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Taxonomy Development for Virtual Reality (VR) Technologies in Healthcare Sector

Maram Almufareh, Duaa Abaoud(✉), and Md Moniruzzaman

Claremont Graduate University, Claremont, USA
{Maram.almufareh, Duaa.abaoud, Md.moniruzzaman}@cgu.edu

Abstract. The paper presents a Design Science Research (DSR) project, which was conducted to develop taxonomy for Virtual Realty VR technology in healthcare. In this paper, we discuss the process involved to design a comprehensive taxonomy framework of VR technologies that classify VR tools within the healthcare industry. The framework is intended to help practitioners, researchers, and developers to agree on a common language in order to analyze the usefulness and gaps in existing VR applications in healthcare. The taxonomy guide evaluates the process of VR tools to determine where each VR device fits in the healthcare industry; identifies the uniqueness and originality of new VR devices; and recognizes the needs and gaps for further VR application development within this industry.

Keywords: Design science research · Virtual reality · Technology Healthcare · Taxonomy

1 Introduction

Currently, Virtual Reality (VR) technologies have emerged as an innovative mainstream tool with immense potential to transform the way human beings experience environments [1]. VR technology has the potential to revolutionize nearly every aspect of life, and healthcare (HC) is one of the main fields that has begun integrating VR technology into medical practice. Computer scientists and healthcare practitioners have been working to develop and implement applications using VR technologies to provide general and specialty health care services [6, 20].

There are many uses of VR in the HC industry. For example, VR is employed in surgical procedures to perform a remote surgery or telepresence, augmented or enhanced surgery, and for simulation as part of the planning process of operations. VR is utilized in other areas like medical therapy, preventive medicine, medical education and training, skill enhancement, rehabilitation, visualization of massive medical databases, and architectural design for health-care facilities [14, 20].

With this massive interest in VR, there is a need to build a classification framework of VR technologies to help practitioners, researchers, and developers agree to a common language in order to analyze the usefulness of existing VR applications, and to understand where a new application may fit with existing ones [17]. This urgent need for a useful taxonomy extends also to categorize and streamline current investigations

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and practices in order to improve aspects of healthcare by extracting greater value from the existing information depository.

This paper presents the use of DSR to build and evaluate the taxonomy of VR technologies in healthcare. This proposed taxonomy would contribute new knowledge to design science research and Virtual Reality research in healthcare, as a taxonomy currently does not exist. The following sections elaborate on the development and evaluation processes, which will explain how our taxonomy was created and how it will solve the problems currently experienced [2].

2 Background

In 1987, Jaron Lanier introduced the term "Virtual Reality" through his Visual Programming Lab (VPL). Molin [14] defined Virtual Reality (VR) as "a fully three-dimensional computer-generated 'world' in which a person can move about and interact as if he were in an imaginary place." VR technologies have already expanded their reach into various domains for creative experiences, particularly in the healthcare field. However, to date research evaluating the full potentiality of VR in the healthcare field is still lacking. VR systems became popular because they are entirely different from interactive computer graphics or multimedia systems thanks, in part, to a sense of presence they create in a virtual world [14].

Over the past decade, VR applications have already penetrated fields from education and entertainment to critical applications like healthcare applications [8, 14]. Highlighting the importance of virtual environments and related technologies in medicine, we can point to the steady growth in use of VR by medical practitioners in order to help their patients [6].

Current VR literature provides a comprehensive review of existing and future trends applications in a wide-ranging industries, as previously mentioned [18]. The literature also identifies some essential characteristics and key elements of experiencing virtual reality that is not limited to immersion, sensory feedback, and interactivity. Sherman and Craig [18] categorized virtual reality systems according to the user interface involved with the VR experience, and focused mainly on the way participants interact with VR and how the user perceives the environment.

Gobbetti and Scateni [4] focused on virtual reality applications and discussed the characteristics of some past, present, and future VR products. Various existing virtual reality applications have been categorized in terms of user input (Position/Orientation Tracking, Eye Tracking, Full Body Motion) and sensory feedback (Visual, Haptic, Sound, etc.). Gobbetti and Scateni [4] argued that the complexity of VR tools make the selection of the ideal tool, with well-defined functionality, difficult. A significant step, then, would be to ease the investigation process by ensuring that the VR solution can be integrated smoothly with standard business practices. This study, then, will fill this need by comparing the features and abilities of VR tools with other competing technologies in an attempt to guarantee the selection of the right set of tools [19]. A systematic review of the existing literature on virtual reality in medicine reveals the lack of consensus on the meaning of VR and that there are no clear guidelines to characterize VR [21–25].

Duncan et al. [3] introduced training and education as critical dimensions of VR usage. Their research introduced six categories: population, educational activities, learning theories, learning environment, supporting technologies, and research areas [3]. Rehabilitation is another growing VR dimension. Kim [9] discusses many weaknesses, limitation and opportunities within the research concentrated on VR for rehabilitation and therapy, and argues that continued analysis of the files is critical for VR development. A classification framework, such as we posit, would aid decision-making about the use of VR as a tool for therapeutic intervention [11]. Computer-assisted surgery is another primary dimension in the literature. It has become one of the revolutionary technological developments in the medical field, but evaluation of the efficiency of training VR simulators for robotic surgery has not yet been confirmed [13].

Many researchers have standardized research approaches to address the need of their communities and to provide a clear and distinctive way for future developments like designing prototypes, models, products/applications, theoretical frameworks, and taxonomies [10, 17]. Taxonomies, as a tool, provide a structure and an organization to the knowledge of a field, thus enabling researchers to study the relationships between concepts and, therefore, hypothesize about these relationships [5]. Glass and Vessey [5] illustrated the use of taxonomies in understanding the science behind design principles of observed artifacts. Taxonomies are another consideration of grounded theory and help to explain any divergence from previous research findings.

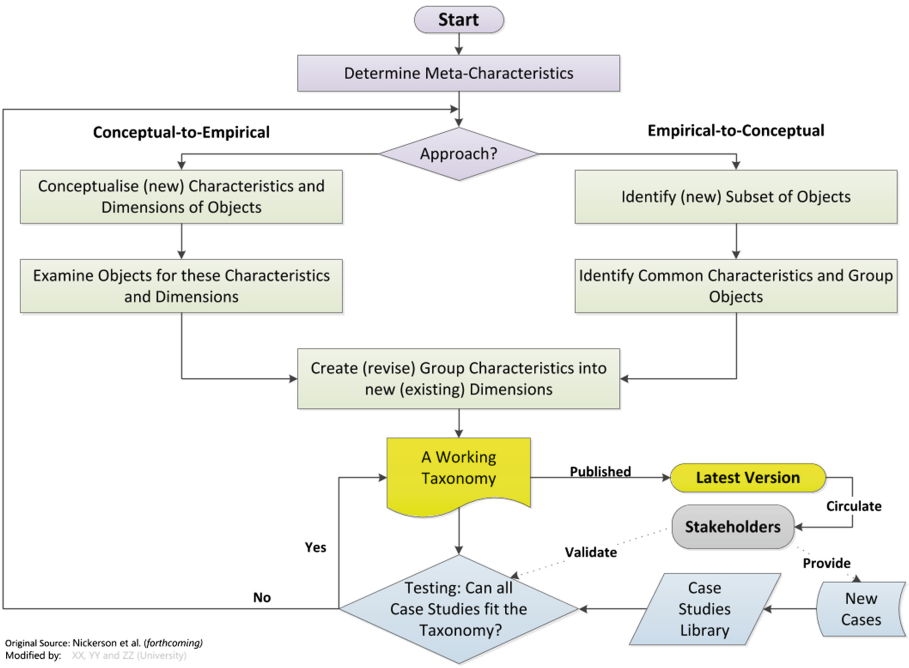

Fig. 1. Iterative process of selecting meta-characteristics [13]

Despite the fact that taxonomy plays a significant role in research to understand and analyze complex fields, to the best of our knowledge, to date there has not been any research focused on the taxonomy of recent VR technologies in healthcare [2]. To this end, our research will design a conceptual model to provide a classification framework, or taxonomy, for Virtual Reality technologies in the healthcare domain.

3 Research Questions

Emerging VR products make the development of a unified classification method, incorporating the specifics of each system, an extremely challenging task. That is why it is important to answer these questions: What are the different criteria or dimensions that can build a holistic taxonomy tool for VR technology in healthcare? What kind of virtual reality technologies are in use in the healthcare domain, and what are their value propositions? What are the needs and gaps for the future development of VR technology in healthcare?

4 Methodology

Design Science Research (DSR) is the adopted approach in this research. Design science is mainly a problem-solving paradigm that builds and evaluates artifacts. The artifact that is designed and evaluated in this study is a classification framework of Virtual Reality (VR) technologies in healthcare.

5 Design and Build Phase

Through our project, we aim to provide a clear and distinctive way for future developments in VR systems in the healthcare field. We have developed an efficient taxonomy by creating a construct and formulating a framework, thus designing a conceptual model for Virtual Reality technologies in the healthcare domain.

This artifact will provide in-depth insights into existing VR applications in healthcare and bring forward new development opportunities in this emerging field. This paper attempts to position itself as a pioneering research study in this proposition. In order to develop the proposed taxonomy, the following diagrams were used to elaborate the process of selecting meta-characteristics by analyzing features described in the literature and those included in existing VR technology.

To do that, we studied existing & prospective VR technology products by analyzing secondary data, and initially classified VR products by considering their utility/usability, user characteristics and the type of technology used. However, after a number of iterations using Bailey's model, we created the proposed solution [12]. This taxonomy adds to the knowledge of classification as well as Virtual Reality Systems to a great extent.

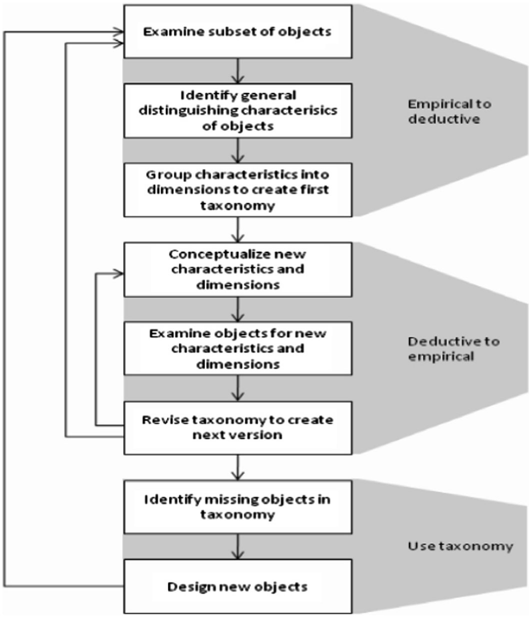

Fig. 2. Taxonomy development method [16]

In order to build the taxonomy, the following steps were conducted [15, 16]. To consider the characteristics, a tentative list of criteria was created at first. These criteria were chosen in light of both literature and industry. This list included the following items: utility, user characteristics (patients, surgeons, or physicians), and the purpose and type of technology used. We used Bailey's model in order to refine the criteria in the first step to determine the meta-characteristics. During this second phase, we came up with three major dimensions: user input, type of technology and application (Fig. 3).

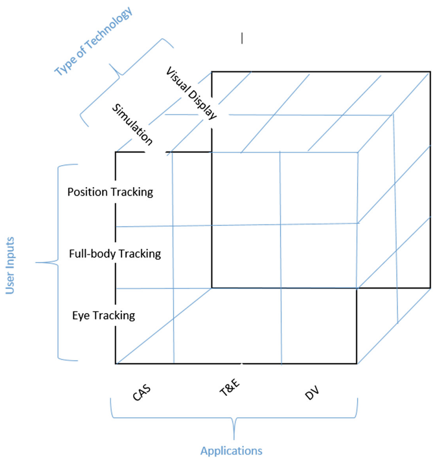

Fig. 3. 2nd iteration

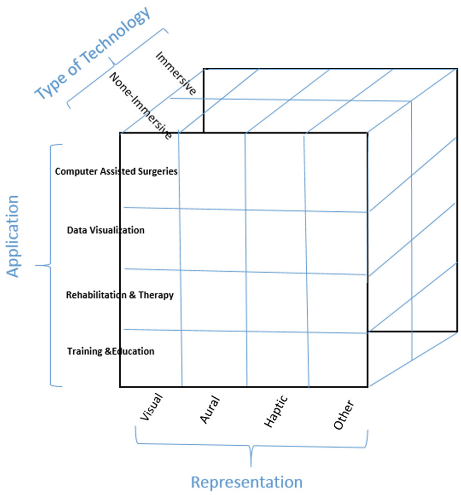

Fig. 4. 3rd iteration

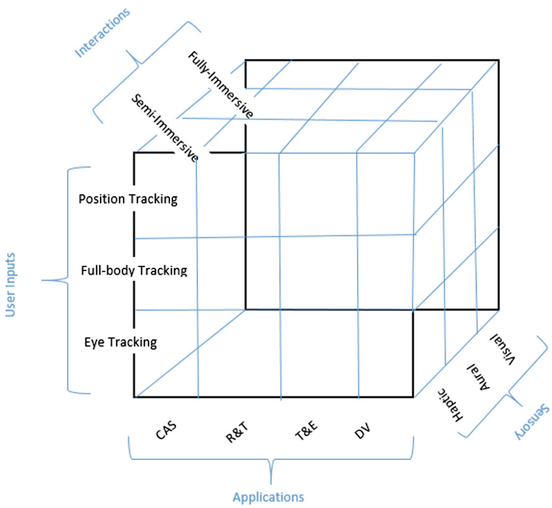

Fig. 5. 4th iteration (4-dimensional analysis of features of VR technologies)

1. In order to cross check the validity of our selection of meta-characteristics, we used two different iterative processes (Figs. 1 and 2) namely, empirical to deductive and deductive to empirical approaches which we found from previous literature [13, 16].
2. During the third iteration, after analyzing more characteristics, we further realigned the previously created dimensions into a set of three new dimensions with different sub-dimensions: type of technology, application, and representation. Figures 3 and 4 illustrate the development of taxonomy during the second and third iterations.
3. After the fourth and final iteration, a four-dimensional taxonomy was proposed (Fig. 5):
   (a) User Input: Position Tracking, Eye tracking & Full body motion
   (b) Interaction: Fully immersive, non-immersive and semi-immersive
   (c) Sensory: Visual, aural, and haptic
   (d) Application: Computer Assisted Surgeries (CAS), Data Visualization (DV), Rehabilitation & Therapy (R&T), Training & Education (T&E).

6 Evaluation Phase

Evaluation of the designed artifact is a key activity in Design Science Research (DSR) as it provides feedback for further development and assures the rigor of the research in the context of the knowledge it contributes to the knowledge base [2, 7]. The evaluation approach not only needs to address the quality of the artifact utility, but also the quality of its knowledge outcomes. This study has evaluated the artifact by mapping the commercial market products (industry-based VR technologies) to the taxonomy.

Table 1 Presents a market mapping that covered 17 different types of VR tools and technology using the developed taxonomy and shows how the current VR products fit within the designed artifact. Market mapping introduces a visual analysis of the current situation; the focus of VR development; and the market needs and gaps. Moving forward, this will enable us to seek and work with practitioners and researchers in the field to verify the efficiency of the taxonomy in practical use.

In this preliminary attempt, we have identified several key design dimensions and service provider objectives that play an important role in both the success of the service platform as well as the business. We have discussed these dimensions and objectives in order to provide some indication as to what role they might contribute to the overall design of digital services. In the near future, we hope to conduct detailed qualitative interviews and quantitative data collection from digital service companies to map the taxonomy, and uncover further interesting facets about their design, and continue breaking new ground in this critically important field.

Table 1. Commercial literature and market mapping

Virtual Reality Technologies	User input			Interaction		Sensory			Application			
	Position tracking	Eye tracking	Full body motion	Fully-Immersive	Semi-Immersive	Visual	Aural	Haptic	*CAS	*DV	*R&T	*T&E
Microsoft HoloLens (Headset)		⊠		⊠		⊠				⊠	⊠	
[VirtaMed ArthroS™ simulator				⊠		⊠		⊠	⊠	⊠		⊠
MAGNETOM Amira (MRI scans)									⊠	⊠	⊠	
Facebook Oculus Rift (Headset)	⊠	⊠		⊠		⊠				⊠	⊠	
Samsung Gear VR (Headset)		⊠		⊠		⊠				⊠	⊠	⊠
Google Glass (Headset)		⊠		⊠		⊠	⊠		⊠	⊠	⊠	⊠
Google Card-board (Headset)		⊠		⊠		⊠				⊠	⊠	
Jaunt Neo (Camera systems)				⊠		⊠				⊠		⊠
Google Jump (Camera systems)				⊠		⊠				⊠		⊠
360cam(3D cam-era systems)				⊠		⊠				⊠		⊠
Microsoft Kinect(3D Depth Camera)				⊠		⊠				⊠		⊠
Da Vinci Robotic surgery				⊠				⊠	⊠	⊠		
MindMaze MindMotionPRO			⊠	⊠				⊠				

HTC Vive (Headset)		⊠		⊠		⊠				⊠	⊠	⊠
hapTEL virtual reality platform			⊠	⊠		⊠		⊠		⊠		⊠
Dexmo Dexta Robotics			⊠	⊠				⊠	⊠			⊠
iRobot RP-VITA								⊠			⊠	

*CAS – Computer Assisted Surgeries, DV – Data Visualization, R&T – Rehabilitation & Therapy, T&E – Training & Education

7 Conclusions

This taxonomy aims to raise awareness for its lack in this emerging technology's research. We categorized a list of the latest 17 VR technology products to test and evaluate our artifact. We understand that the proposed dimensions are not exhaustive. However, this taxonomy is expected to work as a guideline for future VR commercial and research development. In future, we hope to analyze more applications and research efforts so that our taxonomy can reach a wider audience. This study contributes to the existing knowledge base by creating a potential avenue for further research and sheds more light on a problem that is of increasing value.

We believe the taxonomy is a useful tool in evaluating the market presence and trajectory of various organizations involved in providing digital services. One of the values of the taxonomy is to give a more structured breadth to the evaluation of factors that might not be considered by the digital service designers. Likewise, we anticipate that designers with a more thorough understanding of the business and interaction objectives might be weak in understanding the technical objectives. Thus, one of the specific requirements proposed by this taxonomy is for developers to understand the business, technological, and interaction objectives of the organization.

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