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CHALLENGES IN THE IMPLEMENTATION PROCESSES OF AUGMENTED REALITY IN THE MANUFACTURING INDUSTRY

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Abstract. *This research explored the implementation processes of Augmented Reality (AR) within industrial contexts. Despite the recognized potential of AR in advanced manufacturing, the adoption of AR in the manufacturing industry remains complex, with insufficient literature detailing concrete implementation procedures. A rigorous methodology was employed to review existing literature, using the Scopus research platform, 1380 documents were initially found and subsequently screened through a staged process, reducing to eight pertinent works. The investigation focused on identifying characteristics of AR implementation procedures and detecting knowledge gaps. Subsequently, seven key questions were developed as a comparative tool and to outline the crucial areas of AR implementation, including requirements verification, testing, and validation, suitability of AR activities, hardware and software determination, user interface design, and infrastructural requirements. The results indicate a lack of a comprehensive and consolidated AR implementation framework within the industrial context. This highlights the necessity for further research and development of AR implementation procedures in the manufacturing industry. The work offers essential insights for further academic and industrial exploration.*

Keywords: *Augmented Reality, AR, Implementation, advanced manufacturing, industry 4.0*

1. INTRODUCTION

With the development of advanced manufacturing technologies such as Augmented Reality (AR), there is an increasing interest in developing and evaluating methods of implementing new technologies and techniques that can assist in manufacturing processes in their productive roles when adopting these technologies.

According to Azuma (1997), Augmented Reality (AR) is a variation of Virtual Reality (VR). VR technologies completely immerse the user within a synthetic environment. While immersed, the user cannot see the real world around them. In contrast, AR allows the user to see the real world, while virtual objects are superimposed or compounded with the real world. Therefore, AR complements reality, rather than replacing it completely. Ideally, it could appear to the user that virtual and real objects coexist in the same space. As an observation, AR can be applied to all the senses, and not only to vision, thus enabling greater proximity to factual reality.

Although the term "mixed reality" is not commonly used, it defines an interface based on the overlay of computer-generated virtual information (dynamic images, spatial sounds, and haptic sensations) with the user's physical environment, perceived through technological devices. When virtual information is brought into the user's physical space, allowing for their natural interactions, it is referred to as AR. (Kirner e Kirner, 2011)

The applicability of AR spans diverse knowledge areas, many times providing supplementary benefits through its symbiotic fusion with real-world settings. Any human activity requiring access to information for enhanced execution stands to gain from AR. If this information is three-dimensional and directly related to the current environment, then AR holds the potential to be the most optimal solution. (Tori e Hounsell, 2020)

Investigation and development of methods, technologies, and resources that make the manufacturing processes faster, more dynamic, flexible, efficient, and less costly, thus, more economical, are considered necessary. In this way, the challenge is to design and implement manufacturing systems with integrated VR and AR that can enhance manufacturing processes as well as product and process development, leading to shorter lead times, reduced costs, and improved quality. The ultimate goal is to create a system as good as the real world, if not better and more efficient. (Nee and Ong, 2013)

According to Masood and Egger (2019), AR is an important technology for the Industry 4.0 approach (apud Bis Research, 2018). As these approaches promote a human-centered industrial environment, AR is an approach to enlarge the worker (apud Kagermann *et al*, 2018). This technology allows humans to access the digital world through a layer of information positioned superimposed on the physical world.

Despite its vast potential, widely recognized by experts, business analysts, and researchers, AR still encounters difficulties in full implementation and adoption in industrial processes and operations (Martinetti *et al*., 2019). The absence of a consolidated procedure with a step-by-step for the analysis and implementation of AR in an industrial context could be one of the justifications for the challenge of implementing AR in an industrial context. The lack of information or procedures to assist the implementation of AR is cited in the works of Loizeau *et al*. (2021), Mueller *et al*. (2017), Masood and Egger (2020), Kostov and Wolfartsberger (2022) and Oenema (2019).

Currently, not many methods contemplate the implementation process of AR technology within an industrial context to aid manufacturing activities. Therefore, this study established the following objectives:

- Identify related works that provide guidelines or proposals for a procedure to implement Augmented Reality, regardless of the area of application.
- Examine the key characteristics by comparing and identifying information gaps in various works related to AR implementation procedures. Consider which characteristics would be crucial when proposing a method to implement Augmented Reality in an industrial context.

2. RESEARCH METHOD OF RELATED WORKS REGARDING AN AR IMPLEMENTATION PROPOSAL

The research methodology for related works was based on the work of Booth *et al*.(2016) to gather relevant information from the research to be conducted. The steps adopted to obtain the works related to this research will be described below.

Searches were performed on the Scopus research platform to identify related works that provide guidelines or proposals for an AR implementation procedure. Scopus was chosen because it offers a wide range of scientific article data, theses, publications, and books. The page referenced in Scopus (2023) provides the coverage of information available on this search platform.

The use of the Scopus platform brings the advantage of exporting the searches performed, thus, it is possible to conduct an external treatment of the data obtained through the searches performed through data processing software.

In this stage of the research, filters were not considered by year of publication or area of application of the research. It is understood that an AR implementation procedure can have numerous steps in common in the most diverse areas and is not necessarily dependent on recent technologies for its design.

To obtain the works that may be related to the objectives of this research, the searches conducted on the Scopus platform were used to identify potential works related to proposals for a procedure to implement Augmented Reality. The selected search terms were employed to query the titles, abstracts, and keywords of the documents encompassed within the Scopus platform's index.

As a result, employing the search parameters outlined in Table 1, a total of 1380 documents were obtained, after excluding duplicate results, from the searches conducted on the Scopus platform using the specified search terms strings on June 1, 2023.

Table 1. Search parameters in the Scopus platform.

Search terms strings	((“augmented reality” or "mixed reality" or "extended reality") AND implementation AND framework)
	(“augmented reality” or "mixed reality" or "extended reality") AND (deploy OR deploying OR deployment) AND framework
	(“augmented reality” or "mixed reality" or "extended reality") AND (deploy OR deploying OR deployment) AND process
	(“augmented reality” or "mixed reality" or "extended reality") AND (deploy OR deploying OR deployment) AND guideline
	(“augmented reality” or "mixed reality" or "extended reality") AND (deploy OR deploying OR deployment) AND guide
	(“augmented reality” or "mixed reality" or "extended reality") AND “implementation framework”
	(“augmented reality” or "mixed reality" or "extended reality") AND guideline AND framework
	(“augmented reality” or "mixed reality" or "extended reality") AND guideline AND process
	(“augmented reality” or "mixed reality" or "extended reality") AND guideline AND implementation
	(“augmented reality” or "mixed reality" or "extended reality") AND “implementation method”
	(“augmented reality” or "mixed reality" or "extended reality") AND “implementation framework”
	(“augmented reality” or "mixed reality" or "extended reality") AND “implementation process”

	(Augmented or mixed or extended) AND reality AND guideline AND implementation

As a second step to refine the obtained results, a screening was performed on the titles and abstracts of each document. The objective at this stage was to select the documents that could offer a proposal for an AR implementation process, regardless of the application context. At this stage, 375 documents were selected.

In the third stage, a more thorough screening was conducted on the introduction and conclusion sections of each document. The objective was to identify documents that could present a well-structured proposal for the process of implementing augmented reality (AR), regardless of the specific application context. During this stage, a total of 110 documents were selected.

In the fourth stage, a screening of the remaining documents was conducted with a focus on the document quality and relevance to the theme of this study, therefore the following quality criteria for document selection were adopted:

i. Description of augmented reality (AR) implementation process methodology, regardless of the application context.
ii. Presentation of results from the methodology or an AR implementation case using the proposed methodology.
iii. Relevance of the document to the research objectives and raised research questions.

Based on the above-mentioned criteria, a total of eight documents were selected.

In the fifth stage, a deep review of the selected documents was performed, followed by an identification of knowledge gaps in line with the questions that aim to achieve the research objectives and the creation of a synoptic table.

Figure 1 provides an overview of the Research Method for related works in terms of an AR implementation proposal.

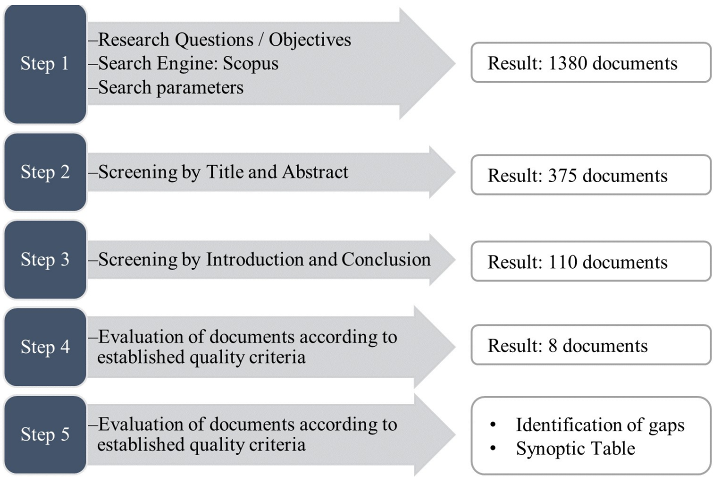

Figure 1. Summary of the Research Methodology in related works regarding an AR implementation proposal.

Table 2 presents the selected works by application area and the main objective.

Table 2. Selected works by application area and the main objective.

Author(s)	**Application Area**	**Main Objective of the Work**
Chimienti *et al.*(2010)	Industry / Manufacturing	Propose standard guidelines for the correct implementation of AR systems to guide operators during product assembly, achieving time-saving advantages, error reduction, and precision improvement.
Daineko *et al.*(2022)	Education	Evaluate the use of mobile technologies, such as AR, in the educational process and the difficulties and advantages of this method.
Gong *et al.* (2021)	Industry / Manufacturing	Provide general guidelines for developing Extended Reality systems in manufacturing with improved usability and user acceptance.
Loizeau *et al.* (2021)	Maintenance	Identify the characteristics of the tasks that affect the impact of AR to generalize the results of field experiments obtained.
Muhlan *et al.* (2021)	Industry / Manufacturing	Provide a method for implementing AR considering the social, technological, procedural, and organizational dimensions.

Pray and Mcsweeney (2018)	Inspection / Quality	This paper discusses the driving factors for the use of wearable technology in the offshore industry, current and future capabilities, and use cases of wearable technology, as well as experience, lessons learned, and next steps in the implementation process.
Ramos-Hurtado *et al.* (2022)	Construction	Provide subsidies for the use of AR in safety inspection processes on construction sites and methodological recommendations for the development and evaluation of these applications in AR.
Van Lopik *et al.* (2020)	Industry / Manufacturing	Address the need for AR content creation methods that support non-AR experts without requiring content libraries, 3D models, programming expertise, or infrastructure changes that are flexible enough to adapt to changing processes and editing.

3. DEFINITION OF KEY QUESTIONS

As part of this research work, there is a crucial need to develop and address key questions that would facilitate the understanding and evaluation of existing works on AR implementation procedures. These questions would also help identify knowledge gaps in current practices. Such questions are essential in advancing the research and expanding the understanding of the intricate processes involved in AR integration within an industrial context. Given that AR technology has yet to be fully adopted in many industrial applications, these inquiries serve as a navigation tool that guides through the complexity of AR implementation.

In developing the questions, significant characteristics of an AR implementation procedure were taken into consideration. These characteristics could potentially bring substantial benefits within an industrial environment. The objective is to identify and understand the most critical aspects of AR implementation and integration. Consequently, this could facilitate the design of an AR implementation process that is both effective and efficient. Each of these key questions builds upon existing literature and attempts to cover broad areas of interest related to AR implementation.

Furthermore, these key questions also contribute to the identification of gaps in the current knowledge about AR implementation in industrial contexts. By considering a diverse range of issues, from the requirements of using AR, the necessity of testing and validation, to the evaluation of task complexity and the choice of hardware and software, these questions investigate the critical factors influencing the success of AR implementation.

The key questions are presented and explained below, providing a foundation for the evaluation of existing works and forming a basis for further research and discussions on this subject.

Proposed key questions:

i. **Are there steps to verify the requirements or criteria for using AR?**
Rationale: The works of Quandt *et al*. (*2018),* Vidal-Balea *et al*. (2020), Danielsson *et al*.(2021), Dasgupta *et al. (*2019), Swan and Gabbard (2008) place as a fundamental and initial step the verification of the requirements with the users or clients of the activity to be performed with the use of AR.

ii. **Are there Steps aimed at Testing and Validation after developing a prototype or case study with the use of AR?**
Rationale: To validate the requirements or criteria used for the use of AR, it is pertinent to a step that aims to perform tests and validation of the expected conditions. The importance of this stage is reflected in the work of De Souza Cardoso *et al*. (2020a) who studied the application of AR in an industrial context, where 97% of the applications were tested to ensure the feasibility and compare the advantages and disadvantages of AR in relation to a traditional process.

iii. **Is there a procedure for defining the choice of activities that can benefit from the use of AR?**
Rationale: The complexity of a task may vary according to the type of equipment and subtasks to be performed (Loizeau *et al.*, 2021). Thus, a procedure to evaluate each task and subtasks, and classify them according to complexity, performance scenario, and constraints is interesting in an industrial context that may have several scenarios for performing activities with AR.

iv. **Is there a procedure for defining the hardware device to be used in the AR solution?**
Rationale: The choice of the hardware device is directly influenced by the requirements or criteria of the activities to be performed with the use of AR. The organization must ensure the ample variety of available hardware systems possess the requisite capability to accomplish tasks efficiently while mitigating ergonomic strain on employees (Masood and Egger, 2019). Consequently, a method of choosing the best device for a given task is a necessary step to meet the requirements or criteria for using AR.

v. **Is there a procedure for defining the software to be used in the AR solution?**
Rationale: The choice of the Software Development Kit (SDK) is also a necessary step in conjunction with the choice of the AR device. There is no single approach to choosing a tool for the development of augmented reality technologies, different authors characterize their choice based on the number of supported platforms, ease of code transfer to different platforms, performance, and more (Vakaliuk and Pochtoviuk, 2021). Therefore, a

procedure that guides the choice of SDK in conjunction with the requirements and criteria for the adoption of AR can facilitate the AR implementation step.

vi. **Is there a procedure for defining the User Interface using AR?**
Rationale: Masood and Egger (2019) indicate the usability of the user interface as an item of high relevance to the success of the adoption of AR. Therefore, a procedure for evaluating the proposal of the user interface in the solution with AR should be considered in the initial stages of evaluation in the adoption of AR.

vii. **Is there an integration method or one that describes the infrastructure required for AR implementation?**
Rationale: According to Masood and Egger (2019), the scalability of the AR solution is of interest to the industry. That scalability goes through integrating the AR solution with the factory infrastructure needed to support the implementation of AR for use on a larger scale of users.

4. DISCUSSION OF RELATED WORKS REGARDING THE KEY QUESTIONS.

The objective of this section is primarily designed to provide a compact perspective on the eight selected works, aiming to correlate each with the key questions that have been developed. The objective herein is not only to reiterate what these works are about, but rather to highlight how each contributes to the key questions in focus.

4.1 Guidelines for Implementing Augmented Reality Procedures in Assisting Assembly Operations. Chimienti *et al.*(2010)

Chimienti *et al*. (2010) propose a standard procedure for implementing an AR application to assist operators during assembly tasks. The authors suggest that in order to optimize the effectiveness of the AR system in assembly training, it is necessary to conduct rigorous validation using a diverse sample of users. This can be achieved by employing a carefully designed questionnaire to gather insightful feedback on aspects such as procedural fairness, clarity of instructions, ergonomics, and overall efficiency.

The article started with the premise of utilizing AR in an assembly task. The authors recognize that it is possible to use a standard procedure for implementing AR in a generic approach, but there is a lack of emphasis on providing further details on how this approach should be adapted for other types of assembly tasks. Moreover, there is also a lack of focus on evaluating the requirements necessary for AR utilization. Therefore, questions (i) and (iii) were considered not addressed.

The proposed validation step is presented at a high level, suggesting the adoption of a questionnaire to evaluate procedural fairness, instruction clarity, ergonomics, and AR effectiveness and efficiency, and to validate the AR application using a sample of users having different levels of experience and competences. However, without providing detailed instructions on how to conduct the tests and validate the AR system, question (ii) was considered partially addressed by this work.

The approach for the selection of AR hardware is based on the specific characteristics of the working environment and the assembly process to be executed. It utilizes selection charts to determine the most suitable device. However, the tasks that support this stage are conducted at a high level and do not include a detailed description and methodology that guide the hardware selection activity. In this way, it was considered that this work partially addresses question (vi).

The standard procedure developed by the authors includes some steps addressed by the key questions. The user interface, and software implementation stages, addressed by questions (v) e (vi), respectively, do not have a reasonable level of detail, even at a high level. Therefore, these questions were considered not addressed.

4.2 Development of a mobile e-learning platform on physics using augmented reality technology. Daineko *et al.*(2022)

Daineko *et al*. (2022) addresses the development of a mobile e-learning platform in Physics using Augmented Reality (AR) technology. The authors proposed a methodology for the use of AR in the field of education. To validate the developed project, a Nielsen questionnaire was used to formulate evaluation questions regarding AR. However, the questions were mainly focused on the outcome of the students utilization of AR, as they were the end-users of the AR application. Thus, it did not address whether the developed application fulfilled the expected objectives with the implementation of AR, and the authors acknowledge this limitation of the tests and the approach taken in the AR application. Consequently, it is considered that this study partially addresses research question (ii).

The remaining questions of this study were considered "not addressed" as the work did not provide a sufficient approach to address them, even at a high level.

4.3 A Framework for Extended Reality System Development in Manufacturing. Gong *et al.* (2021)

Gong *et al.*(2021) introduce a comprehensive framework for developing and integrating extended reality (XR) systems in manufacturing. The framework focuses on improving usability and user acceptance of XR systems. It is derived from six case studies and consists of five iterative phases: requirements analysis, solution selection, data preparation, system implementation, and system evaluation. The framework is validated through empirical evidence and aligns with previous studies. By emphasizing a user-centered approach, the framework enhances the usability and adoption of XR systems in manufacturing.

This paper highlights the understanding of requirements as one of the initial stages in the framework proposed by the authors and emphasizes that gaining a comprehensive understanding of the requirements is an important first step for the successful development of an XR system for the manufacturing industry. Methods such as observation, stakeholder workshops, contextual investigation, storyboarding, and prototyping, adopted from the user-centered design approach, have proven effective in identifying requirements. However, this work does not address or cite reference works on how the requirements for implementing or using AR should be developed in the various stages of the proposed implementation framework. Thus, it is considered that this work partially addresses question (i).

In the proposed framework for AR utilization, the authors address a stage for evaluating the AR system with feedback and testing from users. Although there is a dedicated stage for testing and validating the AR, the authors provide a high-level overview of this stage without further details on the activities involved in the cases studied in this work. Therefore, it is considered that this work partially addresses question (ii).

The framework of user-centered extended reality system development for manufacturing activities proposed by this work addresses the topics discussed in questions (iii), (iv), (v), and (vi). However, in the case studies and the development of the framework proposed by the authors, there is an absence of reasonable detail regarding these activities, even at a high level. Therefore, although this study briefly addresses the mentioned questions, it was considered that these questions were not adequately addressed.

4.4 Methodology for the Field Evaluation of the Impact of Augmented Reality Tools for Maintenance Workers in the Aeronautic Industry. Loizeau *et al.* (2021)

Loizeau *et al*. (2021) addresses the use of AR in maintenance activities in the Aeronautics Industry. The authors highlight the need to meet the maintenance requirements in the aeronautical sector and the constraints in the aeronautical maintenance sector, and the possibility that AR can assist operators in aeronautical maintenance tasks. They emphasize the importance of gathering the necessary information for maintenance tasks through requirements and propose a methodology for the utilization of AR in aeronautical maintenance tasks. Thus, by providing a detailed methodology proposal that considers the concerns of AR utilization requirements in each stage of maintenance tasks, this work is considered to address the question (i).

The authors propose a dedicated stage for Reviews and Validation with the Users. With methodologies for selecting evaluation criteria for the impact of AR in aeronautical maintenance and for implementing an AR tool to assist in aeronautical maintenance tasks, the authors describe the stages of each methodology, evaluating the benefits of the proposed activities to be assessed with AR. With available criteria and observation methods for AR evaluation, it is considered that this work fulfills question (ii).

Regarding the proposed main stages of AR implementation, this work emphasizes the selection of activities to be performed with AR. By providing detailed descriptions of maintenance activities and methodologies for evaluating the added value of AR utilization, assessing the results of AR applications, and implementing AR in maintenance tasks, this work addresses question (iii).

In the elaboration of the Main steps for the deployment of an AR app in the industry proposed by the authors, there are the stages of software selection, hardware selection, and content creation, which could cover questions (iv), (v), and (vi), respectively. However, this work arbitrarily addressed these stages. Therefore, despite the existence of these stages, no elaboration explained the decisions made during the implementation steps of AR. Therefore, it is considered that this work does not address the above-mentioned questions.

4.5 A Review and Implementation Framework of Industrial Augmented Reality. Muhlan *et al.* (2021)

This work is a comprehensive review that addresses the utilization of augmented reality (AR) in the industry, presenting a comprehensive framework for its implementation. The author explores a wide range of AR applications in various industrial sectors, highlighting both the benefits and challenges faced in its adoption. The proposed framework encompasses crucial aspects such as proper hardware selection, specific content development, efficient system integration, and rigorous performance evaluation.

In the framework proposed by the authors, there is a stage for the validation and evaluation of AR. However, the validation and evaluation of augmented reality (AR) are briefly discussed, emphasizing the evaluation of collected data, identification of potential flaws, and continuous pursuit of process optimization to ensure high quality and stability. Thus, it partially addresses question (ii).

The remaining questions of this study were considered "not addressed" as the work did not provide a sufficient approach to address them, even at a high level.

4.6 Integration of wearable technology for inspection tasks. Pray and Mcsweeney(2018)

Pray and Mcsweeney (2018) explore the application of wearable technology, such as smart devices, in performing inspection tasks. The authors discuss the benefits of this integration, including improved efficiency, accuracy, and safety in inspection activities, as well as the challenges faced during implementation. The article provides valuable insights for professionals and researchers interested in adopting wearable technology in inspection contexts.

The authors address the Use Cases of AR applications by development and a list of the AR use cases. This list is high-level and superficially covers some items to be considered when choosing activities to be conducted with AR. Therefore, it is considered that this work partially addresses question (iii).

The work includes a step for the selection of AR hardware and software devices. A prior assessment and user engagement through interviews, questionnaires, and needs assessments are utilized to choose suitable hardware and software platforms for wearables, using a matrix template for evaluation. The suggestion of using a Matrix Model for assessing hardware and software requirements is presented in a straightforward manner, without providing detailed characteristics or processes for defining the hardware and software equipment. Therefore, it is considered that this work partially addresses questions (iv) and (v).

The remaining questions of this study were considered "not addressed" as the work did not provide a sufficient approach to address them, even at a high level.

4.7 Proposal for the Deployment of an Augmented Reality Tool for Construction Safety Inspection. Ramos-Hurtado *et al.* (2022)

The paper addresses the risks and safety challenges on the construction site and proposes a methodology that utilizes Augmented Reality (AR) for the inspection of collective protection equipment (CPE). The study observes the traditional process of safety inspections, identifying its limitations, and suggesting key performance indicators (KPIs) to enhance the efficacy of the process. The proposal involves the use of AR as an intuitive interface for safety inspectors, detailing functional requirements and interfaces for AR applications. A proof of concept was developed and evaluated to demonstrate the feasibility of the proposal. The work contributes to the use of AR in safety inspection processes on construction sites, providing methodological recommendations for the development and evaluation of such applications.

Ramos-Hurtado *et al*. (2022) propose a research methodology to assess the feasibility of AR in safety inspection activities in the Construction field. There is a dedicated phase for defining the objectives of the potential solution and mapping the solution requirements. This work discusses the development of Requirements through application functionalities and Key Performance Indicators (KPIs). Therefore, it is considered that this work adequately addresses question (i).

The work includes a demonstration phase, where the authors dedicate themselves to evaluating the functions of the AR application, application testing, and field testing of the AR application in an appropriate environment. There is a validation of the functionalities of the developed application, testing with the user interface, and the interaction of the 3D AR objects with the real environment. Qualitative and quantitative KPIs have also been developed to evaluate the developed AR application. Thus, it was considered that this work addresses question (ii).

This work focuses on the inspection activity of safety equipment in the Construction area. Nevertheless, there is a concern in detailing the activities to be conducted, such as the elaboration of a workflow of work inspections without the use of AR, verification of each step, and respective classification according to the activity to be developed. After this detailing, the work addresses how AR can be used in each stage and creates a workflow with the proposed AR application. Therefore, it was considered that this work addresses question (iii).

The hardware device and software of AR were addressed in the above-mentioned KPIs, but the work did not address the steps involved in choosing these items. Thus, questions (iv) and (v) were considered as not addressed.

This study also shows concern with the development of the User Interface (UI), thus the authors see it as essential to categorize all these functionalities and determine how the user interfaces (UI) are organized and presented, in order to clearly understand how the application organization works and how the user experiences the various functionalities on each UI screen. With the development of UI proposals and the creation of a workflow to validate the UI with the application to be created, it was considered that this work addresses question (vi).

4.8 Developing augmented reality capabilities for industry 4.0 small enterprises: Lessons learnt from a content authoring case study. Van Lopik *et al.* (2020)

This study focuses on the development and deployment of an Augmented Repair Training Application (ARTA) as a template-based interface to facilitate augmented reality (AR) content creation for Small Enterprises (SE) within the Used and Waste Electronic and Electrical Equipment sector (UEEE/WEEE). The research addresses the complexity and limitations faced by SEs in creating customized AR training support due to the specialized knowledge and infrastructure requirements. The proposed methodology and implementation are discussed and evaluated through a real-world industrial case study, aiming to enable SEs to overcome barriers to AR adoption and enhance training processes in the Industry 4.0 manufacturing paradigm.

Van Lopik *et al.* (2020) provide lessons learned from a case study on the development of Industry 4.0 AR in small businesses to support knowledge sharing between expert and novice workers for a phone repair task. In the case study covered by this work, the identification of high-level requirements is initially conducted through a series of meetings, interviews, and observations. However, the work does not provide a breakdown of the high-level requirements, and some definitions, such as AR hardware selection and SDK definition, emerge as predefined and are not addressed in the requirements phase. Therefore, this work partially answers question (i).

The work proposes a Multi-modal model framework to support, with one of the stages focused on the verification and implementation of AR. The authors propose an iterative stage to allow refinement of the AR application through usability tests and feedback gathered through use. The verification stage is addressed at a high level and more focused on the AR content to be used in the project. Thus, it is understood that this work partially answers question (ii).

The paper does not address a method for selecting activities that can be performed with AR. Furthermore, although it briefly mentions the arbitrary choice of an SDK for AR application development, it does not describe any steps that could address issues (iii) and (v). Therefore, these questions were labeled as "not addressed" in the paper.

Although there is a stage for the selection of AR hardware, the author does not describe the steps for selecting the chosen device or elaborate on the criteria for selecting an AR device. Thus, question (iv) was defined as not addressed.

The work used a template with a user interface as a way of transitioning from the visualization of instructions to the use of AR. Although the steps of creating the template focused on the user interface are not detailed, the authors listed other reference works focused on user interface development that they used for the construction of the proposed template. Therefore, it was considered that the work acceptably addresses question (vi).

4.9 Absence of Infrastructure Definition for AR implementation in related works

Unfortunately, none of the presented works exhibited the necessary attention to addressing the fundamental infrastructure requirements associated with implementing AR, related by question (vii). This notable absence raises concerns regarding the comprehensiveness of the analysis and exploration of the technical foundations essential for the effective integration and deployment of AR systems. The omission of in-depth discussions on infrastructure, encompassing hardware, network connectivity, data storage, and integration with existing systems, represents a significant gap in the related works, limiting the depth of insights available regarding the practical challenges and considerations critical to a robust AR implementation strategy. Therefore, it is essential for future research efforts to address this gap by thoroughly investigating and elucidating the infrastructure prerequisites that are crucial for the successful implementation of AR in various settings.

4.10 Creation of a Synoptic Table of the works related to the key questions

Figure 2 will present a Synoptic Table that defines the relationship between the selected works and the proposed key characteristics. This method of organization will provide a holistic overview of how each study intersects with the focal areas of this research.

Author(s)	i - Requirements for the use of AR	ii – Approach to AR Testing and Validation	iii – Choice of activities with AR	iv – AR device definition	v – SDK Definition	vi – User Interface Definition	vii – Infrastructure Definition for AR
Chimienti *et al.(*2010)	○	◑	○	◑	○	○	○
Daineko *et al.(*2022)	○	◑	○	○	○	○	○
Gong *et al*. (2021)	◑	◑	○	○	○	○	○
Loizeau *et al. (*2021)	●	●	●	○	○	○	○
Muhlan *et al*. (2021)	○	◑	○	○	○	○	○
Pray and Mcsweeney(2018)	○	○	◑	◑	◑	○	○
Ramos-Hurtado e*t al. (*2022)	●	●	●	○	○	●	○
Van Lopik *et Al. (*2020)	◑	◑	○	○	○	●	○

Legend : ○ Not addressed ◑ Partially addressed ● Addressed

Figure 2. Synoptic Table of the works related to the key questions.

5. CONCLUSION

The present work extensively examined literature concerning the implementation process of Augmented Reality (AR), with the objective to identify key features and knowledge gaps in existing AR implementation procedures. A comprehensive research process was performed, including meticulous searches on the Scopus platform, systematic screening, and selection of relevant works, followed by the development of key questions. From an initial array of 1380 documents, eight central works were identified, which provided significant insights into AR implementation procedures, regardless of their application context. Subsequently, seven key questions were developed based on the study's objectives and prevalent research inquiries. These questions aimed to evaluate the existing literature regarding crucial aspects of AR integration, including verification of requirements, testing and validation processes, suitability of AR for different activities, determination of hardware and software requirements, User Interface design, and necessary infrastructural considerations.

The results of this research emphasize the complex challenges and potential gaps associated with AR implementation in the industrial context. Although a considerable collection of literature outlines the theoretical potential of AR, a comprehensive and cohesive procedural framework for its implementation in industrial contexts is largely absent. The work revealed the absence of consensus regarding the optimal approach to AR adoption in industrial settings, highlighting the need for further exploration in this area. Future academic and industrial research is justified to develop a robust, adaptable, and holistic methodology for AR implementation in diverse industrial scenarios. A more thorough understanding of AR integration in industrial settings will prepare for more effective, efficient, and economical manufacturing processes, thereby contributing to the next stage of industrial development.

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