Extended Reality in Information Systems Education: Analyzing Technology Readiness Levels

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***Abstract*— Extended Reality (XR) and its associated domains, Virtual (VR), Augmented (AR), and Mixed Reality (MR) technologies provide cutting-edge technological affordances in emerging learning environments. Information Systems Education (ISE) key activities are teaching and training. Teaching activities involve conceptual understanding whereas training activities consider practical applications and their implementation. To investigate the impact of XR in ISE, it is important to contextualize the Technology Readiness Level (TRL) of applications within the educational ecosystem. The progression from initial ideas (TRL-0) to full commercial applications (TRL-9) will provide widespread acceptance and affordability of XR applications in ISE. A deeper understanding of that progression will indicate the emergence of a new teaching and training paradigm within ISE. It will also reduce the gap between conceptual understanding and practical implementation which is prevalent within ISE. Hence, the aim of this study is to comprehend the TRLs of XR applications within ISE. For this, a systematic review of literature in the Association for Information Systems - eLibrary database was conducted on the articles published between 2014 and 2024 using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) method. A total set of 114 articles was coded into a spreadsheet and subsequently analysed using the spreadsheet slicer functionality. The outcome of the analysis shed insights into the type of XR applications used in IS Education, their TRLs, distribution of articles over time, research methods and the theoretical foundation of studies. The preliminary results reveal that VR applications are widely used in IS Education with TRL- 2 followed by TRLs 4 and 1. The distribution of articles saw a steady progression in recent years. Whereas systematic literature review was a predominant method used in many articles to understand the implications of XR applications in ISE. Due to the rapid advancement in spatial computing and the emergence of the metaverse, periodic reviews will be essential for a comprehensive understanding of TRLs of ISE applications.**

Keywords*— *Extended Reality (XR), Information Systems Education (ISE), Technology Readiness Level (TRL)

I. Introduction

Extended reality research in information Systems education is an interdisciplinary area of study that emphasises the use of theories, methodologies, and tools necessary to facilitate the integration of research findings and practical implementations into educational environments [1]. It focuses on the intricate dependencies between various factors that affect the efficient integration of immersive learning technologies, such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), into real-world educational settings. The objective of this paper is to bridge the gap between research and practical applications and to evaluate the prospective influences of these emerging technologies on education [2]. Extended reality use in education research can improve educational tools and enhance learning outcomes by discovering effective techniques for integrating immersive technology, learning theories, and systems affordances [3][4]. For example, XR in education has the potential to improve individual learning performance [5], enhance memory performance [6], create authentic learning environments [7], and maximise immersion in virtual learning environments for implicit learning [5]. An example of virtual reality is the Meta Quest, augmented reality is IKEA Studio App and mixed reality is Microsoft HoloLens. The spectrum of Extended reality and its associated domains are illustrated in Fig. 1 to understand the technological continuum along with reality [8].

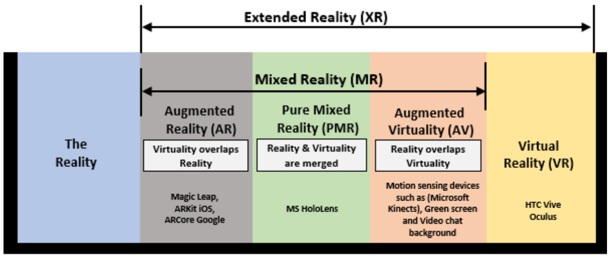

Fig. 1 The spectrum of VR, AR, and MR Fields, adapted from [8].

However, in order to fully realize the advantages of XR into educational practices, XR devices and applications must undergo multiple stages of development and testing that assess the Technology Readiness Level (TRL). This study seeks to provide a current compilation of evaluations of XR technology applications in education, encompassing both simulated tasks in laboratory settings and practical scenarios.

TRL is a framework used to assess the level of technical development that a technology has reached during its acquisition phase. It provides technologists with a reliable reference point to comprehend the progression of technology, independent of their technical expertise. TR Levels are typically determined by conducting a Technology Readiness Assessment (TRA) standard that evaluates an application's concepts, technology requirements, and technology capabilities [9][10][11]. They were first created by NASA in the 1970s to evaluate the level of advancement of a technology as it goes through the stages of research, development, and deployment. TRLs use a numerical scale ranging from 1 to 9, with 9 indicating the highest level of technological maturity [9][10][11]. Several companies have adopted TRLs for their own needs. The European Union (EU), for example, has standardised the NASA readiness-level criteria [11], making it easier to apply them across various industries, not limited to space exploration [9][10]. It is necessary to systematically handle TRLs in order to facilitate the progression of a technology from its initial conception to its research, development, and eventual deployment [12]. Universities and government funding sources primarily prioritise TRLs 1-4, whereas the private sector mostly concentrates on TRLs 7-9 [13]. The term 'Valley of Death' refers to the commonly overlooked stage of technology development, namely TRLs 4 to 7, where both academics and the business sector fail to prioritise investment. Although they show potential, many worthy innovations fail to reach the end of their development process and be put into use [13][14].

The objectives of this study are three folds: 1) to examine the current body of literature on the utilisation of TRL for assessing the maturity of extended reality applications in education; 2) to establish a widely accepted definition of readiness and its associated terms applicable to extended reality technologies; and 3) to verify the suitability and adoption of TRLs for comprehending immersive technology research in educational settings.

II. Background and Related Work

The objective of this paper is to establish a method for assessing the Technology Readiness Levels of various Extended Reality technologies in the field of education, particularly in Information Systems education. It is crucial to maintain a broad scope in order to encompass and analyse all XR-related disciplines and sub technologies, whether they originate from industry or academia. Before doing so, it is important to establish a clear definition of XR technology and determine its ability to encompass new innovations and advances from all stakeholders involved in the development and production. It is important to understand that XR is not a single technology, but rather a field of research that encompasses various subareas, each of which has and will continue to develop distinct technologies.

In addition to readiness levels, it is crucial to acknowledge that XR also enhances cognitive abilities across various levels. These include learning performance [5], memory performance [6], emotional changes [15], implicit learning [5], mental states such as motivation, attention, concentration, and satisfaction [15], ccollaborative learning [16][17], and teacher-student interaction [18]. A technology that is tailored for a specific, regulated domain may achieve a higher Technology Readiness Level compared to a technology that is broader in scope, could be applicable to several scenarios and jobs, or even adaptable to unregulated scenarios [8]. Before delving into details, we first define Extended Reality and its associated domains.

A. *What is Extended Reality (XR)?*

AR, VR, and MR are acronyms used by industry professionals to denote XR. XR is a term that includes augmented reality (AR), virtual reality (VR), mixed reality (MR), and other associated technologies [19][20]. Therefore, our literature study was especially concentrated on these technologies (Fig. 1). Virtual reality (VR) technology provides a completely immersive experience in a computer-generated environment. Virtual reality (VR) users often wear a headset that transports them from a real-world space to a computer-generated environment, creating a highly engaging and realistic experience. Recent developments in virtual reality technology are pushing the boundaries of these environments, leading to a more authentic and real-life visual and behavioral experience. Furthermore, they encompass assistance for additional sensory modalities, including tactile, auditory, and olfactory awareness. From an educational context, VR has the potential to increase student involvement and enhance learning results [21][22][23].

Augmented reality is the technique of overlaying a computer-generated image onto the real-world surroundings. Pokémon GO, a widely popular mobile game, revolutionized the use of AR by presenting computer-generated monsters placed on lawns and sidewalks while players navigate their immediate surroundings. Augmented reality can serve as a highly effective technology for boosting educational experiences inside the classroom setting. Virtual objects can enhance visual cognition by providing students with opportunities to investigate and engage with them. Additionally, it aids in the cultivation of spatial abilities that hold significance in the discipline of science, technology, engineering, and mathematics (STEM) education [20][22][22][23].

Mixed reality is the integration of real-world materials and computer-generated graphics to create an immersive experience where users can interact with both the digital and physical worlds concurrently. Mixed reality (MR) simply integrates real and virtual things, enabling them to exist together within a single visual interface. Users can interact with mixed reality environments using a headset, phone, or tablet. They possess the capacity to physically manipulate digital objects or incorporate them into the physical environment. Within the MR environment, we are presented with the choice of either incorporating virtual elements into the physical world or incorporating physical objects into virtual worlds [20][21][22][23]. The adoption of technologies could be easily understood with the degree of readiness to address market needs. Hence, we define and examine Technology Readiness Level in the next section.

B. *What is Technology Readiness Level (TRL)?*

Technology Readiness Level is a systematic approach used to determine the amount of advancement of a particular technology or process. The values are assigned on a scale ranging from 1 to 9, with 1 representing the lowest point and 9 representing the highest point. Below is a concise overview of the 9 levels [10][24][25][26]. Further information on TRLs 0 - 9 and relevant examples are outlined in Table I.

TABLE I. Technology Readiness Levels and methods used for evaluating XR technologies, adapted from [10][24][25][26]

Stage of Development	*TRL*	*Description and Supporting Information*
Basic technology research	TRL 0	**Unproven idea:** No analysis/testing performed.
	TRL 1	**Basic Research:** Preliminary scientific study has been undertaken as part of basic research. Principles are formulated and verified based on their quality. The emphasis is placed on exploration rather than practical uses. **Example:** Published research that identified the principles that underlie a concept.
	TRL 2	**Applied Research:** Preliminary practical applications are determined. The viability of a substance or

Stage of Development	*TRL*	*Description and Supporting Information*
Research to prove feasibility		procedure to address an issue, fulfil a demand is verified. **Example:** Published research that outlines the application and initial analysis of underlying principles.
	TRL 3	**Critical Function or Proof of Concept Established:** Essential operation or demonstration of feasibility commenced. Practical research progresses and initial development initiates. Empirical studies and laboratory experiments confirm the analytical forecasts of individual components of the technology. **Example:** Experimental data, measured parameters of interest in comparison with analytical predictions.
Technology demonstration	TRL 4	**Lab Testing/Validation of Alpha Prototype Component/Process:** Lab testing and validation of the alpha prototype component/process involves the design, development, and testing of components and processes in a laboratory setting. Evidence demonstrates that performance objectives can be achieved through projected or modelled systems. **Example:** Results of laboratory testing. Comparison with system performance goals.
	TRL 5	**Laboratory Testing of Integrated/Semi-Integrated System:** Validation of system components and processes is accomplished in a suitable setting through laboratory testing of integrated or semi-integrated systems. **Example:** Results of laboratory testing in simulated environment. Identified barriers for target performance goals and plans to overcome them.
System development	TRL 6	**Prototype System Verified:** The demonstration of a system or process prototype in a fully functional environment (at the beta prototype system level) has been confirmed. **Example:** Results of the prototype testing in simulated lab environment. Data are close to target expectations.
	TRL 7	**Integrated Pilot System Demonstrated:** An integrated pilot system was demonstrated, showcasing a prototype system or process in an operational setting at the integrated pilot system level. **Example:** Results of the prototype testing in operational environment demonstrate success.
System launch and operation	TRL 8	**System Incorporated in Commercial Design:** The system has been integrated into commercial design and has successfully undergone testing and demonstration, namely a pre-commercial demonstration, to ensure its functionality and effectiveness. **Example:** Results of testing in its final configuration. Assessment of it meeting its operational requirements. Plans, options, or actions to tune and finalize the design.
	TRL 9	**System Proven and Ready for Full Commercial Deployment:** The system has been validated and is now prepared for complete commercial implementation, since it has demonstrated its effectiveness through successful operations in the intended setting. **Example:** Reports on real application performance.

To elaborate on the different TRLs, at TRL 1, scientific study is in its first stages, and the preliminary findings serve as a foundation for future research and development. TRL 2 involves the examination of fundamental concepts and the development of early experiments or tests based on the initial discoveries. In this stage, technology remains highly speculative. When experimental or test results confirm the initial concept, the technology is classified as being at TRL 3. Typically, at this stage, a combination of analytical and laboratory investigations is necessary to determine the readiness of a technology for advancement into the development phases. During the TRL 3 phase, a proof-of-concept model is built. Based on the evidence presented, it can be inferred that the new technology is scientifically viable. At TRL 4, the technology has undergone validation at the laboratory level, with each component being tested. As a result, a laboratory prototype will be ready. TRL 5 builds upon TRL 4, aiming to provide a testing environment that closely resembles real-world conditions. However, the environment is still under controlled conditions. Based on the information presented, it can be inferred that the new technology is technically viable. During TRL 6, it is necessary to showcase the prototype in an actual setting to validate the practicality of the engineering. At TRL 7, the technology necessitates the demonstration of a functional model or prototype in a practical setting, usually under real-world conditions and with time constraints. Based on the evidence presented, it may be inferred that the new technology is dependable from a technological standpoint. TRL 8 signifies that a technology is at a stage where it is prepared to be integrated into an existing technology or system. Once the technology system has successfully demonstrated its effectiveness throughout operations, it can be classified as TRL 9 and regarded as a commercially viable technology. In addition to general TRLs, other forms of readiness levels are discussed in the literature [12]. Hence, we discuss those dimensions in the next section since XR applications are likely to exhibit other characteristics.

C. Other forms of Readiness Levels

In addition to the TRLs 0 – 9, there are three more scales which are Legal, Organizational, and Societal Readiness Levels [12]. With the sole exception of the Legal scale, the other proposed scales closely align with the anticipated advancement of Technology Readiness and should be strengthened and endorsed in any technology adoption pilot program that aims to achieve success [12].

The Organizational Readiness Level (ORL) assesses the organizational impact of a technology, product, process, or intervention. It is an ad hoc maturity model for innovation's organizational influence. The ORL comprises an innovation's results and larger implications on the organization deploying it. Relevant areas include professional responsibilities, competencies, abilities, organizational functions, procedures, and physical infrastructures [12]. The Societal Readiness Level (SRL) is a method used to evaluate the extent to which a social project, technology, product, process, or innovation has been successfully incorporated into society [27]. A low societal readiness level indicates that society is not fully prepared for a specific technology. The successful integration of the technology into society will necessitate a carefully designed adjustment plan. Accordingly, the success of the plan should be directly related to the level of social acceptance of the technology [28]. It is also evident that the TRL scale does not have a thorough methodology for evaluating a technology's readiness in terms of human support, performance, usability, and user satisfaction [9]. Although there are existing Human Readiness Level (HRL) frameworks, there is currently a lack of guidance on how to progress to different Technology Readiness Levels. The

HRL's primary focus is on the human aspect of the system, with the goal of making technology more centered around humans. This is done to enhance human performance, ensure safety, and increase user satisfaction. The HRL should not be used in isolation, but rather complement the TRL [9]. Therefore, it is necessary to develop a new TRL framework that incorporates human and social considerations, including co-design and pilot testing with end users. This framework must ensure that XR development and implementation are not only highly efficient but also socially acceptable and ready for human utilization. By adopting and implementing a new XR-TRL (Extended Reality Technology Readiness Level), the field of design and implementation research may ensure thorough testing and validation of XR applications before they are deployed. This approach reduces possible risks and enhances the safety, satisfaction, and efficiency of end users [29].

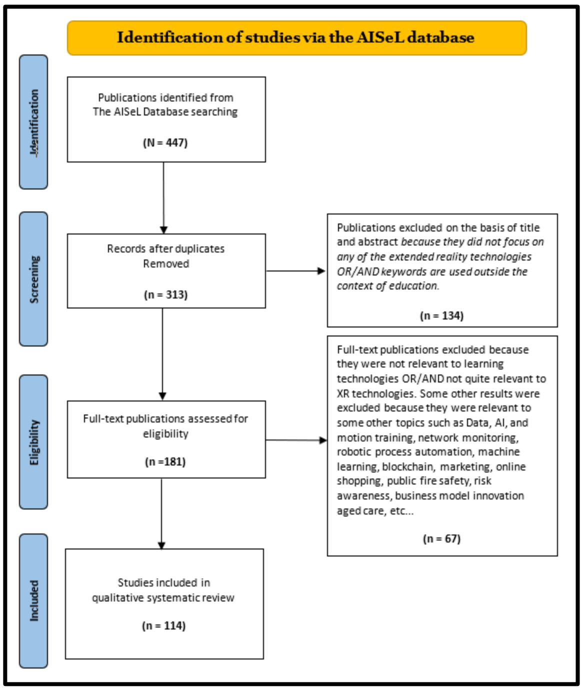

Fig. 2. Literature search and screening process using PRISMA

III. RESEARCH METHODOLOGY

Following the PRISMA guidelines [30], we used their technique to conduct a Systematic Literature Review (SLR). Fig. 2 shows the flow of the process, which are described below:

A. *Identification and search strategy*

We did a search on the AISeL database to find publications relevant to XR in education. The search covered the time period from 2014 to May, 2024. Focusing on a singular database can provide the capacity to replicate, uphold rigor, and exhibit transparency in the search procedure [31]. To ensure the quality of research articles in Information Systems Education, we limited our search to the AIS collection with specific relevance to XR.

We utilized a search string in two phases, wherein two distinct sets of terms were merged and subsequently applied to the AISeL databases. The initial query employed was TITLE-ABS-KEY, which included the terms "virtual reality," "augmented reality," "mixed reality," and "extended reality," combined with the terms "education," "learning," "training," "teaching," "educator," "student," and "learner." In the second phase of our search enquiry, we employed a compilation of often associated phrases related to XR technologies, such as Virtual World, Virtual Environment, Immersive, and Gamification, in our initial set of enquiries. They were combined with the frequently linked terminology in the realm of education, encompassing education, learning, training, teaching, educator, student, and learner. In the next section we discuss the eligibility criteria of the selected articles.

B. *Screening of research articles*

The research articles obtained from the keyword-based search were evaluated using the titles and abstracts. A comprehensive analysis was conducted on a total of 447 studies. Only publications that were relevant to XR were selected. After eliminating duplicate entries and excluding papers based on their title and abstract, we had a set of 181 articles. We next evaluated the entire articles using our selection criteria, resulting in a final selection of 114 publications for inclusion in this review.

To ensure the selection of relevant articles, a set of eligibility criteria was established. The eligibility criteria are as follows:

- The study should evaluate the XR technology either in a laboratory setting or in a real-world environment.
- The article must not pertain to special needs schooling.
- The study should incorporate hands-on activities instead of relying on computer models.
- The study should involve individuals who are involved in education such as teachers, trainers, students, or workplace trainees).
- Articles must be published between January 2014 and May, 2024
- The research must include some or all of the subcomponents of XR, AR, VR, and MR.
- The research must specifically focus on the utilisation of at least one of the XR technologies and applications in education.
- The paper must possess well-defined research theories, experimental designs, or prototypes.
- The papers must be completely accessible and is written in English.

C. *Data extraction*

The 114 selected papers were documented in an Excel spreadsheet. Each record contained information about methods and theories used in the study, educational setting, XR technology type, and the level of TRL. The purpose of recording the aforementioned elements is to identify the factors that influence the TRL in each study. At this stage, an analysis table was used to describe the key features of each article, including the educational application, target participants, characteristics of the XR technology, study methodology, theme type, and results of the study. Once all the columns in the table were completed, except for TRL, the analysis table was reviewed and TRL values (ranging from 1

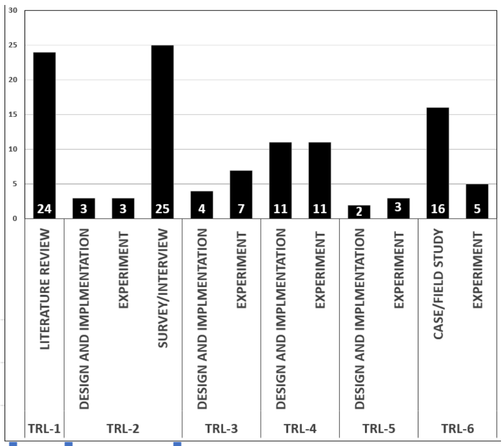

Fig. 3. Number of studies, research methods and TRLs.

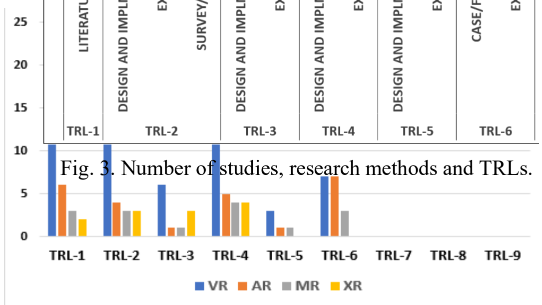

Fig. 5. TRL for each specific technology category

to 9) were assigned to each paper according to the guidelines provided in Table I. Because the TRL was not directly included in any of the reviewed papers, its analysis and inclusion was crucial. Table II shows the various TRL values and the corresponding characteristics required to accomplish corresponding levels.

IV. Findings

A. Distribution of TRLs across Research methods

Fig. 3. illustrates the utilisation of various methodologies, including design and implementation, case study, survey, experiment, and literature review used in the studies on extended reality in education. With respect to TRLs, the experimental approach (29) is the most often utilised method, followed by the survey method (25). An empirical study was done to examine how the attributes of XR technologies trigger cognitive and affective responses in users. An experimental study was carried out to quantify time, quality, knowledge transfer, and motivation. The study also investigated the influence of usability, cognition, imagination, and comprehensibility as mediators [32]. Furthermore, these enquiries sought to assess the influence of XR on student involvement [33]. Another study conducted supplementary tests to measure the influence of XR technology on educational achievements [34]. Specialised XR designs were utilised by researchers to enhance individual learning performance [35] [36]. Researchers have employed the survey methodology to examine the determinants of XR adoption, encompassing its advantages and barriers [37][38]. The researchers employed surveys to examine the theoretical differentiation between task immersion and technology immersion in the context of individual learning utilising immersive XR technology [39]. The case studies were conducted at TRL 6, however the experimental design and execution methodologies indicate the ability to undertake research at a higher level, specifically at TRL 4.

B. Distribution across Research Theories

Cognitive theory, affordance theory, learning theory, grounded theory, and technology acceptance model are widely adopted theories in XR research. These theories facilitate the identification of XR's application in education such as improved individual learning performance, enhanced memory performance, authentic learning environments, emotional changes experienced in virtual environments, and maximization of immersion in virtual learning environments for implicit learning.

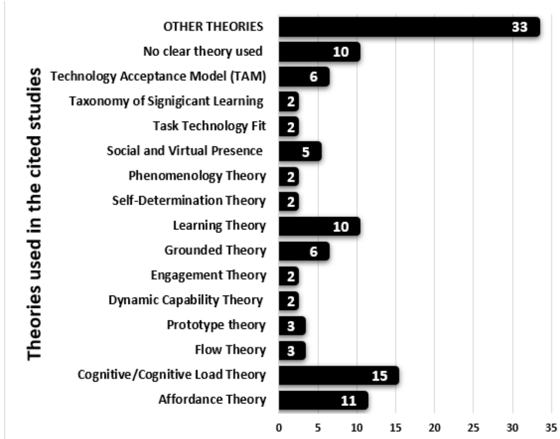

Fig. 4. Notable research theories in the literature

As illustrated in Fig. 4. this review found that cognitive theory was the most used theory in XR research, in 15 studies. Affordance theory and learning theory were also generally adopted, in 11 and 10 studies respectively. Grounded theory and the technological acceptance model were used less frequently, in 6 studies each. The utilisation of research theories has facilitated the recognition of XR's application in education, encompassing benefits such as enhanced individual learning performance [5], improved memory performance [6], the establishment of authentic learning environments [7], exploration of emotional alterations encountered in virtual settings [15], and the optimisation of immersion in virtual learning environments for implicit learning [5]. The aforementioned theories can be employed to examine the impact of XR on the cognitive and emotional well-being of individuals, encompassing heightened motivation, attention, concentration, and contentment [15].

These theories can also be utilised to investigate instructional principles such as student-centered learning and collaborative learning [16][17]. They can be used to identify details and accessibility of information, such as facilitating access to teaching and learning content [40] and enhancing teacher-student interaction [18]. Furthermore, these theories can ascertain an individual's learning style, such as their learning curve or their level of creativity [41]. They can be used to assess understanding of the content, improvement in spatial abilities and memory [42][43]. Most of the theories that were employed in the reviewed studies go beyond Technical Readiness Levels and focus on Cognitive Readiness in Social Sciences which is one of the gaps that must be addressed in future research.

C. Assessment of TRL in Information Systems Education

Based on the literature that were evaluated, TRL 2 stood out among the other TRLs as the most evident readiness level, followed by TRL 4 and TRL 1. Virtual Reality is the most discussed technology among the XR technologies, with a total of 63 references since 2014 (Fig. 5/6). In addition, the data extraction reveals that the phrase "extended reality" or "XR" is not commonly referenced in comparison to other terms (Fig. 6). This indicates a preference for defining specific technology rather than the more encompassing category to which it belongs to. The spread of XR technology across the years 2014 – May 2024 is illustrated in Fig.6. This shows an increase in VR studies compared to other technologies.

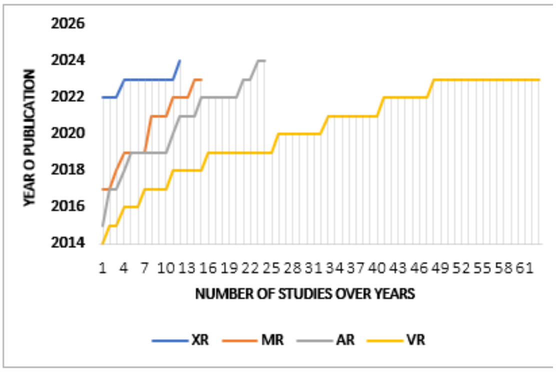

Fig. 6. Number of studies on each technology

D. Distribution of Information Systems Education research

Table II shows which studies had information systems education-related XR components. The predominant theories utilised in these studies are Learning Theory, Affordance Theory, and TAM Theory whereas a diverse range of study methods were employed. Regarding the Technology Readiness Level, it is observed that most studies focused on fundamental technological research, primarily based on research to prove feasibility and XR technology demonstration.

TABLE II. XR STUDIES INCLUDING RESEARCH METHODS, THEORIES, AND TRLS.

Research Method	*Research Theories*	*TRL*	*Refs.*
Design and Implementation	Learning Theory	TRL-2	[44]
	Learning Theory	TRL-3	[45]
	Social & Virtual presence	TRL-5	[46]
	SAMR theory	TRL-4	[47]
Experiment	Authentic Learning	TRL-4	[7]
	Technology Acceptance (TAM)	TRL-2	[48]
	Self-Determination Theory	TRL-5	[49]
	Embodied Cognition	TRL-4	[6]
Case/Field Study	Learning Theory	TRL-6	[50]
	Affordance Theory	TRL-6	[51]
	Curiosity Theory	TRL-6	[52]
Survey/ Interviews	Affordance Theory	TRL-2	[17]
	Phenomenology theory	TRL-2	[53]
	Technology Acceptance (TAM)	TRL-2	[54]
Literature Review	Affordance Theory	TRL-1	[55]
	Dynamic Capability	TRL-1	[18]
	Fink's Taxonomy	TRL-1	[41]

We observed that there are limited studies on XR technologies linked to IS education. Only 17 instances of IS Education were recognized in this review (illustrated in Table II). This limited sample size is insufficient for discerning the TRL trends or accurately characterizing the degree of XR-TRL that are unique to Information Systems Education. However, upon examining the IS-education studies listed in Table II, we observe that most of the literature review studies fall under TRL1. Therefore, it can be concluded that most other types of studies were carried out in controlled laboratory settings with low Technology Readiness Levels (TRL) of 4 and 5. Only three case studies were completed in an actual operational environment, reaching a TRL of 6. This clearly demonstrates the lack of development and readiness of XR technology in the field of education, highlighting the necessity for additional assessment and development in real-world operational settings. Fig 5. illustrates that most of the VR studies examined in the 114 evaluated papers were classified as TRL 2 followed by TRL 4 and 1. This is to be expected, as studies were either reviews or surveys. Regarding other kinds of XR studies, it was observed that most of them were conducted in a laboratory setting at TRL 4.

V. CONCLUSION AND FUTURE DIRECTIONS

The aim of this study was to comprehend the TRLs of XR applications within ISE. The outcome of the analysis shed insights into the type of XR applications used in IS Education, their TRLs, distribution of articles over time, research methods and the theoretical foundation of studies. The preliminary results reveal that VR applications are widely used in IS Education with TRL- 2, followed by TRLs 4 and 1.

In this study we adopted the existing TRLs from the literature and applied that in the context of XR applications. We propose the implementation of a novel framework or set of rules for assessing the readiness of XR technologies. This proposed methodology aims to address the limitations that arise when applying the existing TRLs to assess XR technologies. The guidelines from Social Readiness Level (SRL), Human Readiness Level (HRL), and other applicable multidisciplinary readiness levels can be included. Additional research must be undertaken to evaluate the present suitability of TRLs for XR technologies. The implementation of XR in the educational sphere necessitates a diverse research approach incorporating researchers from other domains especially teaching and learning.

To conduct future studies assessing the readiness of XR in education, we recommend utilizing readiness-vs-generality charts as suggested by [56]. It can provide insight into the trade-off between the breadth of XR as a general technology, its overall applicability, and its level of readiness. More generality in technology capabilities lead to lower level of TRL [56]. To determine the essential characteristics that make XR technology inherently ready, we must examine the methodologies, experiences, data, and other aspects of XR solutions in education. Additional variables that may impact the pace and adoption of XR technology in education include the financial overheads associated with implementing solutions, the dynamics of the technology market, delays caused by regulations, and the level of social acceptance [56]. Additional evaluations of relevant scenarios should be undertaken to analyze and discuss on the future role of XR in education as a technology that brings about significant changes, as well as how the readiness-vs-generality may be utilized for predicting outcomes in the short to long-term [56].

XR does not refer to a single, unique technology. Instead, it comprises multiple primary domains of research and innovation that have yielded a range of technologies. XR technology encompasses multiple concepts and utilizes various forms of devices and applications. Therefore, it is difficult to categorize the technology and impossible to account for its full capabilities. The chart of readiness-vs-generality might be used as practical tool that could be beneficial in the development of a new Framework for Extended Reality Readiness (XRR). It also has to be noted that although technology can be ready, just in relation to its hardware and software components, incorporating the human factor [9] is very critical in the successful adoption of emerging technologies such as Extended Reality.

This study was based on articles collected from the AISeL database. Only 17 studies were identified with respect to XR technologies in IS education. There are, nonetheless, shared characteristics in the implementation of XR in IS education and other educational domains. Therefore, it is important to examine XR using interdisciplinary methods. We find that the TRL by itself is insufficient for assessing the implementation of XR. We found none of the studies in our collection had a TRL of 7 to 9. Therefore, we should broaden our research scope to encompass other databases to bridge this gap.

In a nutshell, the research on the Technology Readiness Level of Extended Reality in Information Systems Education, is currently in its early stages. To improve the current situation, it is imperative to develop alternative frameworks and employ other methodologies in future research. It is also crucial to effectively consider theories such as Affordance Theory, Task-Technology Fit, and Learning Theories. Another critical issue in the development of a new XR framework is the inclusion of fundamental capabilities of XR technologies, such as mental rotation, spatial-visualization, and spatial perception [57].

In the short term, future work should focus on conducting reviews by incorporating additional databases. It would be beneficial to employ other tools and approaches, such as Fink's taxonomy of meaningful learning, to effectively structure and organize the existing knowledge and explore the interconnections between various concepts [41]. Bibliometric analysis [26] is a method that can be employed to examine the relationships and interactions among several significant elements, including publications, authors, keywords, journals, and institutions which could add value to future research on Extended Reality and its associated domains.

REFERENCES

[1] Y. K. Dwivedi *et al.*, "Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy," *International Journal of Information Management*, vol. 66, p. 102542, Oct. 2022, doi: 10.1016/j.ijinfomgt.2022.102542.

[2] A. Koohang *et al.*, "Shaping the Metaverse into Reality: A Holistic Multidisciplinary Understanding of Opportunities, Challenges, and Avenues for Future Investigation," *the Journal of Computer Information Systems/the Journal of Computer Information Systems*, vol. 63, no. 3, pp. 735–765, Feb. 2023, doi: 10.1080/08874417.2023.2165197.

[3] N. Mohammadhossein, A. Richter, and S. Lukosch, "Benefits of Using Augmented Reality in Learning Settings: A Systematic Literature Review," 2022. [Online]. Available: https://aisel.aisnet.org/icis2022/learning_iscurricula/learning_iscurricula/4

[4] F. Martínez-Plumed, E. Gómez, and J. Hernández-Orallo, "AI Watch: Assessing Technology Readiness Levels for Artificial Intelligence," Publications Office of the European Union, Luxembourg, 2020. doi: 10.2760/15025.

[5] J.-P. Huttner and R.-B. Susanne, "An Immersive Memory Palace: Supporting the Method of Loci with Virtual Reality," *Americas Conference on Information Systems*, Jan. 2017, [Online]. Available: http://dblp.uni-trier.de/db/conf/amcis/amcis2017.html#HuttnerR17

[6] B. John and J. C. Kurian, "Making the world a better place with Mixed Reality in Education," pp. 1–11, Dec. 2019, [Online]. Available: https://aisel.aisnet.org/acis2019/37/

[7] B. John and J. C. Kurian, "Mixed reality in the Information Systems Pedagogy: An authentic Learning Experience," *International Conference on Information Systems*, pp. 139–151, Dec. 2019, [Online]. Available: https://aisel.aisnet.org/siged2020/4/

[8] C. Flavián, S. Ibáñez-Sánchez, and C. Orús, "The impact of virtual, augmented and mixed reality technologies on the customer experience," Journal of Business Research, vol. 100, pp. 547–560, Jul. 2019, doi: 10.1016/j.jbusres.2018.10.050.

[9] G. Salazar and M. N. Russi-Vigoya, "Technology Readiness Level as the Foundation of Human Readiness Level," *Ergonomics in Design*, vol. 29, no. 4, pp. 25–29, Jun. 2021, doi: 10.1177/10648046211020527.

[10] M. Héder, "From NASA to EU: the evolution of the TRL scale in Public Sector Innovation," *the Innovation Journal*, vol. 22, no. 2, p. 1, May 2017, [Online]. Available: http://eprints.sztaki.hu/9204/

[11] A. Mutreja, J. Chan, G. Peko, and D. Sundaram, "Design for Immersion: Immersive System Affordances and Aspects," 2024. [Online]. Available: https://aisel.aisnet.org/pacis2024/track12_hci/track12_hci/3

[12] H. Freude, C. Reßing, M. Knop, M. Mueller, and B. Niehaves, "Agency and Body Ownership in Immersive Virtual Reality Environments: A Laboratory Study".

[13] S. Nwaka, "Technology Readiness Levels, the Valley of Death and Scaling Up Innovations," in *Springer eBooks*, 2021, pp. 99–107. doi: 10.1007/978-981-16-0155-2_7.

[14] S. A. Gbadegeshin *et al.*, "Overcoming the Valley of Death: A New Model for High Technology Startups," *Sustainable Futures*, vol. 4, p. 100077, Jan. 2022, doi: 10.1016/j.sftr.2022.100077.

[15] J. Gonnermann and M. Teichmann, "Influence of Pre-Experience on Learning, Usability and Cognitive Load in a Virtual Learning Environment," 2023. [Online]. Available: https://aisel.aisnet.org/amcis2023/sig_ed/sig_ed/25

[16] S. Kahal, R. Jestice, and R. Huang, "Gender Effects in Directed versus Incidental Learning in a 3D Virtual World Simulation," *AIS Transactions on Human-computer Interaction*, vol. 15, no. 1, pp. 55–82, Mar. 2023, doi: 10.17705/1thci.00083.

[17] L. Tölle, E. Slawinski, J. Fromm, and M. Mirbabaie, "A Social Network Approach for Investigating Social Influences on Effective Use: Demonstration in Virtual Reality Collaboration," *ICIS 2023 Proceedings*, 2023, [Online]. Available: https://aisel.aisnet.org/icis2023/adv_theory/adv_theory/5

[18] J. Arbelaez, J. Kurian, and G. Beydoun, "Metaverse in Education: A Dynamic Capability Theory Approach," *AIS Electronic Library (AISeL)*. https://aisel.aisnet.org/siged2023/20/

[19] R. Doerner, W. Broll, P. Grimm, and B. Jung, Virtual and Augmented Reality (VR/AR). 2022. doi: 10.1007/978-3-030-79062-2.

[20] L. A. Cárdenas-Robledo, Ó. Hernández-Uribe, C. Reta, and J. A. Cantoral-Ceballos, "Extended reality applications in industry 4.0. – A systematic literature review," Telematics and Informatics, vol. 73, p. 101863, Sep. 2022, doi: 10.1016/j.tele.2022.101863.

[21] R. Vital, S. Sylaiou, D. Koukopoulos, K. Koukoulis, P. Dafiotis, and C. Fidas, "Comparison of extended reality platforms and tools for

viewing and exhibiting art," Digital Applications in Archaeology and Cultural Heritage, vol. 31, p. e00298, Dec. 2023, doi: 10.1016/j.daach.2023.e00298.

[22] P. A. Rauschnabel, R. Felix, C. Hinsch, H. Shahab, and F. Alt, "What is XR? Towards a Framework for Augmented and Virtual Reality," Computers in Human Behavior, vol. 133, p. 107289, Aug. 2022, doi: 10.1016/j.chb.2022.107289.

[23] I. Bruno *et al.*, "Technology readiness revisited," Sep. 2020, doi: 10.1145/3428502.3428552.

[24] "Technology Readiness Level (TRL) Assessment Tool," [Online]. Available:https://ised-isde.canada.ca/site/clean-growth-hub/sites/default/files/attachments/TRL-e.pdf "2.2 Technology readiness levels (TRL) | EME 807: Technologies for Sustainability Systems." https://www.e-education.psu.edu/eme807/node/557

[25] I. Bruno, A. Donarelli, V. Marchetti, A. Schiavone Panni, B. Valente Covino, and F. Molinari, "Technology Readiness revisited: A proposal for extending the scope of impact assessment of European public services," 2019. [Online]. Available: https://ec.europa.eu/isa2/sites/isa/files/technology_readiness_revisited_-_icegov2020.pdf

[26] O. Öztürk, R. Kocaman, and D. K. Kanbach, "How to design bibliometric research: an overview and a framework proposal," *Review of Managerial Science*, Mar. 2024, doi: 10.1007/s11846-024-00738-0.

[27] "Societal Readiness Levels (SRL) defined according to Innovation Fund Denmark." https://innovationsfonden.dk/sites/default/files/2019-03/societal_readiness_levels_-_srl.pdf

[28] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement," *PLoS Medicine*, vol. 6, no. 7, p. e1000097, Jul. 2009, doi: 10.1371/journal.pmed.1000097.

[29] L. Salvador-Carulla, C. Woods, C. De Miquel, and S. Lukersmith, "Adaptation of the Technology Readiness Levels for impact assessment in implementation sciences: The TRL-IS checklist," Heliyon, p. e29930, Apr. 2024, doi: 10.1016/j.heliyon.2024.e29930. Available: https://www.sciencedirect.com/science/article/pii/S2405844024059619?ref=pdf_download&fr=RR-2&rr=8b72b3cf9f90aad8

[30] S. K. Boell and D. Cecez-Kecmanovic, "On being 'Systematic' in Literature Reviews in IS," *JIT. Journal of Information Technology/Journal of Information Technology*, vol. 30, no. 2, pp. 161–173, Jun. 2015, doi: 10.1057/jit.2014.26.

[31] Technology Readiness Assessment Best Practices Guide. 2020. [Online]. Available: https://ntrs.nasa.gov/api/citations/20205003605/downloads/%20SP-20205003605%20TRA%20BP%20Guide%20FINAL.pdf

[32] T. Stejskal, K. Kethüda, and J. Pfeiffer, "Knowledge All Around Me: Comparing the Effect of VR, Text and Desktop on Learning Outcomes," *AIS Electronic Library (AISeL)*. https://aisel.aisnet.org/ecis2023_rp/394/

[33] J. C. Mankins, "Technology readiness assessments: A retrospective," *Acta Astronautica*, vol. 65, no. 9–10, pp. 1216–1223, Nov. 2009, doi: 10.1016/j.actaastro.2009.03.058.

[34] N. Xi, J. Chen, F. Gama, H. Korkeila, and J. Hamari, "The Effect of Operating in Many Realities on Memory: An Experiment on Memory Recognition in Extended Realities," *Proceedings of the ... Annual Hawaii International Conference on System Sciences/Proceedings of the Annual Hawaii International Conference on System Sciences*, Jan. 2021, doi: 10.24251/hicss.2021.544.

[35] V. Salikutluk, H. Kampling, and B. Niehaves, "The Influence of Situational Factors and Gamification on Intrinsic Motivation and Learning," *Wirtschaftsinformatik*, pp. 1904–1915, Jan. 2019, [Online]. Available: https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1340&context=wi2019

[36] R. Seiler and D. Widmer, "Extended Reality in the World Wide Web: Investigating and Testing the Use Cases of WebVR Manuals," Proceedings of the ... Annual Hawaii International Conference on System Sciences/Proceedings of the Annual Hawaii International Conference on System Sciences, Jan. 2022, doi: 10.24251/hicss.2022.641.

[37] Y. Lin and A. Suh, "The Role of Spatial Ability in Learning with Virtual Reality: A Literature Review," Proceedings of the ... Annual Hawaii International Conference on System Sciences/Proceedings of the Annual Hawaii International Conference on System Sciences, Jan. 2021, doi: 10.24251/hicss.2021.011.

[38] K. Jahn, H. Kampling, H. C. Klein, Y. Kuru, and B. Niehaves, "Towards an Explanatory Design Theory for Context-Dependent Learning in Immersive Virtual Reality.," *Pacific Asia Conference on Information Systems*, p. 235, Jan. 2018, [Online]. Available: https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1234&context=pacis2018

[39] X. Bao, M. Shou, and J. Yu, "Exploring Metaverse: Affordances and Risks for Potential Users," *ICIS 2022 Proceedings*, p. 8, 2022, [Online]. Available: https://aisel.aisnet.org/icis2022/sharing_econ/sharing_econ/8

[40] H. Kampling, A. Schwarze, O. Heger, and B. Niehaves, "Conceptualizing Immersion for Individual Learning in Virtual Reality," *Wirtschaftsinformatik*, pp. 330–344, Jan. 2019, [Online]. Available: https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1201&context=wi2019

[41] N. Mohammadhossein, A. Richter, and S. Lukosch, "Augmented Reality in Learning Settings: A Systematic Analysis of its Benefits and Avenues for Future Studies," *Communications of the Association for Information Systems*, vol. 54, no. 1, pp. 29–49, Jan. 2024, doi: 10.17705/1cais.05402.

[42] Y.-T. Wang, K.-Y. Lin, and T. K. Huang, "An analysis of learners' intentions toward virtual reality online learning systems: a case study in Taiwan," 2021. [Online]. Available: https://hdl.handle.net/10125/70796

[43] [43]P. Diegmann, M. Schmidt-Kraepelin, S. Eynden, and D. Basten, "Benefits of Augmented Reality in Educational Environments - A Systematic Literature Review," *AIS Electronic Library (AISeL)*. https://aisel.aisnet.org/wi2015/103/

[44] [44]I. Wohlgenannt, J. Fromm, S. Stieglitz, J. Radianti, and T. A. Majchrzak, "Virtual Reality in Higher Education: Preliminary Results from a Design-Science-Research Project," *ISD*, Jan. 2019, [Online]. Available: https://aisel.aisnet.org/isd2014/proceedings2019/NewMedia/5/

[45] V. Stylianou and A. Savva, "Learn-by-doing virtually; a gamified and metaverse design for group projects aiming at enhancing constructivist and collaborative learning," *AIS Electronic Library (AISeL)*. https://aisel.aisnet.org/siged2022/3/

[46] [46]M. Frydenberg and D. Andone, "Enhancing and Transforming Global Learning Communities with Augmented Reality.," *Journal of Information and Systems in Education*, vol. 29, no. 1, pp. 37–44, Dec. 2018, [Online]. Available: http://jise.org/Volume29/n1/JISEv29n1p37.pdf

[47] H. Gösling, T. Dreesbach, J. Vogel, and E. Kochon, "Linking Augmented Reality with Peer Tutoring in Vocational Learning Environments: A Multi-Agent-Based Approach," *European Conference on Information Systems*, Jan. 2021, [Online]. Available: https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1020&context=ecis2021_rip

[48] A. Jacobs, Y.-C. Pan, and S. Joel-Edgar, "Are you in or not? A study into student intention to use immersive metaverse for learning," *AIS Electronic Library (AISeL)*. https://aisel.aisnet.org/ukais2023/4

[49] T. D. Grace and J. F. Cohen, "Business Process Management and Digital Game Based Learning," *AIS Electronic Library (AISeL)*. https://aisel.aisnet.org/amcis2016/ISEdu/Presentations/35/

[50] A. Mitchell, "Metaverse adoption for the teaching and learning of project management: an exploratory study of student use," *Deleted Journal*, vol. 12, no. 1, pp. 76–92, Mar. 2024, doi: 10.12821/ijispm120104.

[51] B. John, J. C. Kurian, R. Fitzgerald, and D. H. L. Goh, "Students' Learning Experience in a Mixed Reality Environment: Drivers and Barriers," *Communications of the Association for Information Systems*, vol. 50, no. 1, pp. 510–535, Jan. 2022, doi: 10.17705/1cais.05024.

[52] I. Reychav, L. Zhu, and D. Wu, "Identifying the elationship between technology curiosity and knowledge absorptive capability in an augmented reality smart class," Jan. 2017, [Online]. Available: https://aisel.aisnet.org/siged2017/6/

[53] A. Haj-Bolouri, "The Experience of Immersive Virtual Reality: A Phenomenology Inspired Inquiry," *Communications of the Association for Information Systems*, vol. 52, pp. 782–814, Jan. 2023, doi: 10.17705/1cais.05238.

[54] J. F. George, M. Chi, and Q. Zhou, "American and Chinese Students and Acceptance of Virtual Reality: A Replication of "The Role of Espoused National Cultural Values in Technology Acceptance," *AIS*

Transactions on Replication Research, vol. 6, no. 1, p. 1, Jan. 2020, doi: 10.17705/1atrr.00044.

[55] Z. Hong, C. F. Choi, and B. W. Fong, “Tell me, show me, involve me: Supercharging Collaborative Diagnosis with Augmented Reality,” *AIS Electronic Library (AISeL)*. https://aisel.aisnet.org/sighci2023/4/

[56] F. Martínez-Plumed, E. Gómez, and J. Hernández-Orallo, “Futures of artificial intelligence through technology readiness levels,” 2021. [Online]. Available: https://doi.org/10.1016/j.tele.2020.101525

[57] S. Tiwari, B. Shah, and A. Muthiah, “A Global Overview of SVA—Spatial–Visual Ability,” *Applied System Innovation*, vol. 7, no. 3, p. 48, Jun. 2024, doi: 10.3390/asi7030048.