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ORIGINAL ARTICLE

Suitability- and utilization-based cost–benefit analysis: a techno-economic feasibility study of virtual reality for workplace and process design

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Abstract

Virtual reality (VR) is increasingly being used in the corporate environment. Benefits of using VR have also already been identified in the area of combined workplace and process design. However, whether organizations should invest in VR for this use case is only feasible with knowledge of all operational and strategic costs and benefits. Since previous methods for simulating the costs and benefits of information systems rely strongly on prior knowledge and experience, these approaches are not effective for novel technologies such as VR for less tested use cases due to low empirical databases. In order to provide a more accurate cost–benefit analysis (CBA) of the use of VR for strategical planning like workplace and process design, design science research is applied. Subsequently, by including task technology fit theory, a suitability- and utilization-based CBA method emerged. The contribution thus provides, first, a systematically derived method for quantification and simulation of costs and benefits of strategic VR use in organizations. Second, it provides concrete insights into factors influencing profitability of an investment in a specific VR system for strategic planning projects for workplace and process design based on case study insights.

Keywords Cost–benefit analysis · Task-technology fit · Virtual reality · Process modeling · Workplace design

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1 Introduction

By using virtual reality (VR), organizations are increasingly taking advantage of infinite space, non-existent material costs and creativity fostering through immersion (Bowman and McMahan 2007; Vogel et al. 2021; Wolf et al. 2017). Market-ready VR solutions for operational product design, manufacturing operations or quality assurance are already available (Cohen et al. 2018; Damiani et al. 2018). Initial VR artifacts have also been developed for strategical tasks like the design of workplaces and the processes carried out in the associated environments (Pöhler et al. 2021). While the evaluation of combined workplace and process design in VR identified benefits like higher user satisfaction, potentials for spatial error analysis or the ability to experience redesigned processes (cf. Pöhler and Teuteberg 2021, Pöhler et al. 2021) compared to classic 2D applications, there is a lack of economic consideration. Organizations should know whether an investment in a VR system for workplace and process design also delivers economic long-term profitability. As with any investment, the question is: is it worth it?

Introducing new information systems (IS) like VR systems into existing organizational structures is a strategic decision (Earl 1993; Luftman et al. 1993). In the long term, the costs and efforts of implementing and using IS should not exceed the benefits (Jenkins and Harberger 1997; Götze and Bloech 2013). It is therefore useful to have a good estimate of the investment decision already in advance and to determine the costs and benefits of an IS investment as accurately as possible (Purwita et al. 2019). A cost–benefit analysis (CBA) provides the management, as the decision-makers, with clear key economic indicators such as return on investment (ROI) or net future value (NFV) (Asche et al. 2018; Oesterreich and Teuteberg 2017). This distinguishes it from more descriptive methods of decision making such as the balanced scorecard or multi-criteria decision making (Purwita et al. 2019). For the purpose of IS investment decision making, several authors have already carried out a CBA in organizational contexts. For example, Nanath and Pillai (2013) apply a CBA to evaluate cloud computing for start-ups as well as for large companies and Vaughan et al. (2013) examine the implementation of construction information management systems by applying CBA case studies.

However, most of these IS considerations have in common that they take ex-post observations of the investment decision, lack long-term considerations or work with previous knowledge and experiences from transferable use cases for their decision making, which is not possible for novel IS in less tested use cases (Oesterreich and Teuteberg 2018a; Fridgen and Moser 2013). This represents a problem, as for decision makers in organizations, ex-ante considerations are relevant in the proposal phase of IS investment decision making (Renkema and Berghout 1997). In the case of novel technologies in new use cases, like VR for workplace and process design, there is a lack of possibilities to estimate the basic suitability and thereby the derived future utilization of the technology. This poor database on knowledge and experience leads to unacceptable inaccuracies in later CBA considerations. Additionally, pure assumptions or expert estimates of quantified costs and benefits, as for example

Oesterreich and Teuteberg (2017) or Murphy and Simon (2002) perform in their IS CBAs, would lead to erroneous economic metrics.

Thus, it becomes apparent that for the presented case of VR for workplace and process design due to lack of historical and transferable data, conventional CBAs for IS are not feasible for ex-ante decision making about an investment. In order to take an appropriate long-term view of a VR investment for strategic organizational projects, it should first be determined whether the technology is suitable for the projects and tasks at hand and which utilization can be expected from it. To ensure applicability of our targeted suitability and utilization-based CBA methodology not only for the specific case of VR for workplace and process design, but for the superordinate class of using VR for strategic planning of internal projects in organizations, we performed design science research (DSR) according to Hevner (2007). By subsequently applying the DSR-generated CBA to a realistic use case of a company, we aim to provide an estimate of the long-term profitability of an investment in a specific VR system for workplace and process design in organizations. Therefore, our goal is to answer the following two research questions (RQs):

RQ1 How can an ex-ante CBA be designed for decision making about investing in VR systems for strategic planning of internal projects—like for workplace and process design projects—in organizations?

RQ2 To what extent and under which circumstances can an investment in VR for workplace and process design be considered as profitable for organizations?

In order to answer these questions, we first address the theoretical foundations in the second section. In this context, we present the use of VR for workplace and process design. Subsequently, we give an overview of methodologies for economic ex-ante decision making in IS and introduce the Task-Technology Fit (TTF) theory by Goodhue and Thompson (1995), which guides the design of our suitability- and utilization-based CBA methodology as kernel theory (Kuechler and Vaishnavi 2008; Gregor and Hevner 2013). In Sect. 3, we present our overall research approach of using DSR for developing and applying a suitability and utilization-based CBA for the class of VR systems for internal projects in organizations. In Sect. 4, guided by TTF theory, we first determine current problems of IS investment methods and VR specifics for CBAs to derive requirements, which finally lead to four design principles (DPs) for our CBA methodology. Second, we evaluate and refine the DPs with the help of expert interviews. Third, we transform and instantiate the DPs into our CBA methodology and forth, we apply and demonstrate the methodology to our specific VR system in a case study. In Sect. 5, we give an answer to our RQs and discuss the implications and limitations of the contribution. The sixths section presents the conclusion of our work.

2 Related work

2.1 Workplace and process design in virtual worlds

In recent years, VR has increasingly developed from a small market niche technology in the direction of an effectively applicable and widely used technology (Cipresso et al. 2018; Cohen et al. 2018). This is mainly due to the development of highly modern and affordable head-mounted displays (HMDs), such as those produced by Meta, HTC or the announced market release of Apples new HMD for 2024.[1] While the private persons already benefit strongly in the gaming or entertainment sector, organizational and industrial use is mainly in the field of equipment design or virtual training (Cohen et al. 2018). In contrast, the use of VR as tool for less operational and more strategic purposes is still in the exploratory phase in organizations.

In the field of workplace and process design, the first software artifacts have also already been developed in virtual worlds in recent years. For example, Brown et al. (2011) have developed a virtual world in which processes can be generated with a modeling language close to Business Process Modeling and Notation (BPMN). However, in this approach there is a lack of adaptability and inclusion of the environment in the generated process models. Likewise, a desktop version is still used here, so that the advantages of highly immersive HMDs are not exploited. Harman et al. (2015) also only use desktop worlds, but ensure that processes and environments are linked. Using modern HMDs, Oberhauser et al. (2018) show for the first time approaches how process models can be represented highly immersive. Zenner et al. (2020) generate an approach in which process models can be experienced in VR, but at the same time can be physically sensed in reality through certain shapes and contours. Pöhler et al. (2020) and Pöhler et al. (2021) are the first to present an artifact that enables active process modeling in realistic, highly immersive, and modifiable work environments using advanced VR-HMDs. This VR system, as an instantiated and tested VR-based IS, will be the subject of our later investment consideration and will also be explained in more detail in this course with regard to its components (see Sect. 4.2).

The evaluation of the VR artifact in form of short-term effects exhibited great potential by increasing motivation to use and linking immersive environments to the processes performed in them (Pöhler and Teuteberg 2021, Pöhler et al. 2021). Although considerations of the long-term use of the system and its effects have already been made in qualitative form (Pöhler and Teuteberg 2022), there is a lack of clear economic indicators as to whether an investment in such an IS would be worthwhile. In order to support organizations in their investment decisions, it is necessary to enable them to consider the long-term economic aspects of the use of VR for workplace and process design.

[1] On 5th June 2023 Apple announced the market release of new Apple Vision Pro in a keynote: https://www.youtube.com/watch?v=GYkq9Rgoj8E (Accessed 14 Jul 2023).

2.2 Quantitative ex-ante decision making in IS

When making decisions about investing in new IS, managers have a variety of methods at their disposal (Ozturan et al. 2016). While methods such as the balanced scorecard (Kaplan and Norton 2007) tend to be more qualitative and descriptive, key performance-driven managers as decision makers can use quantitative methods such as CBA to gain direct insight into the economic profitability of an investment (Oesterreich and Teuteberg 2017). To address the generally increasing role of financial and accounting metrics in decision making (Vokshi and Krasniqi 2017; Collier 2015), indicators such as ROI or NFV can be helpful (Purwita et al. 2019). These can be calculated using CBA. Sassone and Schaffer (1978) developed a general approach for a CBA in project evaluation and King and Schrems (1978) created an IS specified approach, which have both found frequent application in the evaluation of IS investments (e.g. Pick 2005; Unal and Yates 2010; Oyekola and Xu 2020; Oesterreich and Teuteberg 2017). These CBAs have in common that they initially provide a transparent overview of costs and benefits by applying systematic reviews or the recourse to cost and benefit taxonomies and use case studies, comparative studies or simulations for demonstration.

IS cost overviews such as those presented from Irani et al (2006) can be used to identify and specify cost types. With regard to benefits, a distinction must be made between tangible and intangible benefits (Murphy and Simon 2002). Benefits are considered tangible if they are quantifiable, measurable and at the same time have a direct economic impact on the profitability of the company (Remenyi et al. 1993; Pöhler and Teuteberg 2022). If not all of these aspects are given, the benefit is intangible. In order to meet the demands for economic parameters for decision making while including intangible benefits, a transformation of intangible into tangible benefits is required (Murphy and Simon 2002), which is possible by applying utility effect chains based on Schumann and Linß (1993). The quantification of these transformed intangible benefits is another problem and extremely difficult (Kreiss et al. 2016). To transform the intangible benefits into economic values and overcome this problem, Hares and Royle (1994) developed a strategy, which quantifies the transformed benefits with the help of expert estimates.

To measure long-term effects of a financial assessment transparently, it is useful to apply visualization of financial implications (VoFI) based on Grob (1989) as specific CBA method. VoFI simulation is grounded on realistic assumptions of taxes, loans and interest rates and has been applied by different authors like vom Brocke and Lindner (2004), Oesterreich and Teuteberg (2017) and Bensberg et al. (2022) to show long-term IS investment effects. However, since these approaches quantified the costs and benefits using expert estimates, market benchmarks or solely artificial data, their results are subject to a large degree of uncertainty.

Especially for our class of novel IS, VR systems for strategic projects in organizations, pure estimations without incorporating suitability, future utilization and technological follow-up costs and benefits are not accurate enough. Adaptations must be made to existing methods, combining and extending them to enable applicability to VR technology in less proven strategical use cases. Therefore, in order to ground

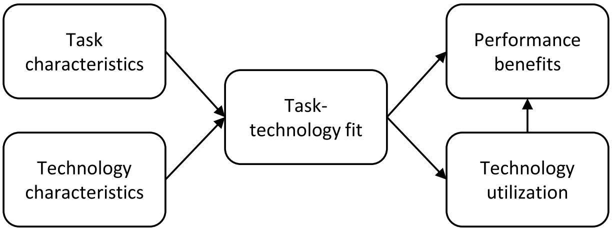

Fig. 1 Task-technology fit core model (Goodhue and Thompson 1995)

economic parameters on a more accurate database, we include TTF theory (Goodhue and Thompson 1995) as kernel theory in the design science approach.

2.3 Task-technology fit theory

The TTF theory assumes, that outcomes depend upon a fitting between the task to be performed and the technology to perform the task (Galbraith 1973). Goodhue and Thompson (1995) were the first to specify this assumption and to formalize the TTF theory (cf. Fig. 1). The TTF theory has subsequently positioned itself as one of the central theories on the adoption and use of information technologies by individuals and organizations and has also already been combined with the *Technology Acceptance Model* (TAM, Davis 1985). The core model consists of the five elements *task characteristics*, *technology characteristics*, *task-technology fit*, *technology utilization* and *performance benefits*. The TTF measures the extent to which task characteristics are fulfilled by the technology used and is therefore an indicator for the suitability of the technology. A good TTF ensures a higher utilization of the technology and also higher performance benefits. Simultaneously, a higher utilization also ensures that performance benefits increase. Similarly, a poor matching of task and technology can also indicate whether technologies are unsuitable for handling tasks and are therefore less used. According to Goodhue and Thompson (1995), high ratings in eight dimensions of an IS lead to a high TTF: quality, locatability, authorization, compatibility, production timeliness, systems reliability, training and relationship with users.

TTF theory has been extensively applied to explain the use of IS based on its characteristics and the tasks to be performed (cf. Furneaux 2012). While the effects of TTF theory are confirmed for many IS by using surveys (e.g. Chang 2008) or experiments (e.g. Fuller and Dennis 2009), to the best of our knowledge, no systematic integration and consideration of the effects of TTF on costs and benefits in terms of a CBA exist. For our further considerations in this paper, we refrain from extensions of the core TTF approach (see Fig. 1), such as the inclusion of personal human characteristics or the linkage with TAM, for reasons of clarity and applicability of our generated CBA.

3 Research approach

To answer RQ1 and to develop a method for suitability- and utilization-based CBA for investment decisions on using VR for strategic planning in organizations, we drew on Hevner's (2007) DSR framework (Fig. 2). The goal of the design science approach is to develop prescriptive design knowledge in order to solve present real-world issues and challenges from the problem space by drawing on a large body of proven knowledge, theories, methods, and models from the solution space (vom Brocke and Maedche 2019; vom Brocke et al. 2020). In doing so, we generated two different types of artifacts: On the one hand, we generated literature-based design knowledge by developing DPs for the specific CBA. On the other hand, these DPs were instantiated in the following so that a practically applicable method for suitability- and utilization-based CBA for investment decisions on using VR for strategic planning projects in organizations emerged.

The generation of our artifacts is first based on a conceptualization of the problem space. Following the guiding principles of Maedche et al. (2019), we first defined stakeholders, needs, goals, and requirements of the DSR project. *Stakeholders* were determined to be decision makers in organizations or developers and researchers who want to examine their strategic VR systems in terms of organizational feasibility. The *need*, "which is the essence of the problem" (Maedche et al. 2019, p. 25), was identified as the lack of adequate ex-ante methods to assess the profitability of an investment of the class of VR systems to be used for internal strategic projects in organizations. The *aim* is to create an applicable CBA with a database that enables an adequate CBA to satisfy the needs. The first *requirement* is to increase the quality of the CBA for the mentioned class of IS. As a further requirement, due to the limited data available, the suitability and the future utilization of the VR system should be included in the analysis.

To unfold the need, we searched for challenges and problems in other quantitative economic ex-ante evaluation and decision-making methods of IS investments, focusing on CBAs, using a systematic literature review following vom Brocke et al.

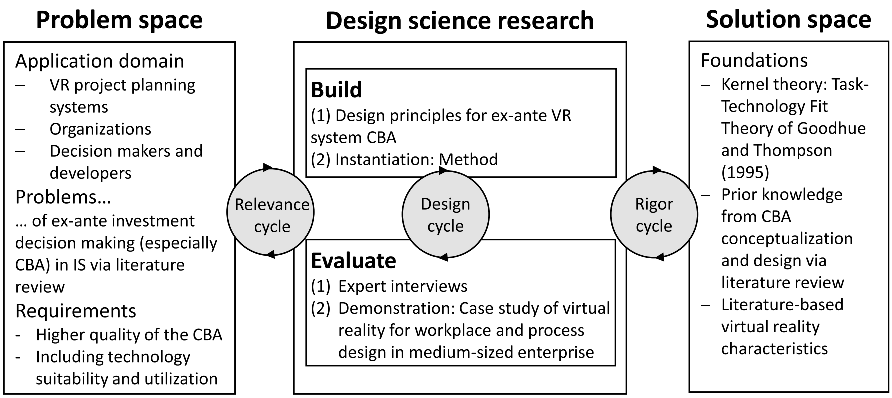

Fig. 2 Specified design science approach based on Hevner (2007)

(2009). We focused on problems relevant to our problem class (VR, strategic planning within organizations). We searched Scopus, EbscoHost, and Google Scholar databases using the search string *("decision making" OR "ex-ante evaluation" OR "cost–benefit analysis" OR "cost benefit analysis" OR cba) AND "information systems"*. To broaden the database, we also explicitly searched for CBAs for certain technologies, since "information systems" is often not mentioned as a generic term in the publications. We included technology trends of the past decades such as "enterprise resource planning," "customer relationship management," "cloud computing," "blockchain," "artificial intelligence," "virtual reality" and "augmented reality." Only sources from the topics of information systems, accounting and business administration were included. We carefully extracted the relevant sources by sorting through titles and abstracts. Furthermore, we performed an extensive forward and backward search for the relevant texts. Finally, relevant challenges were extracted from 27 full texts. Some of the challenges identified were explicitly derived from the literature (deduction), while others were aggregated by missing considerations in other ex-ante CBAs (induction).

For the solution space, the TTF theory guided the design of the CBA as kernel theory, since it enables the required linkage of suitability, utilization and benefits (Furneaux 2012). Supplemented by literature on the relevance of suitability and utilization of technologies in investments, we derived requirements for our CBA. In the solution space, we also used existing solutions based on the search string of the problem space, which we could use to overcome our specific CBA challenges. Reference is made, among others, to the CBA approach of Oesterreich and Teuteberg (2017), to counteract a monolithic structure of design knowledge, as vom Brocke et al. (2020) demand it. In addition, the specifics of VR were included in the considerations to enable a specific technology-centric CBA generation and to derive requirements from it.

Combining problem and solution space and with the help of the anatomy of a design principle according to Gregor et al. (2020), we were able to finally derive 17 requirements (R) and four central DPs for our suitability- and utilization-based CBA including aim and user, context, mechanism and rationale of the DPs. The DPs were evaluated by four expert (E1–E4, Table 1) interviews according to Gläser and Laudel (2010), resulting in a restructuring of the DPs at the end of the first build-evaluate cycle. The interviews were semi-structured and took 44 min in average.

The experts were three scientists from the field of accounting and information systems and one from industry, which had all had advanced knowledge in CBA development and application, DSR or in organizational IS adoption (Ø age = 32,5 years). Since it already became clear after the first two interviews that the formulation of the DPs was on a too general level, we adjusted and specified them. The last two interviews were then based on the redesigned DPs, which were finally updated, based on the expert's entire feedback. In the second build-evaluate cycle, we instantiated the refined DPs and developed the method for suitability and utilization-based CBA. Subsequently, we demonstrated the method with the use case of VR for workplace and process design in a specific German company, so that initial statements about the usefulness and applicability of the specific CBA method could be obtained. In the same course, it was also possible to answer RQ2, because by applying the CBA, we were able to derive statements about the circumstances under which an investment in VR for workplace and process design is profitable for organizations.

4 Design and evaluation of the CBA

4.1 Derivation and evaluation of design principles

TTF theory of Goodhue and Thompson (1995) and it's eight dimensions guided us in generating the DPs from two perspectives: on the one hand, our methodology should be designed to aim at incorporating TTF aspects into the cost–benefit consideration of strategic VR use in organizations. On the other hand, the methodology itself should also be designed to lead to a highly suitable, utilizable and beneficial CBA from a TTF perspective, so that it fits the need for a CBA specified for VR with low database on suitability and utilization in organizations.

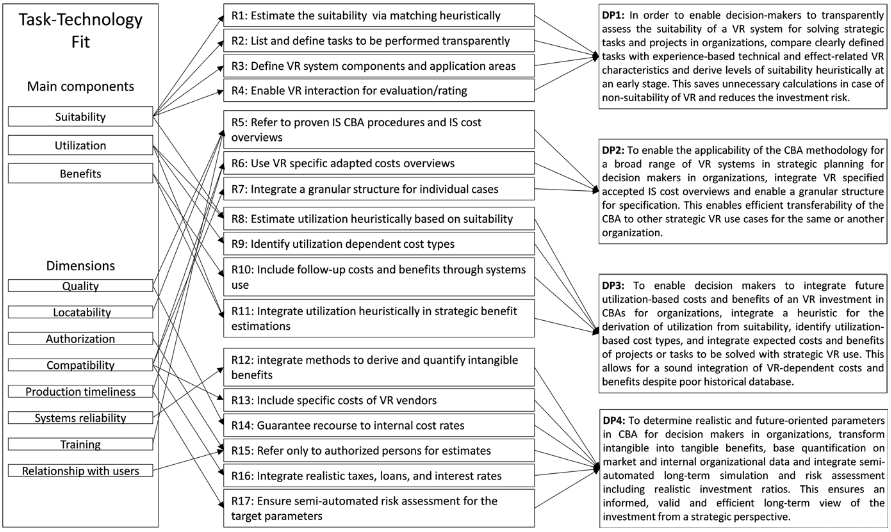

Fig. 3 Design principle development of an ex-ante CBA for strategic VR systems

Table 1 Expert overview

ID	Job description	Age	Gender	Experience*	Interview duration
E1	Post-doc	40	Female	13	38 min
E2	Research assistant	31	Male	4	31 min
E3	Manager	31	Male	6	57 min
E4	Research assistant	28	Female	3	51 min

*years of experience in CBA, IS adoption or DSR

This dual perspective is along the lines of Kuechler and Vaishnavi (2008, p. 492), who "note that kernel theories inform both the effect we seek in the artifact (the "Goal") as well as suggesting the "Prescribed action."" The DPs listed in the following represent the final state after adjustment based on the expert interviews (Fig. 3).

According to Goodhue and Thompson (1995), the suitability of the technology to be determined via the TTF is a decisive factor for the achievable benefits from its utilization. DP1 therefore aims to include technology suitability in investment decisions. New IS like VR has usually not yet been proven in organizational environments, so there is not a large database on its suitability (Fridgen and Moser 2013). Therefore, investing in a technology whose suitability has not been empirically proven would be risky for organizations (Benaroch et al. 2006; Hekkert and Negro 2009; Willcocks 2013). Previous ex-ante CBA approaches in IS assume a fundamental compatibility between technology and task because of transferable data (e.g. Nayar and Kumar 2018; Vaughan et al. 2013). Due to the lack of data for VR in strategic organizational use, the TTF should allow for a heuristic estimation of the suitability of VR via a match between task characteristics and technology characteristics (R1). In addition, many CBAs in IS lack focused and clear definitions of the specific tasks that the technology is intended to solve (e.g. Unal and Yates 2010; Oesterreich and Teuteberg 2017). However, task definition is fundamental to enable a technology to be deployed with respect to the needs of organizations (Diaper 2004). Therefore, at the beginning of a CBA, the tasks to be performed with VR should be listed and defined transparently (R2). At the same time, the VR system with its solution concept, possible application areas, and technological and effect-related characteristics (cf. Straatmann et al. 2022) should be elaborated and clearly defined (R3) in order to enable a comparison. Particularly in the case of new technologies such as VR, potential future users should be given the opportunity to characterize the system by means of interactive trials (R4, Ørngreen and Levinsen 2017). Therefore, DP1 states:

In order to enable decision-makers to transparently assess the suitability of a VR system for solving strategic tasks and projects in organizations, compare clearly defined tasks with experience-based technical and effect-related VR characteristics and derive levels of suitability heuristically at an early stage. This saves unnecessary calculations in case of non-suitability of VR and reduces the investment risk.

The second DP aims to improve reliability, locatability, compatibility, and reduce the learning curve (cf. Goodhue and Thompson 1995) for applying the methodology. Many CBAs in IS refer solely to a rough framework such as Sassone and Schaffer (1978) or King and Schrems (1978) for generating a CBA that is purely adapted to the specific use case at hand (e.g. a use case in a specific company with the software of a specific vendor) and is not transferable (e.g. Unal and Yates 2010; Hwang and Manandhar 2009). First, our CBA should also refer to proven IS CBA procedures (R5, Oesterreich and Teuteberg 2017). Second, to enable transferability to a broad class of organizational use of VR for strategic application, proven cost overviews like Irani and Love (2000) or Irani (2002) should already be adapted to VR specifics (R6, Oesterreich and Teuteberg 2017), but third should be able to be detailed in a granular way adapted to the individual case (R7). This leads to DP2:

To enable the applicability of the CBA methodology for a broad range of VR systems in strategic planning for decision makers in organizations, integrate VR specified accepted IS cost overviews and enable a granular structure for specification. This enables efficient transferability of the CBA to other strategic VR use cases for the same or another organization.

The third DP follows from the determination of the suitability according to Goodhue and Thompson (1995), so that estimating future utilization and achievable benefits of an IS investment should be enabled based on suitability. Previous cost categorizations mainly distinguish between initial and ongoing costs (e.g. Oesterreich and Teuteberg 2017; Dier and Mooney 1994), whereas utilization, which particularly influences personnel costs, does not specifically play into the considerations. Therefore, based on the suitability of the VR system the utilization should be derived via heuristics (R8) and cost types that are utilization-dependent, should be identified (R9) so that utilization can be included into their quantification (Devaraj and Kohli 2003). In addition, the quantification of IS benefits lacks the inclusion of technology follow-up costs and benefits by utilizing the technology. As Devaraj and Kohli (2003) have shown, the actual use of IS plays a major role in the performance and benefits of organizations. Especially for strategic tasks and projects, the benefits tend to be of a long-term nature (Rainer and Prince 2022; Feeny and Ives 1990). Therefore, the long-term costs and benefits that arise from the strategic projects and tasks and are only realized through the use of the VR system should be monetary defined and included (R10). Depending on suitability and utilization, the degree to which the targeted benefits can be achieved should be heuristically determined (R11). Together, this leads to DP3:

To enable decision makers to integrate future utilization-based costs and benefits of an VR investment in CBAs for organizations, integrate a heuristic for the derivation of utilization from suitability, identify utilization-based cost types, and integrate expected costs and benefits of projects or tasks to be solved with strategic VR use. This allows for a sound integration of VR-dependent costs and benefits despite poor historical database.

The fourth DP aims at a long-term view of the investment through the CBA methodology and thus ensures high quality through authorized, current and future-oriented data (Goodhue and Thompson 1995) when applying a CBA. Operational benefits can often be easily measured, quantified, and integrated into CBAs through terms like time savings (Bryde et al. 2013; Nanath and Pillai 2013) or lower error rates (Vitharanage et al. 2020). Quantifying intangible strategic benefits, on the other hand, remains difficult (Murphy and Simon 2002; Oesterreich and Teuteberg 2018a). Our CBA should therefore integrate methods to derive and quantify intangible benefits in order to make strategic benefits assessable at the organizational level (R12, Oesterreich and Teuteberg 2018a; Pöhler and Teuteberg 2022). Additionally, quantification often requires estimates that are subject to uncertainty due to a small database and poorly selected data reference points (Bannister and Remenyi 2000; Kaplan and Norton 2007; Oesterreich and Teuteberg 2018a). Therefore, specific costs of VR hard- and software vendors should be included (R13), recourse to internal cost rates (e.g. personnel cost rate, downtime costs, failure costs) of the implementing organization should be guaranteed (R14) and only authorized persons ("experts") should be included in monetary estimates (R15, Murphy and Simon 2002; Anandarajan and Wen 1999). Moreover, cost–benefit considerations in IS are often focused on a short time horizon and not sufficiently on the long term (e.g., Nayar and Kumar 2018; Unal and Yates 2010) and the traditional approaches are not based on realistic values for taxes, credits, and interest rates of the investing organization (Oesterreich and Teuteberg 2017). Similarly, there is a lack of standardized and non time consuming risk considerations in CBA, so that results are not examined in terms of the variation of dependent metrics due to varying input parameters (e.g. Nayar and Kumar 2018). Therefore, CBA should include the integration of realistic financial parameters (R16, Oesterreich and Teuteberg 2017) and the possibility of standardized and semi-automated risk assessment simulation (R17, Oesterreich and Teuteberg 2017). Summarized DP4 arises:

To determine realistic and future-oriented parameters in CBA for decision makers in organizations, transform intangible into tangible benefits, base quantification on market and internal organizational data and integrate semi-automated long-term simulation and risk assessment including realistic investment ratios. This ensures an informed, valid and efficient long-term view of the investment from a strategic perspective.

The DPs listed here represent the final state after the expert interviews were conducted. In these, according to the guidelines of Sonnenberg and vom Brocke (2012), the DPs were evaluated with regard to the criteria *understandability, clarity, completeness, elegance, level of detail, internal consistency* and *applicability*. Because the DPs were not specified in VR for the first two interviews, E1 and E2 each missed the focus on the specific technology in the CBA ("the focus on information systems in general is still very very broad" (E1); "But it would certainly also be possible to focus on an industry or wherever and then maybe have a little more concrete statements already in the DPs as well." (E2)). Therefore, after the first two interviews, the DPs were already adapted so that they were more tailored to VR as IS. Additionally, E2's feedback "I find aim and rational a bit similar" led us to pay particular attention for taking additional care on this differentiation, focusing that rational refers to the overall strategic problem rather than an operational subproblem. Additionally, E1 suggested to integrate artificial intelligence (AI) as she stated: "At this point, I would raise the question whether it is not better to somehow assess internal data sources by means of analysis models, i.e. Big Data, which is AI based, and less to limit oneself to the opinion of certain persons." We considered this to make sense in principle because of the rising trend of AI in general, but which we refrained from because of missing mature solutions for our specific CBA method. The feedback from E3 and E4 then already referred to the VR-specific DPs. E3's feedback led to more stringency, because more attention was paid to avoid redundancy between the DPs (e.g. " I don't know now if that's not already covered in Design Principle 1".) He questioned the elegance of each DP, since he found the mechanisms too bulky. He also considered that in DP3 and DP4 the user was not quite clear. We adjusted this by shortening the mechanism to the most necessary and integrating the decision makers as users in each case. E4 considered both the completeness and the comprehensibility of the respective four DPs as given, but would have liked to have hoped for more concrete instructions in the mechanism at some points (e.g. "It is interesting to see if this granular structure could be broken down some more" (E4)). However, since a granular structure is case-specific, this requirement was not implemented. Overall, the scores in the evaluation criteria were high, so that the criteria were largely met. The experts only noted several times that some of the DPs were formulated too long in terms of elegance. However, in order not to endanger clarity and completeness, no focus was placed on elegance, as this was defined from the outset as a non-mandatory criterion with lower priority.

4.2 Development of the CBA method

Based on these 17 requirements and the four DPs, we have developed a method for suitability- and utilization-based CBA for strategic VR systems (Fig. 4) as instantiated artifact (cf. Hevner 2007). It is based on the general four phases of Sassone and Schaffer (1978) as a framework (referring to DP2) and integrates TTF heuristics for utilization and suitability assessment (referring to DP1, DP3), validated IS cost frameworks (referring to DP2) and methodologies for long-term cost and benefit quantification and risk assessment (referring to DP4). Thus, it is divided into the four phases (I) problem definition, (II) design analysis, (III) quantitative analysis, and (IV) presentation and validation of results. These phases are explained in more detail in the following including the DPs to which they reference in brackets and the databases they are based on (grey boxes in Fig. 4, DP4).

4.2.1 Problem definition

The CBA starts by clearly defining the application scenario and providing an overview of the structure and functions of the technical solution (Sassone and Schaffer 1978). Therefore, the technical solution concept and its components as well as possible application areas of the VR system are presented. At the same time, the projects for which the organization could potentially apply the VR system are introduced. If there are several independent strategic projects, a list of the individual projects can be generated (DP1). In this way, both the VR system and the upcoming projects of

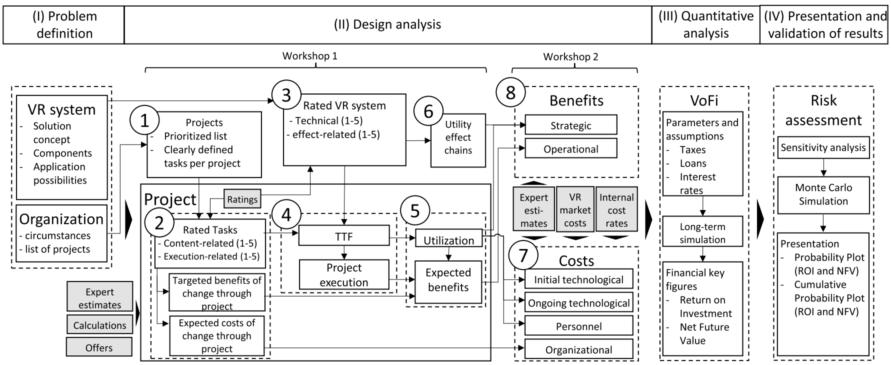

Fig. 4 Overview of the CBA method for strategic VR use in organizations

the organization are outlined on a high level. This introduction can also be made before the workshops for participants that are introduced in Phase II. In addition, calculations of the upcoming projects should already be taken as a database at this point in time and inquiries should be made with the accounting or potential vendors to estimate which costs and annual benefits the respective projects to be executed with VR can be expected (DP3, DP4).

4.2.2 Design analysis

Especially in the second phase, the design of the CBA, the four DPs are implemented as it represents the core of the novel method. In order to integrate this phase in a structured manner with regard to the inclusion of the TTF in the cost–benefit considerations, a subdivision into 8 steps occurred, which serve as a guiding framework in the suitability and utilization-based quantification. Steps 1 to 5 can take place in workshops with potential future users of a organization (DP1). Steps 7 and 8 can take place with the help of another workshop with experts who have insights into internal cost rates and VR market prices (DP4). Within the workshops, different methods can be used to determine the results, such as discussions, paper queries or, in the case of quantitative queries, averaging (Beermann and Schubach 2013).

Step 1 The first step is to systematically characterize and prioritize the planned future strategic projects, that can potentially be planned by using the VR system. For this purpose, these projects can be characterized with bullet points (DP1). Priorization can be used to determine the order in which projects are processed, since not all projects can be implemented at the same time if capacities (e.g. personal, financial) are limited.

Step 2 In the second step, a project-specific characterization of the tasks takes place. Both content-related aspects of the tasks (subject and application-specific) and the desired way of solving the tasks (e.g. collaborative, creative, etc.) can be characterized and evaluated in terms of their importance. To enable good comparability with the technology characteristics at a later stage, it can help to bundle the characteristics across the respective projects. This means that the same characteristics can be evaluated for each project and in the following the technology (the VR system) has to be characterized and evaluated only once with regard to the fulfillment of these characteristics. This saves time and effort in the later TTF consideration. An evaluation on a scale from 1 (very unimportant) to 5 (very important) is useful (cf. Joshi et al. 2015). For manageability and clarity, it also makes sense to limit the list to about ten characteristics (DP1). A rating of the importance of the characteristics for solving the project can be done e.g. via index cards of individual workshop participants, so that a consensus is reached via mean values or discussion. Likewise, estimates of targeted monetary benefits (e.g. annual savings), expected costs of change (initial investment costs) by applying the project and expected project durations, this means the time till projects can be realized and implemented, should be obtained based on prepared data sources from phase 1 (calculations, inquiries, DP4).

Step 3 The characteristics of the tasks, rated according to their importance, are translated in step 3 into characteristics of the technology that would lead to the

Table 2 Characteristics derived from TTF matching

Tasks solved in %	Project execution quality	Benefits factor	Utilization
100%	Very high	1.0	Very high
< 100% and ≥ 90%	High	0.95	High
< 90% and ≥ 70%	Medium	0.8	Medium
< 70% and ≥ 50%	Low	0.6	Low
< 50%	Not given	0	Not given

fulfillment of each task. For example, the task "Enable creative thinking" would be translated into the technology characteristic "Creativity promotion", so that the matching of task and VR technology performed in Step 4 is prepared. In order to enable an evaluability for all workshop participants, the VR system to be implemented should be able to be tried out and experienced on sample cases (DP1). This allows a better assessment of application scenarios and characteristics of the technology, because "hands-on activities in a safe environment can help bring technology into play" (Ørngreen and Levinsen 2017, p.77). The assessment of the technology property is carried out analogously to step 2 by consensus or by forming average values on a scale from 1 (does not apply) to 5 (fully applies). Both technological and effect related characteristics should be considered by the workshop participants during the rating process (DP1).

Step 4 By means of the rated characteristics of tasks and technologies, the suitability of the technology for the planning project can be estimated. Based on the tasks to be performed, the technology characteristics should be assessed with regard to their suitability for solving the task. If, for example, the task "Enable creative thinking" is rated with a 4 for a project, a rating of at least 4 would be required for the technology characteristic "Creativity promotion" in order to fulfill the task. A lower rating than 4 leads to unfulfillment of the task. The sum of the fulfilled tasks can then be used to calculate the share of fulfilled tasks of the total tasks, which can be expressed mathematically in the "benefit factor". Based on the summarized respective TTFs, a heuristically estimation of the project execution is possible. Lower task accomplishment leads to lower quality and this leads to lower benefits, as more errors occur in the form of defects, delays or quality losses (project-specific expressions). A gradation of the quality of the execution (mathematically "benefit factor", Table 2) into defined levels is useful. Informed by existing maturity models (cf. Paulk et al. 1993), the levels listed in Table 1 were chosen (DP1). If a technology cannot solve half of the tasks appropriate, it is declared as unsuitable and a project cannot be planned and executed with the VR system (benefits factor is zero). By setting the benefits factor to zero, the lack of suitability for a certain project is determined at an early stage and this project, including its expected costs and benefits, is no longer included in the calculations (DP1, DP3).

Step 5 The targeted benefits from the project calculated in step 2 are balanced with the benefit factor, so that the losses due to the lack of task fulfillment by the VR system can lead to lower "expected benefits" (DP3). At the same time, also according to DP3, the future utilization of the system is heuristically derived according to TTF relationships (high TTF leads to high utilization; low TTF leads to low utilization; Table 2). The categorizations of future utilization determined there serve as important anchor points for later quantification of costs and benefits, since they are incorporated into personnel costs, for example, and determine the progress of the project and thus the time at which benefits are generated from internal strategic projects of organizations.

Step 6 Since Step 6 requires extensive research (e.g., systematic literary research), it is recommended outside of workshop formats. To determine the long-term benefits of the specific strategic VR system for strategic planning in organizations (DP4), the method of utility effect chains according to Schumann and Linß (1993) and Oesterreich and Teuteberg (2018b) is applied. This enables the identification of long-term impacts of technologies on organizations and provides the opportunity to transform intangible benefits into tangible benefits (DP4). For example, an economically unquantifiable benefit (intangible), such as "higher employee satisfaction", could be transformed into quantifiable benefits (tangible) like "low absence costs due to illness". The benefits identified by applying the utility effect chain methodology provide the basis for the quantification of strategic benefits in step 8.

Step 7 In this step, the costs of an investment in the VR system are considered in their entirety. We refer to the established cost overviews of Irani and Love (2000) and Irani (2002) for IS investment (DP2). Thus, we distinguish the following costs of a VR investment for strategic use in organizations (DP2):

- *Initial technology related costs:* VR hardware equipment (headset, controller, powerful computer), software (acquisition, modification, installation, configuration), consulting, infrastructure
- *Ongoing technology-related costs:* Hardware maintenance and update, software maintenance and update, support, energy, system supplement and synchronization
- *Personnel costs:* User training, management and administration, operational activities, costs of in-house application customization, changes in salaries
- *Organizational costs:* Business process restructuring, change management, disruption, resulting costs by systems utilization (cf. Fig. 4, "Expected costs of change through project(s))")

These can be specified for each technology and organization, resulting in a list of costs incurred (DP2). When quantifying the costs, workshop formats with experts are useful. These should be conceptualized in a way, that on the one hand internal organizational experts with access to internal cost rates and, on the other hand, VR technology experts in form of system suppliers should be incurred (DP4). Current VR market and license prices can be used for the technology-based costs. Depending on the system, costs should be identified that are utilization-dependent (DP3). Nevertheless, statements on the influence of utilization on costs can already be made independently of the specific system. Ongoing technical costs depend, among other things, on the costs of updates, maintenance and support. In case of more frequent utilization, in particular, higher internal support costs are to be expected. The expected utilization plays a particularly important role in the personnel costs, since the operational system utilization is included per employee hour in the costs. In the case of organizational costs, the follow-up costs of system use play a central role, so that the expected costs of change from projects are included here (see step 5, DP3). The quantification of the respective costs can be based on internal cost rates and management estimates(DP4), who are informed by the expected utilization and benefits from workshop 1 for each project to be solved with VR system. In summary, for a VR planning system for the strategic organizational projects, the cost categories listed above should be included and, where necessary, adapted. Thus, our overview leaves space for granular structure to be adapted for the specific VR use case and organizational circumstances, as there is no "one cost overview fits all solution" (DP2).

Step 8 When determining and quantifying benefits, a distinction must be made between operational and strategic benefits. Operational benefits result from the content-related application of the VR system within the specific internal projects of the organization. Therefore, operational benefits result from the sum of the expected benefits of the individual projects planned with the VR technology. In terms of operational benefits, however, utilization also plays a role by enabling projects to be completed faster than expected and savings to be realized more quickly as a result of higher utilization. The heuristic is that high to very high utilization will lead to a 1/3 reduction in project duration, medium utilization will lead to no reduction in project duration, and low utilization will lead to a 1/3 increase in project duration (derived from Pellerin et al. 2013a, 2013b). Therefore, this aspect also has a retroactive effect on the time at which costs for projects (investment costs) are realized (Step 7). We assume that, if no VR system would be used for planning, the projects could not be implemented and benefits could not be generated at all (DP3). The strategic costs are rather long-term effects that arise at the level of the organization and not inside the specific projects. We therefore address the tangible benefits transformed in step 6, and quantify them using estimates from experts in the organization, who are informed by the future utilization and suitability of the technology (DP4).

4.2.3 Quantitative analysis

Subsequently, the quantified values can be integrated in a CBA by applying the VoFI method according to Grob (1989) and simulating the investment with key figures like ROI and NFV. As VoFI is based on realistic values of loans, taxes and interest rates, it meets the requirements to perform realistic and transparent long-term simulation of an investment in an organizational context (DP4). The simulation period can be chosen differently, but it is recommended to consider an investment over at least five years (e.g. Oesterreich and Teuteberg 2017; Bensberg et al. 2022). Especially in the case of technologies such as VR for strategic use, benefits become effective later and a long observation period is worthwhile (Pöhler and Teuteberg 2022).

4.2.4 Presentation and validation of results

The key figures and results determined by the VoFI simulation can subsequently be presented in a way which represents the risk consideration understandable and comprehensible (DP4). First, a sensitivity analysis according to Savvides (1994) can be used to determine which of the input parameters has the greatest effect on the output parameters NFV and ROI. This can then be used to perform a best, base and worst-case consideration (cf. Oesterreich and Teuteberg 2017). To further extend these three cases, a Monte Carlo simulation can be performed. This allows to efficiently generate variations of the input parameters and to simulate results of the output parameters for many different cases semi-automated (DP4, Grob and Hermans 2009; Savvides 1994). If the results are presented in a plot diagram, transparent statements about the profitability of an investment under uncertainty are possible. In addition, a context-specific investigation of the VoFI can also be used to examine in more detail the extent to which certain input variables, especially those who affect the most sensitive, influence the output parameters.

4.3 Demonstration and application of the CBA method

Subsequently, the four phases of the generated CBA were tested sequentially by applying it to a realistic use case with employees of a German small and medium-sized enterprise (SME) in order to demonstrate the applicability of the methodology and to be able to assess the profitability of an investment in a specific VR system for workplace and process design according to RQ2.

4.3.1 Applying phase I: problem definition

The company for the case study in our scenario is a SME from Germany in the manufacturing industry, which is in a period of structural change and has several independent internal strategic projects that are to be implemented in the following years. First of all, we worked with management of the SME to identify five upcoming projects that should be implemented strategically in the area of workplace and/or process design in the coming years. This resulted in the following five projects: Redesign of reception area and office space, improvement of the receiving department, digitization of welding production and quality assurance, introduction of sales software, improvement of internal logistics and outgoing goods.

The VR system that needs to be proven for planning and managing these projects is presented next. The VR system for workplace and process design (VR-WPD system) consists of the components *VR-Interaction*, *3D-Environment*, *Process Modeling Kit*, *Evaluation* and *Multi-user* function *(cf.* Fig. 5, Pöhler et al. 2021).

The *VR-Interaction* provides for an appropriate application of VR with modern hardware like Oculus Quest 2. Users are given the opportunity to change locations in the virtual world by means of a teleport function, which is executed by using the touchpads of the controllers for quick locomotion. The creation of boxes and

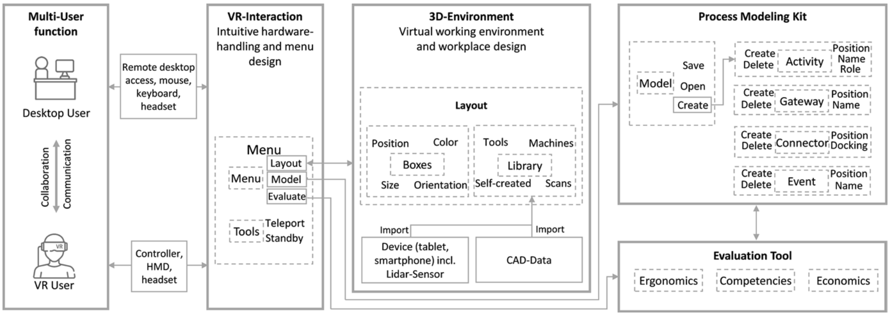

Fig. 5 Solution concept of the VR-WPD system (based on Pöhler et al. 2021)

elements from a library can be performed in the layout area. The import option for computer-aided design (CAD) data enables efficient *3D Environment* creation. True-to-scale replicas of the exterior walls can be shaped by using floor plans of already existing buildings or buildings in planning status. Boxes are the standard forms for the design of interior shapes. Standard industrial elements and tools as well as office elements can be called up in the library. After creating elements initially, users can adapt their size, position and color. Light Detection and Ranging (LiDAR) scans of the environment, as they can be created with a smartphone, can be uploaded into the library (cf. Fig. 6, a, b). The P*rocess Modeling Kit* is based on BPMN, as activities, gateways, connectors, and events can be called up (cf. Fig. 6, c). All elements have in common that they can be named using a VR keyboard and placed in the virtual environment (cf. Fig. 6, e). To evaluate the modeled work environments and processes, users can apply the *Evaluation tool*. Competencies (cf. Fig. 6, d), ergonomics (cf. Fig. 6, f) and economics of individual process steps and entire processes can be rated via scales. By implementing a *Multi-User* function, collaborative work between several users is possible. The desktop user can provide location-independent support via the headset and markers in the VR environment to assist navigation. An extension to multiple simultaneous VR users is also possible. The VR-WPD system can be used both for stand-alone workplace design and for process modeling in already generated virtual work environments. Application is possible as single-user by experts as well as collaboratively in workshops without long training periods (cf. Pöhler et al. 2021). Since different process variants can also be compared with each other, the system can also be applied for a target/actual process comparison (cf. Pöhler et al. 2021).

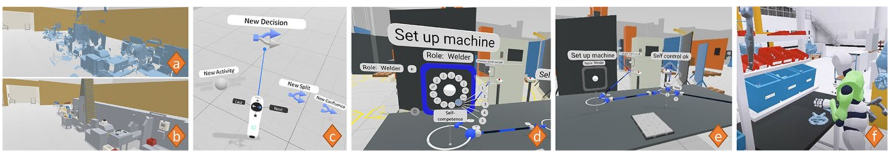

Fig. 6 Insights into the VR-WPD system (based on Pöhler et al. 2021)

4.3.2 Applying Phase II: design analysis

The steps 1 to 5 of Phase II were conducted in workshops with seven participants (skilled employees as well as persons from middle and upper management) of the SME. The second workshop for the economic quantification was held with two persons from upper management and controlling of the SME and one employee of the VR system vendor.

Step 1 The projects were predefined for the workshops by listing the changes from the actual to the target state (Table 3). Subsequently, they were prioritized (P1-P5) so that a time sequence was determined by discussion, as only one project can be executed at a time due to limited employee capacity.

Step 2 For each project, the workshop participants then indicated in bullet points which content-related and which execution-related characteristics are required in planning the projects. From the total tasks, the ten tasks that occur most frequently across all projects were then selected. An independent rating on a scale of 1 to 5 was then used to determine the importance of the task for the successful planning of each project. Afterwards, mean values were calculated from these seven ratings about task importance. In the same course, the expected investment costs per project and the targeted annual savings were determined on the basis of previously conducted forecasts and management estimates (see economic values Table 3).

Step 3 The test persons who had not already used the VR system in the course of previous workshops were offered the opportunity to test the VR-WPD system interactively. Using an example process, they were able to actively design workstations and model processes in the virtual environment. After all participants had familiarized themselves with the system, they subsequently rated, derived from the tasks, technical and effect-related characteristics of the system on a scale of 1 to 5 in terms of their degree of fulfillment (cf. Table 4).

Step 4 and 5 For each project, the matching of task and technology was performed based on the ratings from step 2 and 3. Table 4 shows how the participants rated the suitability of the system for planning the respective projects. For evidence of interrater reliability, we calculated Krippendorff's α for the technology characteristic ratings using SPSS statistical software (Hayes and Krippendorff 2007). The calculated α of 0.704 can be interpreted to infer at least "tentative conclusions" (Krippendorff 2018, p. 241), as it lies in the interval between $0.667 < \alpha \leq 0.8$. The overall result was that, with the exception of P4, all projects could be carried out with the VR-WPD system at a high to very high quality. Since P4 is more of a pure software project with little need to integrate spatial components, the VR-WPD system is unsuitable for it (Benefits factor: 0). Thus, it was already clear at this point that P4 would no longer be included in the further CBA. Multiplying benefits-factor by the targeted savings yielded the expected savings. In addition, the expected project durations were derived from the expected utilization, so that P2 and P5 each require only 2 instead of 3 years until implementation (duration reduction of 1/3). Additionally, based on the expected values for the utilization of the system generated in the workshops, a better database for estimating the costs and benefits of the system in steps 7 and 8 was generated.

Table 3 Overview of the SMEs strategic restructuring projects

ID	Project (exp. duration)	Definition (actual state → target state)	Expected costs [€][a]	Targeted ann. savings [€][a]
P1	Digitization of welding production and quality assurance process (2 years)	production plan in paper form → digital production plan long walking distances → short process paths poor documentation → accurate defect documentation inefficient use of space → efficient use of production space unclear communication channels → use of a standard messenger for communication	300,000	142,000
P2	Redesign of reception area and office space (3 years)	old, unergonomic furniture → ergonomic, modern furniture no task-oriented seating arrangement → sitting together of employees with frequent contact inefficient space utilization → integration of non-bulky furniture	200,000	35,000
P3	Improvement of the receiving department (2 years)	no standardized control forms → standardized control forms documentation on papers → digital documentation with tablets no standardized process → definition of a standard process no clear process guidelines and communication channels in case of irregularities → definition of a deviation process no fixed storage locations → declared but flexible storage locations	350,000	163,000
P4	Introduction of sales software (2,5 years)	no standardized sales process → define standardized sales process filing of offers in mails and folders in Explorer → working in one system status of an offer or inquiry per customer not retrievable and not mobile → desktop and mobile solution no customer database → data base with all customers, offers and their status	230,000	114,000
P5	Improvement of internal logistics and outgoing goods (3 years)	no standardized internal delivery documents → standardized internal delivery formats documentation on paper → digital documentation with tablets no standard process → define standard process no process for irregularities → define deviation process no clear storage locations → declared but flexible storage locations	260,000	108,000

[a]The values are the result of management estimates made based on cost estimates from suppliers for the projects, internal cost rates and comparative values from market and comparable companies

Step 6 First, the long-term benefits of using VR for workplace and process design at the organizational level were identified and transformed into tangible benefits by applying Schumann and Linß's (1993) utility effect chains. For example, aspects such as higher identification with the company, better digital skills or lower absence due to higher mental health can be mentioned (Pöhler and Teuteberg 2022). Therefore, in a first step, general benefits resulting from the use of the VR are determined via literature. The identified benefits are then summarized and transferred in a way that a quantification is possible. For the use of the VR-WPD system in organizations, the strategic as well as the resulting quantifiable benefits are presented in Table 5. The amount in form of monetary values of these quantifiable benefits, which can be used later for CBA, depends on the specific organizational use case (Step 8). Based on preliminary work by Pöhler and Teuteberg (2022), six economically quantifiable strategic benefits could be identified in summary (see Table 5), which are explained in the following.

A utilization of VR has proven to lead to increasing employee satisfaction (Brade et al. 2016; Chan 2019). Similarly employees do not have to be exposed to dangerous situations when, for example, process sequences and work in hazardous environments are simulated (Joshi et al. 2021). These two aspects lead to savings, as both the mental and physical health of employees are promoted, which leads to lower absence times (Slemp and Vella-Brodrick 2014). The fact that the use of VR is fun for employees due to the high level of immersion has a positive effect on employee loyalty to the company (Chan 2019). At the same time, the use of innovative technologies has a positive impact on the external image of companies (Huang and Kunc 2012). This enables companies to save costs for recruitment (Oesterreich and Teuteberg 2018a). If employees accept VR, this can also have positive effects on the general acceptance of other digitization activities (Pöhler et al. 2021). This in turn reduces the costs of convincing employees and pushing the change in organizations. Since VR enables multi-user collaboration over long distances, workshops can be conducted purely virtually (Hoppe et al. 2018), which saves travel costs (Sarkady et al. 2021). Likewise, the use of VR eliminates the costs for physical materials (Muttaqin et al. 2020; Kloiber et al. 2020), as prototypes do not have to be created with cardboard. Customers can be convinced by VR (Nielsen and Nielsen 2008), which represents the image of a modern organization and saves marketing costs (Oesterreich and Teuteberg 2018a).

Step 7 According to IS cost frameworks of Irani and Love (2000) and Irani (2002) we distinguish between *initial and ongoing technology related, personnel and organizational costs*. Table 6 provides an overview and explanation of specified costs of an investment in the VR-WPD system. In addition, the three columns on the right draw a connection to the procedure model from Fig. 4. They indicate whether the costs are not affected, medium or high affected by utilization, which was identified through discussion among workshop participants.

Initial technology-related costs: Depending on the choice between a standalone solution like the Quest 2 or an HMD connected to a powerful computer (e.g. HTC Vive Pro), different initial hardware costs occur. Multi-user workshops require a large screen for desktop users to co-create. Installation and configuration cause costs for integrating the work environment by generating LiDAR scans and importing

Table 4 Resulting values after TTF matching for all projects

No	Characteristic of the VR-WPD system	Category	⌀ Rating	Tasks solved in…[b]				
				…P1	…P2	…P3	…P4	…P5
1	Creation of large number of modeling elements	technical	3	(5)	x (2)	(5)	(4)	x (3)
2	Immersive, spatial vison and experience	effect-related	5	x (4)	x (4)	x (4)	x (2)	x (4)
3	Fast and effortless rearrangement of objects	technical	5	x (4)	x (4)	x (4)	x (2)	x (4)
4	Barrier-free collaborative working	effect-related	4	x (4)	x (4)	x (4)	(5)	x (4)
5	Analyzing effects on ergonomics	technical	4	x (4)	x (4)	x (4)	x (2)	x (3)
6	Assessing competencies	technical	4	x (4)	x (3)	x (4)	(5)	x (4)
7	Defining and calculating KPIs	technical	3	(4)	x (3)	x (3)	(5)	x (3)
8	Documentation and storage	technical	2	x (2)	(4)	x (2)	(4)	x (2)
9	Experienceability of digital elements	technical	3	x (3)	x (3)	(4)	(4)	(4)
10	Creativity promotion	effect-related	5	x (4)	x (3)	x (3)	x (3)	x (3)
		Benefits factor		0.8	0.95	0.8	0	0.95
		Utilization		Medium	High	medium	not given	high
		Exp. ann. Savings		€113,600	€33,133	€130,400	€0	€102,600
		Duration till implementation		2 years	2 years	2 years	–	2 years

[b]x: task solved by VR-WPD system; (No.): averaged rating

Table 5 Strategic benefits and resulting quantifiable benefits of VR and its utilization

Strategic benefits		Resulting quantifiable benefit
Increasing employee's satisfaction	→	Reduction of costs for mental and physical health awareness
Enhancing safety	→	Reduction of churn and recruitment costs
Increasing the fun factor at work	→	Reduction of churn and recruitment costs
Increasing the attractiveness of the organization	→	Reduction of change management costs
Increasing the acceptance of new technologies	→	Reduction of change management costs
Enabling exchange over long distances	→	Reduction of travelling costs
Reducing travelling effort	→	Reduction of material costs
Reducing the amount of paper	→	Reduction of material costs
Reducing the amount of material for prototyping	→	Reduction of marketing costs
Improving corporate image	→	Reduction of marketing costs

CAD data. The costs incurred by recreating the working environments using the layout tool must also be considered. Particularly at the beginning, external consulting specialists from the field of VR implementation, workplace design or process management can be helpful (Irani et al. 2006).

Ongoing technology-related costs: Since VR is subject to rapid innovations, costs for upgrading the hardware must be expected to stay up-to-date. In addition, costs for new installations can be expected when new software versions with new features have to be installed. External system support can also be consulted during use. Depending on utilization, the energy costs such as electricity and heating that are generated during use must also be considered. But at the total cost level, they account for a negligibly small proportion for VR systems (Yin et al. 2022). Depending on the TTF, it can also be estimated whether additional systems must be used in order to achieve tasks to be carried out with a high quality. These can be, for example, tools for calculation (cf. Table 3, score 3) or additional storage effort (cf. Table 3, score 2) which may not be possible with the VR system. In addition, a software rental model generates costs for the annual rental of the software.

*Personnel costs***:** Costs for the secondment of participants to training courses to learn the handling of the VR-WPD system are to be expected. The strategic management of integration includes, among other things, the participation of employees in information events. In addition, key users can be defined who, as internal VR experts, serve as contact points in the event of problems (Berg and Vance 2017). The effort and costs for the key users as first level support depend on the utilization of the VR system. Depending on the number of strategic projects for workplace and process design and the type of use (alone, multi-user, workshops), personnel costs will be incurred through the operational use of the system. Efforts are required if VR environments are synchronized with changes in reality, e.g. when machines are moved. Increasing competencies like digital skills of employees (Oesterreich and Teuteberg 2017) need to be compensated with a wage increase to prevent poaching.

Organizational costs: Business process restructuring costs are based on the integration of new technologies into existing processes. The costs of change management must also be considered, as greater effort can be required, especially for those with less technology affinity. Costs of disruption can arise, for example, if productive activities are disrupted by the use of VR. However, since VR unlike augmented reality offers the benefit that it does not interact with the real environment in operational use, few negative influences on productive processes are to be expected (Zawadzki et al. 2020). The costs resulting from the utilization of the system relate to the primary use of the system and the resulting effects. Since it is a tool for workplace and process design, the investment costs arising from the planning and changes targeted with the projects are considered as organizational costs (see "expected costs of change through project", Fig. 4).

Based on the transparent cost listing from Table 6 and the impact of expected utilization per cost type, calculations using SME internal cost rates, VR market and license prices and management estimates were used to quantify the costs. The individual quantified cost values per cost type can be found in the in the subsequent VoFI simulation in Sect. 4.3.3.

Step 8 The operational benefits are already included into the benefits that result per project from the utilization of the VR system (cf. Fig. 4 "expected benefits"). Thus, the operational benefits in monetary form are evident by summing up the annual expected savings for all projects. The duration until the first realization of savings per project can be seen in Table 3. As expert estimates are suitable for quantifying the effects of the utilization in a company-specific context (Hares and Royle 1994), the experts from the SME estimated the derived tangible strategic benefits from step 6 in form of annual savings informed by suitability and future utilization of the VR-WPD system (Fig. 4 "strategic benefits"). The individual quantified benefits for operational benefits per project and for each strategic tangible benefit can be found in the subsequent VoFI simulation in Sect. 4.3.3.

4.3.3 Applying phase III: quantitative analysis—the VoFI CBA

After quantitatively evaluating the types of costs and benefits based on their future utilization, they can be embedded in a framework for simulating long-term investments using the VoFI calculation from Grob (1989). The prioritization indicated which projects are included at which point in time, and the determined duration indicated the point in time when savings can be achieved through a project for the first time. For example, for P1 with the highest priority and a project duration of 2 years, the annual savings were included in the calculation for the first time after year 3. Similarly, investment costs were included for the first time at this stage, assuming a 10-year depreciation period.

Table 6 Costs of VR-WPD investment based on Irani and Love (2000) and Irani (2002)

Cost type	Specification	Affected by utilization		
		Not	Medium	High
Technology-related costs				
Initial				
Hardware equipment	VR headset, controller, tracking boxes	x		
	Powerful computer/gaming laptop	x		
	Screen and headsets	x		
Software	Acquisition costs of the VR software	x		
Software installation and configuration	Costs for installation of the software	x		
	Costs for generating and collecting LiDAR and CAD data	x		
	Costs for building virtual worlds based on LiDAR and CAD	x		
Consulting	Costs for initial consulting for workplace design, process design or VR implementation	x		
Ongoing				
Hardware maintenance and update	Update and maintenance costs of hardware because of technological change	x		
Software maintenance and update	Costs of updating new versions because of new features		x	
Support	User support for operative use of the system			x
Energy	Cost of electricity and heating			x
System supplement and synchronization	Cost of additional systems, as the main technology does not cover all task requirements	x		
Rental costs	Costs for the rental of the software license		x	
Personnel costs				
User training	Costs for internal and external training for handling workplace and process design using the VR software	x		
Management and administration	Costs for managing the strategic integration of VR in the company	x		
	Costs for key user support			x

Table 6 (continued)

Cost type	Specification	Affected by utilization		
		Not	Medium	High
Operational activities	Costs of using the VR tool for operational workplace and process design (alone, workshops)			x
Costs of in-house application customization	Continuous readjustment of virtual working environments	x		
Changes in salaries	Pay increase based on improved employee skills			x
Organizational costs				
Costs of business process restructuring	Integrating the new system into work practices	x		
Costs for change management	Costs of changes coming through the new system	x		
Cost of disruption	Costs of disrupting other business processes through installation or utilization	x		
Resulting costs by systems utilization (= Expected costs of change)	Costs arising from the use of the system, which are costs depending on projects to be planned with the system			x (timing)

We subsequently incorporated the total determined initial and annual costs and savings into the transparent VoFI overview, which can be seen in online Appendix A[2]. VoFI represents a clear overview of original and derivative cash flows (Oesterreich and Teuteberg 2017). This also considers repayment and interest conditions that the company has to price in for the planned investment. We performed the simulation with the Excel-tool and the procedure of Oesterreich and Teuteberg (2017), adapted all cost types, and quantified benefits to the specifics of the use case. In doing so, we ran the simulation with the basic parameters listed in Table 7.[3]

Based on these parameters, the derivative cash flows and financial indicators are calculated using the VoFI simulation. In each one year lasting period, we calculated and balanced all cash in- and outflows of loans, investments and taxes, which is followed by aggregating the net balance of all loans and funds for a ten-year period (cf. Oesterreich and Teuteberg 2017). We thus were able to examine the future value of the company's investment, as the main variables of NFV and ROI were calculated automatically with the Excel-tool (cf. Table 8, third tab in Online Appendix A).

If the NFV is positive or the "ROI exceeds the [value of the] opportunity interest rate" (Oesterreich and Teuteberg 2017, p. 350), an investment can be categorized as profitable (Götze and Bloech 2013; Grob 1989). In this VoFI simulation for the investment in the VR-WPD system, the NFV results in €525.843 and the ROI is calculated with 59.5% after ten years. This shows that economical profitability is given for the considered use case.

4.3.4 Applying Phase IV: Presentation and Validation of Results

Since economic evaluations are primarily influenced by input variables, we use a sensitivity analysis to find out how much ROI and NFV would be affected by a change in different starting parameters. Using best-case (+10% deviation) and worst-case (-10% deviation) scenarios, we were able to demonstrate that the sensitivity is strongest for changes in total cash inflow (NFV = +22.7%/−24.3%). Even in the worst-case scenario, we determined positive overall values for ROI and NFV (cf. Table 9).

However, in a sensitivity analysis as presented in Table 9, only a few cases can be investigated, since manual adjustment quickly requires a high computational effort (cf. Savvides 1994). In order not to have to adjust individual parameters for each simulation run manually, we utilized probabilistic risk assessment by assessing a Monte Carlo simulation to generate 1,000 different cases. A probability distribution of the most sensitive input parameter was chosen, which in our case was a normal distribution of the total cash inflow of 10% (cf. Oesterreich and Teuteberg 2017). Figure 7 presents the simulation results for the dependent variables of NFV and ROI

[2] Online Appendix A—VoFI simulation for the VR-BPM system: https://tinyurl.com/4beeh3p9. Small changes were made to the cost categories that concern the VR system provider to protect the VR provider's pricing model, but these balance out over the total calculation.

[3] The assumptions here represent a specific individual case based on the SME under consideration and must be adjusted for other cases according to the geographic region and the market conditions (interest rates, tax rates) prevailing at the time (cf. Oesterreich and Teuteberg 2017).

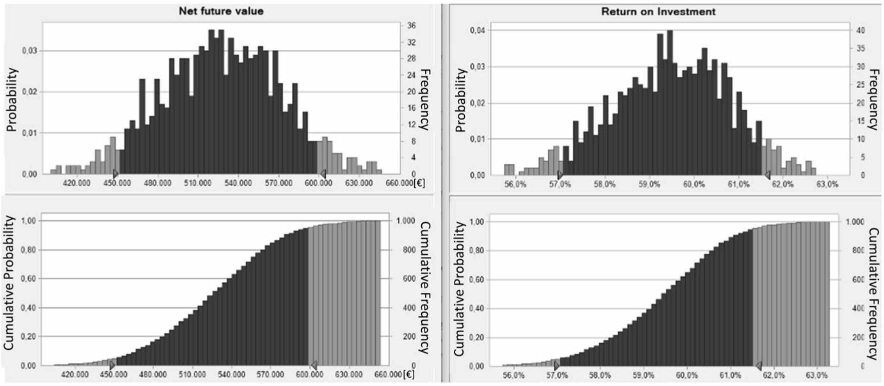

Fig. 7 Risk assessment of the VR investment (NFV and ROI)

based on 1,000 runs. As can be seen from the graphical representation, there is a 90% probability that the NFV will be at least €451,226 and the ROI will be at least 57.1% after a ten-year period in our use case.

It is also worth taking a detailed look at the total cash inflow as most sensitive input variable and how it is generated. For this purpose, a closer look at the VoFI overview of the total cash inflow is helpful (Online Appendix A). In our observations, the total cash inflow is generally at a high level, which is due to two factors. First of all, there is a large number of feasible projects for which the VR-WPD system can be used. If an organization had only one use case instead of several, the total cash inflow would be significantly lower. Second, these projects are all expected to be profitable (the expected savings exceed the expected investment costs in the long term usually after two to three years, cf. Table 3) and can therefore be calculated with high annual savings in the long-term view. Thus, the total cash inflow benefits particularly strongly from the revenues generated by the projects planned with the VR-WPD system.

5 Discussion

The goal and motivation of this contribution was to answer the question of whether VR technology for workplace and process design is profitable from a cost–benefit perspective (RQ2). However, since existing methodological approaches for ex-ante CBA would not have answered RQ1 satisfactory, this paper initially answered the question of how to develop a method for suitability and utilization-based CBA of VR systems for strategic planning in organizations (RQ1). Guided by the DSR approach from Hevner (2007), we developed literature-based DPs, evaluated them by experts and instantiated a CBA method to answer RQ1. The CBA demonstration, in the form of a case study simulation, provided valuable insights into factors that influence the profitability of investments in VR for workplace and process design, and thus provided answers to RQ2.

Table 7 Parameter settings using VoFI for VR-WPD

Economic life (t): 10			Tax rate: 40%								
Interest conditions				Amount		Interest		Duration			
	Internal funds			5,000		3.00%		10			
	Instalment loan			10,000		5.00%		9			
	Bullet loan			10,000		5.00%		9			
	Annuity loan			3,000		5.00%		9			
	Loan in current account			1,200		10.00%					
	Financial investment					2.00%					
	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7	t = 8	t = 9	t = 10
Net cashflow (CF)	− 29,200	− 19,800	− 52,300	67,450	44,950	68,550	31,050	155,550	127,050	241,750	239,250
Total cash inflow		15,000	15,000	128,600	128,600	161,850	161,850	292,250	292,250	394,850	394,850
Total cash outflow		34,800	67,300	61,150	83,650	93,300	130,800	136,700	165,200	153,100	155,600

Table 8 VoFI calculation for the VR-WPD investment (based on settings of Table 7)

VR investment	t=0	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10
Series of net cash flows	−29,200	−19,800	−52,300	67,400	44,900	68,433	30,933	155,500	127,000	241,967	239,467
Bullet loan											
+Credit intake	10,000										
−Redemption										−10,000	
−Debitor interest		−500	−500	−500	−500	−500	−500	−500	−500	−500	
Annuity loan											
+Credit intake	3,000										
−Redemption		−272	−286	−300	−315	−331	−347	−365	−383	−402	
−Debitor interest		−150	−136	−122	−107	−91	−75	−57	−39	−20	
Loan in current acc											
+Credit intake	1,200										
−Redemption		12,857	33,101	−36,791	−10,367	0	0	0	0	0	0
−Debitor interest		−120	−1,406	−4,716	−1,037	0	0	0	0	0	0
Financial investment											
−Reinvestment	0	0	0	0	−15,159	−40,517	−18,530	−93,478	−77,526	−137,302	−149.308
+Disinvestment	0	0	0	0	0	0	0	0	0	0	0
+Creditor interest	0	0	0	0	0	303	1,114	1,484	3,354	4,904	7.650
Taxes											
−Payment		0	0	−23,521	−16,021	−26,026	−11,379	−61,356	−50,733	−97,263	−97.592
+Refund		9,596	23,083	0	0	0	0	0	0	0	0
Net funding	0	0	0	0	0	0	0	0	0	0	0
Balances											
on instalment loan	10,000	8,889	7,778	6,667	5,556	4,444	3,333	2,222	1,111	0	0
on bullet loan	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	0	0

Table 8 (continued)

VR investment	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7	t = 8	t = 9	t = 10
Series of net cash flows	−29,200	−19,800	−52,300	67,400	44,900	68,433	30,933	155,500	127,000	241,967	239,467
on annuity loan	3,000	2,728	2,442	2,142	1,827	1,497	1,149	785	402	0	0
on loan in current acc,	1,200	14,057	47,158	10,367	0	0	0	0	0	0	0
on financial invest,	0	0	0	0	15,097	55,675	74,205	167,683	245,209	382,511	531.819
Net balance	−24,200	−35,674	−67,378	−29,176	−2,224	39,734	59,722	154,676	233,696	382,511	531,819
Financial measures											
Future value of investment											531,819
Future value of opportunity											5,977
NFV											525,843
ROI											59,5 %

Table 9 Overview of the sensitivity analysis

	Input variable: total cash inflow		
Financial measures	Worst case (– 10%)	Base case (0%)	Best case (+ 10%)
NFV	397,830	525,843	645,276
ROI	55.1%	59.5%	62.7%
Increase (+)/Decrease (–) of NFV	– 128,013	0	+ 119,433
Percentage change of NFV	– 24.3%	0%	+ 22.7%
Increase (+)/ Decrease (–) of ROI	– 4.3%	0%	+ 3.3%
Percentage change of ROI	– 7.3%	0%	+ 5.5%

First of all, the CBA we have developed differs from previous approaches for quantitative ex-ante evaluation in IS in being problem-driven using the DSR approach based on literature-based DPs. To the best of our knowledge, we are the first to develop CBA for IS based on DPs according to Gregor et al. (2020). Previous approaches have been less rigorous in deriving their CBA method and rather transfer and operationalize existing frameworks and approaches to their use cases (e.g., Nanath and Pillai 2013; Vaughan et al. 2013). However, as such an approach would have led to inaccuracies in the quantification of costs and benefits due to a small database for our considered use case (Fridgen and Moser 2013; Oesterreich and Teuteberg 2018a), a novel CBA approach was necessary. The DPs generated provide operational design knowledge not only for a specific use case, but for a group of use cases, so that classification as a "nascent design theory" is justifiable (Gregor and Hevner 2013). In the following, we will also critically review the components on which our CBA is based:

- *Suitability and utilization:* The suitability and utilization included in the CBA based on TTF theory serves as a means of providing a valid database for quantification. As confirmed by the expert interviews, the basic inclusion of both aspects makes sense if the database is lacking. However, care must be taken that the inclusion of both aspects is made heuristically, which represents a simplification of reality (Romanycia and Pelletier 1985). By limiting to certain specifics of technology and task and matching them, not all aspects of a TTF can be covered. In addition, the utilization derived from the suitability is based on general maturity models and thus a justified but not verified derivation, which would rather have to be proven specifically per case via structural equation modeling. Since this would contradict a practical applicability of the CBA, it was assumed that the correlations and causalities of the TTF theory can be transferred to any IS like our VR case.
- *Technology follow-up costs:* The technology follow-up costs were strongly included in our considerations. Due to the fact that IS, in this case VR, for strategic use in organizations primarily also results in strategic benefits (Pöhler and Teuteberg 2022), we have included the savings from successful planning of the respective projects in our CBA. This inevitably results in a dependency of the

profitability of the VR investment on the respective profitability of the projects executed with it. Moreover, the timing of the realization of follow-up costs and benefits is based on estimates, which entails uncertainties. For a better comparability, an additional consideration of the same projects planned by conventional IS could provide comparative values on profitability.

- *Quantification techniques:* The difficulties in quantifying future benefits in ex-ante CBA in IS could be reduced by incorporating TTF heuristics based on more valid data, but the databases (expert estimates, internal cost rates, averages) continue to provide uncertainties that can lead to inaccuracies in the quantified values. Thus, as recognized by Murphy and Simon (2002) and Oesterreich and Teuteberg (2017), the quantification of benefits in CBA remains a complex and uncertain area.
- *Long-term view and risk assessment:* The determination of strategic benefits by means of utility effect chains is subject to uncertainty, since the final chain only represents one specific state of many possible ones (Oesterreich and Teuteberg 2018a). Thus, the procedure cannot completely eliminate the risk of non-accounting of utility effects that have an impact on the CBA. The risk assessment is also based on assumptions, so that, for example, in conservative assessments, stable framework conditions (e.g. no crises) and a low variability of input parameters are assumed.
- *Sustainability:* In addition, it has been suggested by experts that certain mechanisms of sustainability are not accommodated in the CBA method. For example, "the technological rapidity and dynamics" (E3) as well as the changing degree of maturity of VR ("can it not change over time that the technology at some point proves to be suitable?", E4) were not accommodated explicitly. However, this could be solved by "a rolling consideration", as requested by E1, and thus the CBA could also be conducted again at later stages.

However, in addition to these specific limitations of our elaboration, answering RQ1 also provides valuable implication for science and practice. By rigorously elaborating and evaluating our DPs, we were able to expand the knowledge base for conducting ex-ante CBA of IS with low suitability and utilization data. To counteract a monolithic structure of design knowledge, other researchers can build on our design knowledge for their IS CBAs (vom Brocke et al. 2020). Especially in research projects, where novel IS is often used for untested use cases, the TTF-based CBA method could be transferred and thus replace a good historical database in investment considerations. In practice, especially decision makers in organizations planning to use VR for planning and designing internal change projects can benefit from the method.

Additionally, by applying the four phases of our developed CBA method to specifics of a SME from the manufacturing industry, we could give an answer to RQ2. An increase of ROI by 59.5% and NFV by 525,828 € could be simulated in the long run by investing in and applying the VR-WPD system. Because these values are positive (against a scenario of zero action), it can be assumed that an investment in a VR-WPD system is recommendable for the specific use case. However, the profitability is based on certain circumstances, which we subsequently derive from the details in Online Appendix A. First of all, such a VR system incurs high annual license costs for multi-user access. Thus, an acquisition only makes sense if companies generally want to initiate many strategic projects for workplace and process design in the near future, e.g. for companies that are implementing the digital transformation in production, like the SME in our use case. With higher utilization, strategic restructuring projects can then be executed faster and savings can be achieved more quickly. The VR system can be used especially for tasks where high demands are made on spatial changeability, collaborative working and creativity of the users. In contrast, higher costs would be incurred if a high quantity of elements to be modeled needs to be compensated with a long modeling time or if the calculation of economic key figures would have to be performed by additional tools (cf. Table 3). Another cost-saving factor for the SME was that a large amount of CAD data was already available, so that the time-consuming creation of the 3D environment with the VR-WPD system would tend to have less negative impact. Using VoFI simulation, we could confirm that the general benefits of VR for workplace and process design like high motivation to use (Pöhler and Teuteberg 2021) or high usefulness (Pöhler et al. 2021) can lead to monetary benefits. It is also worth noting that the hardware costs only account for a negligible proportion of the total costs, which is consistent with cost–benefit considerations of VR use for medical purposes (Wood et al. 2009; Lloréns et al. 2015; Pottle 2019). Rather, the costs arising from an organizational perspective are more influential financially, which confirms the results of Irani et al. (2006).

Answering RQ2 leads not only to scientific, but above all to practical findings. For research, we demonstrated applicability of our specific CBA for strategic VR use in organizations. Accordingly, this method is in general also transferable to other strategic VR systems in other application areas than workplace and process design, which needs to be validated in future research. For practitioners deciding on an investment in VR, the findings on profitability and cost structure are particularly relevant. We were able to confirm generalized findings by Irani et al. (2006) with our determined cost structure, meaning that practitioners should not focus on hardware but rather on organizational follow-up costs. For entrepreneurs who want to use VR for workplace and process design, we were able to demonstrate that it can be profitable. The limitations of the findings are due to the method, which are already described in the limitations of answering RQ1, and general uncertainties of CBA like the risk of overlapping of cost and benefit types (Irani et al. 2006), the dependence on system boundaries (Oesterreich and Teuteberg 2017) or the heuristically simplification of adoption processes of IS in organizations (Depietro et al. 1990). In addition, as can be seen from the interrater reliability, there has been some uncertainty in the evaluation of the technology characteristics, which can be attributed to differences in experience and attitudes towards VR technology. Finally it must be said, that investment decisions are not made solely on the basis of monetary simulations as they are often dependent on the decision maker's beliefs, visions and risk aversion (Oesterreich and Teuteberg 2017; Savvides 1994).

6 Conclusion

With this contribution, we have on the one hand developed a method for a suitability- and utilization-based CBA of the implementation and strategic application of VR in organizations. Thus, we meet the need for a more objective and grounded quantification of costs and benefits of novel IS with low database. Applying DSR, we have generated and evaluated four DPs that we could finally instantiate, leading to a CBA method for combining TTF theory and general quantitative investment decision making methods in IS. On the other hand, by applying the procedure to a VR system for workplace and process design, we were able to demonstrate that an implementation and application of the VR system can be profitable for organizations. We identified, that profitability arises if a sufficient number of profitable use cases is available and if high requirements for a creative, joint solution of problems with reference to spatial components is necessary. With this contribution, we have thus substantiated, that the benefits of VR for workplace and process design, which could not be quantitatively defined before (cf. Pöhler and Teuteberg 2022), can be expressed in terms of quantifiable economic values.

Future research should validate the method by applying it to other VR systems for strategic use in organizations. In addition, performing the CBA method in a modified form would be useful to examine the same use cases of the same SME with a conventional workplace and process design system in terms of its profitability.

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