Augmented, Virtual and Mixed Reality Simulation, Vol. 118, 2023, 135–147
https://doi.org/10.54941/ahfe1004449

Development of the Model-Based Planning System for Augmented Reality in Industrial Plant Maintenance

Vadym Bilous[1] and Kirill Sarachuk[2]

[1]Chair of Automation Technology, Brandenburg Technical University of Cottbus-Senftenberg, Siemens-Halske-Ring 14, 03046 Cottbus, Germany
[2]Chair of Business Administration, Planning and Innovation, Brandenburg Technical University of Cottbus-Senftenberg, Erich-Weinert-Str. 1, 03046 Cottbus, Germany

ABSTRACT

Augmented reality (**AR**) is extensively used in modern industrial automation, especially in industrial plant maintenance (**IPM**). The growing amount of both research and practical projects explore, develop, and integrate the AR applications for a variety of tasks in IPM. With the introduction of AR, the accomplishment of tasks like training of maintenance staff, the visualization of instructions during maintenance and error correction, the visualization of plant control processes, and many others become more visual, interactive and are, therefore, considerably simplified. At the same time, the expansion of AR in IPM does not match the high potential it has demonstrated. The reasons for this comprise the implementation and adaptation issues (high risks and cost of the specific AR implementation), the technical problems (hard- and software-related), special developer requirements, etc. Therefore, a model for planning the implementation of AR in IPM and for the benefit prediction in terms of AR efficiency is required. To fill this research gap, we propose a concept of the model-based planning system (**MBPS**) for AR in the industrial plant maintenance. This system should provide a deep scientific analysis of the feasibility and necessity of using AR to solve tasks in the automation field. Additionally, this MBPS should enable predictable planning and forecasting of the results of AR integration, like efficiency, applicability, quality, and other criteria, and therefor support the decision making about AR implementation.

Keywords: Augmented reality, Planning system, VR

INTRODUCTION

The Augmented Reality (**AR**) technologies emerged in the third quarter of the twentieth century and significantly accelerated over the last couple of decades along with the increasing hardware computing power. Reaching its peak of interest in the previous decade (Palomäki, et al., 2010), they attracted a lot of investments and contributed to many of the projects (Grand Review Research, 2021). Since 2018, AR technologies have approached the plateau of productivity and have become ready for broader commercial use (Technavio, 2021; Markets and Markets, 2020) which was documented well in the recent scientific literature (Berger, et al., 2016; Bilous, et al., 2021; Bilous, et al., 2022; Bilous & Sarachuk, 2023; Kim, et al., 2019; Prinsloo & Van

Deventer, 2017; Tejedor-Calvo, et al., 2020). Alas, a rapidly increasing interest towards AR from a wide commercial perspective does not correlate with the theoretical efficiency.

While successful adoption of AR in the past was largely determined by the price and quality of hardware components (which are more widespread and more accessible to the public today), nowadays the software engineering and the development of the information and communication technologies[1] (ICT) play a crucial role. With respect to the latter, the modern AR technology level is represented by an established ecosystem of applications and frameworks available for developers (Glover & Linowes, 2019) – for instance, the introduction of *ARCore* and *ARKit* made the technology available on more than 700 million devices (without considering third-party apps), mostly beneficial to the end-users (Technavio, 2021). What is, however, missing is the comprehensive system based on theoretical knowledge and scientific analysis for selecting tools and resources to solve a particular industrial task. This is important for the planning and forecasting tasks in science, industry, and the market.

This paper proposes the model of such planning system for AR solutions which may be used primarily by managers and project personnel planning to solve problems in the industry, but also by programmers and automation engineers. Our paper unfolds as follows: we first describe the motivation and background literature for the study. After that, we briefly describe the model-based planning system for AR and its tasks. Then, we discuss the MBPS conceptual scheme for AR and draw the overall conclusion.

BACKGROUND INFORMATION

AR technologies have recently faced wide adoption in a variety of application areas of science, technology, and industry, as well as in entertainment, recreation, and sports. The ongoing research on industrial application of AR focuses more on specific tasks, benefits, current challenges and problems during implementation, for instance, in manufacturing industry (Devagiri, et al., 2022), automotive domain (Bottani & Vignali, 2019; Boboc, et al., 2020), aerospace programs (Safi, et al., 2019; Rajkumar, et al., 2020), automation (Ahmed, 2019; Mishra, et al., 2020), and several other areas.

Most of those studies focus on benefits and efficiency: mainly, the advantages comprising reduced maintenance or repair times for plants, simplified assembly of technical products, and increased interactivity during mechanical environment operation. Even early studies (Wiedenmaier, et al., 2001) recorded numerical benefit values, like assembly time reductions, in a series of practical experiments by using Methods-Time Measurement (**MTM**) to optimize processes. Along with that, some papers documented scientific outcomes, like a research on the factors that have a general influence on the development and implementation of AR applications or on the usage of

[1]Existing disparities in broadband technology support in this area, which were observed even for technologically advanced countries, may hamper the successful adoption of AR solutions.

AR technologies in general (Bottani & Vignali, 2019; Safi, et al., 2019; Gómez-Puerta, et al., 2019).

The AR domain may boast a large number of publications, which however complicates the *state-of-the-art* description in every particular case, especially while identification of knowledge gaps. We overcame this problem by using the automatic **bibliometric analysis**[2], focusing on papers with industrial application of AR technologies and omitting other irrelevant fields of knowledge. We also narrowed our search to *research and development* (R&D) trends, *technologies*, and *solutions*. Approximately 300 entries (90% of those published after 2015) were extracted from several search engines (mainly Scopus and Web of Science) and consequently were analyzed by KH Coder software. For the whole domain[3] (see Figure 1) we observed a link between augmented reality and 3D model design, automation solutions, construction projects, image tracking, and user interaction environment. Manufacturing and product assembly are detached from the core node, thus indicating weaker connection and lack of scientific research and publications in this common area, despite a large number of projects (e.g., at Fraunhofer Society or Rolls-Royce). Topics such as network service, IoT, and cloud computing are located in the peripheral area and may indicate some possible research gaps.

By looking closely at more detailed topics such as *AR planning*, *AR evaluation* and *prediction of AR results* we may point out a poor connection in the scientific literature (see Figure 2); in fact, forecasting techniques were mentioned in just 15 articles, but rather in general discussion considering possible ways to roughly predict the technical trends and further tasks to be solved by AR (Dalim, et al., 2017; Ahmed, 2019; Bottani & Vignali, 2019; Boboc, et al., 2020). Furthermore, bibliographic analysis did not find any link to the particular methods (like KPI-based predicting of assembly or maintenance time); a manual screening revealed only few papers discussing the way to match the costs and benefits of AR solutions' implementation (Palmarini, et al., 2018; Jetter, et al., 2018; Schumacher & Sihn, 2020; Alam, et al., 2021), neglecting regretfully the profitability aspect.

Hence, the ability to implement the AR is low supported by the relevant forecasting and planning methods in the up-to-date scientific literature. This important theoretical background, however, may be an obstacle to the further adoption of AR solutions in the industrial sector, as long as firms would like to pre-estimate the output value of potential investments. Such model-based planning and AR forecasting systems will also allow, according to the required task, to determine the number of resources required for R&D and ensure the ability to reproduce the experimental results by external researchers of AR with similar input parameters.

[2]**Bibliometric analysis** is a graph theory analysis showing, in particular, keyword relationships between fields of study.

[3]Different research fields and related nodes (definitions) are grouped within several subgraphs displayed by different colours in the co-occurrence network. AUGMERAL stands for core node *augmented reality* and substitutes all similar definitions in the analysed text corpus.

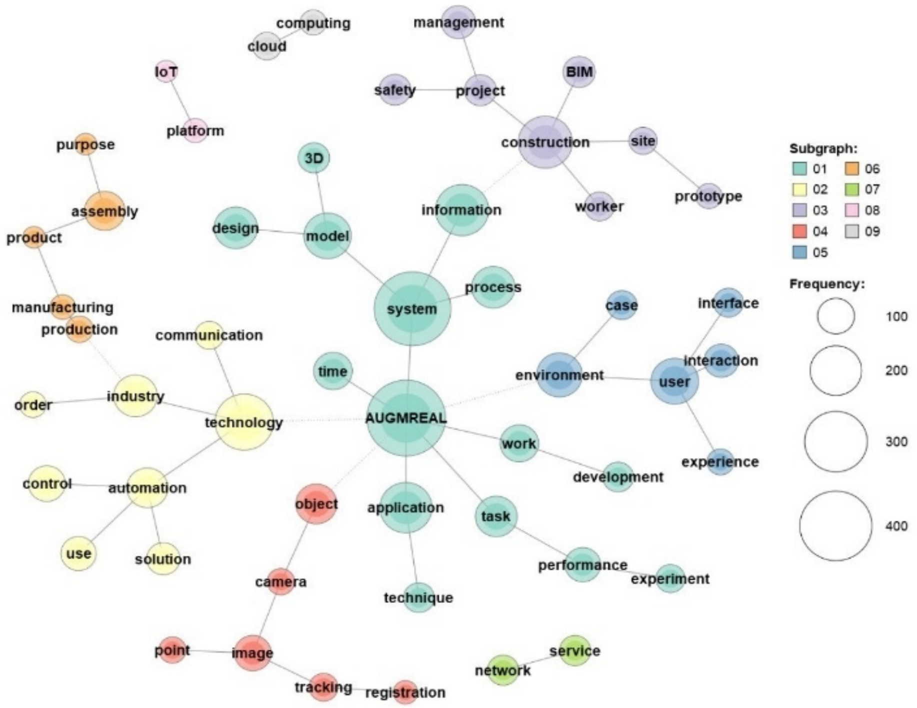

Figure 1: AR in the industry - most popular research areas.

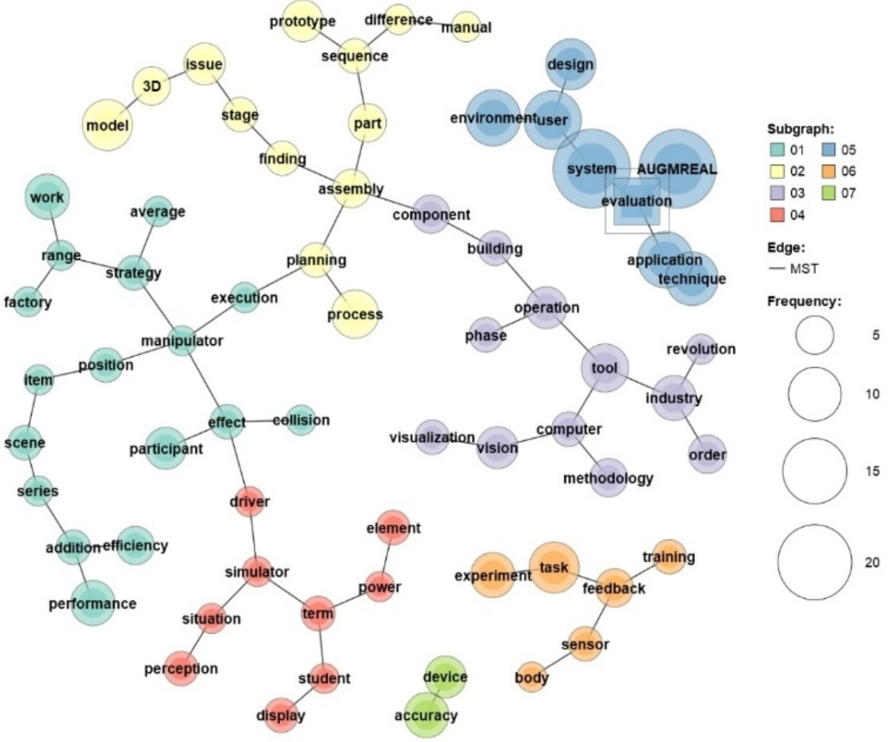

Figure 2: Co-occurrence between publications in the topics methods of planning, evaluation, prediction of results and the domain of AR technology.

MOTIVATION

The area of automation appears to be relatively broad, so this research focuses on industrial plant maintenance (**IPM**). The motivation for this choice is based on articles and existing reviews (Illanes, et al., 2018; Bichia, 2020; Isac, et al., 2020) mentioning an existing problem of both obtaining new knowledge and re-training of employees in automation and in modern industry in general. This is especially actual for the maintenance and error correction for the industrial plants. Modern industry requires highly skilled professionals (Saniuk, et al., 2021; Shafeek, 2018), while the personnel already involved in the process often needs qualification improvement to begin operating the new equipment types and tools quickly. Consequently, it seems to be desirable to implement the AR assistant staff training inside the production processes to achieve a profitable combination (Bottani & Vignali, 2019; Lehmann, et al., 2021). Therefore, the necessity to plan this process becomes obvious.

Another reason to select this research area is the amount of the previous project-related studies and articles (Berger, et al., 2016; Bilous, et al., 2021; Bilous, et al., 2022; Bilous & Sarachuk, 2023) in the department of automation at the BTU university, during which six new AR applications were developed. These mainly acted as interactive assistant system for the plant maintenance. These projects provided a sufficiently broad amount of scientific information about the factors influencing the development of AR in IPM and will provide the necessary background for the MBPS development.

MBPS DEVELOPMENT OUTLINE AND ITS TASKS

A model-based planning system for AR in IPM should be able to analyze the factors influencing the development, implementation, and further usage of augmented solutions, as well as the efficiency of this process (the ratio of resources spent with respect to the benefits obtained). In this way, it should not only be possible to identify the main factors of such influence, but also to find their *scientific validity* and define their *theoretical background*. The model should also be able to determine the *weight* of each main input parameter for the final output.

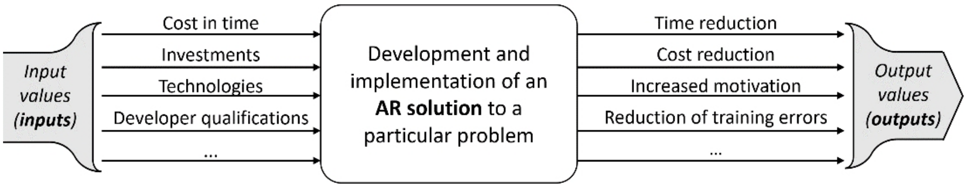

Figure 3: A simple scheme of *inputs* and *outputs* for AR development.

The basic process of AR development and implementation is depicted on the Fig. 3. A full collection of the factors influencing the AR development as well as the required investments and resources will be defined in this project's scope as **inputs**; the benefits of solving particular task with AR compared to other conventional solutions will be denoted as **outputs** or **results**, similar to other studies that review and analyze the factors influencing AR in education (Dalim, et al., 2017), retail (Bonetti, et al., 2018; Perannagari & Chakrabarti, 2019), industry (Pentenrieder, et al., 2007; Alam, et al., 2021; Harikrishnan, et al., 2021), medicine (Eckert, et al., 2019), etc.

Based on the own experience in development and implementation of the AR systems and similar experiences for industrial software in general and for the IPM cases (Kerzner, 2022; Schumacher & Sihn, 2020), we define the following main tasks of the proposed MBPS.

Direct task (**DT**): With a certain pre-defined task is to be solved with the help of AR and applying the given resources (time, financial means, and other inputs), it is required to determine the feasibility of using the AR technology and – if the decision is positive – to calculate the related profits. For example, suppose that an industrial plant or a laboratory unit requires certain staff actions to start, stop or perform a particular production task (such as switching from automatic to manual mode and back). Time, machinery, financial resources, personnel, competences that can be used to develop an AR application visualizing the instructions and guidelines for this task are known. Then, the usage of MBPS should provide an indication of the feasibility of the implementation of AR there and the possible benefits, e.g., reduction of staff training time for the tasks described above.

Inverse Task (**InT**): Here, the type and values (exact or within certain limits) of the required outputs are initially given, while corresponding AR inputs need to be determined. This includes not only the calculation of necessary costs, time, and personnel, but also the selection of the development methods, the estimation of necessary competences, and the identification of influencing factors that may critically affect the project. An example of the InT could be the requirement to reduce the downtime of a particular unit when changing certain components. Then, a formal planning of the development and implementation of an AR application for this task is required, defining the above AR inputs. A comparison of the theoretically calculated values with the actually available ones will allow to identify the missing resources and to take relevant actions.

Mixed Task (**MT**): Considering this option, the AR inputs and AR outputs are partially known. As a result, the MBPS task implies the estimation and optimization of the values and ranges of the unknown variables for the subsequent successful development and implementation of the particular AR solution.

We suppose that exactly the MT will be demanded the most in practice, while DT and InT would be of more theoretical interest and will provide more basic knowledge. However, the Department of the Automation at BTU with a number of laboratory facilities has already developed several AR maintenance applications for the majority of its units, documenting both AR inputs and outputs during the development and test phases (see previous project documented in (Bilous, et al., 2021). Thus, MBPS will be primarily tested and adjusted with the DT and the InT.

CONCEPTUAL SCHEME OF THE MBPS FOR AR

There are several schemes for developing a model-based planning system for solving particular problems in industry and in business. The most comprehensive concept was proposed by (Kosiol, 1962), further developed in (Pfohl, 1998; Bleicher, 1992; Bleicher, 2013) and continuously transformed and applied in (Schierenbeck & Wöhle, 2016; Thommen, et al., 2017). The scheme was originally used for business process organization, but it has also been applied to industry (see for example (Lasisz, 2016).

The proposed approach divides the model into a structural organization level and a process structure level, namely system structure describing the project's units (**SyS**) and process structure (**PrS**). The most important starting point is the partition of the main task into local subtasks (task clustering), and the selection of the resources for their solution (Kosiol, 1962). The process structure describes the course of operational events; the realization, implementation, or execution of the functions for which the supply has been created (Gaitanides, 2013). Thus, the focus is on the process of exploiting the capacity, resources, and elements that have been created in the SyS.

Based on the above-mentioned fundamental studies of planning systems development and considering their further extension in the respective articles, we propose the following general concept of the MBPS for AR in automation (Fig. 4). In addition to the structural and process organization, a *new level* has been added, marked as the user-side input (**USI**). The application of the developed MBPS implies the introduction of a wide number of parameters (the whole scope of AR inputs – resources, factors, etc.). Thus, it is reasonable to allocate a separate structure where the user or the researcher can select, for example, the standard sub-tasks for AR or the resources for them using decision trees or clustered tables. Therefore, the basic structure of the MBPS developed in the current project consists of three main blocks.

Task Framework (**TF**): After the definition of the task for the future AR development, it is divided into subtasks. For example, some common steps of the AR project development like the preparation of the AR elements, shaders, textures, the development of the interaction logic between the AR elements, the selection, or the development of a data transfer system between PLC and AR application, etc. could be regarded as the standard subtasks for the AR system development. The USI for this SyS block includes a list of pre-defined subtasks and a user defined sub-task entry form. The TF and its USI can be developed primarily based on the analysis of the scientific literature and existing projects.

Resources & requirements cluster (**R&R**): This block contains the list of the necessary resources and requirements that are essential for solving the subtasks of the overall AR task. The R&R cluster also includes the list of key performance indicators (**KPIs**) to monitor the results of the task solution using the AR. The selection of elements and KPIs in the USI for R&R can be organised using morphological tables and decision trees. The research and development of R&R and its USI starts with a comprehensive analysis of the research papers which use or/and determine the KPI for AR in IA, like (Schumacher & Sihn, 2020; Kerzner, 2022). Then, it will be essential to assemble

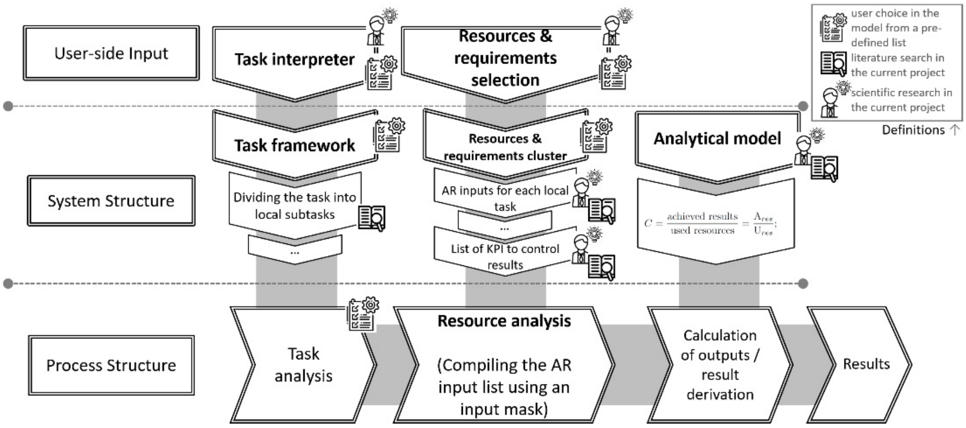

Figure 4: Model-based planning system for AR (MBPS) - conceptual scheme of the model.

the full scope of the AR resources and requirements to enable the usage of such KPIs. This will be based, in particular, on the projects of the department of the current studies authors, like (Le, et al., 2016; Zou, 2018; Kilimis, et al., 2019; Bilous, et al., 2021). Finally, the latter will be compiled into a R&R system.

Analytical model (**AM**): This block implements a mathematical tool to process and analyse the numerical values of the elements selected or generated in the R&R, considering the subtasks from the TF. The main objective is the derivation of the model result, namely the conclusion of the feasibility (or necessity) of applying the AR to the original problem. A local task could be, for example, the evaluation of the overall efficiency as a ratio of the resources spent to the results obtained.

The analytical model is the most important and comprehensive part of MBPS. In a generalized way, the efficiency (**C**) of the AR solution can be defined as:

$$\mathbf{C} = \frac{\text{achieved results}}{\text{used resources}} = \frac{\sum A_{res}}{\sum U_{res}} = \frac{A_{res}^{T} + A_{res}^{E}}{U_{res}^{I} + U_{res}^{D}}; \qquad (1)$$

where **achieved results** (A_{res}) is the cumulative numerical representation of the entire benefit from the implementation of AR[4] (outputs) and **used resources** (U_{res}) is the cumulative numerical representation of the resources spent on developing and implementing the AR technology[5].

However, this is a very basic mathematical representation considering only two AR inputs, and two AR outputs, while a more detailed description will be possible after a holistic analysis of all contributing factors, and must be refined in our further studies. This will include, first, a detailed analysis of the

[4]For instance, time and cost reduction; in this example this value can presented as the sum of reduced training time A_{res}^{T}, and reduced equipment downtime A_{res}^{E}.

[5]For instance, costs, developing time, the knowledge and skills required from the developers etc. (or AR inputs). In our example, it is calculated as the sum of implementation U_{res}^{I} and development costs U_{res}^{D}.

existing components of each value presented in this relationship to expand the number of variables. Research and tests on the developed AR applications will allow the selection of appropriate dimensions (man-hours, percentages, cost per hour, etc.) and determine the relevance (weight) of each element of this equation.

The usage of the MBPS for AR planning should start with the user utilising the appropriate USI to select the type of task in TF and split it into subtasks (task analysis). Then, the R&R cluster, the resources for subtasks from TF and KPIs to control the results will be chosen (resource analysis). After that, the values of the known parameters will be specified, and the unknowns to be found or estimated will be marked. Then, the calculation will start. The AM will show if the unknown parameters can be calculated using the information entered and, if so, derive these. Thus, the TF and R&R cluster represent the AR inputs, and MBPS results are the AR outputs from the Fig. 3.

CONCLUSION

The concept of the model-based planning system presented in this paper is a framework for planning the development and implementation of an AR solution for a particularistic task in automation. It should be able to analyze the factors that influence the development, implementation, and further usage of AR, as well as the efficiency of this process (the ratio of resources spent with respect to the benefits obtained). In this way, it should not only be possible to identify the main factors of such influence, but also to find their scientific validity and define their theoretical background. The model should also be able to determine the "weight" of each main input parameter for the final output.

As mentioned above, the model-based planning system for AR showed in the current article is presented, first, in the form of a conceptual scheme. The main blocks of the model require furthermore in-depth processing. It relates, first of all, to further expanding and developing the analytical model block. This will be provided with the further assembly of the information on the resources and results of already implemented AR projects, including the authors of the current article and his colleagues (Le, et al., 2016; Zou, 2018; Kilimis, et al., 2019; Bilous, et al., 2021; Sarachuk, et al., 2020). The compiling of the collected AR inputs and outputs will be based primarily on the mathematical methods like nonlinear PCA and manifold learning. This can be a simple mathematical framework which does not include every selected variable initially. Later, during developing of new AR applications, the AM will be tested, refined, and become more complex. An important aspect here will be the estimating which AR inputs and AR outputs and which of their coefficients are applicable locally (for example, only for IPM or for VAP), and which are relevant to the automation in general. This information will be systematised in the form of tables. Further, this data can be used for scientific analysis of AR application in particular tasks.

REFERENCES

Ahmed, S., 2019. A review on using opportunities of augmented reality and virtual reality in construction project management. *Organization, Technology and Management in Construction: An International Journal,* Volume 11, pp. 1839–1852.

Alam, S. S. et al., 2021. Factors affecting augmented reality adoption in the retail industry. *Journal of Open Innovation: Technology, Market, and Complexity,* Volume 7, p. 142.

Berger, U., Bilous, V. & Andulkar, M., 2016. Anwendung von der Augmented Reality für die Mensch-Roboter Interaktion bei der Fehlerbeseitigung und bei der Maschinenbedienung. *3D SENSATION-transdisziplinäre Perspektiven,* pp. 37–38.

Bichia, Q., 2020. Accelerated Automation and the Ecosystem of Adaptation to the Changes. *Globalization & Business.*

Bilous, V., Kudelina, L. & Staedter, P., 2021. Modular-Designed AR Application for Improved Human-Machine Interaction and Real-Time Error Correction in Laboratory Units. *Available at SSRN 4084049.*

Bilous, V., Porsch, R. & Spanoudakis, K., 2022. *Augmented Reality: Increasing Availability and Its Implication for SMEs.* s.l., Springer, pp. 349–356.

Bilous, V. & Sarachuk, K., 2023. *Can small and medium enterprises benefit from AR technology? Current challenges and trends.* s.l., s.n.

Bilous, V., Städter, J. P., Gebauer, M. & Berger, U., 2022. Usage of Augmented Reality for Improved Human-Machine Interaction and Real-Time Error Correction of Laboratory Units. *Annals of Scientific Society for Assembly, Handling and Industrial Robotics 2021,* p. 263.

Bitforge, 2019. *Augmented Reality offiziell kein Hype mehr,* s.l.: s.n.

Bleicher, K., 1992. Der Strategie-, Struktur-und Kulturfit Strategischer Allianzen als Erfolgsfaktor. In: *Wegweiser für strategische Allianzen.* s.l.: Springer, pp. 266–292.

Bleicher, K., 2013. *Organisation: Strategien—Strukturen—Kulturen.* s.l.: Springer-Verlag.

Boboc, R. G., Gırbacia, F. & Butilă, E. V., 2020. The application of augmented reality in the automotive industry: A systematic literature review. *Applied Sciences,* Volume 10, p. 4259.

Bonetti, F., Warnaby, G. & Quinn, L., 2018. Augmented reality and virtual reality in physical and online retailing: A review, synthesis and research agenda. *Augmented reality and virtual reality,* pp. 119–132.

Bottani, E. & Vignali, G., 2019. Augmented reality technology in the manufacturing industry: A review of the last decade. *Iise Transactions,* Volume 51, pp. 284–310.

Dalim, C. S. C. et al., 2017. Factors influencing the acceptance of augmented reality in education: A review of the literature. *Journal of computer science,* Volume 13, pp. 581–589.

Devagiri, J. S. et al., 2022. Augmented Reality and Artificial Intelligence in industry: Trends, tools, and future challenges. *Expert Systems with Applications,* p. 118002.

Eckert, M., Volmerg, J. S., Friedrich, C. M. & others, 2019. Augmented reality in medicine: systematic and bibliographic review. *JMIR mHealth and uHealth,* Volume 7, p. e10967.

Gaitanides, M., 2013. *Prozessorganisation: Entwicklung, Ansätze und Programme des Managements von Geschäftsprozessen.* s.l.: Vahlen.

Glover, J. & Linowes, J., 2019. *Complete Virtual Reality and Augmented Reality Development with Unity: Leverage the power of Unity and become a pro at creating mixed reality applications.* s.l.: Packt Publishing.

Gómez-Puerta, M. et al., 2019. Research review on augmented reality as an educational resource for people with intellectual disabilities. *International Journal of Developmental and Educational Psychology,* pp. 473–485.

Grand_Review_Research, 2021. *Augmented Reality Market Size, Share & Trends Analysis Report By Component, By Display (HMD & Smart Glass, HUD, Handheld Devices), By Application, By Region, And Segment Forecasts, 2022–2030.* [Online] Available at: https://www.grandviewresearch.com/industry-analysis/augmented-reality-market

Harikrishnan, A. et al., 2021. Feasibility of augmented reality technology for communication in the construction industry. *Advanced Engineering Informatics,* Volume 50, p. 101363.

Herdina, M., 2020. *Augmented Reality Disappeared From Gartner's Hype Cycle – What's Next?,* s.l.: s.n.

Illanes, P. et al., 2018. Retraining and reskilling workers in the age of automation. *McKinsey Global Institute.*

Isac, N., Dobrin, C. & Badshah, W., 2020. The Impact of Sustainable Transition of Automation on Employees in the Automotive Sector and the Influence of Corona Pandemic. *Review of International Comparative Management,* Volume 21, pp. 429–436.

Jalo, H., Pirkkalainen, H. & Torro, O., 2021. *The State of Augmented Reality, Mixed Reality and Virtual Reality adoption and use in European small and medium-sized manufacturing companies in 2020: VAM Realities Survey Report.* s.l.: VAM Realities Erasmu project.

Jetter, J., Eimecke, J. & Rese, A., 2018. Augmented reality tools for industrial applications: What are potential key performance indicators and who benefits?. *Computers in Human Behavior,* Volume 87, pp. 18–33.

Kerzner, H., 2022. *Project management metrics, KPIs, and dashboards: a guide to measuring and monitoring project performance.* s.l.: John Wiley & Sons.

Kilimis, P., Zou, W., Lehmann, M. & Berger, U., 2019. A survey on digitalization for SMEs in Brandenburg, Germany. *IFAC-PapersOnLine,* Volume 52, pp. 2140–2145.

Kim, J. et al., 2019. A study on the application of packaging and augmented reality as a marketing tool. *Korean Journal of Packaging Science & Technology,* Volume 25, pp. 37–45.

Kosiol, E., 1962. Strukturierung und Organisation. In: *Organisation der Unternehmung.* s.l.: Springer, pp. 19–20.

Lasisz, A., 2016. *Optimization of Quality Assurance-and Control Activities within the Supply Process in Plant Engineering and Construction,* s.l.: s.n.

Le, D. T. et al., 2016. *Self adaptive system for flexible robot assembly operation.* s.l., s.n., pp. 1–5.

Lehmann, M. A., Porsch, R. & Mai, C., 2021. Assembly Process Digitization Through Self-learning Assistance Systems in Production. In: *Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems.* s.l.: Springer, pp. 216–223.

Madsen, O. et al., 2022. *The future of smart production for SMEs: A methodological and practical approach towards digitalization in SMEs.* s.l.: Springer.

Markets_and_Markets, 2020. *Augmented Reality and Virtual Reality Market with COVID-19 Impact Analysis by Offering (Hardware & Software), Device Type (HMD, HUD, Gesture Tracking), Application (Enterprise, Consumer, Commercial, Healthcare), and Geography - Global Forecast to 2025.* [Online]. Available at: https://www.marketsandmarkets.com/Market-Reports/augmented-reality-virtual-reality-market-1185.html

Mishra, A., Karmakar, S., Bose, A. & Dutta, A., 2020. Design and development of IoT-based latency-optimized augmented reality framework in home automation and telemetry for smart lifestyle. *Journal of Reliable Intelligent Environments,* Volume 6, pp. 169–187.

Palmarini, R., Erkoyuncu, J. A., Roy, R. & Torabmostaedi, H., 2018. A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing,* Volume 49, pp. 215–228.

Palomäki, E., Stigzelius, E. & Vartiainen, M., 2010. State of the art – Overview of new applications, practices and concepts in utilizing technology in education, their use in work contexts, global/local aspects for multichannel online services Contents. *BIT Research Centre.*

Pentenrieder, K., Bade, C., Doil, F. & Meier, P., 2007. *Augmented Reality-based factory planning-an application tailored to industrial needs.* s.l., s.n., pp. 31–42.

Perannagari, K. T. & Chakrabarti, S., 2019. Factors influencing acceptance of augmented reality in retail: insights from thematic analysis. *International Journal of Retail & Distribution Management.*

Pfohl, H. C., 1998. Logistics systems. *The faculty of ILiM, Poznań.*

Prinsloo, T. & Van Deventer, J. P., 2017. *Using the Gartner Hype Cycle to evaluate the adoption of emerging technology trends in higher education–2013 to 2016.* s.l., s.n., pp. 49–57.

Rajkumar, A., Ebenezer, H., Snegdha, A. & Goyal, C., 2020. Augmented reality in aerospace engineering real-time application of AR iOS applications. *Materials Today: Proceedings.*

Safi, M., Chung, J. & Pradhan, P., 2019. Review of augmented reality in aerospace industry. *Aircraft Engineering and Aerospace Technology.*

Saniuk, S., Caganova, D. & Saniuk, A., 2021. Knowledge and skills of industrial employees and managerial staff for the industry 4.0 implementation. *Mobile Networks and Applications,* pp. 1–11.

Sarachuk, K. & Mißler-Behr, M., 2020. Is ultra-broadband enough? The relationship between high-speed internet and entrepreneurship in Brandenburg. *Int. J. Tech.,* Volume 11, pp. 1103–1114.

Sarachuk, K., Missler-Behr, M. & Hellebrand, A., 2020. *Ultra-High-Speed Broadband Internet and Firm Creation in Germany.* s.l., s.n., pp. 40–56.

Schierenbeck, H. & Wöhle, C. B., 2016. Grundzüge der Betriebswirtschaftslehre. In: *Grundzüge der Betriebswirtschaftslehre.* s.l.: De Gruyter Oldenbourg.

Schumacher, A. & Sihn, W., 2020. Development of a monitoring system for implementation of industrial digitalization and automation using 143 key performance indicators. *Procedia CIRP,* Volume 93, pp. 1310–1315.

Shafeek, H., 2018. The role of staff skills in lean maintenance. *Journal of Computational and Theoretical Nanoscience,* Volume 15, pp. 1332–1339.

Statista, 2022. *Size of the global industrial automation market from 2020 to 2025 (in billion U. S. dollars).* [Online] Available at: https://www.statista.com/statistics/1219772/industrial-automation-market-size-worldwide/

Technavio, 2021. *Augmented Reality and Virtual Reality Market by Technology and Geography - Forecast and Analysis 2021–2025.* [Online] Available at: https://www.technavio.com/report/augmented-reality-and-virtual-reality-market-industry-analysis

Tejedor-Calvo, S., Romero-Rodríguez, L.-M., Moncada-Moncada, A.-J. & Alencar-Dornelles, M., 2020. Journalism that tells the future: possibilities and journalistic scenarios for augmented reality. *Profesional de la información,* Volume 29.

Thommen, J.-P. et al., 2017. Grundlagen der Organisation. In: *Allgemeine Betriebswirtschaftslehre: Umfassende Einführung aus managementorientierter Sicht.* Wiesbaden: Springer Fachmedien Wiesbaden, pp. 433–445.

Wiedenmaier, S., Oehme, O., Schmidt, L. & Luczak, H., 2001. *Augmented reality (AR) for assembly processes-an experimental evaluation.* s.l., s.n., pp. 185–186.

Zou, W., 2018. *Entwicklung eines Systems für das Programmieren durch Vormachen unter Nutzung der Augmented Reality für roboterbasierte Montagesysteme.* s.l.: Shaker Verlag.

Zou, W., Andulkar, M. & Berger, U., 2018. *Development of Robot Programming System through the use of Augmented Reality for Assembly Tasks.* s.l., s.n., pp. 1–7.