-universal: Refugees are often women, and the ones leaving jobs for war are typically men. With such a support tool, unskilled workers could easier substitute skilled ones. AR-AI tools support people to start work without a specific or specialized education background. The ability to read is of the sole necessity for these tools to be applied, which is not challenging in countries like Ukraine or Mexico [88,89]. To answer RQ3, it is worth underlining the following aspect of the actual research. It was considered that these AR-AI tools were prepared to a high degree for application in uncertain business conditions such as war, epidemic, or human migration. This opinion is supported by saving users'/operators'/employees' time, reducing the duration of the selected manufacturing processes, and especially enabling unskilled employees to perform work in the selected manual production processes. The next phase of answering RQ3 requires industrial implementation to validate the AR-AI tools in external companies. This is currently being processed and will be the subject of interest for further research.

Scientists note that when a user does not have a convenient support tool, prolonged information seeking can lead to frustration [90]. A positive impact on job satisfaction was observed when researching the usage of the presented AR-AI tools. Based on the authors' own results and observations, it can be stated that AR-AI tool users seemed more relaxed, although they could have been assigned slightly more responsibilities to complete, due to the time savings. The users seemed satisfied that they knew what to do and how, and their work was well and efficiently organized. These findings were influenced by the user-friendly way the AR-AI prototype worked: automatically recognizing the job and automatically displaying the desired information connected to the right data in the right place of the right quantity at the right time, resulting in significant savings of the time needed to search for and retrieve information with the right quality (therefore, it can be stated that the 5R rule of logistics and manufacturing can be achieved [91,92]; 5R stands for right goods, right place, right time, right quantity, and right quality).

Moreover, as for employee shortages, some manufacturing processes are likely to come full circle in the near future: For example, in automotive, where the individualization of cars is progressing strongly, some operations initially performed by humans, then transferred to robots, will return to the hands of humans supported by intelligent cognitive systems [70]. This accelerating trend will push the development of convenient support tools even further.

Future research connected to AR-AI technologies as a response to high employee turnover and shortages in manufacturing during wartime or during other civilization challenges is planned. AR-AI tools can become supportive in the challenges in work environments proclaimed in this paper with the attendance of employees who are unqualified or less qualified. AR-AI tools can guarantee a safer operating environment, even though these employees will be allocated within workplaces with which they have minor or no previous experience. Nevertheless, future research connected to AR-AI technologies as a response to high employee turnover and shortages in manufacturing during wartime or other civilization challenges is planned with the objective of broader verification of the presented solutions and validation based on a statistical approach. Further research is needed on the various indirect factors and side effects of using AR-AI tools by unskilled workers. To mention one, Quint et al. [71] noted that when using AR support tools, inexperienced employees may feel "too safe" and, for example, forget to observe their surroundings. This may lead to potentially dangerous situations, especially in environments such as production plants. No publications with research on this interesting topic were found. It creates a research gap in theoretical implications for future considerations.

One last future research inspiration can be proclaimed after [93]. AR-AI technologies and their interactions with human migrations and searching for new job opportunities can become a matter of serious research by representatives of cognitive neuroscience, experimental psychology, or the philosophical perspective (as was presented in [93]).

Sustainability as a concept struggles with three dimensions: environmental, economic, and social. The content of this paper is related to them all. The accelerated deployment of new employees to handle processes using AR-AI tools results in lower utility consumption and less involvement in deploying employees, which is linked to environmental factors.

The economic context is provided by differentiating a microeconomic perspective (the application of the supportive AR-AI tools in a business context) or a macroeconomic perspective (the relevance of AR-AI tools for the labor market). The mentioned macroeconomic perspective, and significant facilitation of the operation of processes while at the same time standardizing them, relates to the social dimension as well. Thus, the research under consideration relates to and satisfies the circle of sustainable development. Hopefully, it will be one in the long-term perspective.

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