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A Review and Implementation Framework of Industrial Augmented Reality

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***Abstract*—The implementation of digital technologies, especially Augmented Reality (AR), in industrial environments is a great challenge for companies due to individual requirements and specifications of each system. After a brief introduction to the topic of AR and the associated digitalization in industrial companies, this paper describes the methodological approach of the applied systematic literature review (SLR) and the results on which the implementation concept is based. 13 AR-related frameworks wholly or partially related to the introduction and integration of this technology in value-adding (manufacturing and assembly) and/or non-value-adding (logistics and maintenance) processes have been assessed. The main part of the paper comprises a concept derived from the literature that is enhanced towards stepwise managerial implementation of AR in the industrial environment. This concept includes a total of four dimensions, two of which are technical (technological and process dimension) and two of which are non-technical (social and organizational dimension). In addition, six process steps have been identified. This matrix is completed by the temporal classification into before, during and after implementation. Based on this organizational concept, industrial companies should be able to introduce AR processes and procedures faster, more efficiently and in a more targeted manner and thus support the deployment of the technology as such. Processes should be optimised in the long term through the introduction of AR. Some processes are suitable for the implementation, while others are not (yet) suitable for AR due to various factors.**

Keywords—industrial augmented reality, industry 4.0, digitalization, systematic literature review, implementation framework

I. INTRODUCTION AND MOTIVATION

Industry 4.0 has become a well-established notion in manufacturing and beyond. It originated in the German government's respective strategic initiative in 2011 [1]. The concept stands for a variety of methods and processes, but also technologies that are altogether intended to revolutionise the production. The long-term goal is an autonomous factory, which is characterised by networking, decentralisation, individualisation, and flexibility [1].

At the same time, manufacturing companies in the 21st century face high competitive pressure. Processes are being continuously evaluated in order to identify wastes and weak points, e.g. bottlenecks, in order to subsequently improve their efficiency. In addition to the automation of processes, digitization offers the opportunity to optimise processes in order to meet the increased diverse challenges and requirements [2]. However, digitising a process does not necessarily automatically mean an increase in efficiency [3, 4].

Digitization and augmented reality (AR) have grown in importance in the industrial environment in recent years [5]. Due to the overall rapidly advancing development of information assistance systems, they are not only becoming more feasible, but also more interesting to use in productive industrial environments. This is due to the fact that although simpler handling steps in manufacturing tend to be automated, the worker per se has to cope with more and more complex knowledge work [6]. In this case, information assistance systems can be used to coordinate the flow of information needed to perform the work tasks. However, not only the opportunities of this technology should be considered, but especially the risks that can arise from its introduction. These can have both economic and social consequences [6, 7].

Due to the specific requirements of this technology, implementation is a major challenge for companies [8, 9]. Most processes run stably and usually not only the error rate is low, but also the error tolerance. For this reason, new systems can only be integrated if they function almost error-free and the ongoing operation is not negatively affected.

Therefore, this paper aims to contribute to reducing the complexity of introducing augmented reality into productive industrial environments from the project management point of view. This is achieved by presenting a preliminary AR implementation framework, considering four dimensions (social, technology, process and organisation dimension).

II. Methodological Approach

Extensive planning approaches for the integration of new technologies in manufacturing companies have already been created and developed by other authors, e.g. [10, 11]. However, as already stated above, assistance systems, especially AR, have different specifications. Therefore, by means of a systematic literature review the state-of-the-art of existing frameworks on the topic of "AR implementation" in industrial companies has been examined in the first place. For the overview of existing frameworks, it was important if they show a sequence of steps (beginning to end of implementation) or if they refer to the general technology or individual areas of AR implementation instead. Papers only dealing with general technology and not considering the implementation beyond the basic theory statements were discarded from the analysis.

The SLR contains contributions from 2011 onwards, as this is the year in which the "Industry 4.0" initiative was launched. This stands for the intelligent linking of machines and processes. Data from machines can be visually and acoustically, and in some cases also haptically, processed and displayed in near-real time through AR, which is why the term Industry 4.0 is closely associated with information assistance systems [12].

As a result of the SLR, it was determined that there is currently no end-to-end framework for AR-specific implementation in industrial companies from a managerial point of view. There were a total of 13 publications that covered sub-areas of the concept and served as the basis for the implementation concept. As described in more detail in Section III, the framework contains a total of four dimensions, two of which are non-technical in nature (social and organisational dimension) and two of which are technical in nature (technological and process dimension). None of the identified publications considered simultaneously all of these four dimensions in a corresponding framework. Most of the publications [9, 13–18] have addressed only one of these four dimensions. The remaining five publications [19–24] have covered two of them each.

Reference [9] structures the main challenges for a successful implementation of AR, e.g. user acceptance or organisational challenges. In addition, the authors found differences between experienced and inexperienced users. Reference [20] gives guidance steps for developers of AR applications, but not for companies to help with an implementation. Also, [21] examines the implementation of the software rather than the overall construct of the implementation. Reference [14] provides a comprehensive overview of generic industrial AR use cases and associated benefits.

The approaches and concepts presented are less specific and do not provide a tangible guideline for the step-by-step implementation of AR in an industrial setting from a managerial point of view. Even general technology implementation concepts, some of which have a step-by-step sequence, e.g. [18, 19, 22], cannot map the specific requirements of AR processes, as topics such as employee training/acceptance, data protection and AR process design have been little researched, especially due to the novel nature of the technology. Nevertheless, there is a high demand for concepts for the implementation of AR processes. This is illustrated in particular by the years of publication of the identified publications. Approximately 70 percent of the references were published after 2019 (9 out of 13), almost 85 percent even if 2018 is included. To close this research gap and to generate added value for companies, a framework was derived and further enhanced to simplify the step-by-step implementation of AR in the industrial environment from a managerial point of view and to serve as a guide for companies to accelerate its introduction.

III. Resulting Framework

Based on general technology implementation ideas and the identified publications on AR implementation conceptions, our concept contains the following process steps:

1) Process selection
2) Technology selection
3) Realization
4) AR Implementation
5) Validation and evaluation
6) Maintenance/improvement

The six steps shown are to take place one after the other, but parts of a subsequent step may already be initiated if the previous step has not yet been fully completed. Moreover, the implementation concept is, according to the morphological box for generating an implementation strategy [25], to be understood as an approximate solution with an option for improvement with participative style of behaviour and with orientation to the maturity level relevant for introduction. Each step includes the four dimensions (social, technological, process and organisational). On the vertical level, activities and processes can be carried out in parallel. Basically, there is no repetition of steps 1–4 in this concept, as the steps are structured in such a way that all stakeholders involved are integrated into the process from the beginning and thus the selected processes (step 1) and technologies (step 2) do not have to be changed or adapted afterwards.

In addition, the framework was developed following the Deming cycle (Plan-Do-Check-Adjust), a method well known in management. The Deming cycle cares for the continuous improvement process, which is here especially of importance, whilst the AR technology is quickly developing. However, the Deming cycle does not only care for the technology aspect in the framework. It is more to be understood to be of relevance for all dimensions, as the constant improvement is needed in all areas for each process. With the designed symbols, the current stage of the Deming cycle is empathised for each implementation step. Moreover, the special symbol empathises that by the two last implementation stages (which correspond to the last two Deming cycle stages) the actions are to be taken with the high frequency. Then, providing these steps after the implementation is of great importance for seeking and remaining high efficiency, and it has not been emphasised in any of the researched papers.

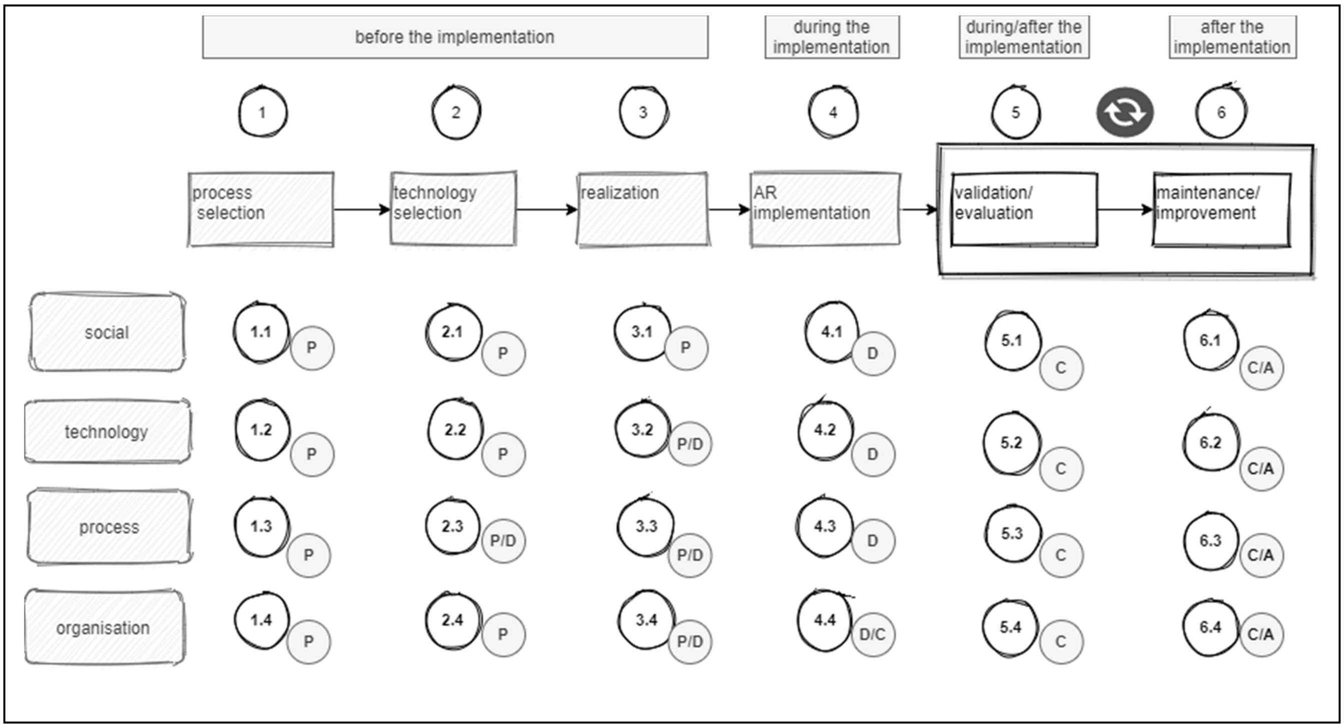

Fig. 1. Simplified depiction of the implementation framework for industrial AR (own figure).

Steps 1 and 2 lay the foundations for implementation. The first step is to select the process. There are processes that are too complex and variable to be suitable for enrichment with AR for the time being. Programming a suitable application and integrating it would require more human and financial resources. User acceptance, which plays a decisive role in implementation, should also not be neglected here. A process that does not immediately generate added value for employees can lead to frustration and aversion towards this technology. In particular, experienced staff may be hindered in their work with specific processes, rather than generating an advantage [9]. The current situation is defined and it is analysed which competences an employee must have in order to carry out the activities.

Furthermore, it must be analysed exactly which technology fits the selected process. There are processes, such as order picking, where the use of a HoloLens offers added value to the current state, but other solutions (e.g. Vuzix or Google Glass) fulfil the necessary requirements better and can enable an optimised target state, even though less technology was installed. Due to the rapidly advancing technological development, a comparison of providers should be made in any case. This is drawn up on the basis of the process selection, during which the first unsuitable models can already be eliminated.

During the realisation (step 3) of the project, the detailed implementation of the technology in the company is planned and prepared. This is the most important step to ensure successful integration. Among other things, the activities to be carried out in the process are defined here. Furthermore, this step is of relevance due to the establishment of the arrangements to prepare the employer for the implementation of AR technology, e.g. determination of the employer's training procedures. For this purpose, experiments are planned to be carried out in the following (see Outlook) in order to research the optimal training and further education method for Augmented Reality in an industrial environment. In addition, during the realisation (step 3), a catalogue of requirements for an application is planned to be created and then the programming of the application is to be carried out by an external provider or the implementation of an existing solution on the market. There are however only a few providers and existing solutions due to the fact that the technology is relatively recent. Legal framework conditions are considered and, if necessary, the selected process is restructured in order to comply with data protection guidelines, labor law regulations and health-related aspects. In addition, the tasks/responsibilities for the implementation are distributed within the company and all costs for an implementation are calculated and presented to the management level.

Once the decision has been made, the implementation is to be carried out in three phases: firstly, under laboratory conditions, then under real conditions, but without interfering with the running operation. In the final step is the integration into the running operation. Throughout the implementation, process data should be collected. Not only process KPIs such as costs, times and error rates should be measured, but also data on user acceptance, employee wellbeing, technology and process design and others.

Steps 5 and 6 take place after the implementation. The collected data is evaluated and, if necessary, weaknesses are identified in order to optimise the process. The last two steps have to be carried out continuously to ensure high quality and process stability. In Fig. 1, the simplified form of the framework is presented.

IV. Conclusion and Outlook

Due to increasingly complex processes and the increased cognitive demands on the work of operators, a need for information assistance systems has been identified in the first section. In addition, it has been found that there is an increased interest in AR solutions in industry. Therefore, in the second section of this paper, a systematic literature review was conducted on AR-related frameworks that address the introduction and integration of this technology into value-added and non-value-added processes. The result is that there is no complex and specific management-oriented framework for the step-by-step introduction of such a technology. Only few general organizational concepts have been created, but a specific framework is necessary, especially due to the fact that the technology is relatively recent and developing.

The evaluation of the concept presented in this paper is conducted in the semiconductor industry. All steps are applied considering the four dimensions presented. In addition to the evaluation through application in practice, a laboratory experiment is planned to be conducted. This addresses the training and further education of employees in the area of augmented reality and which form of training is best suited to generate a high level of user acceptance and thus influence a decisive success factor. The next steps include the further elaboration on individual dimensions of the framework (Fig. 1), implementation of the entire framework for evaluation and the theoretical analysis of training forms, the organisation and implementation of the experiments and subsequently the optimisation of the framework.

The biggest challenge of the framework is its application by companies from industry. Augmented reality is still a young technology, which stands out from other technologies due to its operation and range of functions. This offers many opportunities, but also risks. This framework can be used to minimise the risks on organizational level.

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