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Quality methods in virtual and augmented reality with a focus on education: a systematic literature review

Amelie Karcher[1] · Dominik Arnold[1] · Bernd Kuhlenkötter[1]

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Abstract
With the goal of developing a unified approach for implementation of training for quality methods—with the help of innovative assistance systems—the current state of research is determined within the scope of this work. These quality methods include Quality Management Systems such as Lean Management and Six Sigma. A systematic literature search is conducted to determine the current state of research on Augmented and Virtual Reality data glasses, which are considered here as innovative assistance systems. This search extends without restriction to the date of data collection at the beginning of the year 2022, as Augmented and Virtual Reality data glasses are considered to be particularly immersive technologies. Based on the databases Scopus and Web of Science, an extended systematic literature review was used for the research. By answering the research question and classifying the implemented research work, an overview of the current state of virtual and augmented reality research will be given. This makes it clear that further research is needed, especially with regard to the training of quality methods, to develop specific models and action guidelines.

Keywords Augmented reality · Virtual reality · Systematic literature review · Lean management · Six Sigma · Quality methods

JEL Classification I25

1 Introduction

While growing global competition, companies are exposed to increasing deadline and cost pressure (Deuse et al. 2015). In addition, demographic change and globalization are issues to which medium-sized companies and large corporations must respond today and in the future (Senderek and Geisler 2015). A continuing trend

✉ Amelie Karcher
Amelie.karcher@ruhr-uni-bochum.de

[1] Chair of Production Systems (LPS), Ruhr-Universität Bochum, Bochum, Germany

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toward customer-specific products with an increasing number of variants, smaller batch sizes and an expanded range of tasks and responsibilities can also be observed (Crute et al. 2013). Currently, a growing number of applications based on Augmented Reality (AR) and Virtual Reality (VR) are being developed for industrial purposes (Eswaran and Bahubalendruni 2022). The technology is proving to be very flexible and shows great potential for use in numerous areas. Such innovative technologies can offer the possibility to convey quality methods from Lean Management and Six Sigma immersively. To ensure that this is not just a theoretical possibility, it is important to explore how quality methods can be presented and applied operationally through assistance systems so that added value can be achieved in business applications. To remain competitive, companies must continuously find innovative solutions for improving various industrial processes and focusing value creation (Segovia et al. 2015). In this context, Lean Management, for example, was established in the early 1990s to create highly efficient processes in industry and has since been widely recognized in industry (Kolberg and Zühlke 2015). It is not only the processes that experience innovation, but also the qualification of employees, who are indispensable for the success of the company (Molzbichler and Sturmer 2022; Wildemann 2020). In the context of qualification, the term *education* refers to the process of acquiring new knowledge, skills and competencies beyond one's existing vocational qualification. Education, in the context of further qualification, allows individuals to expand their professional skills, explore new areas and enhance their career opportunities (Halawi and Haydar 2013). Further qualification encompasses various forms of learning, including formal educational programs such as courses, seminars, or degree programs, as well as informal learning in the workplace or through self-directed learning. The focus is on deepening existing knowledge, developing new competencies and preparing for new professional requirements or advancement opportunities. Education in the context of further qualification is a lifelong process aimed at continuously expanding individual knowledge, skills and professional expertise. It can help individuals keep pace with the constantly changing demands of the labor market and advance their personal and professional development. Through further qualification, individuals can enhance their employability, pursue new career paths, or advance within their current field.

The development of assistance systems is seen as an important field of action for qualification measures. Against this background, the compatibility of established quality methods with the increasingly important assistance systems must be analyzed more closely. So far, no holistic overview of methods and projects in connection with virtual and augmented reality could be taken from the literature research, so that a basic, Systematic Literature Review process for the analysis of the research situation and the compilation of a literature review seems to be necessary and will provide an up-to-date overview. A literature review serves as a basis for knowledge growth, facilitates theory development, concludes mature research areas and uncovers new research areas (MacDonell et al. 2010; Webster and Watson 2002). A necessary literature review process is a tool for the analysis and summary of the literature (Booth et al. 2016; Fisch and Block 2018). For this process, a structured framework called Systematic Literature Review (SLR) is utilized, incorporating documented criteria and standards (Dybå et al. 2005), as outlined by (Tranfield et al. 2003). A

SLR is used in different areas such as economy, social policy, nursing (Kitchenham et al. 2009: 8), medicine (Phutrakool and Pongpirul 2022), software development (Babar and Zhang 2009) and process modeling (Zhang et al. 2008). Likewise, the SLR is used in the range of Lean Management and its different areas of application such as in production, administration, logistics, leadership, development or health service (Ilangakoon et al. 2022). Other areas of application are education and digital assistance systems. As evident, there exists a myriad of applications within the specified domains; however, there is no analysis on the combination of VR/AR, quality methods and (further) education could be taken from the literature. Thus, the goal of the analysis is to provide an overview of the current state, as well as the development of viral learning applications to Quality Management Systems (QMS) so far. It would be welcome if direct instructions or guidelines for the creation of such immersive learning environments for quality methods could already be taken from the literature and thus existing research work. This could then be used directly as an aid in the creation to proceed efficiently and sustainably. Such applications could then be used concretely in the qualification of employees within a company or in further education. Especially in Virtual Reality, the location-independent use is considered an advantage, for example, to enable learners during a lock-down of the Covid-19 pandemic to experience a variety of learning and to vary processes (Horst et al. 2021). Through VR, for example, different industries and different value streams with different levels of difficulty can be realized in alternating presentation modes such as comic, entertainment or business. Further advantages are a stronger emotional engagement with the topic, as well as increasing the motivation of learners. It is not always possible, even regardless of a pandemic, to meet in person for a training workshop, for example. However, VR offers a way to mimic this real-world experience through 3D workspaces where people can move freely and communicate in a natural and intuitive way. VR offers a powerful solution that enables education and training staff to learn effectively in an interactive, simulative and immersive environment. These advantages should now be transferred to quality methods in combination with VR and AR. For this reason, it is imperative to analyze the current state of research. Thus, the SLR enables to create a sound understanding of the existing literature and to identify potential gaps in knowledge. It helps identify the potential and opportunities of VR/AR, QMS and education. By bringing these areas together, innovative approaches and solutions can be developed. Identifying best practices and success stories from the literature can help unlock the full potential of these topics. Combining VR/AR, QMS and education can lead to synergies and interfaces that open new opportunities. This research work allows for a closer look at connections and identification of ways in which these fields can benefit from each other. This can lead to improved learning methods, more efficient processes and better use of VR/AR technologies. The SLR provides insights into the practical application of VR/AR, QMS and education. Use cases, application possibilities and experiences can be derived from the literature. This helps companies, organizations and educational institutions to implement and integrate these topics into their working and learning environments. It also shows which areas need further research and which questions are still open. It identifies research gaps and points to possible future developments, which will help initiate new research projects and advance

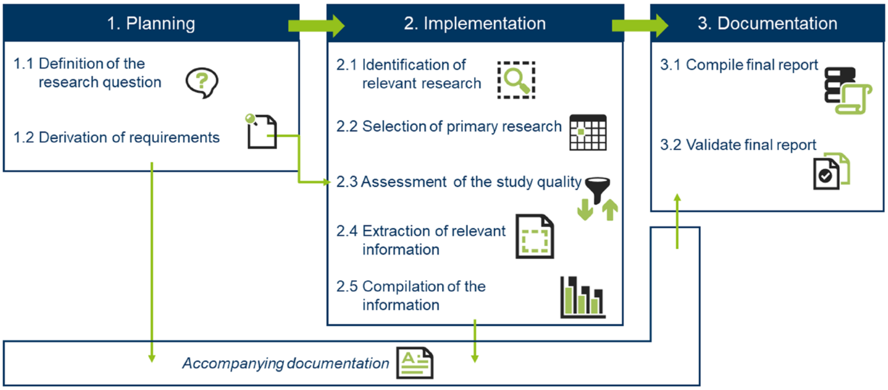

Fig. 1 SLR process I own representation according to (Brereton et al. 2007)

knowledge in the field. To achieve the aforementioned goals, research questions are defined in advance, which are then used to derive the requirements for the SLR, which in turn affect the implementation and results. In the following, however, the entire SLR with all the necessary sub-steps is described first.

2 Research methodology—SLR of QMS with VR/AR

SLR is a method by which existing work by researchers can be identified, selected and evaluated to then analyzed and synthesized the data. The results help to provide an overview of the current state of research, identify research gaps and thus further needs (Boell and Cecez-Kecmanovic 2015; Saad et al. 2021; vom Brocke et al. 2015). Thus, regardless of the topic, SLRs are essential (Webster and Watson 2002). For the intended Systematic Literature Review process, the approach the procedure according to.

- Kitchenham (Kitchenham 2004; Kitchenham and Charters 2007)
- Brereton, Kitchenham et al. (Brereton et al. 2007)
- Webster and Watson (Webster and Watson 2002) and also
- Denyer (Denyer and Tranfield 2009)

will be followed as a guideline. These approaches will be analyzed first and then compared to each other. These approaches will be analyzed first and then compared to each other. According to Kitchenham, one of the most relevant (Shakeel et al. 2018) cited sources (Krüger et al. 2020), SLR consists of three main phases: Planning, Implementation and Documentation. This documented process makes it possible to repeat the SLR to independently verify the results. The process used here, based on the sources mentioned, can be seen in Fig. 1.

Based on the authors mentioned above, our procedure was created, which can be seen in Fig. 1. The diagram shows the process of the SLR, which is divided into three main phases (1 Planning, 2 Implementation and 3 Documentation) and subdivided into further sub-steps. These are presented below.

Phase 1—planning

The first main phase of planning consists of the sub-steps 1.1 Definition of research questions and 1.2 Derivation of requirements, which must be recorded in advance. The definition of the research questions is the most important element of the SLR (Brereton et al. 2007). They determine the data that must be extracted and constrain the aggregation process. The recorded research questions are the first part of the documentation and should not be changed after the requirements have been completed (Brereton et al. 2007). The research questions serve to convert problems or information into answerable questions and to explain these completely (Dybå and Dingsøyr 2008). When conducting SLR, the goal is always to these questions. Depending on the question, the selection of literature, the survey data and their compilation is influenced.

Sub-step 1.2 Derivation of requirements should consider the elements of selection of bibliographic sources to be used, keywords and also selection of inclusion and exclusion criteria (Lenarduzzi and Taibi 2016). To identify bibliographic sources, the databases AISnet, Eric, Google Scholar, IEEExplore, Science Direct, Scopus, Web of Science and Web of Knowledge, among others, can be used for research (Blömer et al. 2020; Brereton et al. 2007; Freina and Ott 2015; Lenarduzzi and Taibi 2016). For the actual search process, the databases used and the applications to be used play a role. Depending on the database, the search terms or the Boolean operators such as AND, OR differ and should be adapted and documented (Brereton et al. 2007). The keywords should be selected specifically, alternative spellings and acronyms should be considered (Lenarduzzi and Taibi 2016). Furthermore, a conceivable translation and its meaningfulness should be considered. The inclusion and exclusion criteria are topic-specific and depend on the objective. Thus, a temporal limitation of the observation area may or may not make sense. If, for example, the SLR is only applied on a national level, this leads to an exclusion of foreign language literature.

Phase 2—implementation

The second main phase Implementation can be divided into 2.1 Identification of relevant research, 2.2 Selection of primary research, 2.3 Assessment of study quality, 2.4 Extraction of relevant information and 2.5 Compilation of the information.

The implementation can be considered as a search process, distinguishing the entire literature into relevant and irrelevant content. The difference between the individual literature databases must be taken into account since different search models as well as query options exist. To avoid the problem of possible result deviations, the search term must be adapted individually for each search database, which increases the time expenditure of the SLR and the error susceptibility of this (Babar and Zhang 2009). Furthermore, this search process can be differentiated into a manual, automated or reference-based search (Krüger et al. 2020; Lenarduzzi and Taibi 2016). To keep the effort as low as possible, an automated search is recommended. However, according to Zhang and Ali-Barbar, an automated search is not sufficient to comply with a fully comprehensive search, so a manual search, albeit more complex, should be carried out as a supplement (Zhang and Ali-Babar 2010). This can be done by an individual Internet search, the addition of gray literature or also by (industrial) research projects.

The factors explained so far have implications for sub-step 2.1 Identifying relevant research. The identification of publications that can be used to answer the research questions is thus a decisive step of an SLR (Zahedi et al. 2016). The subsequent sub-step 2.2 Selection of primary research is usually carried out in a three-step procedure:

- Selection by title:
  The titles of publications captured in the initial search process are checked for applied keywords and content relationships and literature that is not relevant is rejected.
- Selection by abstract:
  The abstracts of the now-selected publications are checked and non-relevant literature is rejected.
- Selection by full paper:
  Of the literature now available for selection, all publications should be complete. These publications are reviewed against the inclusion/exclusion criteria to obtain a final list of primary studies (Brereton et al. 2007; Lenarduzzi and Taibi 2016; Riemann et al. 2020).

Duplicates are also removed during these selection steps. The remaining sub-step 2.3 Evaluation of the study quality requires a practical application and is therefore explained directly in the application area. For the sub-steps 2.4 Extraction of relevant information and 2.5 Compilation of information, different software can assist in addition to classic literature management or spreadsheet programs. For this purpose, various applications are available, that document a collaborative work process in a comprehensible way, as well as the results of the study selection itself (Kohl et al. 2018). Examples are the software CADIMA, HAWC and Rayyan, which differ in aspects such as free accessibility, coding of data, collaborative work or documentation (Kohl et al. 2018).

Phase 3—documentation

The third main phase Documentation consists of the sub-steps 3.1 Compile final report and 3.2 Validate final report. Once the systematic review has been completed and the questions have been answered, documentation takes place, for example using a suitable tool such as a spreadsheet (Brereton et al. 2007). According to Kitchenham and Brereton, it is suggested that these documents and the presentation of results be independently reviewed or submitted for external validation, to a peer-reviewed journal (Brereton et al. 2007).

2.1 Phase 1—presentation of the research questions

Following the SLR process described in Fig. 1, the research questions (RQ) are defined first. These can be subdivided as follows:

RQ1: Are VR/AR used to teach QMS?

RQ2: Which VR/AR systems are used in connection with QMS?

RQ3: Are there implementation models for the use of VR/AR techniques?

RQ4: Are VR/AR being used for training in the education sector?

RQ5: Can a trend of research on the use of VR/AR systems in the context of QMS be identified?

RQ1: Are VR/AR used to teach QMS?

The motivation for this question is to show the current state of VR/AR-based applications in the context of QMS within education or industry. All applications should be considered. This means that the degree of development is irrelevant, for example purpose, environment and complexity are not further considered. In this way, a holistic identification of application areas can be achieved. However, it is relevant that in virtual applications the teaching of the method itself within VR/AR is meant and not the use of the medium itself.

RQ2: Which VR/AR systems are used in connection with QMS?

Here, the technology should first be narrowed down further. In the VR area, no caves, no low-end devices such as Google Cardboard, no 360-degree applications and no simple 3D worlds are considered. The focus is on immersive and interactive virtual applications, which are realized by high-end data glasses. In the AR area, the focus will also be on interactive applications, so that applications using AR data glasses will serve as a basis. Other augmented applications such as viewing 3D models, superimposing head-up displays, etc. are not relevant here.

RQ3: Are there implementation models for the use of VR/AR techniques?

The area of education can be divided into the four areas of primary, secondary, tertiary and quaternary education. For the intended SLR, the focus is in the area of secondary, tertiary and quaternary education, since VR/AR and especially quality methods are most likely to be taught here. With this question, it is to be inquired whether a certain use and/or addressee group is already focused on the VR/AR application. Furthermore, it is interesting to question whether the QMS are rather used in the university or entrepreneurial context. This idea will be taken up again in sub-step 2.5 Compiling the information.

RQ4: Are VR/AR being used for training in the education sector?

Through this research question, we aim to understand how VR/AR technology is currently being implemented in training/education programs to derive generalized conclusions for future applications.

RQ5: Can a trend of research on the use of VR/AR systems in the context of QMS be identified?

For this purpose, the number of publications per time interval is to be displayed to make trend developments visible. This trend is to be compared with the general trend of AR/VR applications.

In the following, the further steps of the planning are presented. For sub-step 1.2 Derivation of requirements, the selection of bibliographic sources is made from the Scopus and Web of Science databases. These databases have provided the most results for related SLRs in the areas of Lean Management (Salentijn et al. 2021), Virtual Reality (Domingueti et al. 2021; Mak et al. 2020), Augmented Reality (Ho et al. 2022; Quandt and Freitag 2021), education (Checa and Bustillo 2020) and oncepts in order to achieve the most comprehensive overview possible. In this context, the term concepts refers to general ideas, models or theoretical approaches as well as concrete procedures, which are related to abstract concepts or frameworks, which are used for the analysis, evaluation or implementation of certain aspects or principles, which are conveyed to the content implementation in the technical realization or also the guidance by VR/AR. The main topics are combined with the subtopics, see Table 1.

This first overview provides an orientation to refine the keywords in the subsequent application. The selection of the keywords is based on common terms from industry and research as well as the available literature research from the respective fields, see Table 1. The final groupings and combinations of keywords, acronyms used and the Boolean operators applied are listed directly in the respective Tables 2, 3, 4, 5, 6, 7, 8, and 9.

In the next step, the selection of the inclusion and exclusion criteria as well as the optional criterion is presented. The latter can be added as an option if further filtering of the results is necessary. Publications are either included or excluded based on their compliance with the following criteria.

Formal exclusion criteria

1. Studies published in languages other than English or German.
2. Studies in which the combination of both keywords is not to be taken in the abstract.
3. Studies that are not open source or accessible through the university networks.

Content exclusion criteria

4. Studies that describe a practical implementation of quality methods within AR/VR and do not describe conceptual or methodological treatises and their application.

Formal inclusion criteria

5. All studies, meaning there is no time limit for the analysis period (reference to RQ5).
6. Studies in which desktop-based Virtual Reality technologies, VR glasses and caves were used as application scenarios (supplementary to RQ2).
7. Studies in which recognizable Augmented Reality technologies, independent of AR glasses were used as application scenarios.

Table 1 Overview of the SLR of the topic—specific keywords

1. Keyword 2. Keyword	Virtual reality	Augmented reality	Lean management/Six Sigma
Virtual Reality	Berntsen et al. (2016)	Hertel et al. (2021)	
Augmented Reality		Dey et al. (2018)	
Lean management/ Lean Six Sigma			Albliwi et al. (2015), Oon et al. (2021), Carnerud (2018), and Salentijn et al. (2021)
Training	Checa and Bustillo (2020) and Mak et al. (2020)		
Education	Bernuy et al. (2021), Domingueti et al. (2021), Noah and Das (2021), Paszkiewicz et al. (2022), Radianti et al. (2020), Zahabi and Abdul Razak (2020), and Kavanagh et al. (2017)	Mystakidis et al. (2022), Noah and Das (2021), Ređep and Hajdin (2021), and Theodoropoulos and Lepouras (2021)	
Learning	Bernuy et al. (2021), Checa and Bustillo (2020), and Kurniawan et al. (2019)	Mystakidis et al. (2022)	
Framework	Zahabi and Abdul Razak (2020)	Muhlan et al. (2021)	

Table 2 Number of results per search term for the topic VR I Database Scopus

Database: Scopus			
Search string [Search: all fields]	No	Search string [Search: by Title, Abstract, and Keywords]	No
{virtual reality}	282,605	{virtual reality}	146,738
{virtual reality} OR {VR}	370,277	{virtual reality} OR {VR}	164,152
{vr}	141	{vr}	44,317
{Six Sigma} AND {virtual reality}	259	{Six Sigma} AND {virtual reality}	17
{Six Sigma} AND {virtual reality} OR {VR}	290	{Six Sigma} AND {virtual reality} OR {VR}	24
{Six Sigma} AND {VR}	58	{Six Sigma} AND {VR}	9
{Lean Management} AND {virtual reality}	130	{Lean Management} AND {virtual reality}	7
{Lean Management} AND {virtual reality} OR {VR}	145	{Lean Management} AND {virtual reality} OR {VR}	8
{Lean Management} AND {VR}	43	{Lean Management} AND {VR}	4
{Lean Manufacturing} AND {virtual reality}	377	{Lean Manufacturing} AND {virtual reality}	21
{Lean Manufacturing} AND {virtual reality} OR {VR}	403	{Lean Manufacturing} AND {virtual reality} OR {VR}	22
{Lean Production} AND {virtual reality}	332	{Lean Production} AND {virtual reality}	34
{Lean Production} AND {virtual reality} OR {VR}	364	{Lean Production} AND {virtual reality} OR {VR}	35
{Lean education} AND {virtual reality}	11	{Lean education} AND {virtual reality}	11
{Lean education} AND {virtual reality} OR {VR}	11	{Lean education} AND {virtual reality} OR {VR}	11

Table 3 Number of results per search term for the topic AR I Database Scopus

Database: Scopus			
Search string [Search: all fields]	No	Search string [Search: by Title, Abstract, and Keywords]	No
{augmented reality}	105,323	{augmented reality}	38,271
{augmented reality} OR {AR}	1,204,504	{augmented reality} OR {AR}	253,653
{AR}	1,127,392	{AR}	230,902
{Six Sigma} AND {augmented reality}	198	{Six Sigma} AND {augmented reality}	4
{Six Sigma} AND {augmented reality} OR {AR}	1,000	{Six Sigma} AND {augmented reality} OR {AR}	11
{Six Sigma} AND {AR}	831	{Six Sigma} AND {AR}	7
{Lean Management} AND {augmented reality}	134	{Lean Management} AND {augmented reality}	6
{Lean Management} AND {augmented reality} OR {AR}	373	{Lean Management} AND {augmented reality} OR {AR}	7
{Lean Management} AND {AR}	267	{Lean Management} AND {AR}	5
{Lean Manufacturing} AND {augmented reality}	375	{Lean Manufacturing} AND {augmented reality}	21
{Lean Manufacturing} AND {augmented reality} OR {AR}	797	{Lean Manufacturing} AND {augmented reality} OR {AR}	27
{Lean Production} AND {augmented reality}	341	{Lean Production} AND {augmented reality}	12
{Lean Production} AND {augmented reality} OR {AR}	874	{Lean Production} AND {augmented reality} OR {AR}	23
{Lean education} AND {augmented reality}	6	{Lean education} AND {augmented reality}	0
{Lean education} AND {augmented reality} OR {AR}	9	{Lean education} AND {augmented reality} OR {AR}	0

Table 4 Number of results per search term for the topics VR + Education I Database Scopus

Database: Scopus			
Search string [Search: all fields]	No	Search string [Search: by Title, Abstract, and Keywords]	No
{education} AND {virtual reality}	80,005	{education} AND {virtual reality}	17,142
{education} AND {virtual reality} OR {VR}	90,769	{education} AND {virtual reality} OR {VR}	17,880
{higher education} AND {virtual reality}	13,450	{higher education} AND {virtual reality}	927
{higher education} AND {virtual reality} OR {VR}	1425	{higher education} AND {virtual reality} OR {VR}	970
{further education} AND {virtual reality}	202	{further education} AND {virtual reality}	19
{further education} AND {virtual reality} OR {VR}	233	{further education} AND {virtual reality} OR {VR}	21
{training} AND {virtual reality} OR {VR}	90,339	{training} AND {virtual reality} OR {VR}	20,960
{training} AND {virtual reality}	83,609	{training} AND {virtual reality}	20,040
{upskilling} AND {virtual reality	67	{upskilling} AND {virtual reality	7
{upskilling} AND {virtual reality} OR {VR}	88	{upskilling} AND {virtual reality} OR {VR}	7

Table 5 Number of results per search term for the topics AR + Education I Database Scopus

Database: Scopus	
Search string [Search: by Title, Abstract, and Keywords]	No
{education} AND {augmented reality}	5497
{education} AND {augmented reality} OR {AR}	6986
{higher education} AND {augmented reality}	391
{higher education} AND {augmented reality} OR AR}	511
{further education} AND {augmented reality}	7
{further education} AND {augmented reality} OR {AR}	16
{training} AND {augmented reality} OR {AR}	5989
{training} AND {augmented reality}	3799
{upskilling} AND {augmented reality	4
{upskilling} AND {augmented reality} OR {AR}	4

8. Studies that have been published in academic journals and/or presented at conferences with at least one peer review.

Content inclusion criteria

9. Studies that implement Virtual Reality based teaching in the form of games, simulations or worlds.
10. In addition, contributions of gray literature and YouTube are added to consider possible opinions expressed in non-scientific works. In this way, the space is created for the consideration of findings in this still very young technology, which were not developed in the classical scientific environment.

Optional criterion

11. Studies, which show a relative citation frequency. As a starting point for the present SLR, a minimum of 20 citations of the scientific contribution is taken as a basis.

After retrieving the search results of the SLR data collection, the inclusion and exclusion criteria are applied to filter the collected publications. This was done according to the described three-stage selection of title, abstract and full paper.

In further planning for the concrete implementation Citavi should be used as literature management software. This program was chosen because of its user-friendliness, the fast processing of large numbers of references, the add-in for Word citations, the integrated PDF viewer and the teamwork. In step 2.4 Extraction of relevant information, the selection will be checked again for its actuality. For the sub-steps 2.4 and 2.5 rayyan is used as a support tool, for the manual search and for the also necessary data extraction and evaluation Microsoft Excel.

Table 6 Number of results per search term for the topics VR + AR + Implementation I Database Scopus

Database: Scopus

Search string [Search: by Title, Abstract, and Keywords]	No	Search string [Search: by Title, Abstract, and Keywords]	No
{Concept} AND {virtual reality}	8792	{Concept} AND {augmented reality}	2746
{Concept} AND {virtual reality} OR {VR}	9267	{Concept} AND {augmented reality} OR {AR}	4996
{Framework} AND {virtual reality} OR {VR}	12,206	{Framework} AND {augmented reality} OR {AR}	6918
{Framework} AND {virtual reality}	11,583	{Framework} AND {augmented reality}	3442
{Conceptual Framework} AND {virtual reality} OR {VR}	480	{Conceptual Framework} AND {augmented reality} OR {AR}	243
{Conceptual Framework} AND {virtual reality}	454	{Conceptual Framework} AND {augmented reality}	155
{model} AND {virtual reality}	33,747	{model} AND {augmented reality}	7116
{model} AND {virtual reality} OR {VR}	37,124	{model} AND {augmented reality} OR {AR}	49,915

Table 7 Number of results per search term for the topic VR I Database Web of Science

Database: Web of Science			
Search String [Search: all fields]	No	Search string [Search topic: by Title, Abstract, and Keywords]	No
{virtual reality}	73,200	{virtual reality}	64,902
{virtual reality} OR {VR}	188,173	{virtual reality} OR {VR}	77,411
{vr}	136,902	{vr}	30,837
{Six Sigma} AND {virtual reality}	6	{Six Sigma} AND {virtual reality}	2
{Six Sigma} AND {virtual reality} OR {VR}	136,907	{Six Sigma} AND {virtual reality} OR {VR}	30,838
{Six Sigma} AND {VR}	38	{Six Sigma} AND {VR}	5
{Lean Management} AND {virtual reality}	29	{Lean Management} AND {virtual reality}	18
{Lean Management} AND {virtual reality} OR {VR}	136,924	{Lean Management} AND {virtual reality} OR {VR}	30,850
{Lean Management} AND {VR}	39	{Lean Management} AND {VR}	8
{Lean Manufacturing} AND {virtual reality}	29	{Lean Manufacturing} AND {virtual reality}	25
{Lean Manufacturing} AND {virtual reality} OR {VR}	136,923	{Lean Manufacturing} AND {virtual reality} OR {VR}	30,855
{Lean Production} AND {virtual reality}	24	{Lean Production} AND {virtual reality}	21
{Lean Production} AND {virtual reality} OR {VR}	136,960	{Lean Production} AND {virtual reality} OR {VR}	30,870
{Lean education} AND {virtual reality}	41	{Lean education} AND {virtual reality}	23
{Lean education} AND {virtual reality} OR {VR}	136,970	{Lean education} AND {virtual reality} OR {VR}	30,872

Table 8 Number of results per search term for the topic AR I Database Web of Science

Database: Web of Science			
Search string [Search: all fields]	No	Search string [Search: by Title, Abstract, and Keywords]	No
{augmented reality}	29,949	{augmented reality}	27,284
{augmented reality} OR {AR}	857,427	{augmented reality} OR {AR}	216,259
{AR}	838,203	{AR}	199,225
{Six Sigma} AND {augmented reality}	5	{Six Sigma} AND {augmented reality}	3
{Six Sigma} AND {augmented reality} OR {AR}	838,207	{Six Sigma} AND {augmented reality} OR {AR}	199,227
{Six Sigma} AND {AR}	269	{Six Sigma} AND {AR}	109
{Lean Management} AND {augmented reality}	23	{Lean Management} AND {augmented reality}	16
{Lean Management} AND {augmented reality} OR {AR}	838,220	{Lean Management} AND {augmented reality} OR {AR}	199,236
{Lean Management} AND {AR}	251	{Lean Management} AND {AR}	18
{Lean Manufacturing} AND {augmented reality}	22	{Lean Manufacturing} AND {augmented reality}	20
{Lean Manufacturing} AND {augmented reality} OR {AR}	838,221	{Lean Manufacturing} AND {augmented reality} OR {AR}	199,241
{Lean Production} AND {augmented reality}	18	{Lean Production} AND {augmented reality}	17
{Lean Production} AND {augmented reality} OR {AR}	838,219	{Lean Production} AND {augmented reality} OR {AR}	199,240
{Lean education} AND {augmented reality}	16	{Lean education} AND {augmented reality}	11
{Lean education} AND {augmented reality} OR {AR}	838,215	{Lean education} AND {augmented reality} OR {AR}	199,234

Table 9 Number of results per search term for the topics VR + AR + Education + Concept I Database Scopus and Web of Science

Data-base	Search string [Search: by Title, Abstract, and Keywords]	No	Search string [Search: by Title, Abstract, and Keywords]	No
Scopus	{education} AND {virtual reality} AND {system}	5486	{education} AND {augmented reality} AND {system}	5486
	{education} AND {virtual reality} AND {model}	3339	{education} AND {augmented reality} AND {model}	3339
	{education} AND {virtual reality} AND {framework}	1157	{education} AND {augmented reality} AND {framework}	1157
	{education} AND {virtual reality} AND {concept}	990	{education} AND {augmented reality} AND {concept}	990
	{education} AND {virtual reality} AND {conceptual framework}	93	{education} AND {augmented reality} AND {conceptual framework}	93
	{education} AND {virtual reality} AND {integration system}	1	{education} AND {augmented reality} AND {integration system}	1
	{education} AND {virtual reality} AND {implementation system}	0	{education} AND {augmented reality} AND {implementation system}	0
Web of Sience	{education} AND {virtual reality} AND {system}	2829	{education} AND {augmented reality} AND {system}	1436
	{education} AND {virtual reality} AND {model}	2541	{education} AND {augmented reality} AND {model}	1060
	{education} AND {virtual reality} AND {framework}	675	{education} AND {augmented reality} AND {framework}	351
	{education} AND {virtual reality} AND {concept}	937	{education} AND {augmented reality} AND {concept}	574
	{education} AND {virtual reality} AND {conceptual framework}	44	{education} AND {augmented reality} AND {conceptual framework}	23
	{education} AND {virtual reality} AND {integration system}	222	{education} AND {augmented reality} AND {integration system}	123
	{education} AND {virtual reality} AND {implementation system}	327	{education} AND {augmented reality} AND {implementation system}	171

2.2 Phase 2—implementation of the SLR

In the following, first interim results of the implementation are presented. Starting with the database Scopus and with the main topic of Virtual Reality, an overview was first created according to the application of the associated search terms, see Table 2. As a result, more than 282,000 publications were identified for the search term Virtual Reality, for example. Thus, it became clear that a consideration of keyword combinations is more meaningful to answer the RQ in a meaningful way. The single keyword seems to be too unspecific to obtain a search-optimized database analysis. Likewise, the use of a restricted search on the Scopus parameters *Title, Abstract and Keywords* seem to be more target-oriented due to the number and the performed search. Consequently, the results with the search field *all fields* were compared with the search field *Title, Abstract and Keywords*, which confirmed the previous thesis. For this reason, the search results with the search field *Title, Abstract and Keywords* serve as the basis for further elaboration.

In the course of an initial review of the results, it was noticed that, despite clear search parameters for VR, a few publications were found on the topic of AR, for example for the parameters Six Sigma and Virtual Reality, around 22 of 259 publications could be assigned to AR.

To obtain a first overview of the topic AR, the identical procedure as already used for VR was applied, see Table 3. In this analysis, it became particularly clear that no qualitative improvement of the analysis was achieved when the Boolean operator OR was added, but the results for the abbreviation AR = action research were added, which is not expedient at this point.

In addition to the duplicate use of the acronym, the AR data collection found that no further relevant research articles were found when the search terms were expanded to include OR {AR}. For example, for the search term {Lean Manufacturing} AND {augmented reality} with 21 results and the search term {Lean Manufacturing} AND {augmented reality} OR {AR} with 27 results, the 21 identical results are included in the 27, see Table 3. The remaining six publications do not exhibit content relevance to the keywords. This duplication of publications may be an exception and needs further verification. For this reason, all relevant results will still be examined together, duplicates will be subsequently removed and no search terms will be excluded beforehand.

For an initial overview of RQ4, the Scopus database was searched using the terms VR and AR in conjunction with the terms education, higher education, further education, training and upskilling. The basis for the latter terms was derived from both the related SLR in Table 1 and the English translations defined in the expert round for the term education.

In the area of VR, it is clear that a restriction is reasonable due to the number of search terms and the number of searches performed in the search field *Title, Abstract and Keywords*. For this reason, the keywords for the subject area of education in the area of AR are applied directly in the search field *Title, Abstract and Keywords* and a search in the search field *all fields* is omitted. For both results, the selection of search terms does not seem to be specific enough and should be specified in a further step.

To get a first overview of RQ3, a search was performed directly in the search field *Title, Abstract and Keywords*, see Table 6.

Likewise, the selected search terms seem to be too imprecise due to the number and the number of searches performed and should be specified or combined in a further search.

The data collection of the search was subsequently extended to the database Web of Science, in which the already presented searches were carried out again. Table 7 shows the evaluation of the search of the individual search terms. It is also to be noted that the separate search of the search term Virtual Reality is not purposeful but should be carried out in combination.

In the search term {Six Sigma} AND {VR} in the search field *all fields* VR is not used as a Virtual Reality abbreviation and in the search field by *Title, Abstract and Keywords*, the keyword Six Sigma is used and not the specific area of Six Sigma, so that no paper with Six Sigma reference was found here.

In the area of AR, the same approach was also taken and AR was also abbreviated as action research and is not target-oriented for the present data collection. The results can be seen in Table 8.

The comparison of the results of the databases shows that identical publications and numbers of publications are found for most of the search terms, such as for the search term {Lean Management} AND {virtual reality}. At this point, it can already be stated that after searching both databases, the number of search results for the parameter VR is significantly more extensive than for the search parameter AR.

To further specify the results from Tables 4, 5, 6, 7, and 8, the search terms are extended. These can be seen in Table 9. An extension of the search term for the acronyms VR and AR is omitted, since this is not purposeful. In both databases, the search is also performed directly in the search field *Title, Abstract and Keywords.*

For the purpose to obtain a first impression of the data collection and the qualitative use to be derived from it, a limitation of the results in the three-digit range is considered reasonable and narrowed down accordingly, in the next step the inclusion and exclusion criteria are applied and selected according to the three-stage procedure (see sub-step 2.2 Selection of primary research).

2.3 Phase 3—evaluation of the SLR

The review of the publications, starting with the respective search terms from Table 2, 3, 4, 5, 6, 7, 8, and 9, leads to the assumption that the respective search terms represent a supposedly extensive literature. However, upon closer examination and the analysis performed by SLR, this unfortunately cannot be confirmed. A large number of the results are irrelevant due to the inclusion and exclusion criteria and lie outside the context of the targeted search terms.

After filtering the results, 58 publications were still available for detailed analysis. Of these, 39 publications could be assigned to the topic area of VR and AR combined with Lean Management and Six Sigma, while the other 19 publications focused on VR and AR in the context of education and concept development. To find an answer to RQ5, Fig. 2 serves as a first orientation.

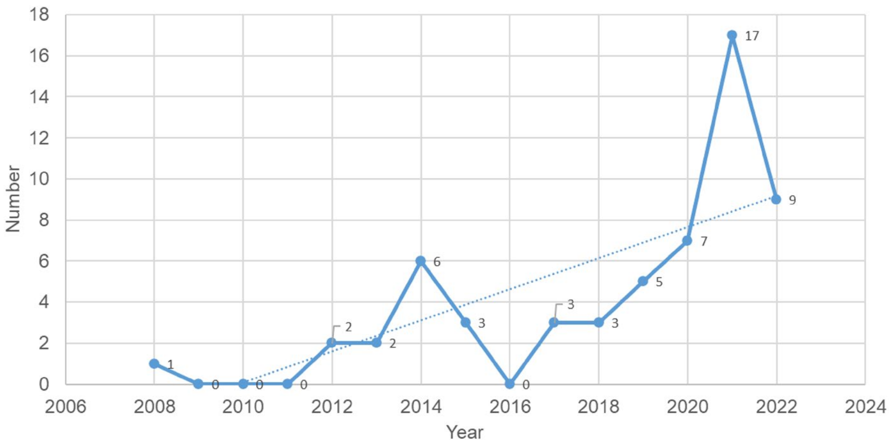

Fig. 2 Number of publications on the specific keywords per year I Own presentation

It should be noted here that the year 2022 has not yet been completed and is therefore only of limited informative value. Otherwise, a clear trend (dashed graph) can be seen in recent years. A particular increase can be seen from 2020 onwards.

This also confirms the chosen inclusion criterion of working with an unrestricted temporal view and is considered a sensible approach for the intended overview. With the present result, the period under consideration for future SLRs could now be narrowed down, for example from 2014 onwards. Due to the low number of publications, the optional criterion of excluding studies with a minimum of twenty citations was waived to comprehensively address the posed research questions.

The next step is the selection by full paper. As a result, 11 full publications are to be noted, which are to be used as further support for answering the research questions. The remaining publications deal with the technologies and their application as well as the applied search criteria, but they are missing an essential element of the focus of the present SLR and therefore they are not helpful in the overall context.

To ensure that the broadest possible spectrum of existing research work is reflected, a manual search is used, as explained in Phase 2—Implementation. In this process, additional publications and projects were added to the status quo. The results of both searches are shown in Table 10, 11, and 12. The listed results have different focuses, once the aspect of research projects (Table 10 and 11) and once the focus on paper (Table 12). Publications that were collected during the SLR or also during the manual search and refer to a project are not additionally noted. Starting with the following Table 10, the projects, their source and the hardware used in the project can be found.

As shown in Table 10 the projects already use head-mounted displays, so there is no need for further selection as envisaged in RQ2. For the project Lean Principles in Earthworks, the hardware usage could not be inferred.

Table 11 shows that few projects deal at all with Lean Management and VR/AR assistance systems as educational technology and publicize this effectively. The

Table 10 Overview of VR/AR research projects

QMS—Research projects	Representative source	Hardware
Portal— Virtuelle Handlungsaufgaben für personalisiertes adaptives Lernen Gestaltung von personalisierten Lernfabrikschulungen in Virtual Reality im Kontext schlanker Produktion (SLR)	Riemann, T.; Kreß, A.;Roth, L.; Görge, D.; Grell, P.: PortaL: Gestaltung von personalisierten Lernfabrikschulungen in Virtual Reality im Kontext schlanker Produktion. Digitale Arbeit, digitaler Wandel, digitaler Mensch? 66. Kongress der Gesellschaft für Arbeitswissenschaft, TU Berlin, Fachgebiet Mensch-Maschine-Systeme/HU Berlin, Professur Ingenieurpsychologie, 16.-18. März 2020, Berlin. GfA-Press, Dortmund 2020	HMD
VR on-site— Virtual Simulation and On-Site Training for First Responders	Mossel, A.; Schoenauer, C.; Froeschl, M.; Peer, A.; Goellner, J.; Kaufmann, H.: Immersive training of first responder squad leaders in untethered virtual reality. Virtual Reality 25 (2021) Nr. 3, S. 745–759	HMD + omnidirectional treadmill
Lean Masterclass— Leading Intelligent Lean—in the Gemba app (SLR)	Netland, T.; Hines, P.: Teaching in Virtual Reality: Experiences from a Lean Masterclass. In: Powell, D. J.; Alfnes, E.; Holmemo, M. D. Q.; Reke, E. (Hrsg.): Learning in the Digital Era. 7th European Lean Educator Conference, ELEC 2021, Trondheim, Norway, October 25–27, 2021, Proceedings. Springer eBook Collection. 610. 1st ed. 2021. Springer International Publishing; Imprint Springer, Cham 2021, S. 155–162	HMD
Anwendung von Lean-Prinzipien im Erdbau— Entwicklung eines Baustellenleitstands auf Basis von Virtual Reality	Kirchbach, K.: Anwendung von Lean-Prinzipien im Erdbau. Entwicklung eines Baustellenleitstands auf Basis von Virtual Reality, Zugl.: Karlsruhe, KIT, Diss., 2014. Karlsruher Reihe Technologie und Management im Baubetrieb. 69. KIT Scientific Publishing, Karlsruhe 2014	n. a
Virtual Quality Toolbox— Learning of quality management in immersive environment (SLR)	Gorski, F.; Starzynska, B.; Bun, P.; Kujawinska, A.: Virtual quality toolbox—learning of quality management in immersive environment. In: Bruzzone, A. G. (Hrsg.): The 4th International Conference of the virtual and augmented reality in Education (VARE 2018). Budapest, Hungary, 17—19 September 2018, Rende, Italy 2018, S. 177–182	HMD
WILLEN— Weiterbildungseffizienz durch aktivierende intelligente lernunterstützende Maßnahmen in nachhaltigen, berufsbegleitenden und hybriden Weiterbildungsprogrammen *	Karcher, A.; Prinz, C.; Arnold, D.; Kuhlenkötter, B.: Training von Qualitätsmethoden in der virtuellen Welt mittels VR-Brillen. ZWF 117 (2022) Nr. 6, S. 419–422	HMD

Table 10 (continued)

QMS—Research projects	Representative source	Hardware
iVRTrain LEAN 5S (Gray literature)	https://www.youtube.com/watch?v=3kJippmludA&ab_channel=IVRTrain	HMD

*Own current research work; HMD, head-mounted display; n. a., not available

Table 11 Overview of VR/AR projects incl. evaluation

Research projects	Assistance system		Secondary e.	Tertiary e.	Quaternary e.	QMS		
	VR	AR	Focus Apprenticeship	University	Further education	Lean Management	Six Sigma	Method
Portal	●	○	○	◑	●	●	○	Value stream analysis
VR on-site	●	○	○	○	●	◑	◑	PDCA-method (Realization of the Plan and Do phase)*
Lean Masterclass	●	○	○	●	◑	●	○	Gemba
Anwendung von Lean-Prinzipien im Erdbau	●	●	○	○	○	◔	○	After triage: Lean application should serve as a solution (outlook), concrete application not recognizable
Virtual Quality Toolbox	●	○	◑	○	◑	◑	◑	Pareto Diagram* Shewhart control chart* Histogram* Fishbone diagram (Ishikawa)* Affinity diagram* why?-why?-diagram* Force Field Analysis*
WILLEN	●	●	○	◑	●	●	●	Methods that overlap from both QMS
iVRTrain LEAN 5S	●	○	○	○	○	◕	○	5S-method

Legend: e. = education; Harvey Balls: Assessment of the degree of application of the respective QMS; * = Assignment retroperspective

Table 12 Overview of VR/AR Paper incl. rating

Publication	Assistance system		Secondary e.	Tertiary e.	Quaternary e.	QMS		
	VR	AR	Focus Apprenticesh ip	University	Further education	Lean Management	Six Sigma	Method
Lean Courses in Process Form - Do as We Learn, Success or Not?	●	○	○	●	○	●	○	PDCA
Immersive virtual reality to vindicate the application of value stream mapping in an US-based SME	●	○	○	○	○	◕	○	Value stream analysis
VR and AR in Lean Manufacturing Classes (SLR)	○	●	○	●	○	◑	○	5S-method
VR and AR in Lean Manufacturing Classes (SLR)	●	○	○	●	○	◔	○	a
A Case Study of Educational Games in Virtual Reality as a Teaching Method of Lean Management (SLR)	●	○	○	●	○	◕	○	5S-method
Adopting lean thinking in virtual reality-based personalized operation training using value stream mapping (SLR)	●	○	○	●	○	◑	○	Value stream analysis
The Application of Information Technologies in Consideration of Augmented Reality and Lean Management of Enterprises in the Light of Sustainable Development	○	●	○	○	○	◔	○	a
Contribution of Virtual Reality for Lines Production's Simulation in a Lean Manufacturing Environment	●	○	○	○	○	◔	○	a
Integrating lean production strategies, virtual reality technique and building information modeling method for mass customization in cabinet manufacturing	●	○	○	○	○	◔	○	a
Sustainability and Digitalization of Corporate Management Based on Augmented/Virtual Reality Tools Usage: China and Other World IT Companies' Experience	●	●	○	○	○	◔	○	a
Preliminary Methodology for the Integration of Lean Construction, BIM and Virtual Reality in the Planning Phase of Structural Intervention in Heritage Structures	●	○	○	○	○	◔	○	a
Augmneted reality in production management classes (SLR)	○	●	○	●	○	◑	○	5S-method (not in detail)
Immersive virtual reality deployment in a lean manufacturing environment (SLR)	●	○	○	●	○	◔	○	Lean principles/ waste (not in detail)

Legend: SLR = Source from SLR; e. = education; Harvey Balls: Assessment of the degree of application of the respective QMS; a = After triage: concrete Lean Managemnet applications not discernible

target group is further education, certain preliminary test runs are carried out with students, which is indicated by the corresponding Harvey Balls in Table 11.

Furthermore, the scope of the application or the direct reference to Lean Management is not always apparent. A specific project dealing with Six Sigma as well as

VR and AR was not found. In the case of the VR on-site project, it should be noted that none of the Quality Management Systems was mentioned by name, but the PDCA method[1] can be assigned to both QMS. The same applies to the Virtual Quality Toolbox (VQT) project. However, methods are used here that can be assigned more specifically to Six Sigma, such as the Pareto diagram. Since the project indirectly addresses both QMS, this will be explained in more detail. The VQT uses VR technology in seven lessons for learning quality tools. These lessons were Pareto diagram, Shewhart control chart, histogram, fishbone diagram, affinity diagram, why?-why?-diagram and force field analysis. These quality tools contain statistical methods, which are classically assigned to Six Sigma. The VR applications were found to be more attractive and convincing learning formats in direct comparison to classical formats, for example lectures, slides and written exercises. Furthermore, the independent learning and the presented interaction possibilities were evaluated as conducive to the project. It should be noted, however, that in the VQT's source reference no structured procedure model for the implementation of such training offers is recognizable. Likewise, no holistic concept in the sense of Lean Management or Six Sigma can be identified since the selection of the chosen methods at the VQT was subjective. Schematically structured, specific VR/AR learning scenarios to Six Sigma with the emphasis on further training are not well-known on basis of further literature searches (Zhao et al. 2019). The further results in this regard are presented in the following Table 12.

It can also be seen here that Lean Management is used in part and that no results can be found on the topic of Six Sigma coupled with VR and AR. It is noticeable that mainly students are focused on as the target group here and that no attention is paid to further education as a target group.

Up to this point the results were presented to the topic area VR and AR combined with Lean Management and Six Sigma. In the following the results with the topics VR and AR in connection with the topics education and concept development are to be represented. For this purpose, the following three publications are to be mentioned, which particularly stood out after reviewing the abstract and full paper and which most closely answer RQ3:

(1) Kavanagh et al. (2017)
(2) Makransky and Peterson (2021)
(3) Rojas-Sánchez et al. (2022)

Paper (1) is an extensive 2017 research that first presents a systematic review of the use of Virtual Reality in education as well as two shifting thematic analyses. The first analysis examined the applications and motivations for developing Virtual Reality education systems reported by educators in the academic literature, while the second examined the issues involved. There were 99 publications to choose from for

[1] PDCA stands for "Plan-Do-Check-Act" quality method and describes a cyclic process for continuous improvement of processes and workflows, involving creating a plan, implementing it, checking the results and taking appropriate actions.

evaluation, 19 publications could be assigned to the engineering application domain and 51% of the applications were within higher education. Further results can be found in the paper. Relevant at this point are the findings that despite the historically longer use of VR in education, acceptance continues to be a challenge, VR applications play only a minimal role in education and the factors of cost, user experience and interactivity play a crucial role in the use and continue to be explored today (Kavanagh et al. 2017).

The latter is also criticized in (2) that educational technologies are not yet adapted (enough) for their concrete use about current possibilities and challenges. Makransky and Petersen think that there is a lack of theories guiding research and application development. This lack is a major challenge in the field. Therefore, the authors feel it is important to develop a research-based theoretical model that provides an understanding of learning in immersive VR (Makransky and Petersen 2021). This paper reviews from the perspective of pedagogy and presents a model with cognitive influences on VR applications, but technical factors play a minor role.

The (3) paper addressed a similar question as RQ3, identified and analyzed the scientific literature with a bibliometric analysis of Virtual Reality and education. The Web of Science, Scopus and Lens databases were used for this purpose for the period 2010 to 2021. The focus of the search was on research publications, the applications of VR in teaching and learning processes in secondary and higher education and other applications in conferences or training processes. As a result, 273 publications published from 2020 to July 2021 inclusive were evaluated. A partial result is that VR is used in different parts of education, but a significant part of institutions still hesitate to include VR in teaching and learning processes. Another result to be repeated from the research is that VR favors self-learning, promotes motivation and engagement of students and educational staff in general and also increases the speed of learning. Another advantage of VR is seen in learning by experiencing and interacting with a (virtual) environment instead of passively receiving the information to be processed. Thus, increasing research interest and therefore increasing research activity in possible applications of VR/AR can be seen. In recent years, improvements in VR learning processes have been observed. Likewise, relevant progress in the application and use of this technology has been recorded. This can be attributed, among other things, to the evolution of VR learning environments: from multimedia to interactive environments with desktop and immersive VR processes, 360-degree tours and various applications and games. Although student engagement and motivation can be improved through the use of this technology, there is much to be learned about the use of e-learning tools, according to the authors (Rojas-Sánchez et al. 2022: 30). Due to the scope, traceability and timeliness of the paper, this source is taken as the basis for answering RQ4, as the authors' search terms were not sufficient or there is a need for another very comprehensive SLR.

2.4 Phase 3—responding to the RQs

Following the responses will be presented in a consolidated manner for each RQ based on the findings of the analysis presented in Sect. 2.3, commencing with RQ 1.

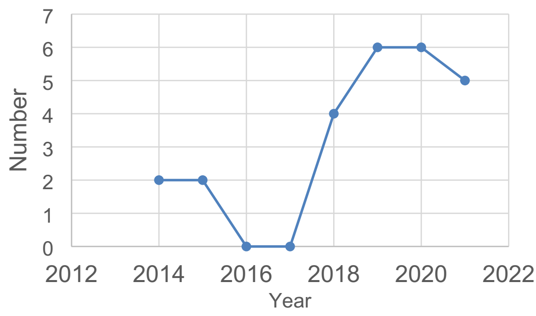

Fig. 3 Trend curve QMS application in VR/AR

RQ1: Are VR/AR used to teach QMS?

A small number of applications can be identified (see Tables 11, 12), mainly Lean Management is implemented in the context of Virtual Realtiy, significantly less in the area of Augmented Reality. For Six Sigma two research works could be identified, but except for the ongoing WILLEN project no further research work on the topic of Six Sigma and Augmented Reality. When looking at projects, the use of Lean Management is mainly analyzed in university and further education contexts, when looking at contributions, the addressee group of universities is exclusively considered. Regardless of the projects or contributions mentioned, it can be stated that the majority of the research work is still at an early stage and shows little progress. There is a huge need to further develop this research by both developing and creating it and studying its impact, such as acceptance of their use in application.

RQ2: Which VR/AR systems are used in conjunction with QMS?

Head-mounted displays were mostly used for these applications, be it a wired or standalone variant, to enable the highest possible interaction and immersive experience. In the area of AR, AR data glasses were also used as in the VR area, see Table 10.

RQ3: Are there implementation models for the use of VR/AR techniques?

A fully comprehensive model was not identified. A model that considers an educational focus, learning as well as cognitive factors was analyzed, see Sect. 2.3. However, the technical factors influencing it are presented in a minor way, leaving open the question of which learning content it should be applied to.

RQ4: Are VR/AR used for training in the education sector?

VR and AR are used in the education sector, see Table 11. The focus here is on use within university education, see Table 12.

RQ5: Can a trend of research on the use of VR/AR systems in the context of QMS be identified?

From the independent research work carried out as well as the SLR carried out here, a clear trend can be seen in VR applications, with an upward tendency (see Fig. 2). In the case of the publications and projects with a thematic focus on QMS that serve as a basis, an increasing trend can also be seen, which is shown in Fig. 3.

This increasing growth must be further promoted and different applications developed, especially in the area of QMS, to achieve the broadest and most diverse spectrum of virtual learning environments possible. This means, for example, virtual learning environments that represent different levels of difficulty in the tasks or cover different learning types and can thus be used flexibly.

3 Summary and future work

The goal of the present analysis is to provide an overview of the current state of the research in the development of virtual learning applications in the field of Quality Management Systems. For this purpose, a SLR was conducted, which includes several steps, including the definition of research questions. For this SLR, five research questions were formulated looking at aspects such as the context and use of QMS in conjunction with VR/AR technology, as well as the education sector. Based on these research questions, formal and content inclusion and exclusion criteria were established to assist in the selection of research findings. These criteria include, for example, the choice of language, the combination of keywords in the abstract, the definition of the hardware used and no time limit on the period of analysis. With these defined framework conditions, the SLR was performed and the intermediate results were presented in tabular form. Various search parameters were used to identify the relevant studies and to document the results accordingly. Based on the SLR conducted, which was unrestricted during the entire period under consideration and thus could consider all results of the databases used until the beginning of 2022, an increasing use of assistance systems such as VR and AR as educational technologies becomes apparent. Here, an increasing trend can be seen from 2017 onwards. However, these need to be researched further, as only a small number of projects on the main topics of QMS, education and models can be taken. Exemplary sub-topics in VR and AR research are to analyze the concrete applications in terms of acceptance, user experience and interactivity. Likewise, the pedagogical integration related to these educational technologies offers a broad spectrum of research. While initial applications of quality methods of VR and AR can be seen, no unified method, concept, or tool has been used. Consequently, further VR and AR applications should be developed, especially in the field of AR. Despite the potential of VR and AR in education, the review identifies several research gaps. There is a need for a more comprehensive and unified approach to the development of VR-based educational content, particularly concerning technical, didactic and methodological considerations. This requires a conceptual approach that combines the requirements of developers from the fields of programming and didactics, operators, users and educators and can take into account the various aspects and the impact on learning. As a result, questions can be derived as to what a procedural model for assessment, selection, implementation and evaluation might look like and whether it can be generalized, for example applied to other methods. A possible model for this could be the Assisted Reality Implementation Model, which is to be created based on the SLR presented here. Further research topics can be to analyze the effectiveness of VR/AR in quality methods education. This means to investigate the effectiveness of VR and AR in teaching quality management methods like Lean Management and Six Sigma. Conduct controlled experiments to measure learning outcomes, retention rates and skill development when compared to traditional classroom instruction. Also the development of Pedagogical Strategies for Immersive Learning. This includes to explore pedagogical strategies optimized for immersive learning environments. Investigate how instructional design, feedback mechanisms and interactive elements in VR and AR environments can enhance the learning experience, particularly in quality management education. It would also be interesting to analyze investigate methods to make VR and AR education more accessible and inclusive. Address issues related to cost, hardware requirements and the needs of learners with disabilities to ensure equitable access to immersive learning experiences. Also interesting areas are the topics such as Ethical Considerations and Cost–Benefit Analysis. The first one means to address ethical considerations in VR and AR education, particularly regarding data privacy, user consent and the potential for bias in content delivery. Develop best practices and guidelines for ethical immersive education. The second one conduct cost–benefit analyses to determine the economic viability of implementing VR and AR in quality methods education. Assess the return on investment for educational institutions and organizations adopting these technologies. This research agenda aims to guide future studies in the field of VR and AR in quality methods education, offering specific areas for exploration and development. These research endeavors will contribute to a deeper understanding of how VR/AR technologies can enhance the teaching and learning of quality management methods and their broader applications in education.

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Data availability The data that support the findings of this study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

References

Albliwi SA, Antony J, Lim SAh (2015) A systematic review of Lean Six Sigma for the manufacturing industry. Bus Process Manag J 21:665–691. https://doi.org/10.1108/BPMJ-03-2014-0019

Babar MA, Zhang H (2009) Systematic literature reviews in software engineering: preliminary results from interviews with researchers. In: 2009 3rd international symposium on empirical software engineering and measurement. IEEE, pp 346–355

Berntsen K, Palacios RC, Herranz E (2016) Virtual reality and its uses—systemativ literature review. In: García-Peñalvo FJ (ed) Proceedings of the fourth international conference on technological ecosystems for enhancing multiculturality. ACM, New York, NY, USA, pp 435–439

Bernuy C, Chumbe S, Garcia C (2021) Virtual reality (VR) in superior education distance learning: a systematic literature review. Int J Inform Vis 5:264. https://doi.org/10.30630/JOIV.5.3.632

Blömer L, Voigt C, Hoppe U (2020) Corona-Pandemie als Treiber digitaler Hochschullehre. In: Zender R, Ifenthaler D, Leonhardt T, Schumacher C (eds) DELFI 2020: Die 18. Fachtagung Bildungstechnologien der Gesellschaft für Informatik e.V.: 14–18. September 2020, Online. Gesellschaft für Informatik, Bonn

Boell SK, Cecez-Kecmanovic D (2015) Debating systematic literature reviews (SLR) and their ramifications for IS: a rejoinder to Mike Chiasson, Briony Oates, Ulrike Schultze, and Richard Watson. J Inf Technol 30:188–193. https://doi.org/10.1057/jit.2015.15

Booth A, Sutton A, Papaioannou D (2016) Systematic approaches to a successful literature review. SAGE, Los Angeles

Brereton P, Kitchenham BA, Budgen D, Turner M, Khalil M (2007) Lessons from applying the systematic literature review process within the software engineering domain. J Syst Softw 80:571–583. https://doi.org/10.1016/j.jss.2006.07.009

Carnerud D (2018) 25 years of quality management research—outlines and trends. IJQRM 35:208–231. https://doi.org/10.1108/IJQRM-01-2017-0013

Checa D, Bustillo A (2020) A review of immersive virtual reality serious games to enhance learning and training. Multimed Tools Appl 79:5501–5527. https://doi.org/10.1007/s11042-019-08348-9

Crute V, Ward Y, Brown S, Graves A (2013) Implementing Lean in aerospace-challenging the assumptions and understanding the challenges. In: Technovation, pp 917–928

Denyer D, Tranfield D (2009) Producing a systematic review. In: Buchanan DA, Alan B (eds) The Sage handbook of organizational research methods. SAGE Publications Ltd, Los Angeles, pp 671–689

Deuse J, Weisner K, Hengstebeck A, Busch F (2015) Gestaltung von Produktionssystemen im Kontext von Industrie 4.0. In: Zukunft der Arbeit in Industrie 4.0. Springer, Berlin, Heidelberg, pp 99–109

Dey A, Billinghurst M, Lindeman RW, Swan JE (2018) A systematic review of 10 years of augmented reality usability studies: 2005 to 2014. Front Robot AI 5:37. https://doi.org/10.3389/frobt.2018.00037

Domingueti DB, Dias DRC, Guimarães MdP, Carvalho DBF (2021) Evaluation methods applied to virtual reality educational applications: a systematic review. In: Gervasi O, Murgante B, Misra S, Garau C, Blečić I, Taniar D, Apduhan BO, Rocha AMAC, Tarantino E, Torre CM (eds) Computational science and its applications – ICCSA 2021: 21st international conference, Cagliari, Italy, September 13–16, 2021, Proceedings, Part X, 1st edn., vol 12958. Springer, Imprint Springer, Cham, pp 641–657

Dybå T, Kitchenham B, Jorgensen M (2005) Evidence-based software engineering for practitioners. IEEE Softw 22:58–65. https://doi.org/10.1109/MS.2005.6

Dybå T, Dingsøyr T (2008) Strength of evidence in systematic reviews in software engineering. In: Rombach D, Elbaum S, Münch J (eds) Proceedings of the second ACM-IEEE international symposium on empirical software engineering and measurement - ESEM '08. ACM Press, New York, New York, USA

Eswaran M, Bahubalendruni MVAR (2022) Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: a state of the art review. J Manufact Syst 65:260–278. https://doi.org/10.1016/j.jmsy.2022.09.016

Fisch C, Block J (2018) Six tips for your (systematic) literature review in business and management research. Manag Rev Q 68:103–106. https://doi.org/10.1007/s11301-018-0142-x

Freina L, Ott M (2015) A literature review on immersive virtual reality in education: state of the art and perspectives. In: 11th international conference elearning and software for education. Carol I National Defence University Publishing House, pp 133–141

Halawi A, Haydar N (2013) Effects of training on employee performance. Int Humanit Stud 5:137–147

Hertel J, Karaosmanoglu S, Schmidt S, Braker J, Semmann M, Steinicke F (2021) A taxonomy of interaction techniques for immersive augmented reality based on an iterative literature review. In: 2021 IEEE international symposium on mixed and augmented reality (ISMAR). IEEE, pp 431–440

Ho PT, Albajez JA, Santolaria J, Yagüe-Fabra JA (2022) Study of augmented reality based manufacturing for further integration of quality control 4.0: a systematic literature review. Appl Sci 12:1–51. https://doi.org/10.3390/app12041961

Horst R, Naraghi-Taghi-Off R, Rau L, Dörner R (2021) Remote emergency teaching and virtual reality education: a case-study using VR nuggets in non-VR courses. In: Lingnau A (ed) DELFI2021 19. Fachtagung Bildungstechnologien der GI: proceedings of DELFI workshops 2021. Hochschule Ruhr West 2021, pp 35–46

Ilangakoon TS, Weerabahu SK, Samaranayake P, Wickramarachchi R (2022) Adoption of Industry 4.0 and lean concepts in hospitals for healthcare operational performance improvement. IJPPM 71:2188–2213. https://doi.org/10.1108/IJPPM-12-2020-0654

Kavanagh S, Luxton-Reilly A, Wuensche B, Plimmer B (2017) A systematic review of virtual reality in education. Themes Sci Technol Educ 10:85–119

Kitchenham B (2004) Procedures for performing systematic reviews. Keele University, Keele, p 33

Kitchenham B, Brereton P, Budgen D, Turner M, Bailey J, Linkman S (2009) Systematic literature reviews in software engineering: a systematic literature review. Inf Softw Technol 51:7–15. https://doi.org/10.1016/j.infsof.2008.09.009

Kitchenham B, Charters SM (2007) Guidelines for performing systematic literature reviews in software engineering, vol 2. https://www.researchgate.net/publication/302924724_Guidelines_for_performing_Systematic_Literature_Reviews_in_Software_Engineering

Kohl C, McIntosh EJ, Unger S, Haddaway NR, Kecke S, Schiemann J, Wilhelm R (2018) Online tools supporting the conduct and reporting of systematic reviews and systematic maps: a case study on CADIMA and review of existing tools. Environ Evid 7:1–17. https://doi.org/10.1186/s13750-018-0115-5

Kolberg D, Zühlke D (2015) Lean automation enabled by Industry 4.0 Technologies. In: IFAC-PapersOnLine, pp 1870–1875

Krüger J, Lausberger C, von Nostitz-Wallwitz I, Saake G, Leich T (2020) Search. Review. Repeat? An empirical study of threats to replicating SLR searches. Empir Software Eng 25:627–677. https://doi.org/10.1007/s10664-019-09763-0

Kurniawan C, Rosmansyah Y, Dabarsyah B (2019) A systematic literature review on virtual reality for learning. In: Proceeding of 2019 the 5th international conference on wireless and telematics (ICWT): 25–26 July 2019, Sahid Jaya Hotel & Convention, Yogyakarta, Yogyakarta, Indonesia. IEEE, Piscataway, NJ

Lenarduzzi V, Taibi D (2016) MVP explained: a systematic mapping study on the definitions of minimal viable product. In: 2016 42th Euromicro conference on software engineering and advanced applications (SEAA). IEEE, pp 112–119

MacDonell S, Shepperd M, Kitchenham B, Mendes E (2010) How reliable are systematic reviews in empirical software engineering? IEEE Trans Software Eng 36:676–687. https://doi.org/10.1109/TSE.2010.28

Mak SL, Tang FWF, Li CH, Lee GTW, Chiu WH (2020) A review on development and application of virtual reality (VR) training platform for testing, inspection and certification industry. IJIET 10:926–931

Makransky G, Petersen GB (2021) The cognitive affective model of immersive learning (CAMIL): a theoretical research-based model of learning in immersive virtual reality. Educ Psychol Rev 33:937–958. https://doi.org/10.1007/s10648-020-09586-2

Molzbichler D, Sturmer M (2022) Zehn Empfehlungen für mehr Produktivität. In: Molzbichler D, Sturmer M (eds) Ubuntu - Mandela für Führungskräfte: Anregungen für Selbstmanagement, Teamarbeit und Konfliktlösung. Springer Gabler, Wiesbaden, Germany, pp 21–24

Muhlan K, Przybysz KA, Lindner F, Akrmanova D, Winkler D, Keil S (2021) A review and implementation framework of industrial augmented reality. In: 2021 26th IEEE international conference on emerging technologies and factory automation (ETFA). IEEE, pp 1–4

Mystakidis S, Christopoulos A, Pellas N (2022) A systematic mapping review of augmented reality applications to support STEM learning in higher education. Educ Inf Technol 27:1883–1927. https://doi.org/10.1007/s10639-021-10682-1

Noah N, Das S (2021) Exploring evolution of augmented and virtual reality education space in 2020 through systematic literature review. Comput Anim Virtual Worlds. https://doi.org/10.1002/cav.2020

Oon F-Y, Aziati AHN, Abu ASE (2021) Business excellence, leadership and lean: a systematic literature review. IJBS 22:332–345. https://doi.org/10.33736/ijbs.3178.2021

Paszkiewicz A, Salach M, Strzałka D, Budzik G, Nikodem A, Wójcik H, Witek M (2022) VR education support system—a case study of digital circuits design. Energies 15:277. https://doi.org/10.3390/en15010277

Phutrakool P, Pongpirul K (2022) Acceptance and use of complementary and alternative medicine among medical specialists: a 15-year systematic review and data synthesis. Syst Rev 11:1–14. https://doi.org/10.1186/s13643-021-01882-4

Quandt M, Freitag M (2021) A systematic review of user acceptance in industrial augmented reality. Front Educ 6:700760. https://doi.org/10.3389/feduc.2021.700760

Radianti J, Majchrzak TA, Fromm J, Wohlgenannt I (2020) A systematic review of immersive virtual reality applications for higher education: design elements, lessons learned, and research agenda. Comput Educ 147:103778. https://doi.org/10.1016/j.compedu.2019.103778

Ređep T, Hajdin G (2021) Use of augmented reality with game elements in education. JIOS 45:473–494. https://doi.org/10.31341/jios.45.2.7

Riemann T, Kreß A, Roth L, Klipfel S, Metternich J, Grell P (2020) Agile implementation of virtual reality in learning factories. Procedia Manuf 45:1–6. https://doi.org/10.1016/j.promfg.2020.04.029

Rojas-Sánchez MA, Palos-Sánchez PR, Folgado-Fernández JA (2022) Systematic literature review and bibliometric analysis on virtual reality and education. Educ Inf Technol. https://doi.org/10.1007/s10639-022-11167-5

Saad SM, Bhovar C, Bahadori R, Zhang H (2021) Industry 4.0 application in lean manufacturing: a systematic review. In: Shafik M, Case K (eds) Advances in manufacturing technology XXXIV. IOS Press

Salentijn W, Beijer S, Antony J (2021) Exploring the dark side of Lean: a systematic review of the lean factors that influence social outcomes. TQM 33:1469–1483. https://doi.org/10.1108/TQM-09-2020-0218

Segovia D, Ramírez H, Mendoza M, Mendoza E, González E (2015) Machining and dimensional validation training using augmented reality for a lean process. Procedia Comput Sci 75:195–204

Senderek R, Geisler K (2015) Assistenzsysteme zur Lernunterstützung in der Industrie 4.0. In: Proceedings of DeLFI workshops 2015 co-located with 13th e-learning conference of the German Computer Society, pp 36–46

Shakeel Y, Krüger J, Nostitz-Wallwitz I von, Lausberger C, Durand GC, Saake G, Leich T (2018) (Automated) literature analysis. In: Carver JC, Hong NPC, Jay C (eds) Proceedings of the international workshop on software engineering for science. ACM, New York, NY, USA, pp 20–27

Theodoropoulos A, Lepouras G (2021) Augmented reality and programming education: a systematic review. Int J Child-Comput Interact. https://doi.org/10.1016/j.ijcci.2021.100335

Tranfield D, Denyer D, Smart P (2003) Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br J Manag 14:207–222. https://doi.org/10.1111/1467-8551.00375

vom Brocke J, Simons A, Riemer K, Niehaves B, Plattfaut R, Cleven A (2015) Standing on the shoulders of giants: challenges and recommendations of literature search in information systems research. CAIS 37:205–224. https://doi.org/10.17705/1CAIS.03709

Webster J, Watson RT (2002) Analyzing the past to prepare for the future: writing a literature review on JSTOR. https://www.jstor.org/stable/4132319?seq=1. Accessed 29 May 2022

Wildemann H (2020) Produktivität durch Industrie 4.0, 2nd edn. TCW, vol 34. TCW Transfer-Centrum GmbH et Co. KG, München

Zahabi M, Abdul Razak AM (2020) Adaptive virtual reality-based training: a systematic literature review and framework. Virtual Real 24:725–752. https://doi.org/10.1007/s10055-020-00434-w

Zahedi M, Shahin M, Ali-Babar M (2016) A systematic review of knowledge sharing challenges and practices in global software development. Int J Inf Manag 36:995–1019. https://doi.org/10.1016/j.ijinfomgt.2016.06.007

Zhang H, Ali-Babar M (2010) On searching relevant studies in software engineering. In: BCS learning & development

Zhang H, Kitchenham B, Pfahl D (2008) Software process simulation modeling: an extended systematic review. In: Wang Q, Pfhal D, Raffp DM (eds) Making globally distributed software development a success story: international conference on software process, ICSP 2008, Leipzig, Germany, May 10–11, 2008 ; proceedings, vol 6195. Springer, Berlin, Heidelberg, pp 309–320

Zhao H, Zhao QH, Ślusarczyk B (2019) Sustainability and digitalization of corporate management based on augmented/virtual reality tools usage: china and other world IT companies' experience. Sustainability 11:4717. https://doi.org/10.3390/su11174717