UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

FACULTY OF PHYSICAL AND MATHEMATICAL SCIENCES

CREDIBILITY DESIGN FACTORS FOR VIRTUAL REALITY TECHNOLOGIES AND APPLICATIONS: A SYSTEMATIC REVIEW

BY

EDMOND TEYE AGBOVI

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A PROJECT SUBMITTED TO THE DEPARTMENT OF COMPUTER SCIENCE, UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE AWARD OF BACHELOR OF SCIENCE DEGREE IN COMPUTER SCIENCE

DEPARTMENT OF COMPUTER SCIENCE

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DECLARATION

I hereby declare that except where specific references are made to the work of others, the contents of this project are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other University.

………………………………………………… Date:

EDMOND TEYE AGBOVI

This project was under the supervision of:

………………………………………………… Date:

MR. MARK ATTA MENSAH

DEDICATION

I dedicate this research to my beloved family and friends who contributed to my successful completion of this program.

ACKNOWLEDGMENTS

I am sincerely grateful to the PhD Candidate, Mr. Mark Atta Mensah, for accepting the offer to work on this project and for the guidance and support he offered during this project. I appreciate every effort and contribution that he made to the completion of this project.

ABSTRACT

As virtual reality (VR) continues to make inroads into critical sectors such as healthcare, education, and commerce, it is vital to assess the credibility of VR environments and evaluate their overall usefulness. This paper provides a comprehensive review of credibility design in VR technologies and applications. The objectives are to: 1) examine the factors that enhance the credibility of VR environments; 2) determine the dimensions used to measure the credibility of VR applications; and 3) catalog the metrics used to assess credibility in VR environments. Adhering to the guidelines set forth by Kitchenham and Charters for systematic literature reviews, the study utilizes academic databases to source relevant research papers. A total of 84 papers that met the inclusion criteria were analyzed, and a thematic summary of the findings is provided. The study reveals that credibility design in VR is a complex and relatively unexplored area that warrants further investigation. Credibility analysis in VR typically focuses on dimensions such as presence, trust, reliability, validity, usability, security, and safety. It also highlights evaluation metrics commonly used to assess credibility, including psychological measures, physiological measures (e.g., eye-tracking, heart rate, skin conductance), performance measures (e.g., accuracy, speed, error rate), and behavioral measures (e.g., click-through rate, bounce rate, conversion rate). Finally, the study discusses the implications of these results for designing credible VR and related environments.

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CHAPTER 1

Introduction

1.1 Background and Context

The essence of virtual reality (VR) applications is to transport users to an entirely ‘new world’ often termed as immersion. VR experiences are immersive and interactive with the potential to change how individuals engage in digital content and environment. Designing VR applications is a complex endeavour that involves integrating various technologies, concepts, and sometimes the designers’ perspectives to create such an environment that can fully absorb users and convince them of their reality.

VR environment can be broadly classified into two categories based on hardware components: mobile and wired head mounted display (HMDs). These environments incorporate a range of hardware components, including haptic devices and multi-sensory devices as output devices, and controllers, navigation devices, and body tracking as input devices for VR applications (Anthes et al., n.d.). Another important considerable that must be employed is VR modelling tools which include 3ds Mac, Maya, CATIA, and VR development tools such as virtual authoring tools, toolkits/software development kits, and application interfaces (Bamodu & Ye, n.d.). The choice of use of these components would have a significant impact on the quality, functionality, and experience of the VR environment.

The widespread applications of VR span critical sectors such as healthcare, construction, and manufacturing (Pillai & Mathew, 2019; Wang et al., 2018;Choi et al., 2015). In healthcare, VR is utilized for medical training, pain management, patient rehabilitation, and therapeutic interventions. In other areas like manufacturing, and construction, VR is employed for design, simulation and training. Despite the increasing integration of VR into these sectors and daily life, the concept of credibility within VR environments remains underexplored. Credibility encompasses a multi-dimensional framework that draws perspectives from various disciplines, including trust, quality, reliability, and believability (Rieh & Danielson, n.d.). In the context of information sciences, these dimensions are particularly pertinent.

This systematic review aims to examine the factors that influence the credibility of VR environments, by critically examining its dimensions in literature. We will explore how these dimensions are analysed and their impact on the user experience within virtual reality settings. Additionally, we will provide an in-depth understanding of credibility and establish useful metrics for evaluating the credibility of VR environments.

1.2 Research Objectives

The specific objectives of this systematic review are as follows:

Objective 1: Examine from literature, the factors that enhances the credibility of VR environments

This objective aims to identify the elements that make a VR environment believable and trustworthy to its users. The discussion will emphasize the key design considerations that promote the high fidelity and of the VR application and good user experience. The factors will also be discussed under three broad classifications: technical factors, human factors, and network factors. The technical factors will generally be based on the hardware and software aspect of the VR, which includes the system performance, the graphics and sound quality. Under the human factors, we will examine those factors from the perspective of the users and their psychological responses to the VR environment. Finally, we will examine the network factors which pertain to the connectivity of VR, which are particularly useful in multiplayer or shared VR applications.

Objective 2: Determine the Dimensions that are Used to Measure the Credibility of VR Applications

We expect that for each of the included studies, there would be at least a perspective from which the quality of a VR experience will be geared towards and for which the VR environment will be designed. Researchers may approach the credible design of VR from different perspectives. In this objective, we would identify the various perspectives (or facets) as the dimensions of a credible VR design. For instance, a study may focus on interactive VR while some others may particularly focus on enhancing realism of the VE. Some studies may particularly identify these dimensions, however, where it is not stated, we would subjectively determine those dimensions. We also expect that some of the studies may focus on more than one dimensions. The various dimensions would enable researchers to appreciate the credible VR design in a multifaceted way.

Objective 3: Catalogue the Metrics Used for Analysing Credibility in Virtual Reality Environments

We will explore the specific metrics and indicators employed to assess credibility within virtual reality environments. We will provide a comprehensive list of useful metrics that are commonly used to evaluate different dimensions of credibility. Both researchers and practitioners would leverage on these metrics in the design and use of VR applications. These metrics would be available as a useful toolkit for these users. These metrics will also be classified into psychological, behavioural, performance and physiological metrics. Those metrics that relates to user's perceptions, feelings and psychological response would be classified as psychological metrics while those that measure user's observable actions and interactions would be classified as behavioural. Also, we will classify those metrics that relate to responses and bodily reactions in a VR as physiological metrics. Finally, those metrics that relates to efficiency, or effectives of a task in VR environment as performance metrics. Understanding these metrics would enable researchers to appreciate the various elements that interplay in VR.

1.3 Research Questions

To achieve the objectives of the review, this study will attempt to answer the following research questions:

1. What are the design factors that positively impact the credibility of the VR applications and technologies?
2. What dimensions are involved in credibility analysis within VR applications and environments?
3. Which metrics are used to analyse the credibility of virtual reality environments?

1.4 Rationale and Significance

This systematic review seeks to establish important evaluation frameworks, dimensions, and metrics that can be used to assess the credibility of VR, a technology that has become an integral part of our lives. Its significance thus, extends to both academic and industrial domains.

Through this review, we intend to present important findings from literature about credibility in VR, with the potential to contribute immensely to the design and development of VR applications. The evaluation factors (approaches and metrics) from literature would contribute to making VR applications more authentic and reliable. This would enhance the VR in various domains, including healthcare, entertainment, education and commerce.

Being able to evaluate VR for credibility would enhance user trust and acceptance. Take healthcare for example, where VR is used for medical training, pain management, therapeutic interventions and rehabilitation, enhancing credibility would enhance users' trust and acceptance of the VR application, and increase their confidence. Patients would likely engage in such VR for any medical procedure.

In academia, credibility in VR is barely explored. This review would bridge the gap in research within VR. It would present a comprehensive overview of the various dimensions and metrics that are used currently in assessing credibility of VR applications. These factors would serve as empirical evidence for the current state of VR. Prospective researchers would be able to build on these findings to bridge the widened gap of credibility in VR in research. In practice, the result of VR credibility evaluation factors would be accessible for designers to make VR applications that would be more acceptable and trustworthy for users.

CHAPTER 2

Literature Review

2.1 History and Evolution of VR, AR and MR

Although VR was first utilized in the 1960s, its origins may be found in the 19th century, when panoramic murals, the first 360-degree works of art, first emerged. Nearly a century later, a mechanical device called the Sensorama used several senses to produce an immersive VR. The system offered a multi-sensory motorbike riding experience. This technology provided the audience with a three-dimensional, full-colour movie together with sounds, smells, the sensation of motion, and the feeling of wind on their faces. (Lum et al., 2020). VR has changed in several ways to resemble the real-world experience more closely. The way individuals interact with virtual worlds and play video games has altered because of this growth. VR has been used in treatment and other fields in addition to video gaming.

2.1.1 Emergence of AR and MR

Augmented Reality (AR) emerged later, with Ivan Sutherland's "Sword of Damocles" project inspiring the concept of overlaying digital information in the real world (Caudell & Mizell, 1992). Sutherland's work created the groundwork for AR, although at this point it was mostly applied to military and aviation settings (Sutherland, 1965). Early wearable computing devices and AR applications enabled the field of AR to gain traction in the late 20th century. Particularly, in the 1980s and 1990s, there was a major advancement in AR technology. The phrase "augmented reality" was first used by researcher Tom Caudell at Boeing in 1990. A turning point in the development of AR was reached when Caudell and his colleague David Mizell created apps to help with manual manufacturing operations (Caudell & Mizell, 1992).

AR apps geared for consumers first started to appear in the early 2000s. The "ARToolKit," an open-source software library created by Hirokazu Kato in 1999, is one famous instance. AR gaming and interactive installations were made possible by ARToolKit, which allowed developers to construct AR experiences on desktop PCs. The widespread use of smartphones with cameras and sensors has made AR widely accessible. The potential of augmented reality in entertainment and location-based experiences was proved by mobile AR apps like Pokémon GO, which became a global phenomenon in 2016.

Today, AR is a widely used technology that is included in smartphones and smart glasses. Numerous industries, including gaming, navigation, advertising, and education, use augmented reality apps. Tech giants like Apple, Google, and Facebook have made significant investments in AR, demonstrating its lasting importance.

AR blends virtual data with the physical environment. Multimedia, 3D modelling, real-time tracking and registration, intelligent interaction, sensing, and other technical tools are used. Its guiding premise is to simulate the actual environment before applying computer-generated virtual information such as text, photographs, 3D models, music, and video to it.

The actual world is improved because of how well the two types of knowledge complement one another (Y. Chen et al., 2019).

Combining aspects of VR and AR, Mixed Reality creates a spectrum that extends from the real world to the virtual one. The development of MR has followed the development of technology and software. Paul Milgram and Fumio Kishino first used the term "Mixed Reality" to characterize settings where physical and computer components coexist in (Milgram & Kishino, 1994) .Their research served as the theoretical foundation for MR. Pioneers in the fields of wearable computing and augmented reality include researchers like Steve Mann. By developing head-mounted displays and wearable cameras, Mann made a major contribution to the creation of MR. In the 2010s, businesses like Magic Leap elevated MR to the fore. With the "Magic Leap One" headgear from Magic Leap, users may effortlessly merge digital material into their actual surroundings. The 2015-released Microsoft HoloLens has been a major player in MR technology, finding use in fields including healthcare, manufacturing, and design. The technology blends the real and virtual worlds together by using sensors to map the surroundings and overlay digital material.

It is worth noting that development in hardware hugely promoted the development of VR, AR, and MR applications, particularly in optics, displays, and sensors. This development may be seen in the shift from bulky, hefty headsets to svelte, user-friendly gadgets. The 2016 release of the Oculus Rift was a significant advancement in VR headset technology.

Currently, VR, AR and MR is characterized by a wide range of applications and a wide-growing market for these applications.

2.2.1 Credibility in Human-Computer Interaction (HCI)

Credibility is a fundamental and multifaceted concept in human-computer interactions. It connotes trust, believability, and reliability of computer and information systems. Fogg and Sundar explained credibility in the context of HCI as the extent to which users perceive a system, an interface, or the information provided by it as trustworthy, reliable, and believable (Fogg, 2002; Sundar, 2008).

Three keywords relate to credibility in the context of HCI. Trustworthiness, which is a level of trust, relates to the confidence that users have in the ability of a system to fulfil its intended purpose, deliver accurate information, and protect their interests (McKnight & Chervany, 2001). In critical systems like healthcare, autonomous vehicles, construction design, and online transactions, trustworthiness is vital to users.

A closely used term for credibility is believability. The notion of believability refers to the user’s perception of the information presented by a digital system as plausible, convincing, and aligning with the user’s expectations (Flanagin & Metzger, 2013a). Users are more likely to engage in believable interfaces and facilitate effective communication. Finally, reliability is explained as the consistency and dependability of a system or an interface to deliver accurate and consistent results (Nielsen, 1994).

Credibility in HCI extends beyond information credibility. While information credibility pertains to accuracy and trustworthiness (Rieh & Danielson, n.d.), HCI researchers and practitioners recognize that credibility also involves system and interface credibility. They explained system credibility as the overall trustworthiness of a digital system or platform. Some of the key features of a credible system include its performance, as well as security, and privacy features. Interface credibility concerns the design and usability of the interface, as well as the user's perception of its effectiveness (Fogg, 2002).

Thus, trustworthiness, believability, and reliability are key concepts of the idea of credibility in HCI, which is intricate and varied. It has a significant role in determining user engagement, contentment, and trust with digital systems and interfaces. For HCI professionals to design and create interfaces and systems that satisfy user expectations and promote pleasant user experiences, understanding and assessing credibility is crucial.

2.2.2 The Role of Credibility in User Experience

Credibility generally influences the user experience. User experience extends beyond the usability of a system. It includes the perception and satisfaction of users when they use or interact with a particular system. It is not just about aesthetics and usability. Credibility has a direct impact on how consumers view, regard, and eventually interact with digital content and systems (Fogg et al., 2001a, 2003a). Some important roles of credibility in user experience include the following.

i. Credibility builds user trust. Users are more likely to trust systems or interfaces that they believe in. In making purchases online, searching for information, or making recommendations, users are more likely to use systems that are trustworthy. A positive relationship between people and technology is fostered by trust, which makes for a more seamless and enjoyable user experience.
ii. It enhances to user satisfaction. Credibility makes users feel satisfied. Users are more likely to be happy with their overall experience when they believe that the content of a system or their interactions with such systems are credible enough (Flanagin & Metzger, 2013).
iii. User engagement and information consumption. Credible content and interfaces are better at engaging users. Users are more likely to engage with and consume information from sources they perceive as credible (Metzger, 2007). This is particularly relevant in situations where users seek information, such as news websites, educational platforms, or e-commerce sites. Credibility influences whether users stay, explore, and return to the system they have used.
iv. It impacts on decision making. Consider a circumstance involving decision-making, the credibility of the system with which a user decides impacts on the user's choices. Users are more likely to make decisions based on information from credible sources or systems that have credibility (Fogg et al., 2001b).
v. Credible user experience will reduce anxiety.

Credibility in HCI is not merely a theoretical concept but a practical one that profoundly influences user experience. Credible digital systems and interfaces enhance user trust, satisfaction, engagement, and decision-making. When researchers and practitioners recognize how credibility impacts HCI and the users of such systems, it serves as guidelines to create such trustworthy, believable, and reliable systems that provide users with maximum experience.

2.2.3 Metrics and Measurement of Credibility in HCI

Measuring credibility is essential to ensure that digital systems, interfaces, and content are trustworthy, reliable, and believable. Here, we identified some of these metrics used to measure credibility in HCI.

i. Surveys and Questionnaires: In surveys and use of questionnaires, Participants might be asked to rate the credibility of a website on a scale of 1 to 5, with 1 denoting low credibility and 5 denoting high credibility (Fogg et al., 2001). These are used together to gather feedback from users. They include items that inquire about users' perceptions of trustworthiness, believability, and reliability. Open-ended questions may also elicit qualitative insights into credibility issues.

ii. Usability Testing: Usability testing involves observing users as they interact with digital systems and interfaces while assessing their credibility-related experiences. Test participants' behaviours, comments, and reactions can provide valuable insights into credibility issues. Usability experts often use think-aloud protocols to capture participants' thoughts and feelings as they navigate a system, shedding light on credibility perceptions (Bastien, 2010; Nielsen, 1994).

iii. Eye-Tracking: By utilizing eye-tracking technology, researchers can observe how users interact with digital interfaces and where they focus their attention on. Eye-tracking can be useful to understand which elements of a webpage or interface users find most credible

(Schall & Romano Bergstrom, 2014; Q. Wang et al., 2014)Areas with longer view or attention times are often interpreted as having higher credibility.

iv. Content Analysis: Content analysis involves critically examining content to assess its credibility. Researchers analyse textual, visual, or multimedia elements for factors such as accuracy, transparency, and completeness (Metzger, 2007b). Content analysis can help identify misinformation or biased information.

v. Objective Measures: Objective measures include quantifiable aspects of a system's performance and behaviour. The accuracy of information provided by a system, or the consistency of its responses can be measured objectively (Fogg et al., 2003b). Such metrics are crucial for assessing the reliability dimension of credibility.

vi. Expert Evaluations: Expert evaluations involve having HCI professionals or domain experts assess the credibility of digital systems and interfaces. Experts can apply their knowledge and heuristics to identify credibility issues that may not be evident to lay users (Nielsen, 1993). Expert evaluations complement user-cantered assessments.

vii. Trust Seals and Certifications: Trust seals, logos, or certifications from recognized authorities or organizations can serve as external indicators of credibility (Metzger, 2007). Users may perceive websites or platforms displaying trust seals as more trustworthy and credible.

viii. Behavioural Data like click-through rates, bounce rates, or conversion rates are useful for credibility assessment. Users who frequently exit a webpage shortly after visiting it may signal some level of dissatisfaction (Fogg et al., 2003a; Pfeuffer et al., 2019). Behavioural data can provide insights into user actions which informs credibility.

2.2.4 Challenges in Measurement

Even though these metrics and methods provide useful information for evaluating credibility, there are still issues. The use of multiple methods is required for a thorough assessment due to the subjective nature of credibility perception, cultural variations, and changing user expectations. Furthermore, it has become more difficult to determine the veracity of information in real time due to the rapid dissemination of information (Flanagin & Metzger, 2013b).

(Flanagin & Metzger, 2013b).

2.3.1 Credibility and Persuasiveness in System Design Principles

The ability to shape user behaviour and attitudes has gain importance in the current world using technology. PSD has become a key idea in HCI. They are used to influence users to take actions, make specific decisions, or change their attitudes (Torning & Oinas-Kukkonen, 2009).

PSDs have become important due to their ability to use technology to influence user behaviour and perception. It thus fills the gap between technology and psychology by using behavioural design principles to create digital systems that have the desired impact on users. PSD is not new concept. However, the digital era has created opportunities for applying and researching persuasion techniques on a large scale.

In this review, we examine the significance of PSD in HCI through exploring the foundations of persuasion, its core principles of persuasive design, and some real-world applications.

2.3.2 Foundations of Persuasion in HCI

For a thorough understanding of and effective application of persuasion techniques in digital interfaces and systems, PSD draws on a rich tapestry of psychological and behavioural foundations. The theoretical support for the creation and use of persuasive design principles in HCI is provided by these foundations.

- Psychological Theories of Persuasion: The cornerstones for comprehending persuasion within PSD are several psychological theories of persuasion. The Elaboration Likelihood Model (ELM) put forth by Petty and (Petty & John T. Cacioppo, 2012)is one of the most well-known theories. Depending on their motivation and capacity for information processing, ELM contends that people either process persuasive messages through a central route (systematic processing) or a peripheral route (heuristic processing). HCI designers can better tailor persuasive strategies to users' processing preferences by being aware of the cognitive processing routes.
- Behavioural Economics: Scholars Daniel Kahneman and Amos Tversky explain the biases and heuristics that affect human decision-making. Persuasive design can benefit from theories like loss aversion, framing effects, and the endowment effect (Thaler & Sunstein, 2009).
- Fogg Behaviour Model: A fundamental framework for PSD is provided by B.J. Fogg's Fogg Behaviour Model (Fogg, 2002). According to this model, behaviour is the result of the confluence of motivation, ability, and triggers. These elements can be carefully manipulated by designers to bring out the desired user behaviours.
- Social Psychology: This is a fundamental principle of PSD. According to Robert Cialdini social proof as being influenced by the behaviours and actions of others (Cialdini, 2007). This foundation is hugely useful in the design of PSDs.

These cognitive and behavioural offers a framework for comprehending how people process information, make decisions and react to persuading stimuli. We can leverage these principles to design systems and user interfaces that are not only useful but also able to compel users in ways that support goals and objectives.

2.3.3 Core Principles of Persuasive Design in HCI

The principles and techniques that form the basis of PSD, which aims to sway user behaviour and attitudes in digital environments. These principles, which are frequently based in psychology and behavioural economics, give HCI specialists a framework for creating user interfaces and systems that compel users to perform desired actions. Some of these principles include:

- Reciprocity: The premise behind the reciprocity principle is that people frequently return Favors and gestures. This can be done in digital interfaces by offering users worthwhile content, unrestricted access to resources, or incentives in return for their participation or actions. The reciprocity principle is used, for instance, when giving away a free e-book in exchange for subscribing to a newsletter (Cialdini, 1984).
- Social proof: Social proof: People frequently use the conduct and deeds of others as a benchmark for their own actions. Digital interfaces can convey a sense of social proof, demonstrating that others have valued the product or service, by displaying user reviews, ratings, or testimonials. This has the potential to be particularly effective in social networking and e-commerce platforms (Cialdini, 1984).
- Scarcity: The idea of scarcity suggests that when opportunities or goods are scarce, people tend to value them more. Scarcity techniques, like "limited time offers" or "only a few items left in stock," are frequently used by e-commerce websites to entice users to make quick decisions (Cialdini, 1984).
- Authority: According to the principle of authority, people are more likely to believe and abide by advice given to them by reliable sources. This can be done in digital design by

emphasizing expert recommendations, displaying credentials, or showcasing affiliations with reputable organizations. (1984, Cialdini).

- Consistency: People have a natural tendency to act in ways that are consistent with their prior commitments and beliefs. Designers can encourage consistency by asking users to make small commitments initially, which can lead to larger, more consistent behaviours over time. For example, a fitness app may encourage users to set achievable goals before committing to a full workout routine (Fogg, 2003).
- Gamification and Rewards: By utilizing gamification principles, designers can add components like points, badges, and rewards to encourage users to interact with a system or carry out desired actions. These game-like elements appeal to users' internal drive for success and motivation (Deterding et al., 2011).
- Personalization: Persuasive design can be improved by adjusting content and recommendations to specific user preferences and behaviours. Personalization attempts to cater content to each user's distinct needs and motivations, acknowledging that these factors vary.(Ham & Midden, n.d.)

For HCI professionals looking to develop digital interfaces and systems that successfully influence user behaviours and attitudes, these persuasive design tenets serve as a toolkit. However, it's crucial to apply these guidelines in an ethical and responsible manner, making sure that the persuasion strategies used serve users' interests and do not jeopardize their autonomy or wellbeing.

2.4 Research Gaps and Open Questions in Credibility Design

While it is true that credibility and persuasive design is one that is evolving, there are still several research gaps that highlight the need for more investigation. We outline some of these gaps.

i. Establishing multidimensional credibility metrics. How can we create thorough, multidimensional metrics for credibility that accurately reflect the nuances of credibility in VR environments? It is necessary to go beyond conventional metrics to consider the aspects of credibility in VR contexts.

ii. Credibility in emerging technologies. An important research area is investigating how credibility is perceived and established in immersive environments like AR, VR, and MR.

iii. Cultural variations in credibility. Investigating cultural differences in credibility evaluation and design can improve cross-cultural VR experiences. Research must be made into the significance of cultural differences in these environments and how they may impact credibility design.

CHAPTER 3

Methodology

Chapter 3 examines the methodological framework that supports this systematic review to understand and explain the factors, dimensions, and metrics determining credibility design within VR environments. By guiding the selection, extraction, analysis, and synthesis of pertinent literature, the methodology presented here ensures the rigor and integrity of the research process. This chapter acts as the cornerstone upon which the subsequent findings and conclusions are built by following a methodical and clearly defined methodology.

3.0 Systematic Review Methodology

Method

The study was conducted based on the Kitchenham and Charters guidelines for systematic reviews. The Kitchenham and Charters guidelines are more suited for software engineering research and practice (Kitchenham, 2007) and are preferred over the PRISMA guidelines which are more oriented towards quantitative, mixed-method reviews, and meta-analysis and not suitable for software engineering systematic reviews (Kitchenham et al., 2023). Constructing VR environments in themselves can be regarded as software engineering.

The Kitchenham and Charters guidelines used in this study are as highlighted below:

a. The planning phase – Here, we defined the research questions, developed inclusion and exclusion criteria, and detailed out a search strategy to identify the relevant studies.

b. The conducting(implementation) phase – we executed the search strategy and extracted the relevant studies, and filtered out papers which do not meet the inclusion criteria as well as repeated studies since the studies were extracted from different sources.

c. The documenting phase – We documented our findings, analysis and synthesis of the

3.2 Search Strategy and Inclusion Criteria

We begin with a thorough examination of the search methodology used to locate relevant literature and the selection criteria that define the inclusion of research papers.

3.2.1 Search Strategy

The success of a systematic review hinges on a well-structured search strategy. In this sub-section, we provide a detailed account of the strategies employed to retrieve relevant studies that align with our research objectives. We employed keywords, synonyms, search terms, Boolean operators, and specific sources to construct an effective search strategy.

Keywords and Synonyms

The careful selection of keywords and synonyms forms the foundation of our search strategy. Our review of credibility design in VR environments is built around these concepts. The keywords selected include:

- Virtual Reality – it represents the immersive environment wherein we explore credibility design.
- Credibility and related words: reliability, trust, authenticity.
- User experience, presence, engagement.

Databases and sources

Six (6) well-recognized academic sources are carefully selected to extract relevant studies for the review. These are IEEE Xplore, Scopus, ACM, ScienceDirect, Wiley, and Web of Science. Some of these sources support the use of wildcards, hence we employed them where supported. For instance, "virtual realit*" and "trust*" were utilized to capture different forms and extensions of the selected keywords. This strategic use of wildcards enhances the comprehensiveness of our search results.

3.2.2 Inclusion Criteria

- Publication date: We considered studies that covered the years 2000 through 2023 in keeping with our goal of including recent developments. This timeframe was selected to capture the both previous and most recent developments and trends in credibility design for VR environment.
- Language of study: Only studies published in English language were considered. This is to ensure effective comprehension of the studies selected and allow for consistency in extracting relevant variables from the studies.
- Type of sources: Our inclusion criteria encompassed two primary types of scholarly sources: conference papers and journal articles. These sources were selected for their rigorous peer-review processes and academic rigor. By focusing on these types of publications, we aimed to ensure the quality and relevance of the literature included in our systematic review.
- The papers must contain a BOOLEAN combination of the keywords (search terms).
- VR have been employed as an environment for studies. For instance, VR is used in study for driving simulations, medical procedures. Instances where the focus of the study is not based on VR credibility but rather on effective implementation of VR for such cases, we excluded such study.

3.3 Data Extraction

In this phase, we implemented the search strategy and the selection criteria to retrieve the various studies from the sources. The papers were filtered and categorized appropriately to prepare them for analysis. A total of 8,805 studies were extracted from the 6 identified sources.

3.3.1 Title Filtration

We started the first stage of filtration based on the titles of the retrieved studies to reduce duplicate entries in our dataset. This procedure led to the discovery of 4,368 papers with duplicate titles, which were then excluded. The inclusion of multiple sources in our search strategy, where the same study may be indexed across different databases, may account for the existence of duplicate titles.

3.3.2 Abstract Filtration

We used abstract filtration, a crucial step to make sure that only studies directly addressing credibility problems in VR environments were used for analysis. We reduced our dataset through this filtration process to papers that clearly satisfied the requirements for inclusion in our systematic review. At this stage, 4,174 were excluded.

This was followed by a full reading of the remaining studies. After this stage, we got 61 papers that were included. These included papers were then used as a seed to generate other relevant studies that we may have missed (during the study extraction phase) through a snowballing process. The snowball process also generated 23 papers thus resulting in a total of 84 papers that were included for this systematic review.

3.3.3 Studies classification

The depth of our research extends to understanding the significance of the selected studies within factors where VR applications were used or examined. This categorization enables us to focus of our examination and sheds light on the various real-world uses of credibility design in VR.

We determined whether the chosen studies involved the implementation of VR environments or were based on an analysis of primary studies. This is useful for understanding the multifaceted nature of the research landscape, which includes both realistic VR applications and analytical investigations into credibility.

Figure 1 below illustrates the various steps involved in the papers' extraction, filtration, and classification.

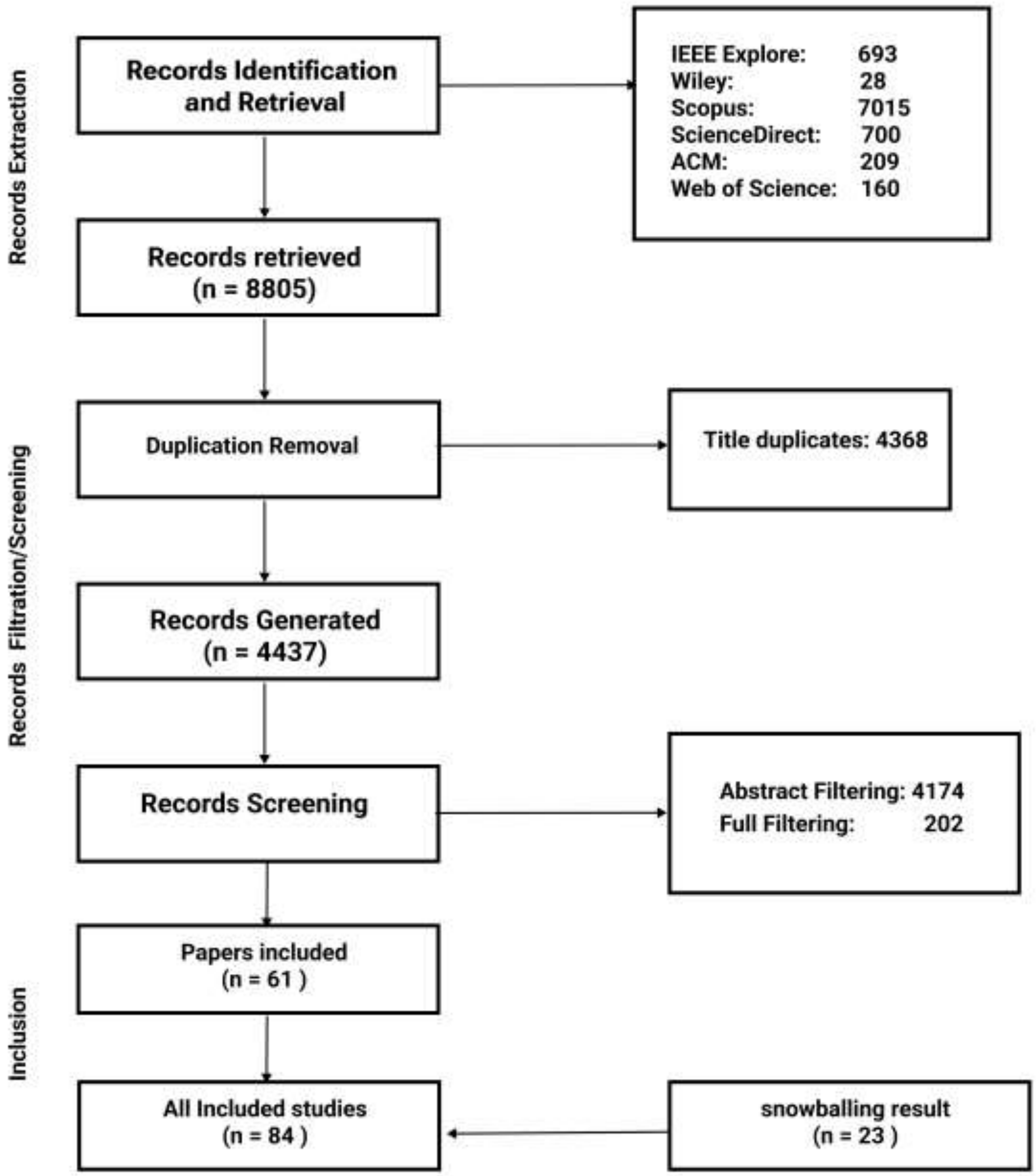

Figure 1: A chart showing the Study Extraction, Selection and Inclusions Process

3.4 Data Analysis and Synthesis

The analysis of the extracted and filtered will be consistent with the objectives of this review. We will employ charts to give a fair pictorial view of the data to demonstrate a clear overview of the findings. These include the dimensions, and the metrics employed in the papers included.

CHAPTER 4

Results and Discussions

In this chapter, we shall consider the results of the study. We explore the papers that were included and discuss the results.

4.1 Analysis

4.1.1 Credible design factors for VR applications and technologies

An important objective of this study is to examine the from literature, the factors that are being studied which makes VR applications and technologies credible.

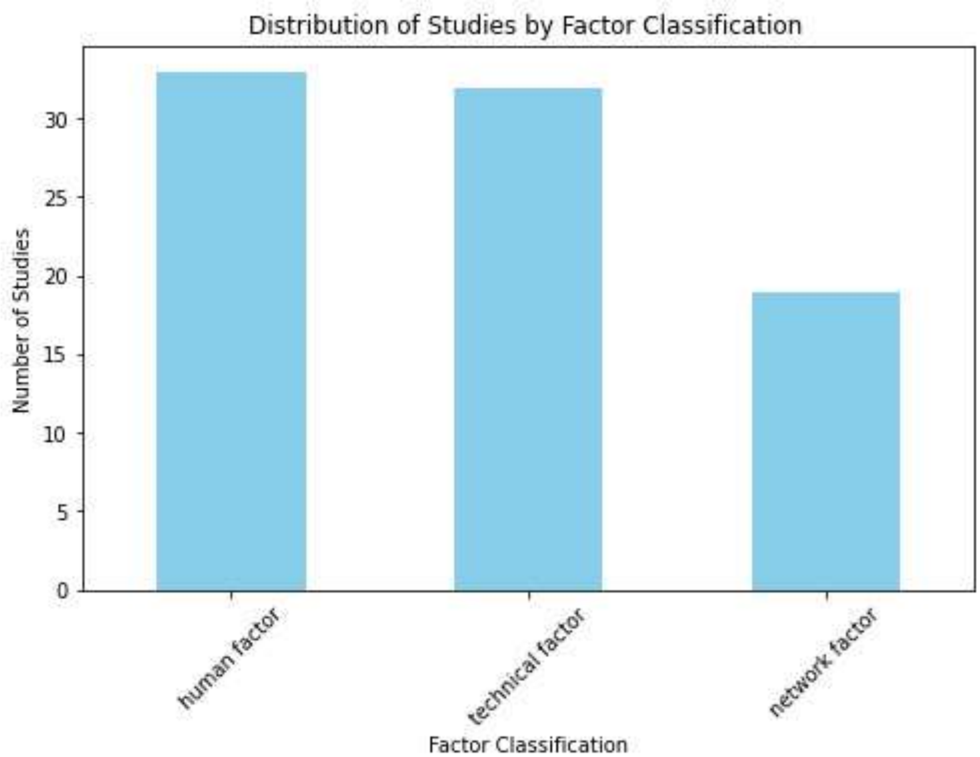

Figure 2: A chart showing classification of the VR credibility design factors.

The chart above shows the classification of the various factors that we have determined from the included studies. 33 (about 39%) these factors are classified as human factors, 32 (about 38%) are classified as technical factors. 19 (about 22%) are also classified as network factors. Thus, in this systematic review, most of the factors that we have determined as credible factors that influence VR design are either from the perspective of the users (human factors) or based on the technical capabilities of the VE. These factors are discussed under the three (3) classifications below.

Human Factors

This review reveals some elements that are crucial for designing VR applications. It includes factors such as presence and embodiment, trust in virtual agents, user interface design, avatar realism and representation, psychological and perceptual considerations, gaze mechanisms, positioning, and emotions analysis which collectively contribute to making VR reality credible.

Interaction Techniques in VEs

This review brings out gaze interaction as an important aspect of the design of human interactions in VR that is vital for controlling objects, selecting options and navigating in VR. Vinayagamoorthy et al. (2004) designed a gaze model which simulated an eye-gaze behaviour based on real-life data aimed to improve non-verbal communications in immersive virtual environments (IVEs). This study on the eye model was found to impact the perceived quality of communication and more effective in communication than cartoonish avatars. It also concluded that non-verbal behaviours such as eye-gaze plays a significant role in virtual communication and can affect the user's experience of presence and co-presence in VEs. In a similar study, the inclusion of eye gaze in avatars resulted in an improved accuracy in identifying where another user is, thereby enhancing the realism and naturalness of interactions within IVEs (Murray et al., 2007; Steptoe et al., 2008). These studies underscore the importance of eye gaze and convergence in creating realistic and effective avatars for collaborative tasks in IVEs. (Andrist et al., 2012) developed a model of gaze behaviour to capture key design variables for virtual agents. They validated that subtle variations in gaze behaviour can significantly impact high-level outcomes such as learning and rapport, providing guidelines for designing for designing effective gaze mechanisms for virtual agents. All these studies on gaze and gaze mechanisms indicate that gaze is an important element in the design of VR which make them credible.

Hand gesture recognition has been identified as an important element of interaction in VR for controlling the environment (Hernandez & Flores, 2014). In their work (Hernandez & Flores, 2014) proposed an algorithm that performs faster (7.62ms per frame) and is robust with an average gesture recognition accuracy of 86%. This study is aimed at increasing the usability and realism of VEs making them credible.

Zhu & Lu (2021)) proposed a computer-aided hierarchical interactive gesture modeling system for VR. focus on interactive gesture modeling in VR. They designed a dynamic gesture recognition method based on fast model and CNN which combines the advantages of model-based and data-driven approaches. Zhu and Lu's findings contribute to the understanding of usability gestures, improving the user experience and efficiency of gesture interaction. This study impacts the credibility of gesture-based interactions in desktop VR applications.

The impact of head nodding as a non-verbal cue behaviour in VR interactions were also studied(Aburumman et al., 2022). The study tested nodding behaviour on trust and liking and found that participants had more liking and trust for a virtual human character that exhibited realistic nodding behaviour. Incorporating such non-verbal cues can enhance the realism and effectiveness of virtual humans in VEs.

Trust and Emotion in VEs

From this systematic review, some studies have revealed emotion and trust as an important factor to be considered in designing VEs. In a machine learning approach, Liu & Huang (2023) classified expression in VR and compared their results with human ratings. The result show that their method outperforms normal and advanced human accuracy for categorizing select facial expressions. This study focuses on identifying emotions in VR based on eye tracking. Understanding users' emotion enables integrating emotions into VEs to ensure credible experiences. Similarly, Makki et al. 2019) explained that the most influential factor on VR wearables is usability, followed by wearability. For emotions, happiness is most dominant factor followed by love. Their study contributes to designing VR prioritizing user needs and comfort as well as creating content that are emotionally engaging into the VR applications.

In their study Papadopoulou et al. (2000) provided an overview of the factors involved in establishing trust between users and Intelligent Autonomous Agents (IAA) in VR. Three trust model dimensions were proposed: human-technology, human-system, and interpersonal. Aside, Papadopoulou et al. identify and categorize various factors such as visual design, system failure, agency, and self-representations as important factors that influence trust in IAA.

Avatar and Self-Representation

In VR, a user is represented as a digital representation in the form of an avatar. The importance of self-representation in VR is emphasised in various studies from this systematic review. The design and control of an avatar is found to impact on its credibility.

Freeman & Maloney (2021) studied self-presentation practices in social VR. Through a qualitative analysis of diverse experiences of self-representation, they have identified consistent avatar identity, interaction dynamics, and self-understanding emerge as important factors that influence social interactions and credibility in VR. Freeman and Maloney found that users tend to present themselves in a way that is consistent with their offline identity, even when customizing for specific social VR platforms. Also, perceptions of avatar aesthetics, gender, race, and age influence interaction dynamics in social VR while constructing and perceiving identity in social VR allows users to experience their everyday self in new ways, discover unknown aspects of themselves, and explore alternative gender identities. Avatar identify, interaction dynamics and self-understanding should be considered when designing avatar for VR environments.

Realistic avatars are important factors for credible social interactions in VR environments (Roth et al., 2016). Roth et al. explored the impact of avatar realism on social interaction quality in VR which compared physical-based and verbal-based social interactions in the real world (RW) VR, using abstract avatars without social cues like gaze or facial expressions. Significant differences were found in presence and physical performance in VR, but verbal task effectiveness was unaffected. Roth et al.'s work suggested that participants can compensate for missing social cues by focusing on other behavioral channels. In a similar study, Aseeri & Interrante (2018) investigated the influence of avatar representation and behavior on communication in social immersive virtual environments. Realistic avatar representation and behavior are noted positively influence communication, emphasizing their role in enhancing the credibility of social interactions. Pan & Steed (2017) also explored self-avatar and face-to-face avatar. They noted that a self-avatar can improve task completion time and trust formation in cooperative tasks, but not in competitive tasks, compared to no self-avatar, and a face-to-face interaction can lead to similar or better outcomes than self-avatar interaction, depending on the task type and collaboration style. The face-to-face interaction is noted to be the golden standard for social VR. Pan and Steed suggested that face to face interaction can produce similar or better outcomes than self-avatar interaction, depending on the task type and collaboration style. Understanding the impact of self-avatars and face-to-face interactions guides the development of effective VR interfaces. However, (Steptoe & Steed, 2008) provided evidence that as we move forward to using higher fidelity avatars, there will be a trade-off between supporting realism of representation and supporting actual communicative task.

Avatar appearance similarity has a significant effect on the perceptions and communication patterns of social VR users (Shih et al., 2023). Shih et al. explored the persuasiveness effects of communicating with avatars of similar appearance in social VR. The study emphasizes the impact of avatar appearance similarity on users' perceptions and persuasive interactions in VR. Users feel more intimate, fluent, and less eerie when interacting with avatars that are similar to their self-representations. Avatar appearance similarity also influences the persuasiveness of the other users' avatars. Users are more likely to change their initial choices after discussing with avatars of moderate similarity than with avatars of identical or dissimilar appearance. Avatar appearance similarity is not a binary factor, but rather a continuum that can have different effects depending on the degree of similarity. Moderate similarity seems to be the optimal level for enhancing persuasiveness, while identical appearance may cause confusion or negative expectations.

Visual and Sensory Experience

A novel prototype that demonstrates the effectiveness of the technique in discriminating human users from bots in a VR checkout environment was developed and found that head orientation, cursor travel distance, travel time, travel speed and trajectory can be used to tell human user part from simulated human inputs in virtual environments (L. Liu & Hsu, 2017).

Ohyama et al. (2007) studied heart rate variability (HRV) during motion sickness. It was found that motion sickness induced by VR provokes sympathetic arousal and increases the low frequency component of HRV, which reflects sympathetic nervous activity. No correlation between subjective symptoms of motions sickness and HRV. High frequency component of HRV does not significantly change during motion sickness induced by VR.

Another important credible factor for VR design is distance validation (Kini et al., 2023). Kini et al. measured distance in VR using inbuilt sensors like laser distance sensor; social presence, user's perceived sense of embodiment measured quantitatively and qualitatively. They noted high correlation between distances measured in VR and the premeasured world distances. Distance validation is found to be crucial for creating high-fidelity VEs and enhancing the user’s sense of embodiment, engagement and motivation thereby contributing to credibility design in VR.

Fantin et al., (2023) measured participants’ Field Dependence-Independence (FDI) levels in a virtual maritime environment before, during and after. They found that cybersickness was more severe in Field Dependence (FD) individuals, and that it was it was associated with decrease in static FD after VR immersion. Dynamic FD decreased after VR immersion, but it was not related to cybersickness. Fantil et al. explained that FD, a personal cognitive style and its effect on perception and performance in VR, is a flexible characteristic that can change according to the context, and that it may reflect an adaptation process to optimize geocentric perception. FD is noted to influencing the subjective experience of VR.

From the included studies, locomotion in VR was also explored as an important credible design factor in VR (Soler-Domínguez et al., 2020). It enables movement of users or their avatars in VEs, which is important for creating immersive and realistic experiences in the VR environment. Their study was focused on the authenticity of two moving techniques in VR: indirect walking and walking-in-place. Soler-Dominquez et al. found no significant difference between the two locomotion techniques for any of the three metrics, which shows that the authenticity of VR does not rely on how one move within the VE.

We have also identified from the included studies that eye blinks also contribute to designing a credible VR environment. Zenner et al. (2023) proposed and evaluated four methods to trigger eye blinks on demand in VR applications. The methods were based on different blink reflexes: Flash (dazzle reflex), Blur (simulated dry eyes), Approaching Object (menace reflex), and Airpuff (corneal reflex). The study found that all triggers except Blur were effective, efficient, and reliable in triggering blinks. It also found that Blur was the least noticeable and distracting, while Approaching Object was the most. It derived recommendations for choosing suitable triggers for different VR use cases, such as Airpuff for fast and subtle blinks, Flash for software-only solutions, and Blur for unnoticeable blinks. His study is important for enhancing interactivity and realism in VR.

Body positioning influences the perceptions of credibility in VR (Bessa et al., 2018). In a study, Bessa et al. compared three methods of learning: hands-on, computer simulation and VR. The participants that were used in activities mimicking celestial bodies’ movements with results indicating that the computer simulations and the VR allowed manipulation of viewing positions, time progressing, and the moon’s orbit. Bessa et al. found from this study that body position significantly affected the feeling of presence.

Control of cybersickness is a factor that influences credibility of VR applications and technologies. (Jones et al., 2004). Jones et al. proposed a validated modified Simonian approach for designing experiments that can identify optimal combinations of factors for minimizing cybersickness and maximizing performance in VR. Reducing the motion sickness that occurs when the visual and vestibular systems of the body disagree on the perceived motion in VR would make VEs safe for users thereby enhancing their credibility.

Erickson et al. (2020) examined how color modes, virtual lighting and perimeter lighting affect visual acuity and fatigue in VR HMDs. Their study found that dark mode was better in dim environments, light mode was better in bright environments, bright lighting improved acuity but increased fatigue, and perimeter lighting had no significant effect. These conclusions can inform the design and implementation of VR user interfaces, particularly when high legibility and reduced visual fatigue are desired.

Deadeye visualization is a technique that uses dichoptic presentation to highlight targets in 3D visualizations within VR whose integration real-world applicability into VR volume rendering shows potential benefits (Krekhov et al., 2019). Krekhov et al. tested preattentiveness, robustness, and depth perception in various scenarios and applies it to VR volume rendering. They found out that Deadeye is effective, accurate and promising for VR design.

Marketing and shopping Experience

We also found from the included studies that Embodied Virtual Agent's (EVA) humanoid avatar and output modalities impact on the interactivity and realism of VEs. S. Zhu et al. (2023) found out that text-and-voice modality is the most effective output modality for EVAs in IVR shopping. Their study showed that the text-and-voice modality outperformed the text-only and voice-only modalities in most dependent variables, such as warmth, communication, trust, comfort, and satisfaction. This suggests that combining text and voice can provide more information and feedback to consumers and make them feel more engaged and comfortable with the EVAs. The interaction between humanoid avatar and output modality is not significant for most dependent variables, except for comfort.

Another important factor we have found from the included studies is Virtual Authenticity (VA) and Virtual Ideality (VI). VA relates to the actual state of a product as presented in a VE while VI relates to the idea state of a product as presented in a VE. Sun et al. (2023) conducted two experiments to examine the effects of VA and VI on consumers' responses, as well as the moderating role of social signals in a VR real estate service platform. The important findings from their study include is VA leads to higher perceived diagnosticity (the belief that VR provides relevant information for decision making, while VI leads to higher inspiration indicating that the actual and ideal states can trigger different cognitive and emotional responses that would influence users' intentions. For perceived diagnosticity and inspiration, they found out they positively affect participants' intention giving that they found the VR display informative and inspiring. The findings could be valuable in designing a credible VR product display in interactive marketing.

Technical Factors

We now explore the technical factors that makes VR credible.

Audiovisual Integration

Among the technical factors we have that semantic reliability of sound on living and non-living visual picture category performance can influence multisensory integration and categorization performance (Yu et al., 2021). Yu et al explored the impact of semantically reliable sounds on the categorization of living and non-living objects in VR. They found out that matching sounds improved categorization of performance for both types and objects. The non-living objects had a more robust multisensory representation, performing better under semantically unreliable conditions. The semantically reliable multisensory presentation had a significant behavioural advantage compared to the semantically unreliable and control conditions.

Collision detection

Collision detection is an important concept in VR that identifies when virtual objects intersect or come into contact in the VR environment (Gregory et al., 2000). The method used for collision detection would impact the user's experience of realism and interactivity. Borro et al. (2004) presents a method for collision detection in massive virtual environments. It was designed for environments with millions of triangles, used in aeronautics for virtual aircraft engine mock-ups and addressed voxel-related issues like memory requirements and optimal size, using advanced memory structures and hashing techniques. They compared several analytical solutions for determining optimal voxel size based on the performance cost function of the algorithm and developed a solution (Collision Solver) which was integrated into an industrial system called REVIMA, with experimental results validating the analytical solutions. The method aims to achieve good interactive frame rates and has been applied successfully in the field. Later, (Echegaray & Borro (2012) also introduced a methodology to easily determine the optimal voxel size for collision detection algorithms. It proposes a performance cost function that depends only on geometric data and can be used to find the best voxel size. The key finding is that this analytical approach can lead to more precise voxel size selection, outperforming traditional methods that rely on factors like the average edge length. This finding has important implications for optimizing collision detection in real-time virtual reality applications, where accuracy and performance are crucial for providing a realistic and interactive user experience.

Display Visuals

Another credible factor explored in the included studies is panoramic imaging for Cave Automatic Virtual Environment (CAVE). Lee et al. (2010) used a digital camera and a panoramic tripod head to capture real images of the environment. These images are used to create a panoramic image representation for the CAVE and then projected onto a virtual sphere inside the CAVE. This was done to increase the user's immersion in the virtual reality environment. They used Stream Control Transmission Protocol (SCTP) to transfer the panoramic images between the master server and the rendering servers in the CAVE for a reliable data communication and fault tolerance for the system. Lee et al's study is focused on increasing user's immersion thereby enhancing credibility of VR environments.

From the included studies, we also determine that consistent interaction (display of VR moving objects) is an important factor. Kharitonov (2008) developed a distributed system of formation flying over locality with a qualitative and quantitative analysis of indicators. He explored main principles of distributed virtual reality systems design with special attention drawn to reliability of systems in terms of consistent interaction. Kharitonov proposed an approach to consistent displaying virtual reality moving objects to reduce influence of hardware limitations and the overall network load through a more flexible way of network traffic management considering movement of dynamics of objects.

Ray tracing is a feasible alternative to rasterization for VR, it can accurately simulate many effects that are difficult with rasterization-based rendering systems Wald et al. (2006). It improves the performance and quality of VR environments. However, it poses computation cost and latency.

User Experience and Interaction

Hooks et al. (2020) studied walking simulators (omnidirectional treadmills) using two separate scenes: for flat-based and bowl-based treadmills. Training session for the participants who were tested one each, on the scenes. Their findings show no significant difference between flat-based and bowl-based treadmills in terms of performance. However, a significant difference in favour of bowl-based treadmills in terms of presence, preference and usefulness. Realism factor was positively correlated with the global scores, 3D depth, and usefulness scores given by participants. age and profession had some influence on the selection and recommendation of VR treadmills.

Saliency in VR is also considered an important factor for designers. Sitzmann et al. (2018) examined how people visually explore virtual environments in VR. They found a fixation bias around the equator in VR, a faster exploration of low entropy scenes, and the potential to adapt existing saliency predictors for VR by considering head movement and gaze behaviour. Sitzmann et al. insights can be applied to various VR applications, such as VR movie editing, panorama thumbnail generation, and saliency-aware compression. Understanding how users interact with VR environments and can inform the design of more engaging and efficient VR systems to make them more credible.

Another study from the included studies explored photorealism. Zibrek & McDonnell, 2019) investigated the impact of photorealism in VR on social presence, place illusion, and empathetic concern. They concluded that photorealism significantly increases the self-reported social presence, making participants feel more present with the virtual character. Also, a realistic environment enhances the place illusion, making participants feel more like they are in a real living room and that the order in which participants viewed the render styles affected their empathetic concern for the virtual character. However, photorealism did not affect the minimum distance participants kept from the virtual character which shows no change in comfort levels. Zibrek & McDonnell's findings suggest that while photorealism can enhance the sense of presence and place illusion in VR, it does not necessarily influence proximity behaviour or empathetic concern unless the presentation order is considered.

Haptic Feedback and Interaction

A tactile feedback system was developed that helps users to perform direct manipulations tasks with more reliability (Scheibe et al., 2007). Scheibe et al. designed this tactile feedback system using shape memory alloy wires for finger-based interactions and integrated it with a VR application for car interior ergonomics and usability studies. This created impressions and vibrations when users touched virtual objects. Their study shows that the tactile feedback system enhances the reliability of direct manipulation tasks in the VE.

Haptic retargeting is also an important factor from the included studies. It was noted to improve the sense of presence in VR when virtual objects are aligned with physical objects (Azmandian et al., 2016). Azmandian et al. study investigated haptic retargeting in VEs assessing user experience and effectiveness of different techniques. They introduced dynamic techniques like world manipulation, body manipulation, and a hybrid approach to align virtual and physical objects. They hybrid technique achieved the highest satisfaction and presence scores. Their study suggested that haptic retargeting as a promising approach to enhance VR experiences by dynamically repurposing passive haptics. Cheng et al. (2017) used haptic retargeting in sparse haptic proxy to manipulate hand-eye coordination, redirecting the user's hand to a physical proxy. Cheng et al. study suggested that sparse haptic proxy can enhance immersion and interaction in VR by simulating detailed environments with simple physical primitives.

Enhancement of self-motion sensation as a factor of credibility. Ouarti et al., 2014) also examined the enhancement of self-motion sensation in VEs using visuo-haptic stimulation. Their study discovered that haptic feedback, synchronized with visual motion significantly enhances the sensation of self-motion when the feedback is proportional to visual acceleration rather than velocity. Also, the combination of visual and haptic cues was found to be more effective in inducing a realistic sensation of self-motion.

Tracking and Latency

Papadakis et al. (2011) presented a system for minimizing end-to-end head tracking latency in VEs using a custom mechanism for latency control. Their system achieved nearly a 50% reduction in initial measured latency by disabling certain features and optimizing data retrieval timing.

Xun et al. (2019) also worked on motion-to-photon latency. They proposed an automated a universal HMD latency measurement system to evaluate the latency of an HMD. The study simulated a user's motion to measure motion-to-photon latency using generated periodic signals in HMD. The method of fitting signal with photosensor makes result time resolution and measurement accuracy guaranteed. For different types of HMDs, only the corresponding SDK needs to be replaced to complete the adaptation.

Controllers and devices

Self-transforming controllers (Krekhov et al., 2017) designed a self-transforming controller that alters its shape and weight distribution between a pistol-like and a riffle-like device. The control was integrated with an HTC Vive for tracking and communication using a telescopic mechanism and a motor. Self-transforming controllers enhances immersion in VR. In a related study, Choi et al. (2018) worked a haptic controller (CLAW) that offers enhanced functionalities like force feedback and actuated finger movement that enables realistic VR interactions.

Omni-Directional Treadmill (ODTs) should also be considered when design credible VR applications. Lee et al. (2016) designed an ODT uses an omni-pulley mechanism for high power transmission efficiency and rapid acceleration/deceleration capabilities. They emphasized the system's simplicity, lightweight design, and high acceleration performance compared to existing ODTs. Their study indicated that the ODT designed could significantly enhance user experience in VR applications by providing a more natural and responsive movement interface.

Biometrics and Eye Tracking

Boutros et al. (2020) discovered the periocular as a potential biometric trait for identity verification in HDMs. They developed a method to align and crop ocular images for reference image selection based on ocular extraction methods (TReeLBP, BSIF, VGG19, MobileNetV3). The VGG19 was recommended for periocular verification in HDMs. They also suggested that exploring other factors that may affect the verification performance, such as illumination, gaze direction, and head pose. Periocular biometrics verification is important for ensuring the security and safety of VEs.

Eye tracking in VR was also determined to be an important consideration for a credible VE. Schuetz & Fiehler (2022) measured spatial accuracy and precision of the Vive Pro Eye built-in eye tracker across a range of 30 visual degrees horizontally and vertically. They noted that high calibration reliability can serve as a baseline for expected eye tracking performance in VR experiments.

Advanced Techniques and Concepts

Spatial mapping (transferring object layouts from virtual to physical rooms) was investigated for presence and trust in VR (Lin et al., 2020) . Lin et al. designed and implemented a system (Architect) that allows assistant to map physical objects to virtual proxies using AR. Their study shows that Architect enhances presence, trust and reduces workload of both users compared to where the assistant guides the player verbally.

Hadjistasi et al. (2022) utilised Erato, an algorithm for implementing Distributed Shared Memory (DSM) in 3D interactive Networked Virtual Environment(NVE). They determined that Erato can provide strong consistency and fault-tolerance guarantees for NVEs. However, it also faces challenges in meeting the real-time demands and the network and processing limitations of NVEs. They suggested that further optimizations and dedicated server nodes are necessary to improve the performance of the DSM service.

Feedback and precoding (H.-Y. Chen et al., 2020). The GAN-based deep learning approach is used to design the precoder and feedback scheme for a multi-user VR/AR system. The generator uses the noise vector and the channel state information (CSI) to generate a precoding vector that maximizes the sum rate of the system under power constraints and CSI imperfections. They believed that such DL-based scheme is promising to be able to provide sufficient network bandwidth for the multi-user VR/AR system

Langbehn et al. (2018) also introduced a novel VR technique leveraging blink-induced suppression for imperceptible position and orientation redirection. It synchronizes VR rendering with human visual processes which allows undetectable camera movements. This approach promises significant advancements in VR locomotion by exploiting natural visual suppression periods. The key conclusions from the study on blink-induced suppression in virtual reality (VR) are:

Imperceptible Redirection: Their study demonstrates that it is possible to imperceptibly redirect a user's position and orientation in VR during natural eye blinks. The findings have significant implications for Redirected Walking (RDW) techniques in VR, potentially improving their performance by approximately 50%. Their approach is orthogonal to traditional RDW methods, offering a new way to enhance user experience in VR without noticeable interference. They suggested that leveraging blink-induced suppression can effectively enhance VR locomotion techniques without breaking user immersion.

Multi-sensory human perception, tactful networking paradigm Picano (2021) proposed a learning framework to model how humans perceive and integrate information from different senses, such as vision, touch, and audition. Picano applied the framework to the context of haptics virtual reality services, which require high-quality and low-latency communication. He explained how the framework can improve the system reliability and resource allocation by considering the human perception limitations and preferences. It was suggested that the proposed framework can be used to support the tactful networking paradigm, which aims to provide human-aware and adaptive environments for immersive and customized user experiences.

Facial performance capture is suitable for social interactions in VEs (Li et al., 2015). Li et al. worked on a Facial Performance Sensing Head-Mounted Display that assesses several variables related to facial performance capture in VR environments. Their study presented a novel HMD that integrates ultra-thin strain sensors and an RGB-D camera for real-time facial performance capture, enabling immersive face-to-face communication in virtual worlds. Despite the face being largely occluded by the HMD, the system can produce 3D facial animations comparable to state-of-the-art facial capture systems, suitable for social interactions in virtual environments.

Zenner et al. (2021) study on blink-suppressed hand redirection (BSHR) suggested that combining techniques can enhance hand redirection in VR. Their study examined a novel technique for VR that leverages blink-induced visual suppression to manipulate the real-to-virtual hand offset without detection can enhance the effectiveness of hand redirection in VR. BSHR adds offset during blinks and adjusts it when eyes are opened. This study validates BSHR's effectiveness in enhancing interactivity and presence in VR by improving hand redirection techniques.

Tarng et al. (2021) investigated the integration of vibrotactile and force cues. Their study suggested that vibrotactile cues are more salient and reliable for haptic perception and force cues can possibly increase the realism of the haptic feedback since force cues can reduce the response time.

Network Factors

Terahertz (THz) Technology

THz has been explored for its use in VR. VR requires high data rates for short distances which can be supported by THz frequency bands for wireless communication. THz offer High-Rate Reliable Low-Latency Communications (HR2LLC) for VR under favourable channel conditions such as guaranteed line-of-sight links, abundant bandwidth, and low molecular absorption. THz can achieve reliability of 99.999% with an E2E delay threshold of 20ms and data rate of 18.3Gbps which can support ultimate VR's needs (Chaccour et al., 2019, 2020, 2022). Y. Wang et al. (2022) designed a novel algorithm that can adapt to the dynamic and unknown users' movement patterns and optimize the reliability of the VR network. THz enables high data rate VR image transmission while VLC enables accurate user positioning and tracking .

6G for VR (Fantacci & Picano, 2021) was modelled as a proposed analytical framework using a stochastic network calculus and martingale theory. The proposed framework can provide end-to-end delay bound and reliability estimation for VR system.

5G and Mulitple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) Systems

Huang & Zhang (2018) designed a Medium Access Control (MAC) scheduling scheme for wireless VR service in 5G MIMO-OFDM systems, which includes three novel functions: video frame differentiation and delay-based weight calculation, spatial-frequency user selection based on ADCU, and link adaptation with dynamic BLER target. The results show that the proposed scheme decreases the overall maximum transfer latency of VR packets and increases the maximum number of served VR clients.

Susloparov et al. (2022) examined traffic balancing with multi-connectivity. They proposed a Delay-Based Traffic Balancing (DBTB) which tries to transmit data over the fast Frequency Range 2 (FR2) link and uses the reliable Frequency Range 1 (FR1) link only when the FR2 link cannot deliver the data in time. The paper indicated that DBTB provides significant improvement in terms of the network capacity for AR/VR traffic and resource utilization of the FR1 link. This is important for smooth VR experiences.

Edge computing in VR

Among the network factors that we have gathered from the included studies, millimetre wave and edge computing was also studied. Gupta et al. (2019) conducted a study that was focused on improving users' experience of streaming 360^0 video over HTTP/2. They proposed a method that utilizes Scalable Video Coding (SVC) to solve the trade-off between network adaptivity and user adaptivity. Their algorithm helps to cope with sudden throughput drops, and the delivery of late layers is terminated using HTTP/2's stream termination feature. Gupta et al. study improved the quality of 360^0 streaming making VR experiences more reliable. A VR caching system was also examined and proposed for a 360^0 VR (Dai et al., 2020). Yang et al. (2018) proposed a framework that consist of three main components: task modularization, scheduling strategy, and trade-off analysis for delivering VR content over wireless network using Mobile Edge Computing (MEC). Another study was also focused on MEC-based mobile VR delivery framework (Y. Sun et al., 2019). It was based on mobile VR delivery using MEC to reduce bandwidth and latency.

Machine learning and Deep learning

Machine learning has been implemented in the study of content transmission, THz transmission, uplink transmission, motion awareness, and data correlation-aware resource management (Chen et al., 2020; Chen et al., 2019; Liu et al., 2021, 2022) . Chen et al. (2020) proposed a framework providing end-to-end delay bound and reliability estimation for VR systems. Liu et al. (2021) also created learning algorithms for viewpoint prediction and phase shift optimization. The Liu et al. (2021) study was also based on an offline and online learning algorithms for viewpoint prediction in uplink transmission, recommending the online GRU algorithm. Kim & Yun (2020) also applied machine learning techniques such as echo state networks, transfer learning, and distributed learning to optimize the resource management and delivery of wireless VR services. The study found that the performance of wireless VR systems can be significantly improved by using machine learning techniques.

From the included studies, Transport Control Protocol (TCP) congestion control is an important design factor in VR. Gital et al. (2014) conducted a study on TCP variants by deploying TCP over wireless networks, considering restrictions such as random link errors, random packet loss, node distance, and constantly changing topology. The study involved the use of algorithms and network media to categorize TCP variants into Loss-Based, Delay-Based, and Hybrid. The study suggested that TCP Vegas, NewReno, and Reno can be modified to conform to the collaborative features of the cloud-based CVE systems, such as consistency, scalability, and security. Gital et al. also suggested that other performance metrics, such as congestion window behaviour, link utilization, and throughput, should be considered in future analysis of TCP variants for CVE systems.

4.1.2 Dimensions that are Used to Measure the Credibility of VR Applications

Based on the included studies used for this systematic review, the key dimensions (perspectives) from which the quality or the credibility of the VE are researched, are exploited. These dimensions are mostly stated in the included studies. In few cases where the dimension(s) is/are not explicitly stated, we have inferred these dimensions in reference to most of the studies that have explicitly stated these dimensions.

The dimensions that we have identified from the included studies include presence, trust, reliability, safety, interactivity among others. These are presented under the technical, human and network factors.

Dimensions for the Technical Factors

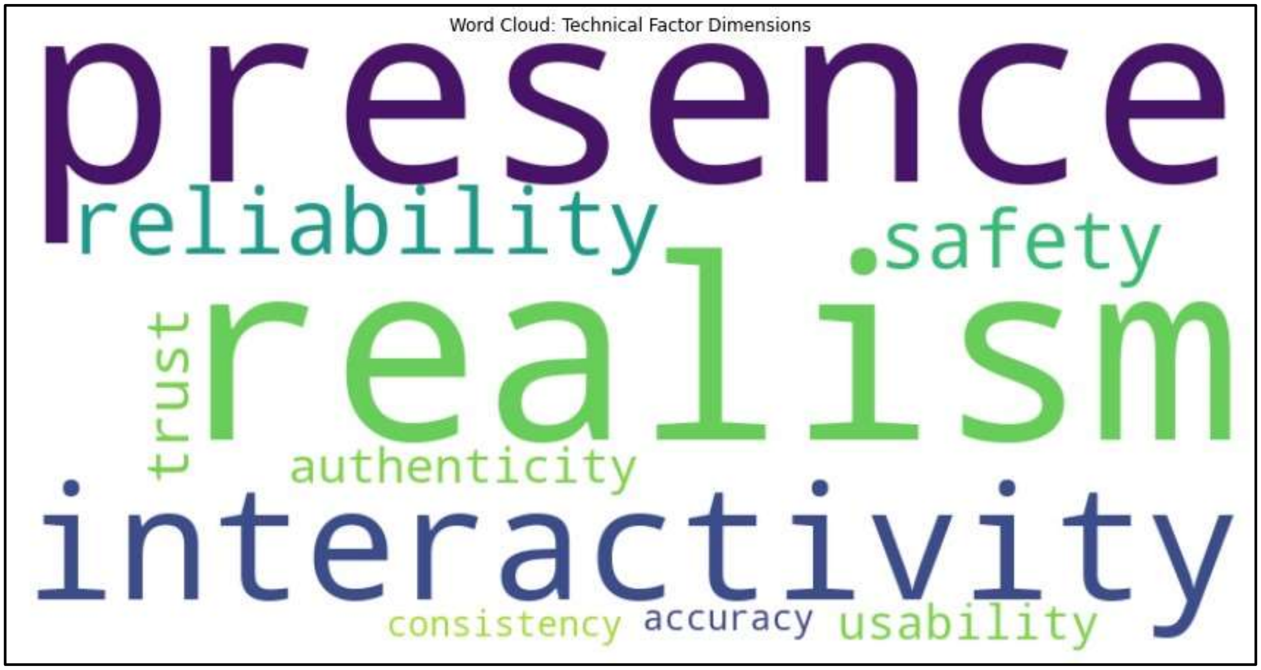

Figure 3: A word cloud of the dimensions for the technical factors

As illustrated in the chart above, presence in VR, reliability of VE, realism, and user's level interactivity are noted as the dimensions that are mostly researched into and for which researchers have directed their VR design efforts. Other dimensions such as trust in VR, authenticity of users in VR, usability of the VE, consistency, and accuracy are also researched into, however, according to our included studies, we have determined that these dimensions have not gain much attention among the technical factors.

Dimensions for the Human Factors

Figure 4: A word cloud of the dimensions for the human factors

The chart above illustrates the dimensions that have been identified among the human factors. The chart indicates that presence in VR, realism of the VE, interactivity of the VE, trust in VR, safety (security) of users in the VE are the most studied dimensions for a credible VR design. Inspiration, reliability, validity, and authenticity in VR are least studied dimensions among the human factors.

Dimensions for the Network Factors

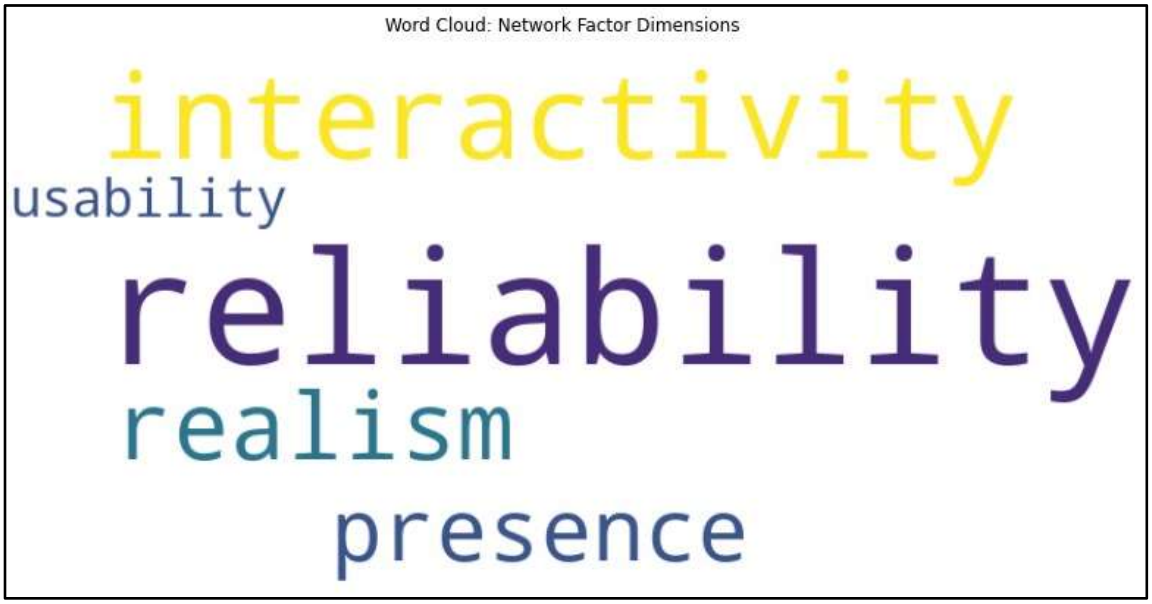

Figure 5: A word cloud of the dimensions for the network factors

Among the network factors, we have determined that reliability, interactivity, realism, usability of VEs is studied for a credible VR design. Reliability of the VE is the most focused dimension in the study of the connectivity (network) of VR.

Generally, among the three broad classifications of the factors of credible VR design from the included studies, we have identified ten (10) different dimensions in the human factors and the technical factors. Only five (5) have been identified among the network factors. Presence in VR, interactivity of the VE, realism, usability, and reliability in VR are identified under all the three classifications. Trust, inspiration, validity, authenticity, and safety of VR are not identified among the network factors.

The Multidimensional Nature of the Study of VR

We have also determined from the included studies that most research do not focus on only one aspect (dimensions) of the VR design. This is illustrated below.

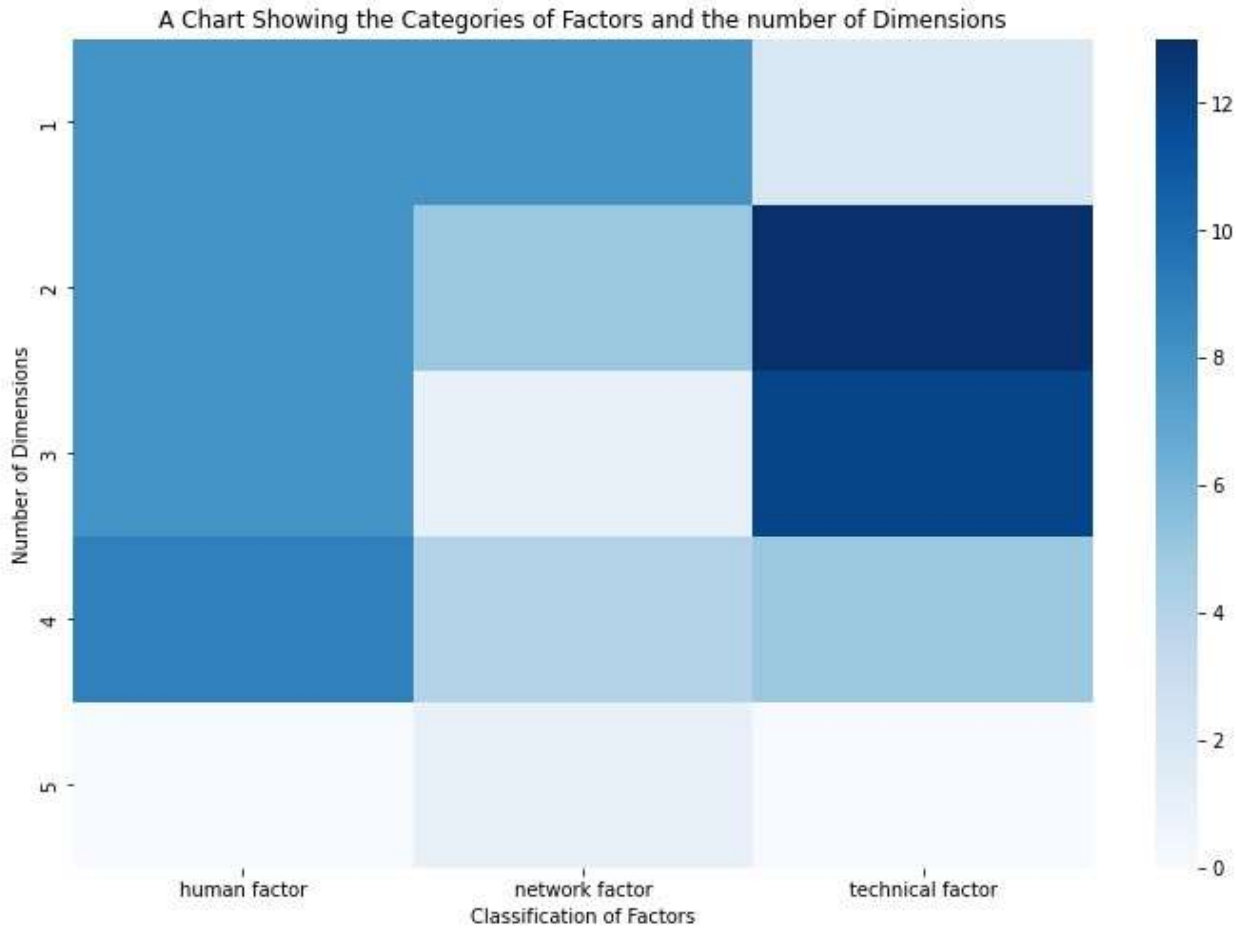

Figure 6: The multidimensional nature of the study of VR

Figure 6 illustrate the nature of the VR study. It indicates the number of dimensions that we have determined from each factor (study) that we have considered from the included studies.

For the human factors, four (4) different dimensions have been identified in about eight (9) of those factors. Also, at least two (2) different dimensions have been explored under sixteen (16) of those studies. We have determined that about twelve (12) factors among the technical factors have explored two dimensions, and additional ten (10) of those studies explored three (3) dimensions.

It is among the network factor where most fewer studies have explored more than one (1) dimensions. However, it is also only among the network factors where five (5) have been explored in a study.

This explains the multidimensional nature of the study of the VR. Thus, a given study could be focused on presence in VR, and would have also include designing interactive, realistic or usable VR.

4.1.3 Metrics Types Used in Studies

As in any study, we have determined the metrics used in VR environments. Researchers employ several metrics based on the environment they have built and evaluate the dimensions that were used to design the VR environment for credibility purposes. Our study reveals such metrics that researchers and practitioners use.

Figure 7: A chart showing the human factor metrics used in the VR studies

Figure 7 illustrates the metrics that we have identified from those studies that relates to the human factors. Some of these metrics include presence level, trust level, cybersickness, usability scores, naturalness of hand gestures, eye gaze, persuasiveness, avatar similarity, sense of embodiment, among the others shown in figure 7. These metrics are measured and examine to evaluate the VEs.

Figure 8: A chart showing the technical factor metrics used in the VR studies

Figure 8 also illustrates the technical (factor) metrics. They include hit rate, voxel size, user feedback, realism level, reaction time, number of correct responses, eye tracking data quality, fault tolerance.

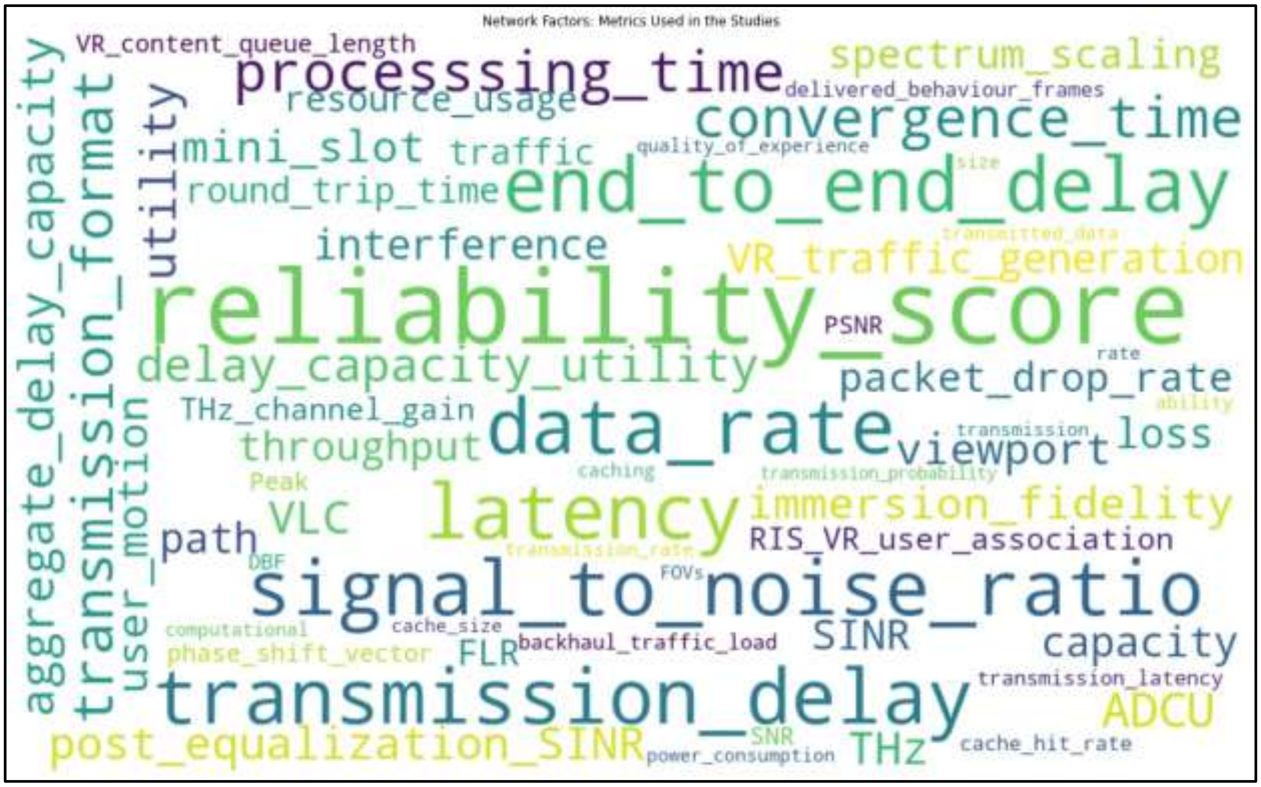

Figure 9: A chart showing the network factor metrics used in the VR studies

Figure 9 illustrate those metrics that are used to measure the connectivity (network) of VEs. They include metrics such as transmission delay, reliability score, signal to noise ration, end-to-end delay, throughput, packet-drop rate, and THz channel gain.

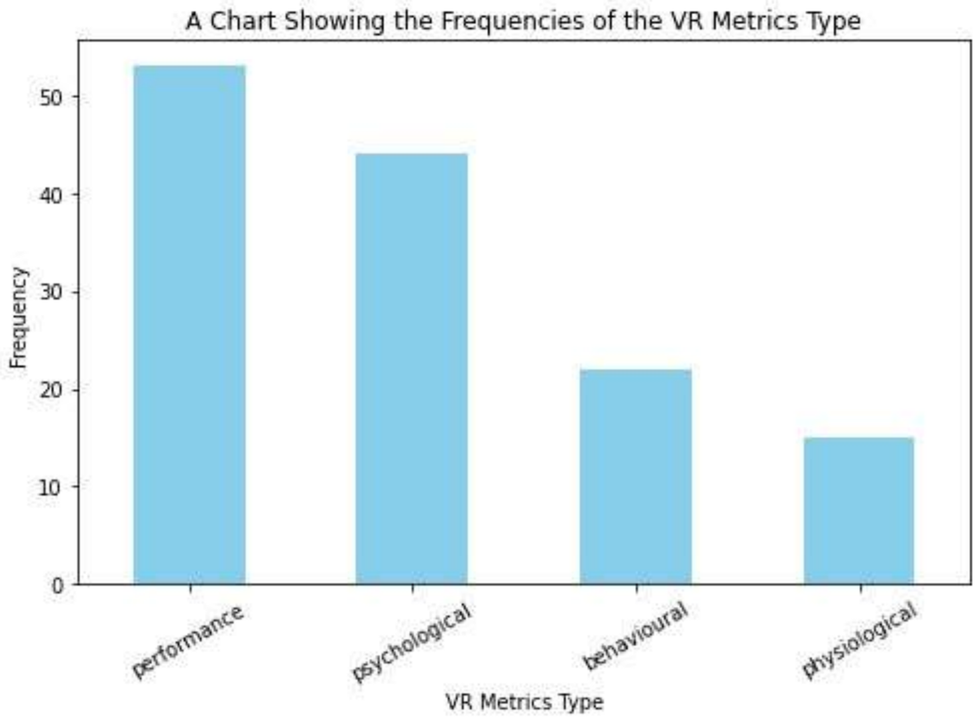

Figure 10: Classification of metrics

Figure 10 shows the category of metrics and the number of these metrics (from our included studies) that are used to ascertain credibility in VR technologies and applications. It is worth noting that in most cases, multiple metrics are used regardless of the number of dimensions of credibility that the researchers are interested in. There are more performance metrics used by researchers than performance, behavioural, and physiological metrics as shown in the graph. This graph does not show the frequency of use of these metrics. It indicates the number of metrics under each category.

Psychological metrics

The perceived trust, realism, presence, and user experience are mostly assessed by the users' perception of the experience while they interact with the applications. The studies found most researchers associate a rating, index or score of these psychological dimensions and use them to subjectively assess the VR environment.

Specifically, we have determined metrics such as presence level, reliability score, trust level or index, user experience score, and acceptance index to measure the credibility of VR applications. Instruments such as surveys, questionnaires, and self-reported assessments are used in measuring these metrics.

Physiological Metrics

These metrics are obtained through bodily observation of the bodily movement of users who are engaged in a VR environment. Researchers obtain such metrics which are useful for evaluating the credibility of the application. These metrics are objective and can be used without bias in the evaluation process. The heart rate variability (HRV) for instance is used to measure stress level, and the pupillometry (a measure of change in pupil size) is used to measure attention or cognitive load. The rest include galvanic skin response (GSR), eye gaze, facial expressions, and voice measures.

Performance Metrics

Some evaluations in VR that we explored are linked to the performances of users while completing a given specific task in a VR environment. They are also objective measures and could be used devoid of biases. These metrics indicate the ability of the users to in use the VR application. To measure, for instance, usability (dimension), participants are allowed to complete a task. The task completion time serves as a useful indicator of how users can use the VR application effectively. The error rate is a metric that can determine specific challenges that users have while interacting with the VR environment. Some other performance metrics include travel distance, travel speed, trajectory, count of actions performed, and latency.

Behavioural Metrics

Users exhibit certain behaviours while interacting with VR applications. Data about these behaviours provide useful measures to evaluate the environment. We can use measures like their willingness to click to assess their level of satisfaction with the application. Additionally, we can assess their likeness to the environment through the decisions they make.

Metrics such as head nodding, knee-jerking, and eye gazing can be used in both behavioural and physiological evaluations.

4.2 Implications for Design and Development

Our study shows some significant considerations in designing credible VR applications.

The major consideration is the need to leverage several dimensions that are empirically noted to contribute to a credible VR environment. Designers must integrate trust, presence, usability, user experience, and validity into the VR environment. Each of these dimensions must be explicitly defined and state the metrics that would be used to evaluate them.

4.2.1 Presence Considerations

To achieve a high presence in the VR environment, designers should utilize high-quality visuals and graphics for a high-resolution display. The rendering techniques used must improve the lighting and produce a good shadow effect. While there are limitations to a sensory system for VR, effort must be made to ensure multi-sensory feedback. There should be a sense of touch through haptic feedback and, limit latency of movement of head and hands. The audio must be realistic and mimic a specific environment. AR can also be used to used alongside for a real-world integration.

4.2.2 Trust Considerations

Trust is a key factor in designing VR applications. Users will feel more confident when they trust the environment, and further improve credibility. Designers must ensure that they provide accurate information and maintain consistency in the environment. The content must be real to make the environment believable. Some other factors that can make the system trustworthy include error handling, security and privacy concerns, and user support.

4.2.3 Reliability Considerations

For a consistent effect or experience in VR, designers must consider the reliability of the environment to ensure that the environment is dependable. With this perspective, the environment is expected to be devoid of crashes or shutdowns. The environment must be tested for performance and stability. For VR that are network dependent, the network connectivity must be strong enough, by implementing relevant protocols that would limit latency. Other aspects such as hardware, data integrity, and bug fixes must also be considered.

4.2.4 Usability Considerations

How usable the environment is playing a key role in credibility design in VR. Designers must take into consideration the user interface. This must be intuitive enough for users to follow easily. The interfaces should include patterns to enhance interactivity in the environment. Since controls are important tools in VR applications, they should be designed to be accessible to different users. Where possible, the menu can be assisted with voice controls to aid interaction. The credibility of the environment would be compromised when users cannot easily use the environment.

4.2.5 Validity Considerations

Validity relates to realism, that is, how well the simulated environment depicts the real world. When the simulation is real, users will find it credible. VR application designs must pay attention to every aspect of the simulation to depict how it would appear in the real world. Validity is closely linked to the presence. Validity promotes presence, however, it must be defined and measured separately as a distinct dimension. Presence relates to the feel of being in a real world, but validity measures how real every aspect of the environment is, in relation to the real world.

4.2.6 Other considerable dimensions

Attention must be paid to other factors such as security and safety, and technical details when designing VR applications. The safety of users should be considered when designing and mounting VR applications.

4.3 Comparison with Existing Literature

Our findings from the review highlight some issues, even though some converge with existing literature. Both presence and trust, presence and usability are extensively researched into as central points in VR. Our study underpins previous work done in this area. What was lacking in existing literature, are the clearly stated dimensions that researchers and practitioners can reference and leverage on as established protocols for design and evaluation. Our study brings together insights from various studies to establish these protocols that can be used to assess the credibility of VR technologies.

In addition, there were no stated frameworks that researchers could use to embark on a VR study. We have identified the approaches used in VR study alongside the dimensions and metrics to establish a model for use in research. This study establishes that different approaches such as experiment, comparative experiment, and case study, are used with the dimensions being measured by metrics to wholistically measure credibility in VR technologies.

4.4 Limitations and Future Work

Our study was limited to specific areas of study to generate insights to analyse how credibility is being explored in VR research.

An important limitation that we wish to state is that our study is limited to only the academic databases from which we have extracted the studies and those that meet the inclusion criteria. We do not examine how the number of dimensions used in a study affects the credibility of the study, hence we cannot conclude on that. We also limit the study to identifying the metrics that are being used in the analysis of a VR environment. Here also, we do not examine the effectiveness of the metrics under consideration.

These limitations open for further research into the dimensions. There is a need to determine how different dimensions impact the credibility of the VR environment. We may also be interested in examining how evaluating the VR environment compares with using a single dimension or two. Additionally, our findings include objective and subjective measures of dimension for evaluating the VR environment. Further study is required to determine which type of measures is fit for VR assessment.

The study recognizes that security and safety are not well-considered in research. We identified this as an important dimension that must be researched.

CHAPTER 5

CONCLUSION

In this chapter, we present the conclusion of our study by summarising the key findings and the recommendations.

5.1 Summary of Key Findings

The study reveals important factors to consider when designing a credible VR and the most useful dimensions of research in VR which include presence, trust, reliability, validity, usability, security, and safety. Also, various metrics are used to evaluate the dimensions identified. These metrics are categorized as psychological, physiological, performance, and behavioural. The metrics are further classified as subjective measures and objective measures.

Additionally, the study explores the approaches used in VR study. Most of the studies are experimental, comparative experiments, case study, and implementation approach that involves designing and creating a VR environment. Most approaches used have extended their work to analysing various factors (dimensions) in their studies. The study approach includes using one or a combination of several dimensions in the analysis of the VR environment and evaluating them based on the metrics. We have considered this whole approach as the framework or the model with which VR study are based on.

5.2 Final Remark and Recommendation

While VR is becoming part of our lives and has taken root in critical areas like health and e-commerce, there is a need to ensure that the VR environments are credible enough. Even though, not much is mentioned of about the credibility of VR applications and technologies, various studies on VR seek to achieve credibility in these environments.

The findings of this study indicate a gap in this aspect of VR. The study paved the way for further research work into the approach, dimensions, and metrics that must be constantly validated due to the evolving nature of VR. It is noted that credibility in VR is a multi-faceted concept, which must draw research from other disciplines.

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