VR-BPMN: Visualizing BPMN Models in Virtual Reality

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Abstract. One impact of the digital transformation of industry is an increasing automation of business processes (BPs) and the accompanying need for business process modeling (BPM) and comprehension. The subsequent increased number of processes and process variants to cover all cases, their deeper integration with information services, and additional process structural complexity affects comprehensibility. While virtual reality (VR) has made inroads in other domains and become readily accessible as a graphical interface alternative, its potential for addressing upcoming BPM comprehension challenges has not been sufficiently explored. This paper contributes a solution for visualizing, navigating, interacting with, and annotating business process modeling notation (BPMN) models in VR. An implementation shows its feasibility and an empirical study evaluates the effectiveness, efficiency, and intuitiveness versus alternative model depiction modes.

Keywords: Virtual reality · Business process models · Visualization BPMN

1 Introduction

The digital transformation sweeping through society affects businesses everywhere, resulting in an increased emphasis on business agility and automation. Business processes (BPs) or workflows are one significant automation area, evidenced by the $2.7 billion market for Business Process Management Systems (BPMS) (Gartner 2015). Business process modeling (BPM) is commonly supported with the standardized notation BPMN (Business Process Model and Notation) (OMG 2011) also known as BPMN2. A primary objective of BPMN is to provide a comprehensible process notation to all business stakeholders while providing complex process execution semantics. Furthermore, BPMS vendor lock-in is avoided in that organizations can retain their intellectual assets in the form of models across vendors and into the future, while the vendors can focus their efforts on a single common notation. Yet despite BPMN's goal for comprehensibility, with a growing number of processes and process variants that attempt to cover more business process cases, their deeper integration with information services, and additional process structural complexity, the comprehensibility of the ensuing BP models for all stakeholders can be negatively impacted.

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Contemporaneously with this BPM automation trend, virtual reality (VR) has made inroads in various domains and become readily accessible as hardware prices have dropped and capabilities improved. Moreover, the VR (mobile, standalone, console, and PC) revenues of $2.7bn (2016) are forecasted to reach $25bn by 2021 (Merel 2017) or $15bn by 2022 with an installed base of 50 m–60 m (Digi-Capital 2018). VR is defined as a “real or simulated environment in which the perceiver experiences telepresence” (Steuer 1992), a mediated visual environment which is created and then experienced. However, the potential to leverage such an immersive VR capability for comprehending and annotating BPMN models has been insufficiently explored. As BPMN models grow in complexity and deeper integration to reflect the business and IT (information technology) reality, and additional information and annotations are needed to help understand them, an immersive BPM environment could provide the visualization capability to still see the “big picture” for structurally and hierarchically complex and interconnected diagrams and provide a motivational boost due to its immersive feeling and the visual rendering of a BP into a 3D space that can be viewed from different perspectives.

This paper contributes a solution concept which we call VR-BPMN for visualizing, navigating, interacting with, and annotating BPMN models in VR. Capabilities include teleportation and fly-through navigation, depicting subprocesses using stacked hyperplanes, drawing annotative associations between BPMN elements, coloring model elements, and textual element tagging with mixed reality (MR) keyboard support. The evaluation investigates its effectiveness, efficiency, and intuitiveness versus alternative BPMN model depiction modes (paper and PC). We assume the models involved have already been constructed to represent some business reality and thus in this paper we do not delve into details on how the models were created or what business reality goal some model interaction intends to achieve, but rather how the models are visualized and comprehended in VR.

The remainder of this paper is structured as follows: Sect. 2 discusses related work. In Sect. 3 the VR-BPMN solution concept is described. Section 4 then provides details on the prototype implementation. The evaluation is described in Sect. 5 and a conclusion follows in Sect. 6. An Appendix contains various figures.

2 Related Work

Work related to VR-BPMN includes the process visualization and virtualization areas. As to process visualization techniques, (Du et al. 2012) provide a survey, concluding that 3D can improve the layout and can increase the information content of process models. Work related to process visualization includes (Betz et al. 2008), who described an approach for 3D representation of business process models based on Petri nets with organizational models, showing that a 3D process representation can facilitate process-specific information access. (Hipp et al. 2015) described and empirically evaluated various business process visualization alternatives: bubbles, BPMN3D that maps data objects associated to a BPMN element to a “third dimension”, network, and thin lines; however, no 3D space nor an implementation is described. (Emens et al. 2016) created a dynamic business process visualization prototype in 2D that can be run in a web browser. In the area of domain-centric process automation, (Westner and Hermann 2017) focus on a virtual training and round-trip engineering scenario using VRfx. BPMN was not used and each 3D object was manually placed. (Holzmüller-Laue et al. 2013) is a web-browser based visualization focused on life science workflows that combines a business process execution simulator based on BPMN, task visualization of operations, and a lab robot simulation.

With regard to virtual worlds, (Brown et al. 2011) investigated collaborative process modeling and communication, implementing a 3D BPMN modeling environment in the virtual world Second Life, and also used the Open Simulator (Brown 2010). Extending this with augmented reality (AR), (Poppe et al. 2011) involves a collaborative virtual environment in Second Life for collaborative process sketching where remote participants are represented as avatars as well as the process in BPMN is projected onto a real space. The 3D Flight Navigator (Effinger 2013) was implemented in Java with OpenGL, and projects parts of BPMN collaboration diagrams onto fixed hyperplanes and provides a heads-up display for navigating the process. As to conferences, neither BPM 2017 in Spain nor BPM 2016 in Brazil shows paper topics directly related to VR or virtual reality. No major BPMS vendors currently sell VR variants of their products. These older studies and the lack of current research involving currently available VR capabilities is needed to determine what value VR can or cannot add.

In contrast to the above, VR-BPMN provides a VR-centric BPMN visualization that utilizes a standard game engine (Unity) and common off-the-shelf VR hardware (HTC Vive), includes comprehensive BPMN support including automatic layout and stacked 3D hyperplanes for subprocesses, visual annotation capabilities (association, coloring, tagging), and MR keyboard interface support.

3 Solution Concept

BPMN models consist of Business Process Diagrams (BPDs) that are composed of graphical elements consisting of flow objects, connecting objects, swim lanes, and artifacts (OMG 2011). Our VR-BPMN solution concept (Fig. 1) focuses on four primary aspects that are affected by VR:

(1) *Visualization*. Since the graphical elements are only specified in 2D, it is thus unclear exactly how these should or could be visualized or mapped into 3D space. While many visual options and metaphors are possible, our view is that diverging too far from the specification would reduce the recognition and standardization afforded by the BPMN specification. We thus utilize different 3D block-like shapes with sides for differentiating elements by type, while retaining the standard BPMN symbols which are fixated onto the sides of those 3D elements to permit perception from different angles. One challenge in 3D space in contrast to 2D space is that one can never be sure if there is not an element hidden behind another element at any particular vantage point if the element is opaque. If one makes the element partially transparent, then it can become confusing as to which element one is focusing on. We thus chose to make the elements opaque in order

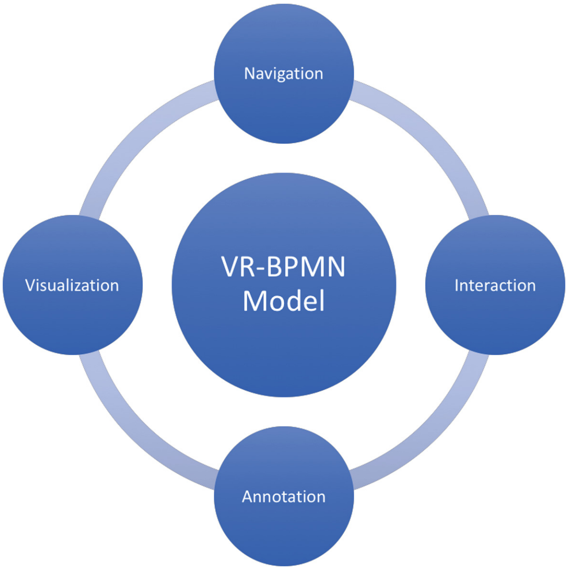

Fig. 1. The VR-BPMN solution concept.

to avoid this visual confusion, and by briefly adjusting one's perspective one can visually check that nothing is "hiding" behind an element. Additionally, visualizing text is an issue in VR due to the relatively low resolutions currently available and the distance to the text. Also, labels for BPMN elements can differ widely in length yet should not interfere with understanding the BPD structure. We thus place labels above the elements (like billboards), make them partially transparent in order not to completely hide any elements behind the label, the labels automatically rotate towards the camera to improve legibility from various angles, and for dealing with longer labels we constrain the maximum billboard width (to reduce overlapping), raise the billboard height, and reduce the text font size. For visualizing subprocesses, hyperplanes are used to take advantage of the 3D space with the subprocess projected onto a plane beneath its superprocess and connected via a glass pyramid to its superprocess. This spatial layout choice is somewhat intuitive since the conceptual relationship of sub and super can be mapped to a 3D space with above and below. However, for certain use cases when comparing subprocess and superprocess elements and their flows in detail, users may wish to have them in the spatially vicinity, so we allow the user to toggle the pyramid height on or off which raises the subprocess to the superprocess plane level.

(2) *Navigation*. The immersion afforded by VR requires addressing how to intuitively navigate the space while reducing the likelihood of potential VR sickness symptoms. Two modes are supported: teleporting permits a user to select a destination and have be instantly placed there (by moving the camera there) - while perhaps disconcerting, it may reduce the likelihood of the VR sickness that can occur when moving through a virtual space. Alternatively, a birds-eye view with

gliding controls is provided, enabling users to fly through the VR space and get an overview of the entire model. With a button on a controller, one can switch between the birds-eye-view and the teleport mode.

(3) *Interactions*. The BPMN specification does not specify exactly how users are to interact and interface with graphical BPMN visual elements. In our VR concept, user-element interaction is done primarily via the VR controllers supplemented by a MR keyboard. We use drag-and-drop element interaction for placing a connective annotation. Rather than only having access to a virtual keyboard that requires cumbersome pointing at each letter and clicking with the controllers, an *MR keyboard* provides access to a real keyboard that can be used for text input by projecting the webcam video stream onto a plane.

(4) *Annotations*. As one is immersed in VR with the headset on, ready access to other external sources of information is hindered and removing the VR headset disrupts the immersion experience. Annotations (a type of BPMN Artifact) can assist users by providing missing information and for comprehending larger or more complex models with notes or details not readily apparent in the model. Thus, we place an increased value in Annotations for placing additional information into the context of the model solution concept. In the BPMN specification textual annotations are signified with a square left bracket floating somewhere apart from any element and an association as a dotted line can be drawn to an element. This unnecessarily clutters the virtual space and dotted lines are more difficult to detect since other objects can be behind them. Hence, our alternative concept of *tagging* enables textual annotations to be placed on any element (including swimlanes or a plane), with the tags situated directly above the element label. Moreover, tagged elements have a colored ribbon indicator on top of their label and the color can be used to indicate some property (such as importance, user, etc.). Tag visibility can be toggled on or off in order to reduce textual clutter if tags undesired. Furthermore, an *association annotation* permits elements to be visually associated via a colored dotted line to be easily visually discernable (by default fluorescent green) and color choice permits a persistent visual differentiation and grouping of elements from others. An association is placed via drag-and-drop, taking one element and dropping it on another and the association itself can also be tagged in addition to the elements, it automatically avoids collisions with objects between the associated elements, and it can extend across hyperplanes.

4 Realization

The Unity game engine was chosen for VR visualization due to its multi-platform support, direct VR integration, popularity, and cost. Blender was used to develop the visual BPMN model elements. For testing with VR hardware, we used the HTC Vive, a room scale VR set with a head-mounted display with an integrated camera and two wireless handheld controllers tracked using two ‘Lighthouse’ base stations.

Visualization. Common BPMN2 elements were realized with various 3D shapes, with the BPMN symbol in black and white placed on the sides in order to be readily perceived (see Fig. 2). Elements are labeled with white text on a semitransparent dark background (rather than white) so as not to detract too much from the primarily white-based BPMN element symbols. Element layout placement is scaled based on the provided BPMN XML layout attributes. Subprocesses as depicted as stacked hyperplanes connected via colored semi-transparent pyramids to their superprocess, as shown in Fig. 3.

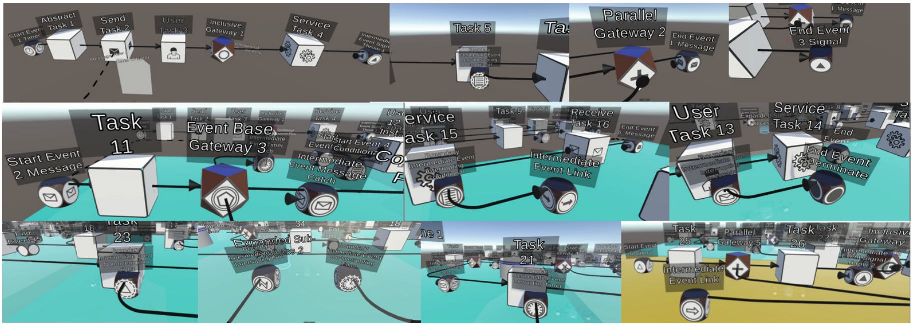

Fig. 2. Collage of various VR-BPMN BPMN2 element screenshots.

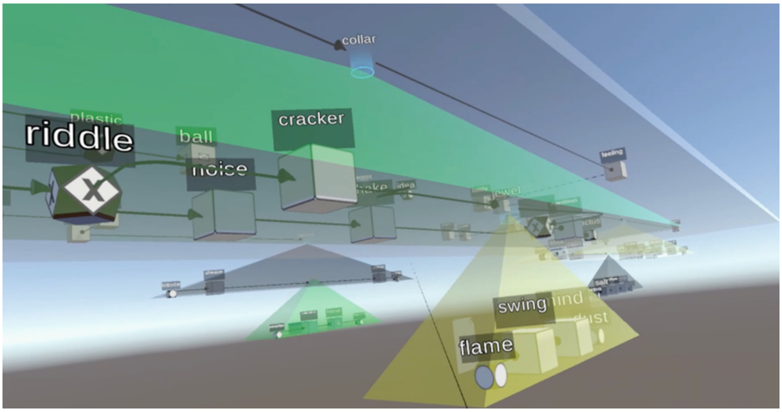

Fig. 3. Layered hyperplanes showing subprocesses as semi-transparent colored pyramids for an obfuscated process example. (Color figure online)

Navigation. With the right menu button on the right controller, one can switch between birds-eye-view and the teleport mode (see Fig. 4). The teleport mode is controlled by the right trackpad by aiming at the target location and pressing the trackpad. The birds-eye-view works with both trackpads, with the left trackpad controlling altitude und the right one forward, backward, left, and right movement. Via the left menu button, a small version of the BPMN diagram, similar to a minimap, is shown to quickly identify the overall location.

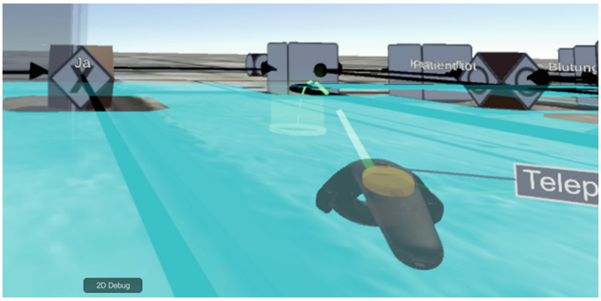

Fig. 4. Teleport interaction example showing VR controller and chosen destination highlighted as green cylinder. (Color figure online)

Interaction. Interaction is done primarily via the VR controllers. By pointing with the controller on an object with a tag and pressing and releasing the trigger button, tag visibility can be toggled on or off. By pointing at an object and pressing and holding the trigger, one can drag-and-drop the object for instance onto another object to place an association annotation. Text input is currently used for adding tags to the elements of a model. Rather than only having access to a virtual keyboard that requires point and click with the controllers, an *MR keyboard* provides access to a real keyboard that can be used for text input by projecting the webcam video stream onto an object's material (see Fig. 5).

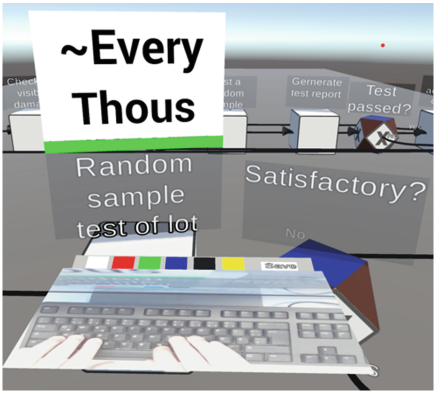

Fig. 5. Tagging in MR mode with tag color palette and real keyboard visible. (Color figure online)

Annotations. By default, all annotation types are given a fluorescent green color to differentiate them clearly from the actual model, but the color can then be customized. Users also can add an annotative association between any elements (see Fig. 6) of the model or even connect several processes. This is done by dragging and dropping from one element to another via a VR controller. Tagging permits users to annotate a selected BPMN element with any additional textual information, the font size is adjusted automatically to fit the available space. A colored ribbon on top of a label indicates that one or more tags exist, and the color is chosen when the tag is placed using a color palette (Fig. 5). Tag visibility can be toggled by selecting an element label. When tags are visible, these are placed on top of the labels on an opaque white background with black text to easily differentiate them from the labels below (Fig. 5). To color either an element ("Compare contents with order" element red in Fig. 7) or tag (Fig. 7 shows yellow, blue, and green tags) the user point with a VR Controller on the target to be colored and selects a color from a predefined color palette (Fig. 5). Figure 8 shows colored swimlanes.

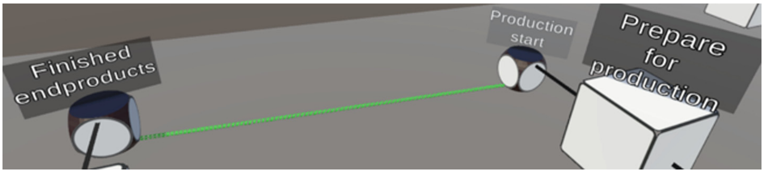

Fig. 6. User added connection annotation (green) between two processes. (Color figure online)

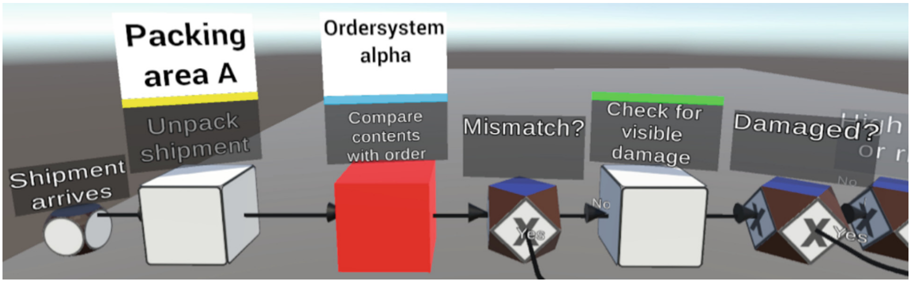

Fig. 7. Tags have a white opaque background and different tag ribbon colors; "Check for visible damage" has a hidden tag; "Compare contents with order" shows a colorized element. (Color figure online)

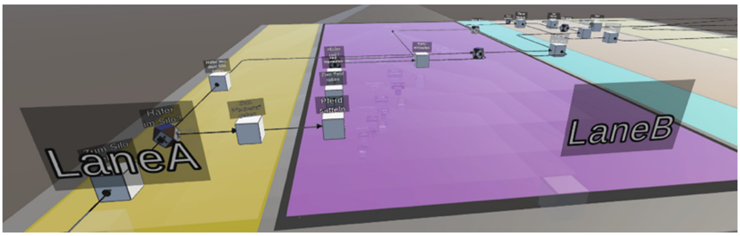

Fig. 8. Overview of a model in the birds-eye-view, showing lanes in different colors. (Color figure online)

5 Evaluation

The VR-BPMN prototype validated the feasibility of our VR-BPMN solution concept. Our empirical evaluation then investigated to what degree BPMN-based process analysis, comprehension, and interaction are affected by a VR environment. For this, we compare VR-BPMN with two other commonly available visual depiction modes: (1) paper-based BPMN analysis and (2) a common PC-based BPMN modeling application tool (Camunda Modeler). To avoid a bias for certain BPM paradigms or tools due to previous experience (such as experienced professionals), we used a convenience sample of master students with little to no prior BPMN experience. The experiments were supervised, a brief training was provided including BPMN anti-patterns, and a debriefing followed. In order not to skew process comprehension due to subject foreign language competency differences, BPMN labels were mostly in the native language of the subjects (German). To avoid interfering with the VR environment and skewing task durations due to subjects reading instructions or answering questions via VR interaction or requiring VR glasses removal, all task questions were asked and answered verbally and noted by a supervisor.

5.1 Paper-Based BPMN vs. VR-BPMN

To compare the comprehension of BPMN processes printed on paper vs. VR-BPMN, a convenience sample of eight Computer Science (CS) students was selected. Four fictional processes were grouped in process pairs, each pair being equivalent in structural complexity but differing in domain nomenclature and slightly in structure in order to avoid familiarity from affecting efficiency, while maintaining equivalent complexity to reduce the treatment variables. The Emergency Patient Treatment process was paired with the Farm process, both consisting of 5 subprocesses, 24 activities, and 6 gateways. An Invoice process (5 activities, 2 gateways, 2 endpoints) was paired with the Mario Game process (5 activities, 4 gateways, 1 endpoint). Whichever process was used on paper was paired with the equivalent in VR-BPMN. To avoid an ordering bias, half started initially with paper. No subject saw the exact same process twice. The task given was to analyze and explain the process (walkthrough).

Figure 9 shows task durations for VR-BPMN vs. paper sorted by the shortest VR times, with the mode order given in brackets. VR-BPMN average task duration was 5:07 vs. 3:36 for paper, a 42% difference. We note that, except for subject 5, the second mode (VR or paper) was faster than the first.

5.2 Tool-Based BPMN vs. VR-BPMN

To evaluate both interaction and process comprehension in VR-BPMN (V) versus a representative common PC-based BPMN modeling tool (Camunda Modeler) (C), a convenience sample of seven Computer Science (CS) students was used. One student experienced VR sickness symptoms and the associated measurements were excluded. The order of which tool to start with first was randomly selected, with three starting with V and three with C. Two BPMN processes were used, the first was a “Student Exam BPM” in German consisting of 5 processes, 18 activities, 5 start events, 7 end

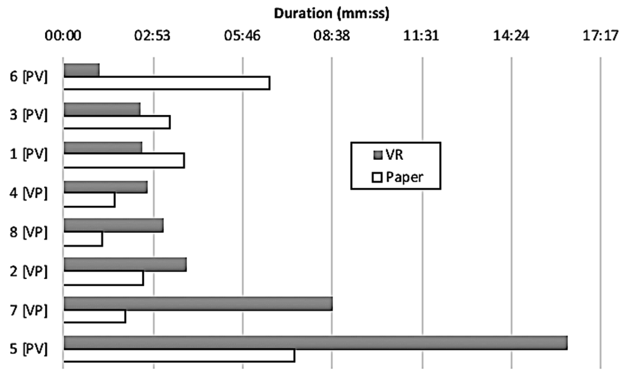

Fig. 9. Subject task duration for paper BPMN model vs. VR-BPMN sorted by shortest VR duration; order given in brackets, V = VR, P = paper.

events, and 6 gateways and is shown in VR-BPMN in Figs. 11 and 12 in the Appendix, the second was a quality-related production processes model in English shown in Fig. 13 and in VR-BPMN in Fig. 14 in the Appendix. Four equivalent tasks were timed for each tool. The tasks were:

(1) Student Exam model: find all BPMN modeling errors,
(2) Quality model: connect all elements that deal with testing,
(3) Student Exam model: Connect the end nodes with the appropriate start nodes, and
(4) Quality model: which tasks must be completed before "Fill out checklist and complaint form."

Task 1's duration was divided by the number of errors found; for Task 2 and 3 the total duration was divided by the the number of connections made (since making these annotations requires extra tool interaction). Results are shown in Table 1, with the expected numbers shown in column 2. Since the domains and processes were unexplained and open to interpretation, the number of connections differed. All Task 1 and 4 elements were correctly identified, so comprehension effectiveness was equivalent. The average of per errror and per connection durations for all four tasks in V was 254s vs. 319s for C, making V 21% faster. Since errors might be clustered in the same process area in Task 1, omitting Task 1 from the sum yields 162s for V vs. 187s for C, making V 14% faster. Five of the subjects indicated a preference for Camunda over VR-BPMN.

Figure 10 shows the total task durations for V vs. C sorted by the shortest V times, with the mode order given in brackets. We note that the second mode is almost always faster than the first, except for subjects 4 and 2 whose duration differences between both modes are minor (17% and 14% respectively) relative to the others' differences. This could be due to a cold-start effect, and in future work we intend to provide a warm-up task in each mode before timing a task.

Table 1. VR- BPM (V) vs. Common BPMN Tool (C) durations in seconds for the four tasks.

Task	Subject	1	2	3	4	5	6	Average
V1	Expect:2	2	2	2	2	2	2	
	Duration (s/error)	38	59	159	26	129	138	92
V2	Expect:5	4	4	8	8	10	7	
	Duration (s/connection)	35	49	43	14	33	35	35
V3	Expect:5	4	4	5	5	4	6	
	Duration (s/connection)	62	54	85	65	79	31	63
V4	Duration (s)	67	72	60	84	39	62	64
V Total (s)								254
C1	Expect:1	1	1	1	1	1	1	
	Duration (s/error)	93	123	118	74	218	163	132
C2	Expect:5	4	4	11	10	9	5	
	Duration (s/connection)	35	23	14	10	10	87	30
C3	Expect:5	4	5	5	6	6	5	
	Duration (s/connection)	30	56	31	30	32	48	38
C4	Duration (s)	43	34	40	140	356	102	119
C Total (s)								319

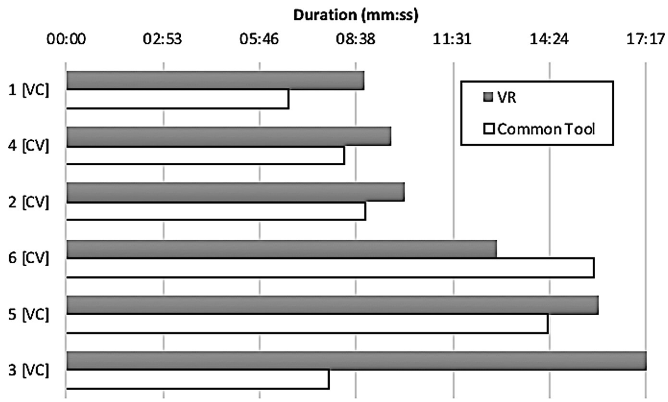

Fig. 10. Subject task duration for a common BPMN tool vs. VR-BPMN sorted by shortest VR duration; tool order given in brackets, V = VR, C = common BPMN tool.

5.3 Discussion

Since BPMN intends to be comprehensible for all stakeholders, and to reduce preexisting personal preferences and biases of BPMN professionals from biasing the results, we believe the use of novices for this experiment was appropriate. Although the sample size was small and did not consist of BPMN professionals, these measurements can provide indicators for future investigation.

The effectiveness of VR-BPMN was shown to be equivalent to the paper and PC tool modes, indicating that all tasks could be performed and the processes analyzed and comprehended.

As to efficiency, VR was 21% faster when taken on a per-error and per-connection standpoint for tasks vs. a common BPMN tool. VR was 14% faster if the error-finding Task 1 is omitted (leaving annotations and comprehension). For the paper mode, VR exhibited a 42% overhead, yet we note that the second mode (VR or paper) was always faster than the first (except for subject 5. The use of VR is more complex than paper, yet with additional VR training, we believe the apparent VR efficiency overheads could be reduced. Since the second mode was often faster than the first, we conjecture that the cognitive burden to become focused on the BPMN task and context (to be cognitively "in flow"), irrespective of the mode, are affecting the durations particularly in the initial mode and can be viewed as a type of overhead. It is likely unique and dependent on the subject's current mental alertness and motivation. It may be analogous to taking an exam, where efficiency increases after one or more questions have been answered. Thus, an efficiency comparison with VR based purely on the total durations can be misleading. Although we did include a training, in future work we plan to insert an additional warm-up round after switching modes to acclimate users within each environment before giving them actual timed tasks. 1 subject was affected by VR sickness, and we will explore possible improvements.

Across all 14 subjects, the intuitiveness of the VR-BPMN interface was rated a 4.2 on a scale of 1 to 5 (5 best). However, a preference for the BPMN tool was indicated by 5 of the 6 subjects. Users tend to prefer what they are familiar to, especially when they don't have much exposure time to the new option. We surmise that VR interaction is not as yet a fundamental competency compared to mouse or paper use, and with further VR experience user expectations may adjust. As VR applications adopt standard VR interaction patterns and expectations (such as button functionality becoming standardized in the VR market like the mouse left and right button), VR use will become more intuitive and natural for users, reducing current overheads. Comments by subjects included that VR model clarity was affected by hidden objects. We thus recommend that BPMN models intended for VR have large spacing between elements to reduce this issue. Further, they complained that the low resolution on current VR-headsets make reading text labels more difficult in VR vs. on 2D monitors or paper. But they also commented that using VR-BPMN was fun, and we conjecture that it can provide a motivational factor towards comprehension.

6 Conclusion

This paper contributed a solution concept called VR-BPMN for bringing BPMN models into VR to provide an immersive BPD experience, and addresses the visualization, navigation, interaction, and annotation aspects affected by VR. A prototype based on the Unity game engine und using the HTC Vive demonstrated its feasibility. Our empirical evaluation showed that its effectiveness for process comprehension in VR was equivalent to non-VR modes (paper and 2D tools). For efficiency, VR-BPMN was 14–21% more efficient than a common PC BPMN tool on a per-connection and per-error basis, yet VR-BPMN was 42% slower than paper use for equivalent tasks. While VR-BPMN was found to be quite intuitive (4.2 out of 5), nevertheless 83% preferred the common PC tool when given a choice of one or the other; hindrances in VR included text legibility and hidden objects in 3D space.

While our results showed that the VR-BPMN solution concept is feasible, that our interaction interfaces are intuitive, and that it can be as effective and efficient as BPMN tools, for broader attractiveness additional capabilities are needed. Future work includes addressing VR sickness, improving the clarity of the models (especially text), integrating additional interactive and informational capabilities, as well as a comprehensive empirical study using BPMN professionals.

Acknowledgements. The authors would like to thank Peter Bolek, Andreas Friedel, Sabine Hager, Matthias Nutz, Philipp-Daniel Wendt for their assistance with the design, implementation, and evaluation.

Appendix

See Figs. 11, 12, 13 and 14.

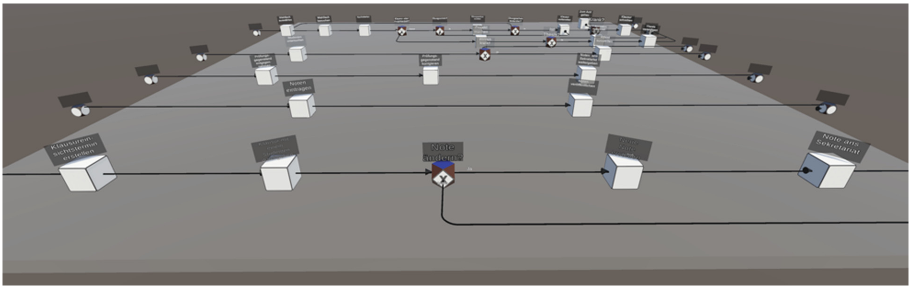

Fig. 11. The Student Exam processes shown in VR-BPMN.

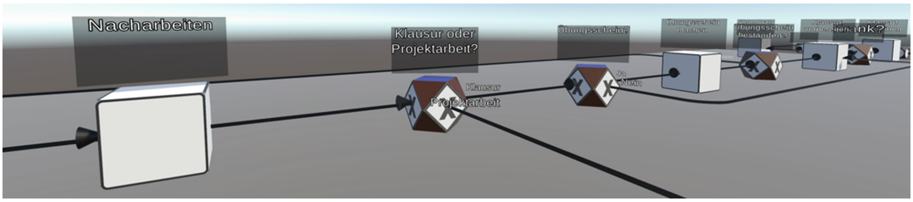

Fig. 12. Close up of Student Exam process in VR-BPMN.

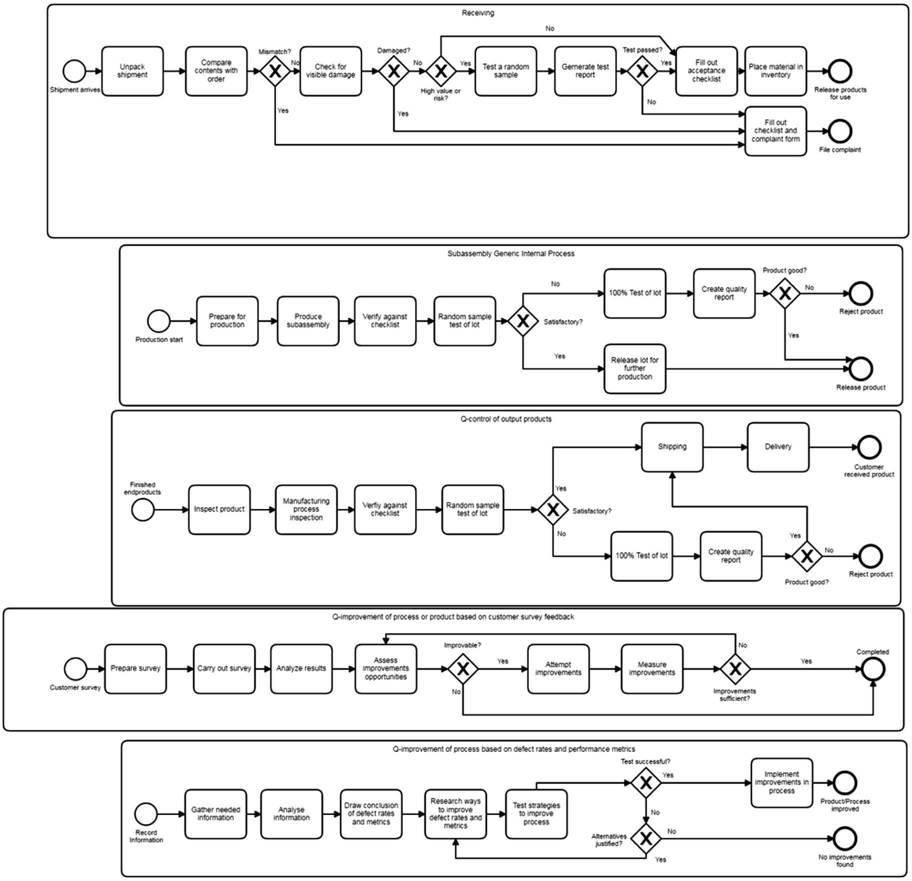

Fig. 13. The Quality Production Processes model as BPMN.

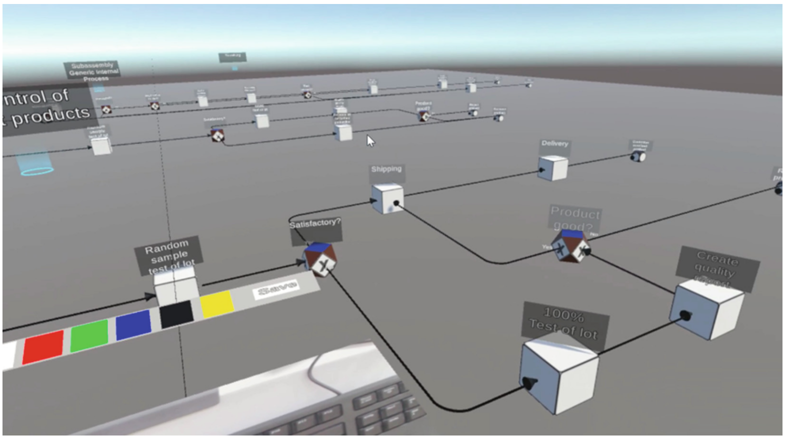

Fig. 14. The Quality Production Processes model in VR-BPMN.

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