Closing spatial und motivational gaps: Virtual Reality in Business Process Improvement

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CLOSING SPATIAL AND MOTIVATIONAL GAPS: VIRTUAL REALITY IN BUSINESS PROCESS IMPROVEMENT

Research Paper

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Abstract

In times of growing digitization and globalization, Business Process Improvement is becoming increasingly important. Prior to improving processes, weak points in existing business processes must be identified. However, such improvement and change processes are often hindered by a weak participation due to lacking motivation among employees. At the same time, conventional process modelling languages do not allow for including the environment in finding weak points. To address these barriers, we compared the use of Virtual Reality to a conventional 2D-paper presentation. For this purpose, we carried out an experiment, in which weak points of a picking process should be identified. We examined and compared the number of identified weak points and the user perceptions in both environments. It turned out that Virtual Reality applications are an effective and motivation-increasing alternative to conventional instruments for use in Business Process Improvement.

Keywords: Business Process Improvement, BPI, Business Process Modelling, Virtual Reality

1 Introduction

Globalization and digital transformation require companies to constantly adapt their business processes (Börger, 2012). For the graphical representation of business processes, process modelling languages such as Event-driven Process Chain (EPC) and Business Process Model and Notation (BPMN) have proven themselves over the past decades. Especially BPMN is used in industry for intuitive and fast creation of business processes. The created processes offer a good overview, so that a quick understanding of the process can be achieved for both process participants and outsiders (Wohed et al., 2006).

However, since business processes can also have weak points and should be adapted to technical progress, new legal regulations or structural reorganizations, they should be reviewed regularly, which is called Business Process Improvement (BPI) (Harrington, 1994). The evaluation of processes should provide comprehensive information in order to be able to evaluate individual process steps and the overall process for possible weak points (Champy and Cohen, 1995). Although automated techniques such as process mining (van der Aalst et al., 2012) already exist to detect weak points, they are strongly customized to digitized (information) processes. For manual or hybrid processes, it is often necessary to use traditional analysis methods such as brainstorming with the help of BPMN overviews (cf. Figl and Recker, 2016). Yet, BPMN can only represent process flows in an abstract 2D form. Especially in processes in which spatial components such as distances or location-dependent activities play a role, the visualization by means of a 3D environment can provide advantages (Pöhler et al., 2020). In order to use visual representation for the weak point analysis, processes should be represented in the environment in which they are performed, what we call “context based” here. This can be accomplished by virtual reality using head-mounted displays (HMDs). VR, unlike augmented
reality (AR), can also be used to recreate an environment that may still be in the planning or design phase without wasting material resources (Pan et al., 2006). In addition, the teleport function in VR offers a quick change of location independent of the real environment and no intervention in the physical production environment is necessary, so that process flows could be disturbed. The resulting 360° spatial experience can be inspiring, stimulating and motivating to the user through the effect of presence (Bowman and McMahan, 2007) and the support of a flow state, in which a user is completely immersed in an activity (Kim and Jae, 2019). This in turn can render business process analysis more effective and lead to the uncovering of more or different types of weak points. In addition, the use of novel technologies like HMD-VR can enhance user experiences, which invigorates process analyses and change processes. These are often carried out in workshops, which are usually perceived as lengthy and tedious (Fromm et al., 2020; Gill, 2002).

Previous work on the symbiosis of business process management and virtual reality, focuses primarily on process elicitation or modelling (e.g. Pöhler et al. (2020) or Thies et al. (2019)). The benefits of generated 3D process representations in terms of process understanding and effectiveness have already been investigated in desktop applications (Leyer et al., 2019) or VR environments (Zenner et al., 2020). Although the detection of weak points in generated processes constitutes an elementary component of process analysis, it has not yet been investigated in a context based manner in realistic virtual industrial environments using head-mounted displays. Therefore, the following research question (RQ) arises:

**RQ:** To what extent is a Virtual Reality application an effective and motivation-increasing alternative to conventional 2D methods when identifying weak points in business processes?

To answer this research question, we chose a structured procedure. In section 2, we first briefly explain the topics of business process management (BPM) as well as their subcategories and virtual reality. Subsequently, we conduct a complete literature search according to vom Brocke et al. (2009) to systematically identify relevant literature. In the third section, we explain the methodical procedure. In order to investigate the differences in the identification of weak points in business processes between abstract BPMN and VR representation, we conducted an experiment. A realistic picking process was examined regarding possible weak points using VR. In addition, a control group was assigned to find weak points of the same process in abstract BPMN representation. Afterwards, we evaluate the results in section 4. In section 5, we discuss our results and compare them with former studies. Implications for research and practitioners are also elaborated. Finally, in section 6, we draw a conclusion, mention limitations and hint at future research work.

2 Related Work

Business process management is a traditional field of business economics. It can be differentiated between strategic and operative business process management (Armistead et al., 1999) (see Fig. 1). In strategic business process management, the focus is more on the entirety of all processes and their integration into the organizational structure. It defines the framework in which operational business process management operates. On the operational level, the focus is on elicitation, modeling, analysis, innovation and implementation of business processes. These steps are performed in a cycle (Dumas et al., 2013, p.23), whereby after the initial elicitation, the designed and implemented processes are monitored instead. The cycle represents the steps of BPI. The identification of weak points within a business process is an elementary part and the foundation of the business process analysis (van der Aalst et al., 2003; Coskun et al., 2008). This is where weak points are to be identified and subsequently evaluated. Based on this, a redesign and innovation of the process can then take place. The challenges of operational business process management and modelling often consist in low motivation of involved parties to change and thus to participate (Schmidt and Nurcan, 2008; Erol et al., 2010).
The concept of virtual reality has already been described by Sutherland in 1965: Here it is emphasized that the user sees VR as a window through which he perceives environments, sounds, feelings and interactions as realistic (Sutherland, 1965). A more recent and technical definition describes VR as “the use of computer graphics systems in combination with various display and interface devices to provide the effect of immersion in the interactive 3D computer-generated environment” (Pan et al., 2006). With the development of high-resolution head-mounted displays (HMD) at the beginning of the 2010s, virtual reality has experienced a new upturn. Well-known companies such as Samsung, HTC, Google or Facebook developed their own HMDs and made them available to the general public. Forecasts for HMD technology range from a positive economic development (Sachs, 2016) to the designation as a new milestone in technology development (Cipresso et al., 2018). In the industrial context, virtual reality is used for various purposes. Design and assembly, immersive training, inspection and quality assurance and repair and maintenance are the main fields of application of VR in industry (Cohen et al., 2018).

The purpose of a systematic literature search is to present the state of research in a topic area as completely and clearly as possible. In our case, the state of research on the use of virtual reality in business process management (BPM) is to be illustrated. In the area of BPM, we focus on the fields of business process modelling and improvement as well as weak point analysis. In order to determine the current status, we applied the methodology commonly used in information systems according to vom Brocke et al. (2009). Since HMD-generated virtual realities are experiencing tremendous progress and have become more mass-market accessible and affordable, we limited our search to sources from the last 15 years.

The terms from the fields of "virtual reality" and "business process management" were combined to create a search string that is as accurate as possible. We searched the databases of Scopus, Google Scholar and SpringerLink using the search string ((VR OR "virtual realit*" OR "virtual world*") AND (BPM OR BPMN OR BPI OR "process management" OR "process modelling" OR "process elicitation" OR "weak point analysis" OR "process analysis" OR "process improvement")). First, we read the titles to assess the relevance. In a next step, we filtered the contributions by reading their abstracts and full-texts. For relevant sources, we also performed a forward and backward search. In this way, we classified a total of 25 sources as relevant for our research. We classified papers as relevant if they address elicitation, visualization or modelling of business processes or examination of modelled processes in virtual 3D environments. In the last step, these sources were clearly presented in a concept matrix according to Webster and Watson (2002) (see Table 1). Thereby, we distinguish between two mediums that create the virtual world (VW): HMD-VR presentation and Desktop-VR,
where a 3D desktop view is selected. Furthermore, we differentiate whether the source deals with pure process visualization, elicitation, modelling, understanding or analysis (which includes identification of weak points). The third differentiating criterion is the representation of the virtual environment, i.e., whether the environment is abstract and thus context-free, realistic and context-free or realistic and context-related.

<table>
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<td>Betz et al. (2008)</td>
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Table 1. Concept-Matrix of Business Process Modelling in Virtual Worlds according to Webster and Watson (2002).
Medium of VW representation
The results of our literature search clearly show that both HMD- and desktop-representation of business processes in virtual worlds are relatively new fields of research. Nearly all relevant publications are from the last decade, between 2010 and 2020. Above all, it can be observed that suitable HMDs for business process representation have not been used until 2018. Previous research is limited to the use of virtual worlds on desktop PCs.

Content focus
Some studies are limited to the pure presentation and visualization of 2D processes in a virtual 3D environment. Thus, previously collected and modelled processes like EPC (e.g. Zenner et al., 2020)) or BPMN (e.g. Brown et al., 2011)) are presented in a VR environment. The integration of the business processes into the virtual world either takes place automatically or is not further explained by the authors.

Other publications focus on the process elicitation. Instead of conducting interviews or filling out overview tables, business processes are surveyed directly in the virtual world. For instance, real processes are gone through step by step in the virtual environment to achieve the most detailed description of a process (Harman et al., 2015; Guo et al. 2012). Collaborative approaches in virtual environments are also used so that users can collectively survey the processes (Pöhler et al., 2020; Poppe et al., 2013).

Once processes are surveyed, the modelling usually takes place directly in the virtual environment. Sometimes, however, it occurs only at the point where processes already elicited outside virtual worlds are refined and thus modelled by the user. Here, prototypes are often presented focusing on the representation and notation of the process modelling language (Oberhauser et al., 2018). Thereby, not only well-known modelling languages such as BPMN or EPC are used in 3D-VW, but also newly developed, VR-specific notations (Pöhler et al., 2020).

Some authors go beyond with their approaches and examine the modelled processes in the virtual world with regard to process understanding. Weichhart et al. (2014), focus on learning the notation and semantics in the virtual world while other authors focus on understanding the content of the process represented (Aysolmaz et al., 2016; Zenner et al., 2020; Thies et al., 2019).

Understanding a business process is a fundamental prerequisite for identifying its weak points as part of process analysis. Until now, only Poppe et al. (2017) have experimentally investigated weak points in business processes in the virtual world. However, they also clearly focus on finding weak points in the notation and the implementation of the representation rather than on the detailed analysis of the represented business process.

Virtual Environment
It becomes evident from the relevant publications that, depending on the focus, more or less emphasis is placed on the presentation and inclusion of the virtual environment (see Figure 2). For example, if processes are created purely to prove the feasibility of a 3D representation (e.g. Betz et al., 2008) or if the business process is purely information technology-based (Oberhauser and Pogolski, 2019), a realistic environment is not used. Some authors use realistic environments without any relation to the process (West et al., 2010; Kathleen et al., 2014). Reference to the environment is mainly created when processes are bound to certain places or equipment (Harman et al., 2015) or are executed at different locations (Leyer et al., 2019). The created environment is then included in and used for the different process management steps such as elicitation or modelling.
Our literature overview shows that business process analysis involving realistic (industrial) working environments using HMDs is still unexplored. In order to fill this research gap, we conducted an experiment to test whether the above-mentioned representation is superior to a traditional paper representation of business processes in terms of effectiveness and to enhance motivation.

3 Study design and methods

3.1 Research design

From the overview of related work, it becomes clear that a conventional process weak point analysis in the context of business process improvement has not yet been investigated in immersive and realistic industrial VR environments. In order to compensate for this, we compared a VR representation (Condition: VR) to a traditional, paper-based 2D BPMN representation (Condition: 2D), whereby we measured both achieved performance and user perception. This is a useful comparison because, for example, weak points on printed business processes are still frequently marked and discussed in workshops using pen and paper. The comparison of paper and AR/VR applications has also been carried out in the past in other subject areas (e.g. Werrlich et al., 2018; Lin et al., 2020). Both environments in our study contained exactly the same information in different representations, so that the name of the activity, the location of its execution, the role performing it and the routes and information paths were visible.

First, we examined whether both representations provided the same quantity of weak points, hereafter referred to as weak point score (WPS). In addition to an overall WPS (WPS0), it should be explored whether there are differences in the two representations with regard to the reference and type of weak points. We investigated whether the identified weak points refer to an individual process step (WPS1), a process group (WPS2) or the overall process (WPS3). To classify the weak points, we used Ishikawa’s error types and expanded them inductively (Ishikawa, 1982). In a next step, a group of experts analyzed, evaluated and clustered the identified weak points.

The use of technology to perform the task as well as the perception of the users should also be measured. The choice of constructs was made in such a way that current problems of business process management are considered, including especially motivational and usability aspects. Since the motivation of employees to participate in such change processes is often low (Coskun et al., 2008), we chose constructs that can increase motivation when they are highly pronounced. These include the
flow state (Csikszentmihalyi, 1975) and presence (IJsselsteijn et al., 2000). Also, constructs of the Usefulness, Satisfaction, and Ease of Use (USE) Questionnaire were implemented, which give a good view of the user's overall perceived usefulness of and satisfaction with the technology (Lund, 2001). At the same time, the cognitive load should be used to measure the potential learning ability of the user when employing different tools (Sweller, 2011).

To answer the research question, we formed two groups, one of which used the HMD and the other the 2D-paper-view. A group of experts subsequently analyzed and clustered the identified weak points. Furthermore, the constructs flow state, presence, usability and cognitive load were determined by self-reported surveys filled out by the participants.

The 28 participants (11 female, 17 male) were mainly recruited through an appeal at a German university. The mean age of the participants was 26 years. Of them, 75% were students or had finished studies with a technical or economic background. Each participant self-reported normal or corrected-to-normal vision. The study session for each participant lasted around 45 min. Due to the non-appearance of two scheduled participants, 15 participants took part in the VR group, whereas only 13 took part in the 2D condition.

3.2 Scenario and experiment conditions

We instructed the participants to put themselves in the role of a process optimizer of a fictional small and mid-size enterprise (SME) from the mechanical engineering industry. For our scenario, we chose an SME because processes in such companies are often less formalized, digitized, technologized and structured due to their smaller financial scope (Hitchens et al., 2003; Hutchinson et al., 2005). Our fictional company generates 70% of its turnover with the sale of specialized machinery and 30% with the sale of spare parts. The company's business processes, which were documented 10 years ago, are now to be analyzed and, if necessary, adapted in the course of restructuring and modernization. There is a pleasant working atmosphere in the company and the employees are open to steps towards modernization and digitalization. They do not see this as a threat to their jobs, but rather as an improvement in their working conditions. A process for picking a spare part, in this case a special screw, was selected for the weak point analysis. The two roles "salesperson" and "order picker" are involved in the execution of the process. A total of 20 activities were necessary to change the order status from "requested" to "commissioned" (cf. Fig. 3).

![Figure 3. The picking process in BPMN (split view).](image-url)
In the **2D condition**, we provided the participants with a DIN A2 and a DIN A3 sheet (see Fig. 4). One illustrated the BPMN representation of the picking process, the other a top view of the activity execution locations (hall and office) with respective markings of process and communication routes. We explained to the participants the basic functionality, structure and elements of BPMN as well as the structure of the hall and office. Afterwards, the process was gone through step by step with the participants, using both the BPMN representation and the top view. Once the participants had verified that they understood the process, we briefly reminded them of the task and explained the procedure for identifying and documenting the weak points.

![The 2D condition in the experiment.](image)

**Figure 4.** The 2D condition in the experiment.

The participants in the **VR condition** received the hardware HTC Vive Pro and a controller to teleport through the environment (cf. Fig. 5). This was the only controller function the participants had to use during the experiment. To create the VR environment, we used the software Layout¹, that allows to create realistic, detailed and true-to-scale working environments, i.e. entire industrial halls including equipment such as conveyor belts, robots, cranes and assembly tables. In the course of a linked research project with the software developer, initial approaches for a prototype have already been implemented, which allow the mapping of process steps in the realistic working environment.

An industrial hall with adjacent office space served as environment for the experiment. The 20 process steps were located at their (fictional) execution places. Each process step contained the name and the executing role of the activity beneath (cf. Fig. 5 in magnifying glass). The activities were numbered and connected to each other by arrows when changing location, so that the user was able to see walking and information paths for easier navigation. The numbering of the activities also made the order visible. First, we introduced the participants to the basic functionalities of the software and instructed them to only use the 360-degree function of the HMD and the teleport function of the controller. After the participants had familiarized themselves with the hardware and the functionalities in the industrial hall during an acclimatization phase of a few minutes, the supervisor took over the hardware again. He then walked the participants through the entire process in the VR environment for further clarification while they followed along on the desktop screen. When there were no more questions about the understanding of the process or its visualization, the task to be performed was briefly repeated and the experiment was started.

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The participants were given 10 minutes to perform the experiment in both the paper-based and VR environment. To promote an intuitive and uninfluenced detection of weak points, we neither provided examples nor a categorization of weak points. In addition, as the main goal was to compare the number of identified weak points (per category) between the paper-based and VR environment, we asked the participants to consider individual process steps as well as their entirety. We adopted the principle of reciting purely negative aspects aloud from reverse brainstorming, a well-known and frequently used creativity technique (Williams and Smith, 1990). Thus, we asked all participants to speak out loud every weak point identified, which was recorded by the test supervisor. This procedure for documentation was chosen in order to guarantee that all mentioned weak points could be included in the subsequent analysis.

### 3.3 Measures and Analysis

For the evaluation of the experiment, the recorded weak points were collected and listed per participant. A panel of experts, consisting of experienced industrial employees in the field of picking and process optimization, examined the weak points with regard to their significance. The use of experts is an approach that Figl and Recker (2016), for example, also use to cluster analyses of business processes in a meaningful way. A requirement for acceptance was that the weak points had a potentially negative impact on the process, the company or the employees from an organizational, technological, communicational, safety-related or ecological point of view. Subsequently, we evaluated the total number of detected weak points (WPS₀), the weak points by reference (WPSᵦₛ, WPSᵦᵢ, WPSᵦᵦ) and the weak points per type for both environments. The weak point types were set up deductively and inductively. Thus, the experts used existing categories from the literature and inductively extended these where necessary. They used six categories from the Cause and Effect Diagram (Fishbone Diagram), a frequently used technique in practice for weak point analysis (Ishikawa, 1982), as a basis. During categorization it became apparent that the called weak points did not fill all error categories of the Fishbone Diagram, while subcategories were useful in some other categories. In the end, six categories of weak points were generated: Information and Communication Technology (ICT) WPSᵦᵦ, Process Routes WPSᵦᵦ, Workflow WPSᵦᵦ, Security WPSᵦᵦ, Sustainability WPSᵦᵦ and Automation WPSᵦᵦ.

In addition, the participants were asked to fill out a questionnaire after the experiment. Apart from demographic data and visual acuity, the questionnaire also asked for previous experience in BPMN, virtual reality and industry. Subsequently, a 7-step Likert Scale was used to assess the constructs of flow state, presence, usability and cognitive load. According to Csikszentmihalyi (1975), the Flow State (FS) describes the merging into a smoothly running activity, which can be advantageous in intuitive weak point analysis. For this purpose, we chose the Short Flow Scale according to Rheinberg and Vollmeyer (2003) that, unlike the original scale according to Jackson and Marsh (1996), is more...
compressed and better applicable to technology use outside of sports or physical activities. Presence (Pr) can also have motivational and inspiring effects on users by allowing them to fully immerse in the environment and interact with it more intensively (McMahan et al., 2012; Murcia-López and Steed, 2016). To make presence measurable, we employed the constructs "Spatial Presence", "Attention Allocation" and "Visual Spatial Imagery" by Vorderer et al. (2004). Spatial Presence means “a sense of being there” (Ijsselsteijn et al., 2000), whereas Attention Allocation is defined as “the devotion of mental capacities to the media product” (Wirth et al., 2007). Visual Spatial Imagery examines the basic ability of the spatial imagination over example situations. To measure Usability (Us), reference was made to the constructs "perceived usefulness", "perceived ease-of-use" and “satisfaction” used in the USE Questionnaire (Lund, 2001; Gao et al., 2018). Through these widely tested constructs of the USE, fundamental statements can be made about participants’ overall perceptions during use. The tripartite cognitive load (CL) should also be examined to monitor whether the application of a new technology results in a cognitive overload. For this purpose, we used the cognitive load theory, which is frequently used in the field of learning (Sweller, 1994). Intrinsic cognitive load is generated by the complexity of the presented learning material. Extraneous cognitive load is influenced by the presentation of the learning material. Both have to be kept as low as possible so that the third component, germane cognitive load, can be maximally pronounced. This ensures that the user can achieve good learning progress. In addition, a total load was queried, as developed by Figl and Laue (2011), to measure the load for the comprehension of process models. Preliminary analysis was performed for each dependent variable to identify violation of the normal distribution using the Shapiro-Wilk test. For variables violating the normal distribution, Mann-Whitney-U tests (MWU) were used to identify group differences. Variables that did not violate the normal distribution were tested for variance homogeneity with the Levene test followed by independent T-tests (TT) to identify group differences. Effect sizes for significant results were assessed using the Pearson correlation coefficient and determination coefficient. (Fritz et al., 2012; Cohen, 2013).

4 Results

Participants of the two groups did not differ significantly with respect to sex (U = 71, Z = -1.442, p = .246), experience in process modelling (U = 79, Z = -.881, p = .414) and experience with the industry (U = 86, Z = -.547, p = .588). Of the 15 VR users, 10 participants (67%) reported to have experience in using HMD-VR. With respect to age there was a significant difference (U = 50.5, Z = -2.198, p = .27) due to two outliers in the 2D condition. After careful consideration, we decided to include the two cases into the analysis, because they reduce the homogeneity of the sample regarding age and thus also reduce the risk of type 2 errors. Table 2 shows the results for the weak point categories found in the two conditions.

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<tr>
<th>WPS</th>
<th>Mean VR</th>
<th>SD VR</th>
<th>Mean 2D</th>
<th>SD 2D</th>
<th>Test</th>
<th>Results</th>
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<tr>
<td>Overall</td>
<td>9</td>
<td>1.93</td>
<td>8.38</td>
<td>3.12</td>
<td>TT</td>
<td>t(26) = .637, p = .53, not significant</td>
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<td>Individual Process Step</td>
<td>5.73</td>
<td>2.28</td>
<td>4.15</td>
<td>2.41</td>
<td>TT</td>
<td>t(26) = 1.780, p = .09, not significant</td>
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<td>Process Group</td>
<td>2.47</td>
<td>1.36</td>
<td>3.23</td>
<td>1.17</td>
<td>MWU</td>
<td>U = 66.5, Z = -1.481, p = .15, not significant</td>
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<td>Overall Process</td>
<td>0.8</td>
<td>0.78</td>
<td>1</td>
<td>0.58</td>
<td>MWU</td>
<td>U = 81, Z = -.84, p = .45, not significant</td>
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<td>ICT</td>
<td>3.33</td>
<td>1.11</td>
<td>2.92</td>
<td>1.32</td>
<td>MWU</td>
<td>U = 83.5, Z = -.664, p = .53, not significant</td>
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<tr>
<td>Process Route</td>
<td>1.93</td>
<td>1.22</td>
<td>1.92</td>
<td>1.5</td>
<td>MWU</td>
<td>U = 93, Z = -.218, p = .84, not significant</td>
</tr>
<tr>
<td>Workflow</td>
<td>2.73</td>
<td>1.39</td>
<td>2.92</td>
<td>1.94</td>
<td>TT</td>
<td>t(26) = -.301, p = .77, not significant</td>
</tr>
<tr>
<td>Security</td>
<td>0.33</td>
<td>0.62</td>
<td>0.15</td>
<td>0.38</td>
<td>MWU</td>
<td>U = 85.5, Z = -.776, p = .56, not significant</td>
</tr>
<tr>
<td>Sustainability</td>
<td>0.4</td>
<td>0.51</td>
<td>0.23</td>
<td>0.44</td>
<td>MWU</td>
<td>U = 81, Z = -.939, p = .44, not significant</td>
</tr>
<tr>
<td>Automation</td>
<td>0.13</td>
<td>0.35</td>
<td>0.077</td>
<td>0.28</td>
<td>MWU</td>
<td>U = 92, Z = -.473, p = 1, not significant</td>
</tr>
</tbody>
</table>

Table 2. Results for weak point categories found in the two conditions.
Although the differences are not significant, it was found that users in the VR environment overall identified more weak points with respect to individual process steps, information and communication technology, process routes, security, sustainability and automation. Users in the 2D environment, on the other hand, identified more weak points within process groups, overall process and workflow. But again, the differences are not statistically significant. However, we agree with Amrhein et al. (2019) and more than 800 signatories that statistically non-significant results are of course worth to be published (non-significant results are biased downwards in magnitude in publications) and are often wrongly interpreted as indicating ‘no difference’ or ‘no effect’. Table 3 shows the results for flow state, cognitive load, presence and usability in the two conditions.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Mean VR</th>
<th>SD VR</th>
<th>Mean 2D</th>
<th>SD 2D</th>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS - Absorption</td>
<td>5.4</td>
<td>0.88</td>
<td>5.39</td>
<td>1.073</td>
<td>TT</td>
<td>t(26) = .042, p = .97, not significant</td>
</tr>
<tr>
<td>FS - Fluency of Performance</td>
<td>5.48</td>
<td>0.98</td>
<td>5.28</td>
<td>1.072</td>
<td>MWU</td>
<td>U = 91, Z = -.302, p = .76, not significant</td>
</tr>
<tr>
<td>CL - Intrinsic Load</td>
<td>2.29</td>
<td>1.02</td>
<td>1.97</td>
<td>0.89</td>
<td>TT</td>
<td>t(26) = .863, p = .4, not significant</td>
</tr>
<tr>
<td>CL - Extraneous Load</td>
<td>1.97</td>
<td>0.86</td>
<td>2.08</td>
<td>1.02</td>
<td>TT</td>
<td>t(26) = -.311, p = .76, not significant</td>
</tr>
<tr>
<td>CL - Germane Load</td>
<td>3.06</td>
<td>1</td>
<td>4.08</td>
<td>1.31</td>
<td>MWU</td>
<td>U = 56, Z = -1.916, p/2 = .028, significant</td>
</tr>
<tr>
<td>CL - Overall Load</td>
<td>5.27</td>
<td>0.96</td>
<td>5.08</td>
<td>1.32</td>
<td>MWU</td>
<td>U = 97, Z = -.25, p = .1, not significant</td>
</tr>
<tr>
<td>Pr - Spatial Presence</td>
<td>5.03</td>
<td>1.07</td>
<td>3.46</td>
<td>0.92</td>
<td>MWU</td>
<td>U = 27, Z = -3.258, p = .001, significant</td>
</tr>
<tr>
<td>Pr - Attention Allocation</td>
<td>6.15</td>
<td>0.77</td>
<td>5.25</td>
<td>0.76</td>
<td>MWU</td>
<td>U = 37, Z = -2.800, p = .004, significant</td>
</tr>
<tr>
<td>Pr - Visual Spatial Imagery</td>
<td>5.27</td>
<td>1.35</td>
<td>5.06</td>
<td>1.69</td>
<td>TT</td>
<td>t(26) = .364, p = .72, not significant</td>
</tr>
<tr>
<td>Us - Perceived Usefulness</td>
<td>5.9</td>
<td>0.8</td>
<td>5.97</td>
<td>0.75</td>
<td>MWU</td>
<td>U = 93.5, Z = -.186, p = .861, not significant</td>
</tr>
<tr>
<td>Us - Perceived Ease of Use</td>
<td>5.23</td>
<td>0.7</td>
<td>5.31</td>
<td>0.96</td>
<td>MWU</td>
<td>U = 91.5, Z = -2.78, p = .004, significant</td>
</tr>
<tr>
<td>Us - Satisfaction</td>
<td>6.19</td>
<td>0.73</td>
<td>5.14</td>
<td>0.86</td>
<td>MWU</td>
<td>U = 33.5, Z = -2.562, p = .002, significant</td>
</tr>
</tbody>
</table>

Table 3. Results for flow state, cognitive load, presence and usability in the two conditions.

There are no significant differences regarding flow state. In terms of cognitive load, there are no major differences concerning intrinsic load, extraneous load and overall load. However, with respect to germane load, users in the VR group reported higher strain. According to Cohen (2013), this is a medium effect ($\eta^2 = .13$). As expected, users felt more present in the VR environment than in the 2D condition, as evidenced by the significant difference in spatial presence. This constitutes a strong effect ($\eta^2 = .379$). Additionally, users reported a substantially higher attention allocation to the stimulus material in the VR environment than in the 2D condition, which also is a strong effect ($\eta^2 = .28$). Differences in visual spatial imagery are not significant. Further, there are no major differences in usability with respect to usefulness, ease of use and ease of learning. However, users reported noticeably higher satisfaction in the VR environment, compared to the 2D condition. Again, this is a strong effect ($\eta^2 = .313$).

5 Discussion

The primary goal of this study was to examine whether the use of Virtual Reality constitutes an alternative to traditional weak point detection in business processes using 2D BPMN diagrams. In addition to the effectiveness of the use of the media, we investigated constructs that can have short- and long-term effects on users to participate in such process changes and increase their motivation.

Compared to the 2D control group, users in the VR environment identified a greater number of weak points. Even though this difference was not statistically significant, it still suggests that no loss of effectiveness is to be expected with the VR application compared to a traditional and abstract 2D BPMN representation. No effects could be found that indicate distraction by the environment or hardware handling and thus lower effectiveness in VR, like Frederiksen et al. (2020) report. Although not significant, there is a difference in the sum of discovered weak points by reference. In the VR environment, the higher number of detected weak points related to individual process steps can be explained by the fact that the users were location-bound for each process step. To analyze subsequent
steps at other locations required the teleport function. Thus, by staying longer at the execution locations, the users focused more on the respective process step. Similarly, the finding that the 2D representation yielded a relatively higher proportion of weak points related to process groups (39% versus 27%) can be explained by the better overview that the paper representation provides on the linkage of individual steps. While switching between process steps on paper required only an intuitive head/eye movement, in VR the users had to operate the controller several times. There are no major differences in the quantity of type of weak points between the two environments. Despite its distinct advantages in the clear presentation of correlations (Nysetvold and Krogstie, 2006; White, 2004), BPMN did not lead to significantly more weak points of the workflow. Although a higher percentage of route weak points were named in VR compared to the total number of weak points found, this result was not significant either. This may have been due to the fact that the additional top view of the hall with paths drawn provided all relevant information for the 2D user. However, we found that security aspects, although rarely mentioned, were named 2.5 times more often in VR than in the 2D representation (WSP\textsubscript{5c}(VR)=5 versus WSP\textsubscript{5c}(2D)=2). In this case, the risk of collision due to the crossing of routes of the picker and transport vehicles, were frequently mentioned by VR users, especially when the user virtually crossed the track. This is consistent with findings of Krokos et al. (2018), who posit that merging space and information in an immersive environment can increase user awareness and strengthen the relationship to the environment. Users of the 2D representation, on the other hand, moved rather erratically, making it much more difficult for them to perceive this danger.

We found no notable differences in the flow state between the two representations. Previous sources had detected higher flow states in VR compared to 2D desktop applications. Here, sports activities were performed in VR (Kim and Jae, 2019) and the increased flow state was also achieved in the business context (Nah et al., 2011). The lack of difference in flow state in the even more analogous 2D representation may be due to the complexity of weak point analyses, which require full concentration, perseverance and transfer. The flow is more aimed at the intuitive passing of less complex content (Nysetvold et al., 2006). As previously demonstrated in other studies (Makransky et al., 2017; Kober et al., 2012), an immersive and realistic VR environment provides clear advantages over 2D representations in terms of presence. In this study, significantly higher impressions of presence in VR compared to 2D representations can be seen. Since it is a realistic industrial hall environment, the user can immerse deeper into the process than in an abstract 2D representation. The high levels of spatial presence and attention allocation can therefore have a motivational effect on users. While we did not observe relevant differences in the usability aspects of perceived usefulness and perceived ease of use, the VR representation scored considerably higher in satisfaction. And this, used correctly, can be an effective means to increase motivation in industrial companies. There are several contributions showing high satisfaction scores for VR use compared to less immersive media (Kim and Jae, 2019; Shelstad et al., 2017). In our case the higher degree of satisfaction can to a certain extent also be explained by the appeal of novelty, as some of the VR-participants (33%) had no prior VR experience. Also for the cognitive load we found no notable differences between the two conditions for overall load, intrinsic load and extraneous load. Therefore, it is surprising that the germane load is significantly higher in the VR condition. However, the effect is not strong enough to elicit a higher overall load among users.

Our results are useful for research and practice. For researchers, the results can be of importance when creating VR prototypes for industrial contexts. The results of the effectiveness measurements, although not significant, can provide insights into the areas of process analysis where VR has potential strengths. Of the participants, 75% had a business or technical background. It is precisely these branches of education that would carry out optimization activities in picking activities. Although no employees of a real company were used as test subjects, the weak points found should therefore still have a high degree of quality. In addition, the strengths of VR for use in recognizing detailed information should be used even more effectively so that significant advantages become apparent. At the same time, however, VR is supposed to provide aggregated views of complex contexts in order to enable optimizations of the underlying links between the individual states. Furthermore, the results can provide practitioners with information about the positive effects that the use of innovative
technologies can have on employee motivation and thus on the results. But in order to convince the broad mass of industrial organizations to invest in VR and to use it in daily business, these applications would have to deliver significantly better effectiveness results than low-cost paper presentations.

6 Conclusion, Limitations and Future Work

The aim of this paper was to answer the question whether a VR application is an alternative to a traditional 2D BPMN representation in finding weak points in business processes. We conclude that the use of a VR application can definitely be beneficial. With similar, even slightly higher efficiency of the VR application, significantly higher values in user presence and satisfaction could be measured. This could be used to counter the prevailing motivational lack to participate in business process management activities. VR applications for weak point analysis could thus be applied in workshops, for example. Also a combination of 2D processing and subsequent VR application would be conceivable. In this way, the user could get an overview of the process based on the BPMN representation, which is then deepened at the detailed level by means of VR.

This study is subject to some limitations. First of all, our results are based on a small sample (n=28). Due to the small number of test persons, it is difficult to generate significances, which entails that the interpretation of the results is strongly based on tendencies. Almost all participants are between 20 and 30 years and thus belong to the group of digital natives who have grown up with digital technologies since childhood (Prensky, 2001). In addition, the proportion of academics and students is very high at 75%. For more meaningful results, it would make sense to conduct the experiment with other age groups and actual operative employees from industry. In addition, the process was completely linear, with no alternative paths to be taken via connectors, which is rarely the case in industrial processes. By deliberately keeping the process simple, we avoided to overwhelm the test persons by a too complex representation. We rather set the focus on the connection between space and activity. However, the VR application could not achieve complete immersion because sensory perceptions such as acoustics (machine and environmental noise), dust exposure or light irradiation were not included and related weak points could thus not be detected.

Future research should therefore work with a larger sample in the industrial sector. More realistic processes should be simulated and more sensory perceptions of the users should be addressed. To fill this open research gap, realistic replicas of real-world SME work environments have already been generated. Studies are planned here in the near future to perform the weak point analysis with real workers in the digital VR twin of their working environment. In addition, the strengths of VR should be better exploited when developing prototypes. The strengths lie primarily in the collaborative work that by means of this technology is made possible over long distances (Jalo et al., 2020). This is especially important in times of reduced travel opportunities due to the corona crisis, but equally important in view of the climate crisis. In addition, it is a strength of VR to be able to analyze states at the detailed level. This can also be helpful in analyzing weak points, e.g. in order to be able to identify potential for improvement in terms of ergonomics or safety. Moreover, possibilities must be created that prevent losing the overall view through immersion. Only if these advantages of effectiveness for VR are expanded or made up for, it will be used more often in the industry outside of playful workshops.
References


