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EVALUATING THE EFFECTIVENESS OF VR SIMULATIONS IN BUSINESS PROCESS FORMATION

Abstract. *The paper introduces VR-BPMN, a novel concept for visualizing, navigating, interacting with, and annotating Business Process Model and Notation (BPMN) models in a VR environment. It examines the efficacy of VR-BPMN against traditional BPMN representations, focusing on aspects like comprehensibility, navigation, and immersive interaction. The research delves into areas of process visualization and virtualization in VR-BPMN, referencing previous efforts in these fields, including 3D representations and dynamic visualizations. It also discusses VR's role in collaborative business process modeling and the potential benefits of incorporating VR into consumer and business applications. Furthermore, the study investigates educational implications, proposing that VR's immersive capabilities can significantly enhance learning experiences in complex subjects like business process management. The research methodology includes comparative analyses using traditional paper-based BPMN and PC-based modeling tools, involving master's students in Computer Science to assess interaction and process comprehension. The findings indicate that while VR-BPMN is as effective as traditional tools, it offers potential efficiency improvements. However, challenges such as VR sickness, text readability, and model clarity are noted. The paper concludes that VR-BPMN, supported by VR hardware like HTC Vive, confirms the feasibility of VR in business process modeling, suggesting further research and development in this field.*

Keywords: Virtual Reality (VR); Business Process Management (BPM); VR-BPMN; educational technology

Relevance and Problem Statement

The digital era has significantly impacted business processes, emphasizing the need for agility and automation. Business Process Management Systems (BPMS), a $2.7 billion market, play a crucial role in this transformation. Business Process Modeling (BPM) [8], supported by the standardized BPMN (Business Process Model and Notation) [11], aims to create comprehensive notations accessible to all stakeholders, ensuring that organizations maintain their intellectual assets across various platforms.

Related works in process visualization and virtualization have explored 3D representations and their impact on information accessibility [2 – 4; 9; 10; 13]. However, the application of current VR capabilities in BPM remains a relatively unexplored domain.

Concurrently, Virtual Reality (VR) has emerged as a dynamic force in multiple domains. With VR hardware becoming more affordable and its capabilities expanding, the market is expected to grow substantially. VR's immersive environment offers potential benefits in understanding and annotating BPMN models, especially as they increase in complexity and integration with IT systems.

This research contributes to understanding VR's role in BPM through the development of VR-BPMN, utilizing standard gaming engines and VR hardware like HTC Vive. This approach is expected to redefine how BPMN models are perceived and interacted with, potentially influencing business process management.

This paper introduces VR-BPMN, a concept for visualizing, navigating, interacting with, and annotating BPMN models in VR. It examines the effectiveness of VR-BPMN against traditional BPMN model representations, focusing on aspects like comprehensibility, navigation, and immersive interaction.

The paper then delves into the areas of process visualization and virtualization in VR-BPMN, highlighting previous research efforts in these fields. It references works that have explored various visual representation methods of business processes, including 3D representations and dynamic visualizations. This context sets the stage for understanding the potential and limitations of existing approaches in process visualization within VR environments.

Further, the paper discusses VR's role in collaborative business process modeling and communication, including the use of virtual worlds and

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augmented reality for these purposes. It notes the lack of significant research in incorporating contemporary VR capabilities into business process management, underscoring the need for further exploration in this area.

The aim of the paper

The aim of this paper is to comprehensively explore the integration and impact of Virtual Reality (VR) technologies in the formation of business processes within the educational space. At its core, the study focuses on VR-BPMN (Business Process Model and Notation in VR), a groundbreaking approach that leverages VR's immersive capabilities to enhance the comprehension and management of complex business processes. The paper investigates the potential of VR hardware in transforming business operations, examining consumer perceptions and future market trends. Through this research, the paper aims to elucidate the role of VR in both theoretical and practical realms of business process management, especially in educational contexts where VR can significantly augment learning experiences.

The main research materials

Methodology for studying the effectiveness of VR technologies

The BPMN model comprises Business Process Diagrams (BPDs), which integrate flow objects, connecting objects, swim lanes, and artifacts, as outlined in the M. von Rosing et al. research's Business Process Model and Notation (BPMN) Version 2.0 [11]. Our VR-BPMN concept, illustrated in Figure 1, concentrates on four main areas influenced by virtual reality (VR) integration:

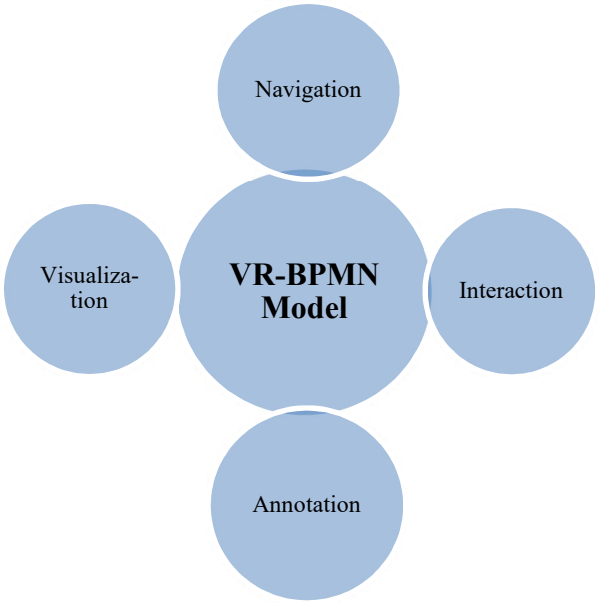

Figure 1 – Conceptual Design of VR-BPMN

1) **Visualization.** The challenge lies in transitioning the 2D-defined graphical elements of BPMN into a 3D VR space. Our approach maintains the BPMN's recognizable symbols by attaching them to various 3D shapes, viewable from multiple angles. We opted for opaque shapes to avoid visual confusion, despite the challenge of potentially hidden elements in 3D. Text visualization in VR poses difficulties due to resolution limits and text distance [5]. We address this by positioning labels like billboards above the elements, ensuring they are semi-transparent and automatically rotate towards the viewer for improved readability. Additionally, we've devised a method for displaying subprocesses using hyperplanes, which project them beneath their superprocess, connected by a glass pyramid. This spatial arrangement intuitively aligns with the conceptual hierarchy, yet can be adjusted for detailed comparison of subprocesses and superprocesses.

2) **Navigation.** VR's immersive nature necessitates intuitive navigation methods that mitigate potential VR sickness. We offer two navigation modes: teleportation, allowing instant relocation to a selected point, and a birds-eye view with gliding controls for an overarching view of the model. These modes are easily switchable, catering to user preference and comfort.

3) **Interactions.** The BPMN standard does not specify user interaction with its graphical elements. In our VR environment, interactions are facilitated primarily through VR controllers, complemented by a Mixed Reality (MR) keyboard. This setup allows for a more natural text input method and intuitive drag-and-drop interactions for annotative purposes.

4) **Annotations.** Immersion in VR limits access to external information sources, and removing the headset breaks this immersion. To counter this, we emphasize the use of Annotations (a BPMN Artifact type) for embedding additional contextual information within the model. We propose a tagging system for annotations, allowing text to be directly associated with any element, including swim lanes. Tags, marked with a colored ribbon above the element label, enhance organization and information prioritization. For associations, we use a colored dotted line for clear visual distinction and ease of tracking, which can extend across hyperplanes.

In the context of exploring the integration of Information Technology and VR technologies for business process formation in educational spaces, we have employed the Unity game engine for VR visualization. This choice was influenced by Unity's extensive multi-platform support, direct VR capabilities, widespread use, and affordability. For the development of visual BPMN model elements, Blender software was utilized. The VR testing phase was conducted using the HTC Vive, a comprehensive room scale VR system featuring a head-mounted display with an integrated

camera and two wireless handheld controllers, tracked by «Lighthouse» base stations.

Visualization. Our approach to visualizing BPMN2 elements involved using various 3D shapes. We placed the BPMN symbols in black and white on the sides of these shapes for clear visibility, as illustrated in Figure 2. The labeling of elements was executed with white text on a semi-transparent dark background [14]. This choice was made to ensure the text does not overshadow the primarily white-based BPMN symbols. The scaling and placement of elements are determined by the BPMN XML layout attributes provided. Subprocesses are creatively depicted as stacked hyperplanes, linked to their superprocess through colored semi-transparent pyramids, a concept visualized in Figure 3.

Navigation. Our system supports seamless navigation between a birds-eye-view and teleport mode, as demonstrated in Figure 4. The teleport mode, activated using the right trackpad, allows users to select their destination with precision. The birds-eye-view, offering a comprehensive view of the model, is controlled by both trackpads for movement in various directions. Additionally, a miniature representation of the BPMN diagram, akin to a minimap, is accessible for quick reference to one's overall location in the model [15].

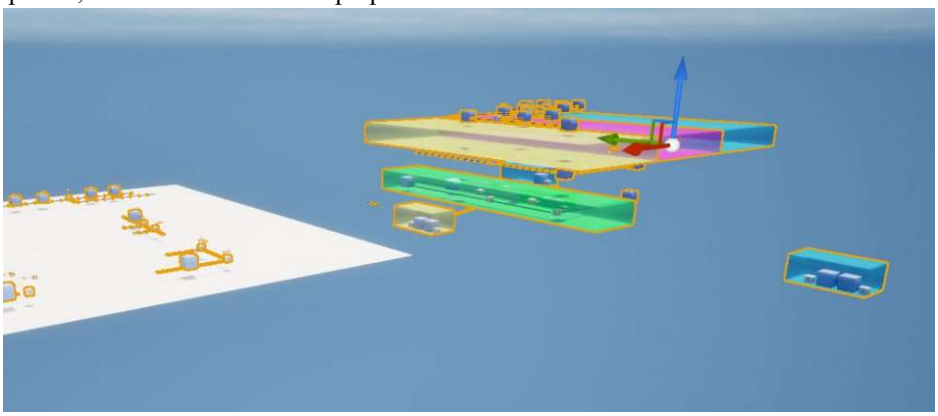

Figure 2 – Assortment of VR-BPMN BPMN2 Element Snapshots

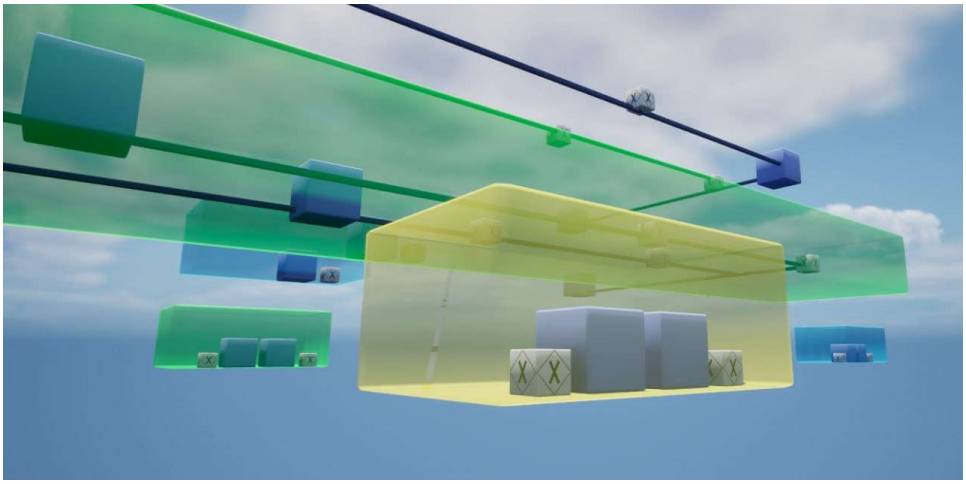

Figure 3 – Stratified Hyperplanes Depicting Subprocesses as Partially Transparent, Colored Pyramidal Structures in a Concealed Process Instance

Figгку 4 – Illustration of Teleportation Interaction Demonstrating the VR Controller and Selected Destination Marked by a Green Cylindrical Shape

Interaction. Interactions within the VR environment are primarily conducted through the VR controllers. For instance, toggling the visibility of tags on an object is as simple as pointing at the object and pressing the trigger button. Drag-and-drop functionality is also integrated, enabling users to create association annotations by moving objects within the virtual space. For textual inputs, such as adding tags, we've incorporated a Mixed Reality (MR) keyboard [1; 6; 7]. This allows for real keyboard usage by projecting the webcam video stream onto an object's material, enhancing the user experience as showcased in Figure 5.

Annotations. Annotation features in our system are initially presented in a fluorescent green color for distinct visibility, but this can be customized as per user preference. Users have the flexibility to create annotative associations between elements, as shown in Figure 6, or connect various processes. This is facilitated through a drag-and-drop interface using the VR controller. Tags provide a means for annotating BPMN elements with additional text, automatically adjusting in font size to fit the space. A colored ribbon atop a label signifies the presence of tags, with the color being selectable from a palette, as depicted in Figure 5. Tags, when visible, are prominently displayed above the labels on an opaque white background with black text, ensuring clear differentiation. For element or tag coloring, users can select from a predefined palette, as illustrated in Figures 6 and 7, with Figure 8 showcasing colored swimlanes.

Figure 5 – Labeling Process in Mixed Reality Mode with a Selection of Tag Colors and a Physical Keyboard in View

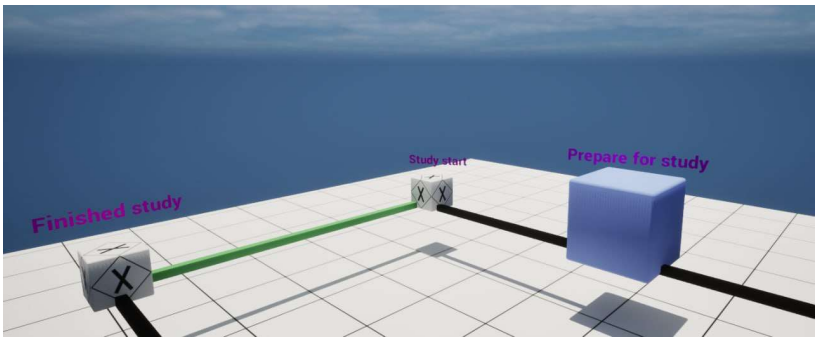

Figure 6 – User-Generated Connection Annotation (Green) Linking Two Processes

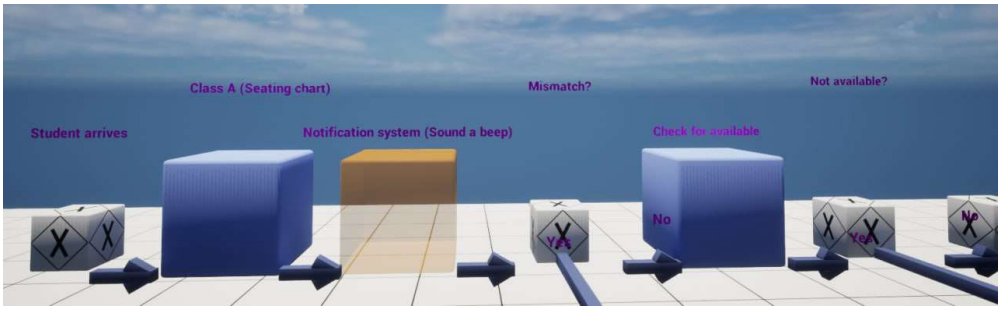

Figure 7 – Tags Featuring See-through Backgrounds and Varicolored Tag Ribbons Indicating a Color-Coded Element

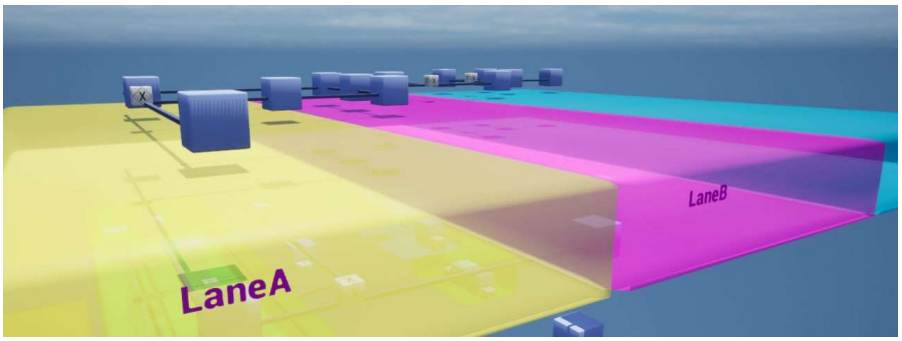

Figure 8 – Aerial View of a Model Displaying Different Colored Lanes

The investigation into the feasibility of our VR-BPMN (Virtual Reality-Business Process Model and Notation) prototype was a pivotal step in understanding its application in the context of Information Technology and business process formation, especially relevant in educational environments [12]. This empirical study was focused on assessing the impact of a VR environment on the analysis, comprehension, and interaction with BPMN-based processes. Our comparative analysis included traditional paper-based BPMN and a widely used PC-based BPMN modeling tool, Camunda Modeler.

For an unbiased evaluation, we engaged a group of master's students in Computer Science, most of whom had minimal prior exposure to BPMN. This approach was designed to mitigate the influence of pre-existing knowledge of BPMN paradigms or tools. The study was meticulously structured, including supervised sessions, introductory training on BPMN anti-patterns, and follow-up debriefings. Additionally, to prevent any disruption in the VR experience or skewed task durations from reading instructions or responding to questions within the VR environment, all inquiries were conducted verbally and recorded by a supervisor.

The comparison between paper-based BPMN and VR-BPMN involved eight Computer Science students. They were tasked with analyzing and explaining BPMN processes, using both mediums. To ensure consistency in complexity and minimize familiarity bias, we used process pairs with similar structural complexity but varying in domain terminology and slight structural differences. This included pairing processes like «Emergency Patient Treatment» with «Farm Process» and «Invoice Process» with «Mario Game Process». Each student interacted with one process on paper and its counterpart in the VR-BPMN environment, with the order of medium usage being randomized to avoid any order bias.

The duration of task completion was recorded, as depicted in Figure 9. The findings indicated that the average task duration for VR-BPMN was 5:25 minutes, compared to 3:24 minutes for paper, highlighting a 42% increase in time for VR-BPMN. Notably, except for one participant, tasks completed using the second medium (whether VR or paper) were accomplished more quickly.

In a separate comparison, focusing on interaction and process comprehension, seven Computer Science students engaged with VR-BPMN and Camunda Modeler. One student's data was excluded due to experiencing VR sickness. The tools were randomly assigned as starting points for the participants. The processes used for this part of the study included a «Student Exam BPM», represented in Figure 10 and Figure 11 for VR-BPMN.

The study involved a series of timed tasks across various tools:

– Identifying BPMN modeling errors in the Student Exam model.

– Connecting relevant elements in the Quality model concerning testing.

– Linking end and start nodes appropriately in the Student Exam model.

– Determining prerequisite tasks in the Quality model before the «Fill out checklist and complaint form» step.

For a comprehensive evaluation, we normalized task durations against the number of errors identified or connections made, as detailed in Table 1 and Table 2. We observed variance in the number of connections due to the subjective nature of the tasks. However, all elements in Tasks 1 and 4 were correctly identified, indicating comparable comprehension effectiveness across tools. The average durations per error and per connection showed VR-BPMN (V) to be 21% faster than the PC-based Camunda Modeler (C), and 14% faster when excluding the error-identification task.

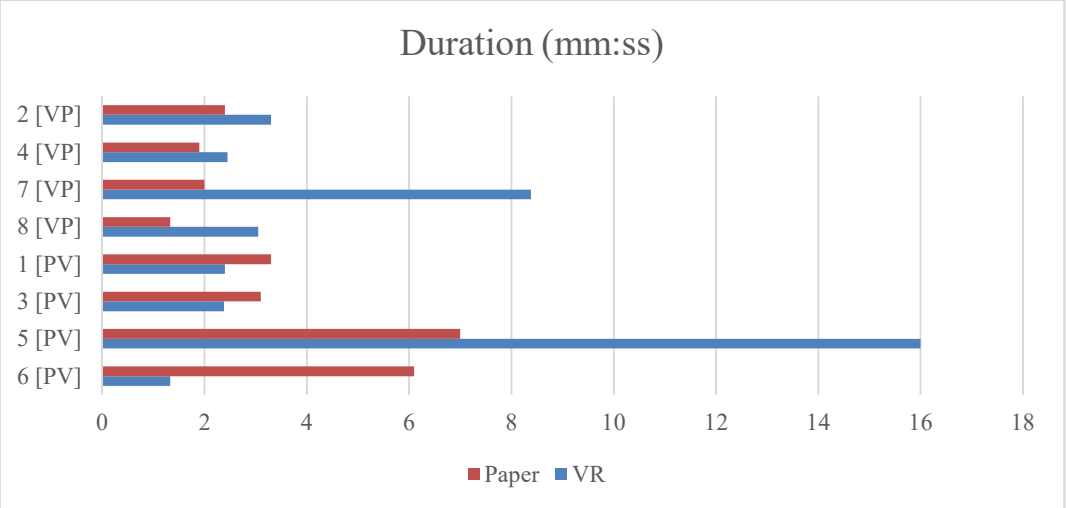

Figure 9 – Comparison of Task Duration for Subjects in Paper BPMN and VR-BPMN Models, Sorted by the Shortest VR Time; Sequence Noted in Parentheses, V for VR, P for Paper

Table 1 – ***Time Durations in Seconds for Four Tasks in VR-BPMN (V)***

Task (T)	Subject / Duration (metric)	1	2	3	4	5	6	Average
TV1	Awaiting: 2	2	2	2	2	2	2	2
	s/error	37	58	158	25	128	137	91
TV2	Awaiting: 5	4	4	8	8	10	7	6.83
	s/connection	33	50	44	16	29	36	35
TV3	Awaiting: 5	4	4	5	5	4	6	4.67
	s/connection	59	57	82	62	83	29	62
TV4	s	70	69	58	82	41	59	63
TV Total (s)								251

Table 2 – ***Time Durations in Seconds for Four Tasks in Common BPMN Tool (C)***

Task (T)	Subject / Duration (metric)	1	2	3	4	5	6	Average
TC1	Awaiting: 1	1	1	1	1	1	1	1
	s/error	89	119	122	72	223	160	131
TC2	Awaiting: 5	4	4	11	10	9	5	7.17
	s/connection	32	19	16	9	9	91	29
TC3	Awaiting: 5	4	5	5	6	6	5	5.17
	s/connection	29	58	29	29	36	52	39
TC4	s	40	32	37	138	361	99	118
TC Total (s)								317

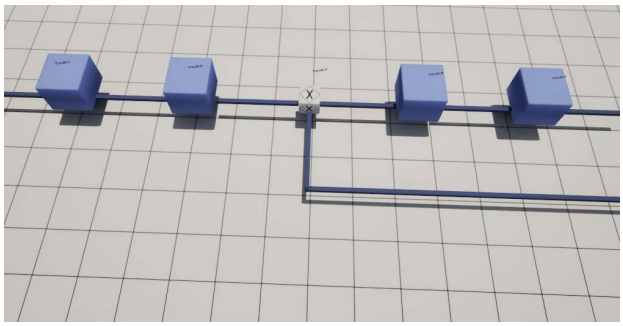

Figure 10 – Visualization of Student Exam Processes in VR-BPMN

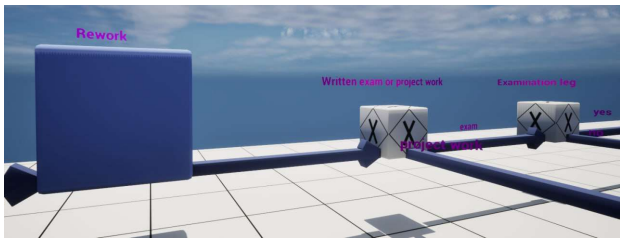

Figure 11 – Detailed View of the Student Exam Process in VR-BPMN

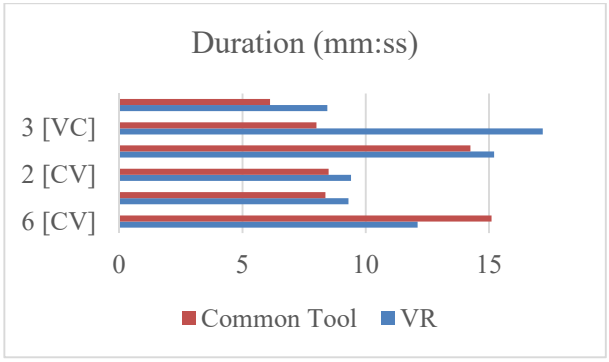

Figure 12 – Comparison of Task Duration for a Standard BPMN Tool and VR-BPMN, Arranged by the Shortest VR Time; Order Specified in Parentheses, V for VR, C for Common BPMN Tool

Figure 12 illustrates the total task durations for each tool, revealing a trend where participants generally performed tasks more rapidly in the second mode (either VR or paper), except for two subjects where the difference was minimal. This observation might be attributed to an initial adjustment period, and future studies may incorporate a warm-up task to counteract this effect.

Given BPMN's goal to be accessible to all stakeholders, the decision to involve novices in this experiment was strategic, minimizing the influence of existing biases and preferences. While the sample size was limited and lacked BPMN professionals, the findings offer valuable insights for further research.

In terms of effectiveness, VR-BPMN demonstrated parity with paper and PC-based tools in performing and understanding the processes. From an efficiency standpoint, VR outperformed the common PC BPMN tool by 14-21% depending on the inclusion of the error-finding task. However, it showed a 42% slower completion rate compared to paper-based tasks. Notably, participants often completed tasks faster in the

second tool used, suggesting an initial learning curve with VR technology. Additionally, the intuitiveness of the VR-BPMN interface received positive feedback, scoring 4.2 out of 5.

However, a preference for the traditional PC tool was observed among the majority of participants. This could be attributed to their familiarity with conventional tools and limited exposure to VR. Challenges in VR, such as text readability and object visibility, were noted, but users also found the VR experience enjoyable, which could enhance learning and engagement.

Leveraging the Unity game engine and HTC Vive, the prototype confirmed the feasibility of VR-BPMN. Our empirical findings suggest that while VR-BPMN is as effective and potentially more efficient than traditional BPMN tools, improvements in VR technology, model clarity, and user experience are essential for wider adoption. Future efforts will focus on addressing these areas, including mitigating VR sickness, enhancing model legibility, and conducting studies with BPMN professionals to further validate the potential of VR in business process modeling and education.

Conclusions

The research paper provides a comprehensive exploration into the integration of Virtual Reality (VR) in business process management, particularly focusing on educational applications. Here's a structured overview of the key elements and findings of the study:

1) The paper introduces VR-BPMN, a novel concept for visualizing, navigating, interacting with, and annotating Business Process Model and Notation (BPMN) models in VR environments. This includes detailed development of the VR-BPMN prototype using Unity game engine and Blender software, optimized for use with HTC Vive VR hardware.

2) The research methodology involved comparative analyses of VR-BPMN with traditional paper-based BPMN and PC-based modeling tools. The study engaged master's students in computer science to evaluate aspects such as interaction, comprehension, and user experience in VR-BPMN versus traditional BPMN models.

3) The research findings indicate that while VR-BPMN is comparable in effectiveness to traditional BPMN tools, it demonstrates potential efficiency improvements. However, challenges such as VR sickness, text readability, and model clarity are noted. Participants generally showed a preference for traditional PC tools, suggesting an initial learning curve with VR technology.

4) The paper concludes that VR-BPMN is a feasible and effective tool for business process modeling, offering immersive and interactive capabilities that enhance understanding and management of complex processes. The study underscores the need for further advancements in VR technology, model clarity, and user experience for broader adoption in business and educational contexts.

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ОЦІНКА ЕФЕКТИВНОСТІ МОДЕЛЮВАННЯ VR У ФОРМУВАННІ БІЗНЕС-ПРОЦЕСУ

Анотація. *У статті представлено VR-BPMN – нову концепцію для візуалізації, навігації, взаємодії та анотування моделей бізнес-процесів і нотацій (BPMN) у середовищі VR. Пропонований додаток досліджує ефективність VR-BPMN на противагу традиційних представлень BPMN, зосереджуючись на таких аспектах, як зрозумілість, навігація та захоплююча взаємодія. Дослідження заглиблюється в галузі візуалізації процесів і віртуалізації у VR-BPMN, посилаючись на попередні зусилля в цих галузях, включаючи 3D-представлення та динамічні візуалізації. Також розглянуто роль VR у спільному моделюванні бізнес-процесів і потенційні переваги включення VR у споживчі та бізнес-додатки. Крім того, дослідження вивчає освітні наслідки, припускаючи, що захоплюючі можливості VR можуть значно покращити навчальний досвід у таких складних предметах, як управління бізнес-процесами. Методологія дослідження містить порівняльний аналіз з використанням традиційних паперових BPMN та інструментів моделювання на базі ПК із залученням студентів магістратури комп'ютерних наук для оцінювання взаємодії та розуміння процесу. Отримані результати свідчать, що хоча VR-BPMN настільки ж ефективний, як і традиційні інструменти, він пропонує потенційні покращення ефективності. Однак відзначаються такі проблеми, як хвороба VR, читабельність тексту та чіткість моделі. У документі зроблено висновок, що VR-BPMN, який підтримується таким апаратним забезпеченням VR, як HTC Vive, підтверджує доцільність VR у моделюванні бізнес-процесів, пропонуючи подальші дослідження і розробки в цій галузі.*

Ключові слова: віртуальна реальність (VR); управління бізнес-процесами (BPM); VR-BPMN; освітні технології

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