Usability Evaluation of VR products in Industry- A Systematic Literature Review

by

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ABSTRACT

VR development practices have a diverse set of practices compared to traditional software development. Tasks like scene design, acoustic design, vergence manipulation, image depth, etc. are specific to VR apps and hence require evaluation processes that may be different from the traditional means. Usability Evaluation is one such process which is being executed in an unconventional way by Industrial Practitioners today. In this paper, the researchers detail a Systematic Literature Review of the Usability Evaluation Methods practised by Industrial researchers while building VR Products. The researchers found that VR Product teams follow unique methods to improve usability in their products. Further, the researchers consolidate these methods and provide insights into choosing the best to build a real-world VR Product based on the defined product constraints.

CCS CONCEPTS

• **Software and its engineering → Software usability**;

KEYWORDS

Usability Testing; Virtual Reality; Industrial Practices; Usability Evaluation; Metrics

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1 INTRODUCTION

VR (Virtual Reality) has a vibrant role to play in coming future. VR is expected to possibly replace mobile devices in future like the way televisions from the past were replaced by mobile devices [13]. VR Products are known for providing a virtual experience [26] for the real-life events using Head Mounted Devices (HMD). It is found to offer opportunities in the fields which require visual training experience [26] and education through simulation studies. A leading market researcher has ranked Virtual Reality as one of the strategic technologies trends of 2018 based on its market share and upcoming business transformations in Enterprise Software[13]. As per Digi-Capital Market Research Report [1], there has been $3 billion dollar investment made in VR Enterprise product market for the year of 2017 in the domains like Education, Health, Art/Design, HRTech, Services, Tourism, News etc. It has become evident that VR technology has become a significant tool for building future personalized products replacing today's smart-phone revolution. It has the potential to account for a large consumer market by the end of this decade.

Traditionally, VR software products are oriented towards Gaming domain [33]. Gaming companies have produced personalized games in single and multi-player format to provide real-time individual experience to players. They paved a path for creating next-level cutting edge means of entertainment. This virtual experience setup is set to transcend into Enterprise Software. However, Enterprise VR products are yet to hit the market at a full-scale due to various challenges like non-standardized HMDs, Usability, Accessibility, lack of guidelines, etc. To explore the spread of these challenges in Industry, researchers have previously conducted a focused empirical study to understand the underlying differences between Enterprise Software Product Development and Virtual Reality Product Development. Section 2 provides few observations from the study. The study showed Usability to be one of the important qualities of VR products and its evaluation as one of contributing factors in the success or failure of VR products. Usability can be defined as the ease of use of a product where ease of use can be considered as a measurable attribute. Recent empirical research by Ulas et al. [41] has also stressed on the need for a new Software Development Methodology for building Enterprise VR products considering usability and maintainability as a significant challenge. The increased number of VR applications being developed by Industry and the need for Usability evaluation on these applications led the authors to conduct a Systematic Literature Review in the existing literature to study about the Usability Evaluation methods exercised in VR Product Development.

The rest of the paper is structured as follows: Section 2 gives the motivation for this paper. Section 3 details the Systematic Literature Review. Section 4 includes a discussion on giving preferences to Industrial practitioners on adopting appropriate methods while conducting Usability studies during VR Product development. We present threats to validity as part of Section 5 and conclusion in section 6.

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2 MOTIVATION

Software practitioners who practice Software Engineering (SE) principles while developing a regular software product are increasingly being used to build VR products [22]. Game developers and designers who are competent in design and strategy planning have created an ecosystem for software developers to enter into VR space [17]. Over a decade, they were able to adopt SE principles to meet their development needs. They are following development guidelines [33] and a game based development cycle [3] to improve their practices. This amalgamation of developers from gaming and SE into VR space opened new avenues and challenges for practitioners. The primary objective of some of the researchers was to ***"understand the modalities of Virtual Reality Product Development in Software Industry"***. Previously researchers have studied these challenges and recorded vital insights. These insights include essential considerations on development practices, testing strategies and potential thrust areas for future research from the VR Industry community.

The authors of this paper in their prior research conducted a study on industry practitioners to record the differences between development practices specific to VR software products and non-VR software products. Some of the observations recorded from Industrial Practitioners study are given below:

- VR Product development is different from traditional Software Product development.
- VR Development process is complicated, unstructured and can be formulated based on the level of practitioners' participation.
- Design and Usability reflect VR Product sensitivities. They have a direct impact on product quality.
- There are almost no comprehensive testing strategies for VR Products to improve over multiple product releases.
- Usability Evaluation is considered to be a costlier affair as it requires a personalized setup. Most of the time they yield fluctuated results as the products tend to be persona based and hence different results are obtained from different participants.
- Design Versioning and Sustenance Maintenance are time-consuming and confusing at times for unstructured VR Product Builds.
- Support tools for VR product development practices was inadequate
- Stakeholder conflicts are far more given the wider variety of stakeholder involved in the development of VR products

Quality of Experience (QoE) is the central aspect of VR Products. As group or mob studies cannot distinguish the outcome of a personalized experience of a single participants, VR Product offerings are currently being generalized for a particular audience and are agreed upon a common ground. Usability is the underlying area which has an omnipresent impact across VR Product Development Cycle. That motivated us to understand the means of usability studies practiced in Industry while building VR applications for target audiences. Subsequently, this research can help future Industry practitioners to choose a better usability evaluation methods as per their future product needs.

3 SYSTEMATIC LITERATURE REVIEW

Software Engineering considers usability as one of the key software quality attributes. Usability is a measure which can be employed for any product. ISO-9241-11 defines usability as *"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use"* [25]. Usability constantly reminds the product owners to consider the end user perception while designing the product. It has to be regulated at every stage of software product development so as to constantly improve the ease of usage. There are Usability Evaluation Methods (UEM) to address various end-user user-cases in a real-world scenario. However, VR practitioners are still unsure of the best available methods to conduct Usability Evaluation. In this paper, we conducted a systematic literature review to record the usability evaluation methods suggested by different researchers while working on assessing the VR apps.

3.1 Research Questions

The Systematic study described in this paper was performed considering the parameters defined by Kitchenham et al. [29]. The primary goal of our study is to capture the usability evaluation methods practised by various Industrial researchers while evaluating their VR products and applications as part of their research. We followed an evidence-based PICOC (Population, Intervention, Comparison, Outcome and Context) method [6] to formulate our research questions. As per PICOC method, our general concepts are presented in Table 1. OUr work tries to address the following research questions:

- ***R1:*** *What are the evaluation methods used to measure usability in VR products?*
- ***R2:*** *What are the metrics captured while conducting usability evaluation in VR products?*
- ***R3:*** *Is there a trend in implementing a certain usability evaluation method in regards to VR products?*
- ***R4:*** *Is there anything unique about usability evaluation setup in Industry VR Products?*

Table 1: Definition of the general concepts using PICOC method

Criterion	Description
Population	Virtual Reality related products and applications
Intervention	Usability Evaluation Methods
Comparison	Comparison between the results captured in various Usability Evaluation Methods
Outcome	Studies where Usability Evaluation Methods are applied on VR based products and applications
Context	Academia, Software Industry and Other Empirical Studies

3.2 Search Strategy

We began our literature review by identifying keywords and some search strings deduced from the research questions. The search strategy was set by a search string enabling the identification of studies that describe the execution of at least one usability evaluation method applied to a VR Industry software product. The search terms were chosen with concepts resulting from the PICOC method.

C1: "Virtual Reality" **OR** "Virtual Programming"
C2: "Usability method" **OR** "Usability technique" **OR** "Usability Engineering" **OR** "Usability Practice" **OR** "Usability Approach" **OR** "Usability Process" **OR** "Usability Test" **OR** "Usability Procedure" **OR** "Usability Study" **OR** "Usability Studies" **OR** "Usability Assessment" **OR** "Usability Evaluation" **OR** "Usability Inspection"
C3: "Industry" **OR** "Commercial" **OR** "Enterprise"
C4: "Publication Year" > "2000"

The resulting string can be formulated as 'C1' **AND** 'C2' **AND** 'C3' **AND** 'C4'.

While constructing the search string, we considered Virtual Reality and Virtual Programming keywords first to filter the papers from VR Space. As we are exploring Usability space, we included all possible potential keywords in regards to Usability. To identify the literature from VR Industry, we included Industry related keywords as the new level filter. In regards to the year of publication, we considered the year - 2000 as a limit to extract the literature. To the best of our knowledge, we believe there wasn't any significant work in the VR space before that. We conducted a multi-level analysis on VR research area and found that the VR technology was highly simplified after the year 2000 with the advent of new hardware. Additionally, we reviewed the search strings multiple times and incrementally developed them based on a peer-review approach. We worked with a few fellow researchers in the research area to build a robust string to generate effective results. Once the search string was finalized, the authors independently conducted the search activity and were able to record identical results. The authors have conducted a string search against all available attributes of a research paper including abstract, Contents of Paper, Keywords, etc. We filtered these attributes further to avoid miscellaneous papers.

3.3 Databases and Paper Selection

The search was conducted using the search string against electronic databases - IEEE Xplore, ACM Digital Library, Scopus and Science Direct. The search ordering was based on the databases that returned most of the results. The search fields were selected to assure that the search process is made similar across these databases. We omitted the grey literature and focused on active publications. Our review considers research papers published until August 2018.

Exclusion Criteria - Articles with poor details about the study setup on VR Products. Articles which had irrelevant information about HCI techniques, topics related to description of usability engineering or Non-Industry papers were excluded. We have also not considered papers which do not mention anything about the commercial aspect of the VR product built as part of their research.

Inclusion Criteria - The paper which contains the use of Usability Evaluation Methods as part of their title, or abstract or keywords considered. The article includes terms related to the search string. The paper consists of the study conducted in Industry or on an Enterprise Product was provided primary consideration. Only papers written in English and whose abstract or title mentions the relevance to our review considered.

3.4 Data Extraction

The process of data extraction was conducted based on the protocol proposed by Kitchenham et al. [29]. For every paper extracted based on the search criteria, we captured the attributes like Type of Paper, UniqueID, Author(s), Editor(s), Title of the paper, Pages, keywords, DOI, year of publication, ISBN, Publisher, Extraction date, Database. As part of data extraction, the search string returned ***84*** papers across all the databases. We implemented the inclusion and exclusion criteria over these research papers. We were able to filter them to ***36*** research papers which hold good for our literature review. Table 2 provides details of these finalized research papers.

4 DISCUSSION

Based on the data, we found that the Industrial researchers have seriously considered Usability Evaluation as a pointer for practical realization of their VR Product. The Table 2 contains the details of Usability Evaluation methods applied on VR apps categorized based on the metric and by the type of Industry. In this section, we dissect our research questions and discuss the relevant observations.

R1: *What are the evaluation methods used to measure usability in VR products?*

Widely Used Approaches - Controlled Experiments are found to be the most widely used usability evaluation approach for Industry-based VR applications. Industries like Health Care, Manufacturing, Simulation studies and Software products have considered this approach as a better way to understand the usability issues. Almost all these applications are built for training and simulation studies. The VR application developers have followed Presence Survey (discusses the mental experience of the user) and Informal Usability Survey (that do not require facilitators) to capture the participants' overall reaction post usability evaluation.

Focused Approaches - Selective domains have made use of Usability evaluation methods for a particular set of end users. Haptic centred controlled Experiments, Pluralistic Walk-through, Subjective and Objective Evaluation are implemented primarily in large-scale enterprise VR applications. Other minor methods include Psychometric Assessment, Workload Assessment and Use-case based Usability testing. Most of these methods are employed on applications like Mixed Reality based Simulator applications, Physiological Signal Sensor training applications and Venepuncture Training for Medicinal Practitioners.

Group Study Approaches - There are applications that require observations from targeted user groups. Usability evaluation methods like Focus Group Experiments, Pluralistic Walk-through, Cognitive

Questionnaire and Task-based Heuristic evaluations are employed for VR Usability Testers to understand the multi-user experience in business sensitive VR applications.

Empirical Methods - Apart from conducting usability evaluation methods, VR Industrial practitioners have applied survey-based empirical approaches to capture the participant feedback to understand the impact of their usability evaluation. Standardized survey methods like NASA Task Load Index, IBM Ease of Use Survey, Social Response Scale and Systematic Usability Survey are implemented mainly on Simulation, Manufacturing and Healthcare related VR applications. The Usability practitioners have adopted these empirical approaches as part of their usability study to understand the Quality of Experience (QoE) of the VR product. All the VR products collected as part of our research followed a usability evaluation method to calculate the desired usability metrics. An empirical approach was also observed to capture the user feedback corresponding to the conducted usability study.

***R2:** What are the metrics captured while conducting usability evaluation in VR products?*

Regular Metrics - Table 2 contains a detailed portrayal of Usability metrics which are captured during the usability evaluation. Of these metrics, Effectiveness, Efficiency and Satisfaction are found to be the most widely captured metrics. There are few unique metrics like Inter-pupillary Distance, Physical Interaction Capacity, Bio-mechanical Feedback, Force Exerted, Galvanic Skin Response, Skin Temperature, Heart Rate and Spatial Orientation Test focused to specific VR applications which are built for handling sensitive tasks and their respective actions.

Unique Metrics - Different practitioners across various VR products calculated the same characteristic in a unique manner. Interaction Capacity is a metric which explains the capacity of a user to interact within the Virtual Environment. Practitioners have captured the user interaction in Virtual Car Interior [32] based on the time spent by a user over each task in the virtual environment. However, in a case of the tourism-based VR application [37], user interactions were captured based on navigation time across the virtual environment. Other studies include projection based applications [19] where the first person experiences were captured based on a wait and response time to calculate the interaction capacity of the participant in usability evaluation.

Novel Metrics - Efficacy is another unique metric which is being captured from a brain injury community-dwelling individuals [36]. The motive of this metric is to understand the ability of the participants to produce intended results decided by a medical practitioner. A degree of dizziness or Vertigo based metric is captured [30] to evaluate the user experience in immersive 3D Map environments. Apart from the above, the rest of the metrics are captured as per usability guidelines using survey-based empirical methods.

***R3:** Is there a trend in implementing a certain usability evaluation methods in regards to VR products?*

Shift in Approach - We find a minor trend as part of the methods and metrics employed in the published works on Industry VR products. There has been a progressive shift on using particular usability evaluation methods over a period. Notably, the training based education VR products have shifted their evaluation strategy from heuristic cognitive based methods to Group based evaluation methods. The probably reason could be due to increased levels of understanding of group learning setups. The domain-specific VR apps pertinent to Health Care and Manufacturing initially followed Controlled Experiments. Later, most of the products adopted Haptic based methods due to the significant change in sensitivity of the tasks involved in the evolving VR product.

Automation in VR - We see a slight trend in automating the usability evaluation methods across products in Industry. Industry researchers have claimed that automation helped the practitioners avoid manual biased results to some extent. However, there is no strong empirical evidence to support their argument. Business critical applications in the area of Construction [16], Health Care [36], Gesture Interaction [12] and Understanding force a certain level of automation with in their VR products. Haptic based virtual environment [34] has some automation efforts by practitioners. Spaceflight operation evaluation [20], Electronic device evaluation [9] has automated means to understanding usability challenges replacing a human-based usability evaluation approaches. A small set of distinct products in the field of Manufacturing [4], Retail Product View [27], Fashion [8] and Museums [19] adopted automated approaches to detect the usability metric and avoid human prejudice during usability evaluation.

***R4:** Is there anything unique about usability evaluation setup in Industry VR Products?*

Product Liability - Industry VR Products are constrained by business decisions in line with the demands of the consumers. They are expected to provide rich set of features that are attractive to their consumers and at the same be released at the right time. Most of the products face setbacks in the Product Quality Evaluation stage. Whenever an abnormal feature flow is identified, the relevant intended behaviour requires serious inspection. The slightest change in a feature flow influences the relative design, code and workflow of the entire VR Product. When compared to non-Industry VR products, Industry VR products are bound to be compliant as they have real-world outcomes. Any loss of data or life has severe consequences in real-world, and it is more concerning for Manufacturing and Healthcare. Most of these applications are involved in training and simplifying day-to-day activities.

Content Development - The results from Usability Evaluation provide more options to VR product stakeholders to enrich the product as needed. Every usability testing cycle requires review from the entire VR Product development teams to compare and critique the change implemented to address the usability issue. Change in feature flow and task-actions drastically impact original design and requires upgradation of the VR content to meet usability requirements. Content Development is comparatively expensive as it requires multi-level design strategy across all the VR Scenes. It is unique for Industry practitioners to comply and also have sanity in content design across the VR Product to provide a quality user experience.

Product Versioning - Industry VR product is poised to stay longer in the market as it is expected to generate revenue. Thus it is common to adopt product versioning methods which are unique to Industry VR Products. It is evident that it is complicated to manage and maintain design versions of VR Product when compared with code-based version repositories. Code repositories are robust and mature when compared with design version repositories. Unlike code repositories, where structure of the artifact is well know, design artifacts involved in VR products, for example, a VR scene design does not have a well established representation. Hence, support for versioning must be looked at from multiple perspectives. Commercial VR Products in Fashion [8], Simulation [45] and HRMS [47] have involved designers in maintaining two or more major design threads such that the design layouts are dynamically altered based on the target audience base.

Effort Estimation - VR Products a relatively recent phenomenon and developers tend to involve a variety of people who are unique to VR production. In contrast to traditional Software Product Development, VR teams include practitioners like VR Scene Designers, Acoustic Editors, Audio/Visual Developers, VR Scene Artists, Content Editors and Integration Specialists who are unique to VR product development. Usability Evaluation results create new work-load across these stake-holders which indicates a rise in product development cost regarding stake-holder effort. None of the VR Products measured initial effort estimation to plan for future releases. It is significant for a VR Product to have an effort estimation strategy to minimize the future product version cost.

5 THREATS TO VALIDITY

In this Systematic Literature Review, we have included only papers written in English. Hence the search terms are defined in this language. The results of search and the filtration process was evaluated with an expert in this field and constant feedback was captured to improvise the search strategy and review the paper. So the possibility of primary studies having been overlooked is minimal, if any. Of course, it is evident that there could be mistakes from authors in regards to the judgment of a research paper while conducting the filtration analysis. Also, while the search strings are widely agreed on by the peer-researchers, is is possible that that a keyword or two may have been overlooked. The publications and discussion as part of this paper have evaluated and classified based on the judgment and experience of the authors, and other researchers may have evaluated the publications previously.

6 CONCLUSION

Through a systematic review, a preliminary investigation regarding the use of usability evaluation methods in Industry ready VR applications was conducted. The primary motivation of this study was to analyze the current state-of-art of usability evaluation approaches published in practice within real-world Industry-ready VR applications. There are domain specific usability metrics which are built for the targeted users for the focused market. Despite the variety of usability evaluation methods and their related usability metrics, there is uncertainty about the most suitable technique for a particular Industry VR product. Our study is intended to serve as a contribution to support decision making in the choice of choosing a usability evaluation method for future Industry VR products. Researchers intend to continue the study on a larger scale to capture further VR Product Development challenges and work towards identifying suitable solutions.

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Table 2: Usability Evaluation Methods - Categorized based on metric and by Industry Type.

Industry	Usability Evaluation Approach	Calculated Metrics	Empirical Method	Primary Studies
Automobile	Heuristic Focused Group Experiment	Interaction Capacity Response Time	Informal Usability Tests	[32]
Education	Psychomotor Assessment	Inter-pupillary Distance	Systematic Usability Scale NASA TLX Survey	[10]
	Pluralistic Walkthrough	Understandability	Presence Survey	[11]
	Cognitive Walkthrough	Engagement , Endurability	Pictorial Rating	[2]
Electronics	Focus Group Experiments	Ease-of-Use User Satisfaction	Usability Survey	[9]
Fashion	Cognitive Walkthrough	Effectiveness	Usability Survey	[8]
Healthcare	Controlled Experiments	Response Time Attention , Efficacy	Informal Usability Survey	[36]
	Focused Group Experiments	Reaction Time Response Time	Usability Survey	[18]
	Cognitive Walkthrough	Average Fixation Duration Effectiveness Response Time Index	Social Communication Questionnaire Social Response Scale	[7]
	Informal Controlled Group Experiment	Ease-of-Use Overall Satisfaction	IBM Ease of Use Survey	[14]
HRMS	Focused Group Experiments	Ease-of-Use Understandability	Usability Tests	[47]
Manufacturing	Cognitive Walkthrough	Efficiency User Satisfaction	Usability Survey	[16]
		User Satisfaction	Presence Survey	[24]
		Ease of Usage	Informal Usability Survey	[15]
	Task based Heuristic Evaluation	Interaction Capacity Response Time Effectiveness	Use-case based Usability Tests	[31]
	Heuristic Information Evaluation	Effectiveness Visual Feedback	Effectiveness Survey	[4]
	Haptic based Subjective and Objective Evaluation	Biomechanical Feedback Physical Interaction Capacity	Subjective Evaluation	[45]
	Controlled Experiments	Understandability	Usability Survey	[40]
	Pluralistic Walkthrough	Efficiency Satisfaction Effectiveness	Systematic Usability Scale	[5]
Retail	Use-case based formal evaluation	Ease-of-use	Informal Usability Test	[44]
	Controlled Focus Group Experiment	Interaction Capacity Efficiency User Satisfaction		[27]
Simulation	Controlled Experiments	Response Time	Subjective Evaluation	[20]
	Haptic based Controlled Experiments	Force Exerted Response Time		[34]
	Physiological Signal based Experiments	Skin Temperature Heart Rate Galvanic Skin Response		[28]
	Context-of-Use	Effectiveness Efficiency , Satisfaction	Cognitive Questionnaire	[42]
	Haptic based Pluralistic Walkthrough	Biomedical Feedback Ease-of-Use	Subjective Responsive Index	[39]
	Task based Focus Group Evaluation	Reaction Time Completion Time	Systematic Usability Scale NASA Task Load Index	[43]
Software	Cognitive Walkthrough	Visual Feedback	-	[21]
	Controlled Experiment	Immersion , Accuracy Comfort , Fun Non-fatigue , Non-dizziness Overall Satisfaction Degree of Dizziness	Presence Survey	[30]
		Visual Feedback	Usability Survey	[12]
		Spatial Orientation Test		[23]
	Qualitative Expert Review	Ease-of-Use	Informal Usability Survey	[38]
	Controlled Experiment	Manipulability Comprehensibility	HAR Usability Scale	[35]
		Interaction Capacity Effectiveness	Informal Usability Survey	[37]
Tourism	Pluralistic Walkthrough	Understandability	Systematic Usability Scale	[46]
	Cognitive Walkthrough	Effectiveness Interaction Capacity	Informal Usability Survey	[19]