Requirements for the Implementation of Virtual Reality in Learning Factories

Methodology and outcomes of a systematic literature review

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PORTAL

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Abstract

Current trends such as increasing flexibility and new digital technologies are changing the jobs in the modern manufacturing industry and constantly demand new competencies from its employees. Therefore, companies are focusing on the training and competency development of their employees. In the context of this trend, learning factories play an increasingly important role. They offer an environment in which employees can develop competencies under practice-oriented conditions. The Institute for Production Management, Technology and Machine Tools (PTW) at the Technical University Darmstadt operates a modern learning factory called CiP (Center for Industrial Productivity) for research, training and education purposes. Within the on-going interdisciplinary research project "PortaL" (Virtual action tasks for personalized adaptive learning) the institute develops personalized virtual reality training scenarios that are intended to become part of trainings within the learning factory.

This paper presents the methodology and results of a systematic literature review to determine general requirements for the implementation of virtual reality in learning factories. The determined requirements are presented and classified into eleven clusters. This leads to a well-structured illustration to support learning factory operators, software developers, and researchers not to lose sight of the different requirements from the literature during the development, evaluation, and optimization of virtual reality in learning factories.

Keywords: Virtual Reality, Learning Factory, Requirements

1 Introduction

Globalization and digitalization, an increasing variety of variants and the constant efforts for continuous improvement are changing the workplaces in all areas of companies. This also requires employees in production to develop new competencies. Conventional forms of teaching and learning are, however, only suitable to a limited extent for the development of new competencies. Therefore, new innovative forms of teaching and learning are being developed and tested. One of these innovative approaches is action-based learning (NAIDU & BEDGOOD 2012). For this purpose, learning factories offer a suitable infrastructure. They provide a practical learning environment for employees to get acquainted with new methods and new technologies to develop the needed competencies in a realistic environment (ABELE ET AL. 2019).

The use of modern media such as Virtual Reality (VR) is becoming increasingly important in production and professional training and opens up new opportunities (ABELE ET AL. 2017). VR enables users to enter and interact with a virtual 3D environment with the help of special glasses (Head-mounted displays, HMD). The technology offers many advantages, especially when real training would be associated with high costs or with high risks for learners. First promising experiences with VR in the field of further education have already been made and improved access to educational content in some areas has been proven (HAGHIGHI 2013, ZOBEL ET AL. 2018).

Within the framework of the interdisciplinary research project “PortaL”, virtual training scenarios are integrated into an existing training concept of the Process Learning Factory “Center for Industrial Productivity” (CiP) of the Technical University Darmstadt. To ensure a high level of quality, a variety of requirements for the application of VR in Learning Factories must be fulfilled. Therefore, a systematic literature review was carried out to identify these requirements. This paper will explain the methodology of the applied systematic literature review, discuss the results, and present a well-structured overview of the requirements. The results obtained offer learning factory operators a valuable tool for implementing VR in their learning factories.

2 Methodology

A systematic literature review is a systematic, precise, comprehensive, and reproducible method for identifying, evaluating, and interpreting the state of the art in science. It is a key instrument for an effective and unprejudiced investigation of a large and constantly growing pool of literature. With the use of online literature databases, the acquisition of literature is considerably simplified and no longer tied to a specific location (FINK 2010).

The applied methodology for the studies carried out consists of four phases. It is based on the ideas of the authors Fink and Potempa, who introduce different methods for systematic literature reviews. The four phases of the applied methodology are outlined further below (FINK 2010, POTEMPA ET AL. 2001).

Phase I

In the first phase of the systematic literature review, the research question is defined. It serves as a starting point and is expressed as follows (BAUER ET AL. 2013, WOLFSBERGER 2010):

What are the requirements for the implementation of VR in learning factories?

In addition to the research question, the objective framework and restrictions of the research are specified. This is also called practical screening. Essential aspects of the practical screening are the selection of databases, definition of the period of observation, literature formats, and languages (FINK 2010, MACHI/MCEVOY 2009).

This systematic literature review uses three literature databases that provide a large number of relevant articles while keeping the number of duplicates limited. Both the concept of learning factories and VR technology have gained high importance in the current decade in the economy, science, and academia. For example, the number of "learning factory" listings on Google Scholar has approximately quadrupled since 2014. Due to the strong intensification of research efforts on learning factories, as well as VR in recent years, only literature from 2013 on is taken into account. Figure 1 summarizes the framework conditions of practical screening.

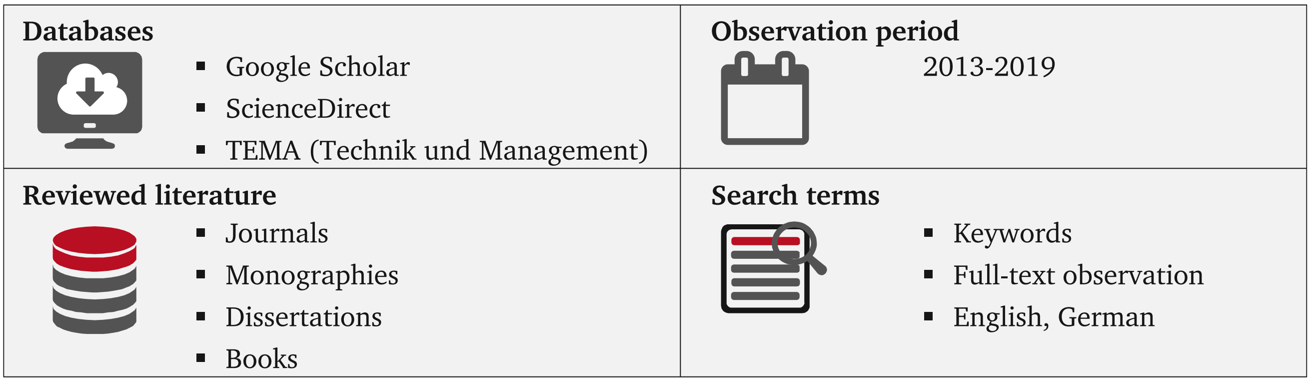

Figure 1: Practical screening conditions

Phase II

The second phase of the methodology serves to determine appropriate search terms. This is a prerequisite for the efficient use of literature databases (OBST 2011).

Based on the research question, the keywords “Virtual Reality” and “Learning Factory” can be identified directly by intuitive looking. These keywords serve as a starting point and are supplemented by common abbreviations and synonyms with the help of the Integrated Authority File (German: Gemeinsame Normdatei GND). This results in two keyword-groups summarized in Figure 2 (GERMAN NATIONAL LIBRARY):

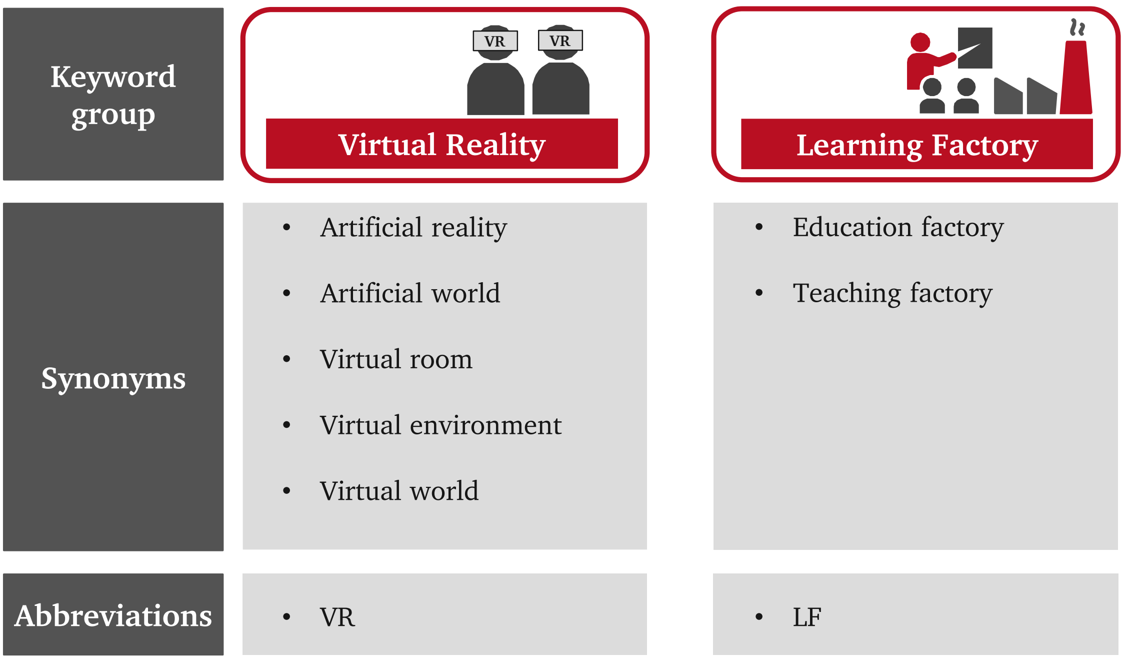

Figure 2: Identified literature keywords

The search will be limited to literature that contains keywords of both groups: “Learning Factory” and “VR”. The plural forms and abbreviations were also taken into account. The link between the terms listed is hence "and". Based on this approach, a total of 311 titles were found in the three databases after removing duplicates.

Phase III

Although the required keywords appear in each of the 311 publications, their relevance for the research question varies. To reduce the number of publications to a manageable amount and avoid dismissing the important requirements, a three-stage filtering process is applied in the third phase. The first stage uses the algorithms of the databases that promise to list its hits with descending relevance. This allows scaling the hit lists by excluding the publications on the lower ranks. To reduce the number of hits to a manageable number, a scaling factor of 25% was chosen (BABIAK 1999). In the second stage, the headings of the remaining publications are reviewed. To pass this stage, a word must be in context with at least one of the following topics:

- Factory/production
- Education/further training
- VR or other digital visualization technology

In the third phase, the abstracts of the remaining publications are examined. The review of the abstracts allows a more precise assessment of whether the title contains requirements. The criteria are therefore more stringent than in the second stage. Publications are dismissed if their abstract is not in context with at least two of the topics. If there is no abstract available, the summary or introduction of the publication is used for the review. Figure 3 visualizes the quantitative reduction of literature along the three outlined filter stages.

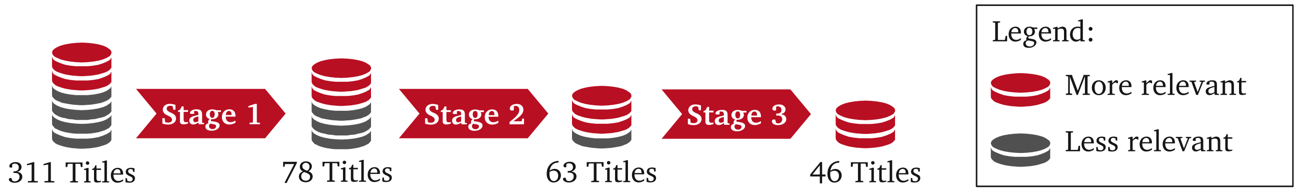

Figure 3: Three-stage literature filtration process

Phase IV

In the fourth and final phase of the methodology, the full texts are scanned for requirements. Various reading techniques are used for this purpose (ZIELKE 1976):

- Informative reading
- Selective reading

- Rational reading

The efficient application of reading techniques enables the handling of large volumes of literature in a reasonable time. The result of this process is described in Chapter 4.

3 Results and discussion

As an outcome of the previously explained systematic literature review, 43 requirements were identified in total. The requirements can be subdivided into eleven clusters for further classification in an inductive process:

- Ethics/Environment/ Compliance
- Economy
- Feedback/Support
- Individuality
- Immersion
- Information-Input
- Infrastructure
- Safety
- Flexibility
- Practical relevance
- Staff

Within the eleven clusters, 41 of the 43 identified requirements could be classified. Two requirements remained unassigned to any of the eleven clusters. These are listed under "others".

Table 1: List of identified requirements

Cluster	#	*Requirement*	Description/ citation	Author (Year)
Ethics/Environment/ Compliance	1	*Include physically disabled people*	Disabled persons in wheelchairs should not be excluded and be able to develop relevant competencies.	POSADA ET AL. (2018)
	2	*Save resources*	Save resources through the use of the synergy effects between different learning factories, to share physical equipment and create a common cloud for virtual environments.	WEEBER ET AL. (2016)
Economy	3	*Reduce costs*	Virtual simulation of various scenarios saves costs compared to training in a real environment.	HAGHIGHI (2013)
Feedback/Support	4	*Give permanent feedback*	"[…] give constant feedback about the learning progress."	ABELE ET AL. (2016)
	5	*Warn and instruct users*	Point out the potential consequences of errors to clarify the need for proper action.	LONGO ET AL. (2017)
	6	*Give visual, acoustic and haptic feedback*	The use of various senses in feedback stimulates the ability to memorize.	TOLIO ET AL. (2019)
	7	*Use motivating and warning sound effects*	“To motivate the learners, sounds and experience points are used to reward the worker for correct actions. Sounds are also used to warn in case of incorrect actions.“	MÜLLER ET AL. (2016)
	8	*Give trainer support*	"Therein, trainers support learners within the processes necessary to acquire intended competencies."	ULLRICH ET AL. (2019)
	9	*Use supportive animations and a consulting tool*	Animations with information about the process, product, etc. should be used.	HAGHIGHI (2013)

	10	*Encourage users to test limits*	The user should be motivated to test the limits of the system and to experience the consequences of exceeding them. This should help him to act reflectively in practice.	QUINT ET AL. (2015a)
	11	*Contact person/expert virtually*	Experts to support the user in case of questions or if he does not know what to do can be contacted in VR.	WEIDIG ET AL. (n.d.)
	12	*Attract attention*	The virtual environment should be designed to attract attention of the participants, e.g. by highlighting objects with signal colors.	MAVRIKIOS ET al. (2019)
Individuality	13	*Consider diverse professional backgrounds*	Target groups with divers professional background should be considered.	HAGHIGHI (2013)
	14	*Consider different types of learning*	Adapt teaching methods to different types of learners to achieve optimal learning success.	HAGHIGHI (2013)
	15	*Implement different levels of difficulty*	Simplifications for participants who lack the necessary know-how should be implemented.	PLORIN ET AL. (2015)
	16	*Enable independent learning pace*	"After the introduction, the students will perform the needed tasks in separate groups at their own pace."	TOIVONEN ET AL. (2018)
	17	*Consider the adaptability of the participants*	Some (older) workers have problems adapting to new technologies. This problem is exacerbated by demographic change.	ULLRICH ET AL. (2019)
	18	*Enable a customized curriculum*	Modularization of the learning content enables a customized configuration of the training.	LANZA ET AL. (2015)
	19	*Bridge gaps in education and training*	Job requirements do often not match or exceed the content of the training. Trainings in VR should bridge these gaps.	CONRAD ET AL. (2019)
	20	*Entrance classification test*	Link previous knowledge e.g. by little games like pairing pictures or words and match training contents to the results.	MÜLLER ET AL. (2016)
	21	*Avoid over-complex visualization*	"The right "amount" of immersion and interaction should be carefully considered case by case to avoid too complex [immersive virtual environments], with possible consequent drawbacks [...]."	MILELLA (2015)
	22	*Use realistic light effects*	The light effects should be realistic.	MILELLA (2015)
Information-Input	23	*Use eye control*	Enable the use of hands for other purposes.	POSADA ET AL. (2018)
	24	*Consider intuitive operability*	The handling of virtual objects should be intuitive.	MÜLLER ET AL. (2016)
	25	*Use gesture control*	Replace clicks with gesture control to simplify user inputs.	QUINT ET AL. (2015b)
	26	*Consider different devices to interact with the environment*	A wide range of interactive devices like 3D mice, data gloves, Wii-motes, and force-feedback/haptic arms/joysticks should be considered.	MILELLA (2015)
	27	*Use voice control*	Enable the use of hands for other purposes, as well as for the inclusion of people with disabilities.	POSADA ET AL. (2018)
Infrastructure	28	*Supplement real training*	"[…] acquired learning experiences may have more potential to get forgotten without further physical practice."	HAGHIGHI (2013)
	29	*Consider the IT infrastructure*	A modern IT infrastructure is required for the implementation of VR. Otherwise, an initial investment is required to set it up.	HAGHIGHI (2013)

Safety	30	*Consider operating manuals, safety guidelines of reality*	Behavior must comply with guidelines and laws. Learning factory training should not lead to misconduct in practice (e.g. switch off the machine completely before cleaning procedures).	LONGO ET AL. (2017)
	31	*Enable safe training of high-risk situations*	Training in high-risk situatios (such as fire to practice the behavior in case of emergency without risk) can be enabled. Even working with robots can be trained safely.	HAGHIGHI (2013)
	32	*Consider data security and protection*	Data security is listed as a current and future requirement for learning factories.	ULLRICH ET AL. (2019)
Flexibility	33	*Enable spatial independence*	The physical presence of participants is often difficult due to large travel distances.	HAGHIGHI (2013)
	34	*Enable temporal independence*	Adaptation of the training to the participants' schedules should be enabled, as long as they can train from home or their workplace (especially modules without trainer support).	HAGHIGHI (2013)
Practical relevance	35	*Implement practice-oriented tasks*	"Learning factories [...] challenges comparable to those of real factories" should be implemented.	ULLRICH ET AL. (2019)
	36	*Introduce up-to-date technologies*	"An ulterior strategic goal is to offer direct or simulated experience with practical relevant up-to-date technologies in production."	ULLRICH ET AL. (2019)
	37	*Consider a wide range of machines and tools*	Equipment of physical learning factories can be limited due to high costs.	MOURTZIS ET AL. (2018)
	38	*Encourage proactive and innovative action*	"Effective knowledge transfer requires companies to develop a learning environment where employees are encouraged to be pro-active and innovative in problem-solving."	KARRE ET AL. (2019)
	39	*Demand agile actions*	Unexpected events that require agile action should be considered. Examples are fluctuations in demand and supply problems.	KARRE ET AL. (2019)
Team	40	*Change of perspective*	After the training, group discussions involving professionals to understand their perspective should be implemented.	CONRAD ET AL. (2019)
	41	*Use of a multi-user-platform*	It should be possible to work on team tasks together with other training participants in VR.	POSADA ET AL. (2018)
Others	42	*Standardize the training and further education*	The learning content should be standardized.	HAGHIGHI (2013)
	43	*Gamify*	Entertaining game elements increase the motivation of the learner.	ABELE ET AL. (2017)

To ensure the comprehensibility of the classification of the requirements into clusters, the contexts in which the respective author describes the requirement are now briefly explained. For this purpose, the author and the year of publication are given first, so that the respective literature can be identified with the help of the bibliography. Furthermore, the code numbers of the requirements identified are given, under which they are listed in the list of identified requirements.

Table 2: Context of the identified requirements

<table>
<tr><th>Author (year): Posada et al. (2018)</th><th>Requirement-Number: 1, 23, 27, 41</th></tr>
<tr><td colspan="2">Posada describes the challenges that employees in smart factories are confronted with and how VR and AR can help to master them. He explains that competency development is also important for physically impaired people, who also work in production. Therefore, in his opinion, it is important that VR/AR technology is also operable for such people (requirement 1: Include physically disabled people). This could be ensured by different types of control, such as eye and voice control. Eye or voice control also allows input to the system during manual work and thus allows the simultaneous use of several senses (requirement 23: Use eye control, requirement 27: Use voice control). A further requirement formulated by Posada is a multiplatform, on which several users can interact with each other (requirement 41: Use of a multi-user-platform).</td></tr>
<tr><th>Author (year): Weeber et al. (2016)</th><th>Requirement-Number: 2</th></tr>
<tr><td colspan="2">Weeber presents a case study describing synergy effects through the networking of learning factories. He explains how these synergy effects can also be used for the application of VR in learning factories and recommends that several learning factory operators share their VR software via a cloud. Thus, all participating learning factory operators can save resources. On the one hand by (partially) dispensing with physical learning environments, on the other hand by increasing the degree of utilization of the IT infrastructure (requirement 2: Save resources).</td></tr>
<tr><th>Author (year): Haghighi (2013)</th><th>Requirement-Number: 3, 9, 13,14, 28, 29, 31, 33, 34, 42</th></tr>
<tr><td colspan="2">Haghighi deals with the advantages and disadvantages of digital learning factories. In his explanations, he describes that a major motivation of such digital models is to save costs by not using real machines and tools (requirement 3: Reduce costs). Furthermore, he explains that animations with further information are important to facilitate orientation and work in the virtual environment for the user (requirement 9: Use supportive animations and a consulting tool). He describes that all activities in learning factories should address people from different professional backgrounds (requirement 13: Consider divers professional backgrounds), but that the focus should be on students and employees with a production-related background. Haghighi explains that there are different types of learners and that for the best possible learning success it is necessary to adapt the teaching methods to each type of learner (requirement 14: Consider different types of learning). He considers additional training in a physical environment to be important to better retain what has been learned (requirement 28: Supplement real training). According to his explanations, important potentials that should be considered when using VR in learning factories are the independence of the training in terms of time and space. He hopes that this will increase the number of participants because they will not have to travel to the course and can adapt it to their schedules (requirement 34: Enable temporal independence, requirement 33: Enable spatial independence). Haghighi generally expects digital teaching to provide validated teaching content and (partially) decouple the quality of training from the competence of the teaching staff.</td></tr>
</table>

This could lead to a high degree of standardization of the learning content (requirement 42: *Standardize the training and further education*). Another important requirement of Haghighi on VR is high safety in the training of risk situations or in risk areas, which could be achieved by the purely simulated danger (requirement 31: *Enable safe training of high-risk situations*). He points out that without advanced IT infrastructure, VR training in learning factories is not possible (requirement 29: *Consider the IT infrastructure*).	
Author (year): Abele et al. (2016)	**Requirement-Number: 4**
Abele describes his ideas on how VR can be used for competency development in a learning factory with a focus on energy-efficient production. At the time of his publication, the concept for the use of VR in this learning factory was just being developed. Abele attaches particular importance to the fact that learners in VR also receive permanent feedback on their learning progress (requirement 4: *Give permanent feedback*).	
Author (year): Longo et al. (2017)	**Requirement-Number: 5, 30**
Longo is concerned with the integration of virtual and augmented reality in smart factories and the optimal relationship between the real and virtual world. He expects Virtual or Augmented Reality to be able to warn employees of wrong actions and to virtually illustrate the potential consequences of wrong actions at the workplace (requirement 5: *Warn and instruct users*). Longo explains that in learning factories, strict attention must be paid to compliance with all guidelines and laws of real production sites, as misconduct in training would most likely be put into practice (requirement 30: *Consider operating manuals, safety guidelines of reality*).	
Author (year): Tolio et al. (2019)	**Requirement-Number: 6**
Tolio describes various trends of the "factory of the future" in his extensive work. Among other things, he explains how the possibilities in VR or AR can be used to use different human senses (seeing, hearing, touching) for feedback to promote memory (requirement 6: *Give visual, acoustic and haptic feedback*).	
Author (year): Müller et al. (2016)	**Requirement-Number: 7, 20, 24**
Müller presents a concept that provides simulation games for training assembly steps. He does not limit himself to VR with HMDs but also considers game consoles with gesture control. He attaches great importance to intuitive handling of the displayed objects and to sound effects that give the learner positive or negative feedback (requirement 24: *Consider intuitive operability*, requirement 7: *Use motivating and warning sound effects*). He describes that a placement test is important to adapt the content and difficulty of the games to the users and to avoid boredom or excessive demands. As suitable tests, he suggests e.g. pair-finding games (requirement 20: *Entrance classification test*).	
Author (year): Ullrich et al. (2019)	**Requirement-Number: 8, 17, 32, 35, 36**
Ullrich describes a roadmap for the digitalization of learning factories and presents a use case in which, among other things, VR is used in the context of training courses in learning factories. He formulates an	

<table>
<tr><td colspan="2">important strategic goal to introduce the participants to up-to-date technologies based on real or simulated experiences (requirement 36: Introduce up-to-date technologies). Furthermore, he points out that due to demographic change, very experienced employees with limited adaptability must be taken into account and recommends practical tasks to refer to the reality of work (requirement 17: Consider the adaptability of the participants, requirement 35: Implement practice-oriented tasks). Ullrich considers professional support of the learning processes by trainers to be indispensable because they can offer the necessary support to the learners if this is needed to achieve the learning objectives (requirement 8: Give trainer support). He mentions the protection of personal data as a topic that is always present when modern media is used (requirement 32: Consider data security and protection).</td></tr>
<tr><th>Author (year): Quint et al. (2015a) and Quint et al. (2015b)</th><th>Requirement-Number: 10, 25</th></tr>
<tr><td colspan="2">In his two works, Quint provides recommendations for the integration of VR and AR into the learning factory curriculum. In his comments, he mentions that the exercises should be designed in a way that motivates learners to test the degrees of freedom and limitations of the system (requirement 10: Encourage users to test limits). To create the necessary sense of presence, he explains that natural gesture control is necessary. A "click" with the help of controllers would not create a feeling of presence (requirement 25: Use gesture control).</td></tr>
<tr><th>Author (year): Weidig et al.</th><th>Requirement-Number: 11</th></tr>
<tr><td colspan="2">Weidig presents a learning factory concept for factory planning with VR support. The participants should plan a factory in VR in teams. For this, they can interact with each other and with virtual contact persons. Weidig considers this as important to support the participants on the one hand and to increase the degree of immersion on the other hand (requirement 11: Contact person/expert virtually).</td></tr>
<tr><th>Author (year): Mavriskios et al. (2019)</th><th>Requirement-Number: 12</th></tr>
<tr><td colspan="2">Mavriskios deals with the added value that holograms can offer in learning factories and the requirements that must be considered when using them. In his presentation, he describes that possibilities such as highlighting objects with signal colors should be used to help users find their way around. Although he refers this to holograms and not to VR with HMDs, his thoughts can be transferred to virtual environments (requirement 12: Attract attention).</td></tr>
<tr><th>Author (year): Plorin (2015)</th><th>Requirement-Number: 15</th></tr>
<tr><td colspan="2">Plorin presents his "advanced learning factory" concept for the development of learning environments and learning modules. He describes how the use of real company data or case studies can be useful for a high degree of realism. However, it should also be possible to adapt the level of difficulty of these studies to the participants to avoid overburdening them with insufficient know-how (requirement 15: Implement different levels of difficulty).</td></tr>
</table>

Author (year): Toivonen (2018)	Requirement-Number: 16
Toivonen describes the combination of a physical learning environment and its digital twin. The aim is to enable learners to familiarize themselves with the machines and systems in the virtual environment and to carry out tests before they practice in the physical learning environment. He attaches great importance to enabling learners to learn at their own pace, even when doing group tasks. Therefore, attention should be paid to a performance gap within groups (requirement 16: *Enable independent learning pace*).	
Author (year): Lanza et al. (2015)	**Requirement-Number: 18**
Lanza presents a curriculum of a learning factory, which was realized at the Karlsruhe Institute of Technology in cooperation with Robert Bosch GmbH. The subject of the learning factory is globalized production. Lanza describes, among other things, the need for modularization of the learning content to be able to configure training courses individually for the participants (requirement 18: *Enable a customized curriculum*).	
Author (year): Milella (2015)	**Requirement-Number: 21, 22, 26**
Milella is evaluating the benefits of using VR in development departments in the automotive industry. He describes that value should be placed on realistic lighting effects, as these have a positive influence on the degree of immersion (requirement 22: *Use realistic light effects*). In addition to a high degree of immersion, Milella recommends several different input devices to increase the problem-solving possibilities (requirement 26: *Consider different devices to interact with the environment*). At the same time, however, he recommends avoiding overly complex visualization as this could distract from the essential learning content (requirement 21: *Avoid over-complex visualization*).	
Author (year): Conrad et al. (2019)	**Requirement-Number: 19, 40**
Conrad describes a learning factory for the training of competencies for industry 4.0, mentioning that the training system does not prepare graduates well for the practical side of the job. Learning factories would be necessary to close training gaps and, for example, to learn how to use Virtual or Augmented Reality (requirement 19: *Bridge gaps in education and training*). Following the learning experience, he recommends group discussions involving practitioners who work with these technologies daily so that the learners can better imagine their perspective (requirement 40: *Change of perspective*).	
Author (year): Mourtzis et al. (2018a)	**Requirement-Number: 37**
Mourtzis sees learning factories as a great opportunity, especially for medium-sized companies. However, he describes the problems of conventional physical learning factories, such as the limitation of tools and machines due to acquisition costs, which greatly limits training opportunities. From this, the requirement of a broad spectrum of tools and machines can be derived, which can also be transferred to VR although he does not explicitly mention this (requirement 37: *Consider a wide range of machines and tools*).	

Author (year): KARRE ET AL. (2019)	Requirement-Number: 38, 39
KARRE addresses the fact that agile acting becomes more important in times of volatile markets and should be an important aspect of training (requirement 39: *Demand agile actions*). He describes it as particularly important that learners are encouraged to act proactively and innovatively to learn how to deal with unforeseen situations (requirement 38: *Encourage proactive and innovative action*). His thoughts refer to learning factories in general but can be transferred to VR.	
Author (year): ABELE ET AL. (2017)	**Requirement-Number: 43**
ABELE gives a comprehensive overview of the state of the art and research in the field of learning factories, in which he also addresses the application of VR. He describes the positive effect of well-designed learning games or game elements that offer a high degree of entertainment and therefore increase the learner's attention (requirement 43: *Gamify*).	

Additionally, a comparison of the popularity of the eleven defined clusters also reveals interesting findings. The results show that the clusters *Feedback/Support* (9 requirements), *Individuality* (7 requirements), and *Practical relevance* (6 requirements) are the most popular. Also, three requirements are assigned to the cluster of *Information-input* and five to *Security*, respectively. The remaining clusters have a scope of two or fewer requirements.

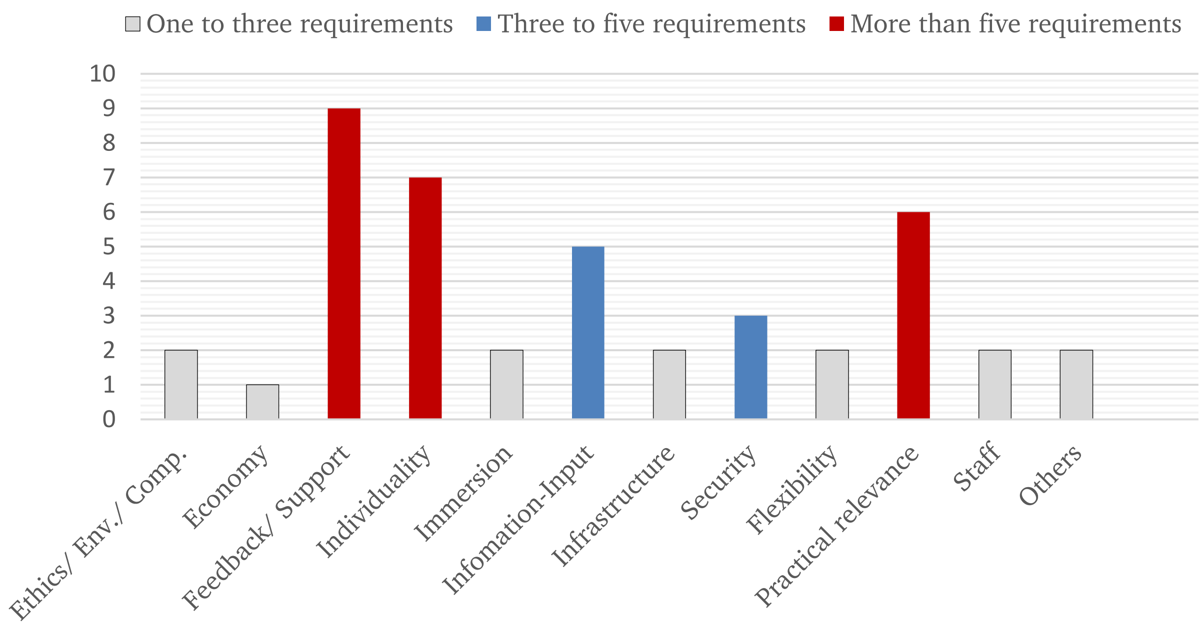

Figure 4: Distribution of requirements in terms of clusters

It is noticeable that there is a disproportion between the temporal distribution of the literature and that of the requirements. For instance, only 19% of the publications of the literature list were published in the early years of the observation period (2013-2015), but more than 40% of all requirements originate from these years. Nevertheless, Figure 6 shows that also new publications of the years 2018 and 2019 describe requirements, that have not been mentioned before. This observation can be explained by the fact that the same requirements in different publications were attributed to the earliest published papers. Taking this fact into account, a certain saturation was to be expected over the years. However, a constant improvement in technological possibilities is accompanied by new requirements, so that new requirements will continue to arise in the future.

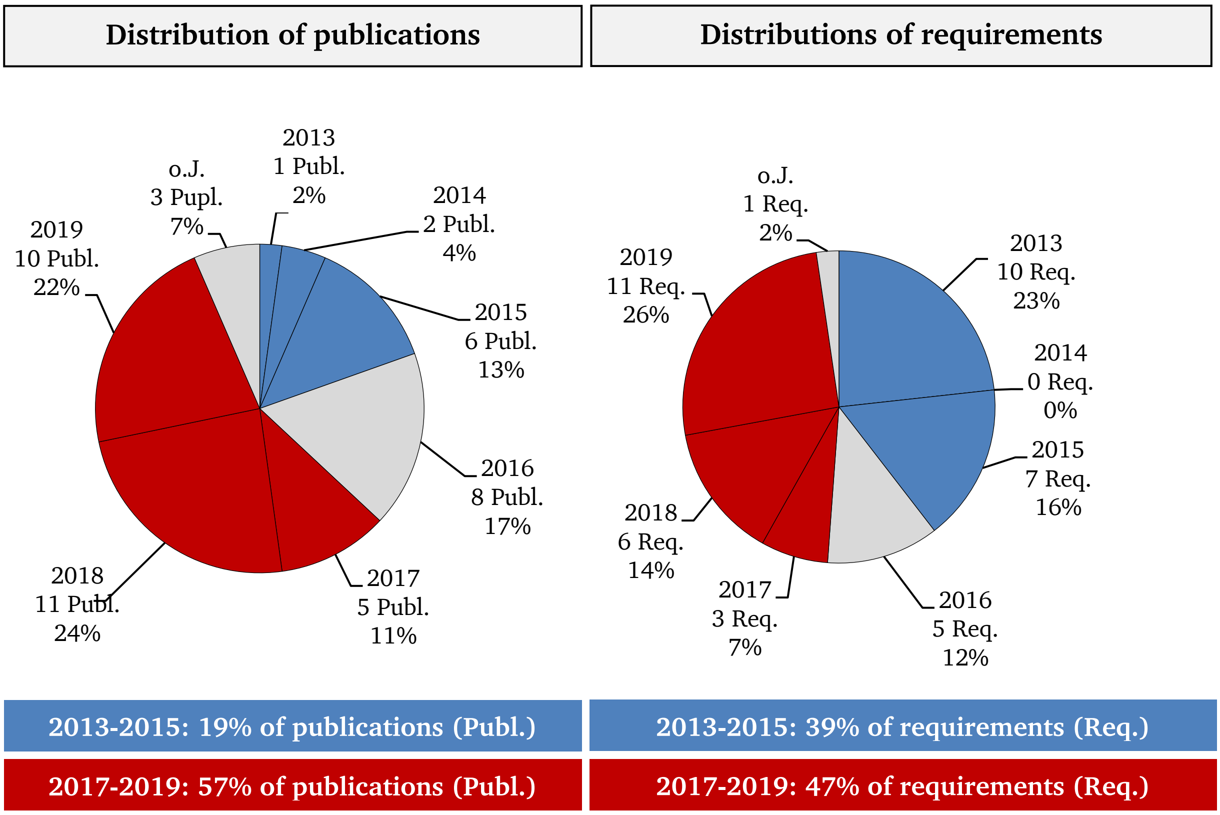

Figure 5: Distribution of publications and requirements in terms of time

4 Summary and outlook

Within the framework of this paper, a total of 43 requirements for the use of VR in learning factories could be identified. The requirements found were divided into three categories and eleven clusters and presented in a tabular form. The results serve learning factory operators, software developers, and researchers as a tool for the development, evaluation, and improvement of VR in learning factories.

After explaining the motivation and objectives of the work, a detailed explanation of the methodology used and the results are given in Chapters 2 and 3. This ensures the reproducibility of the results and enables the reader to assess the expected quality of the targeted results. Following the methodology, the development context of the identified requirements was examined to be able to reconstruct the classification into clusters. Following on from this paper, in the research project PortaL an minimum viable product (also: MVP) is developed, which attempts to meet the most important requirements. The evaluation of the found requirements is planned with the help of the Kano model to determine these basic requirements. The prioritization of the requirements is essential for the next steps in the research project.

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