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Characterizing UX Assessment in the Context of Immersive Experiences: A Systematic Mapping Study

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ABSTRACT

An immersive experience is a multisensory experience across a journey or task that's contextually relevant, enabled by a combination of interactions that create intuitive and emotional value for the user. As the technological landscape has evolved, immersive experiences have become increasingly integrated into our lives. The rise of immersive experiences comes with a focus on how to evaluate those experiences considering User Experience (UX). UX is a multifaceted construct, and its importance differs according to the type of experience. In this scenario, knowing how to evaluate UX is fundamental to understanding whether immersive experiences are pleasant. Despite some attempts to address the UX, a systematic approach to addressing UX in the immersive context still needs to be developed. This paper presents a Systematic Literature Mapping (SLM) to investigate how UX evaluations have been performed and the main UX dimensions that should be considered in immersive experiences, such as engagement, presence, and immersion. Our main result is a theoretical model that we proposed based on the UX definitions and relations from the literature. Our model can help study the relations between UX dimensions, establishing the primary UX dimensions regarding immersive experiences, and as a base for developing new UX evaluation techniques.

KEYWORDS

Immersion; user experience; UX; systematic mapping study; immersive experience; presence

1. Introduction

Interactive systems have become essential to our everyday lives (Costley, 2014). Technology is practically an inseparable part of our lives, and many of the experiences in this world are entirely technological (Jokinen, 2015). As people become more connected and dependent on technology (Rogers, 2009), it becomes deeply rooted in everyday experience (McCarthy & Wright, 2004). Technology has developed rapidly in this context, creating new opportunities for developing and interacting with applications, such as immersive technologies. Immersive technology blurs the boundary between the physical and virtual world, enabling users to experience a sense of immersion (Suh & Prophet, 2018). Furthermore, immersion has also been considered in the context in which the user does not directly interact with the immersive technology itself, but s/he experiences the immersive experience provided by it, e.g., ultra-high-definition television (UHDTV) [S02] and museums with interactive installations [S05 and S07].

With the rapid advancement of technology today, the recognition of usability, usefulness, and utility as sufficient quality attributes has diminished. Instead, User Experience (UX) has emerged as a comprehensive approach for designing and investigating interactive systems, offering a holistic perspective on how users interact with technology (Minge & Thüring, 2018). For interactive systems to thrive, they must meet user expectations and create a positive UX (Marques et al., 2021). According to ISO 9241-11:2018, UX is defined as the *perceptions and responses of users resulting from the use and/or anticipated use of a system, product, or service* (International Organization for Standardization, 2018). Since its inception, the evaluation of UX has grown as a field with diverse approaches (Pettersson et al., 2018). This increasing interest stems from the noticeable advancement of technology (Pyae & Joelsson, 2018). Consequently, research concerning software quality has become intrigued by how individuals "feel" during and as a result of engaging with technology (Hassenzahl, 2018). The success of software products hinges on users' satisfaction while using them (Zarour & Alharbi, 2017).

The dynamic nature of user experience presents challenges for UX evaluation activities (Zarour & Alharbi, 2017). At the same time, researchers have defined immersive technology from various perspectives (Lee et al., 2013; Suh & Prophet, 2018; Väänänen-Vainio-Mattila et al., 2015). For instance, one view emphasizes users' immersive experiences while using the technology (Lee et al., 2013). In that sense, traditional UX evaluation techniques like questionnaires may not be suitable for assessing UX within an immersive context. The use of questionnaires can disrupt the user's immersive experience, leading to a negative impact on their overall experience (Marques et al., 2020). Besides, the field of UX aims to provide a systematic approach for designing

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and analyzing users' comprehensive interactions in an immersive context (Väänänen-Vainio-Mattila et al., 2015). In that context, assessing the quality of immersive experiences has become a trending topic (Zhang, 2020). On the other hand, researchers have conducted limited research to understand users' needs and experiences related to these technologies (Suh & Prophet, 2018; Väänänen-Vainio-Mattila et al., 2015). Such attention raises the question: How are UX evaluations conducted in the context of immersive experiences?

Our primary goal is to provide inputs to support future research in establishing novel UX evaluation solutions for experiences with immersive technologies. To do so, we answer the question above by understanding the current state of UX assessment in the immersive context. We performed a Systematic Literature Mapping (SLM) to identify and systematically enumerate the UX evaluation techniques used to assess immersive experiences, the main UX dimensions evaluated, and the type of immersive experience investigated. SLMs are designed to give an overview of a research area through classification and counting contributions concerning the categories of that classification (Kitchenham et al., 2015; Petersen et al., 2015).

Our results contribute in two ways to the field of UX evaluation involving immersive experiences. First, we present the state of UX evaluation in the immersive context by explaining the leading technologies used to perform UX evaluations, the type of immersive experience investigated, and the most UX dimensions used in evaluations. We also propose a theoretical model of UX dimensions used in UX assessments in immersive experiences. Our model is based on definitions extracted from the papers and aims to define relationships between UX dimensions when considered in the context of immersive experiences. Our model can be helpful for many purposes, such as studying the UX dimensions relations, establishing UX dimensions that should be considered in UX evaluations, and as a base for developing new UX evaluation techniques focused on evaluating immersive experiences.

The remainder of this article is organized as follows: Section 2 presents related work. Section 3 presents the procedures and protocol followed in conducting this SLM. Then, Section 4 presents the obtained results, and Section 5 presents a theoretical model of UX dimensions in the context of immersive experiences. Finally, in Section 6, conclusions and future work are presented.

2. Related work

The growth of immersive technologies, or technologies that provide an immersive experience, is due to the technological advancements that helped make these technologies cheaper (Dirin & Laine, 2018; Lee et al., 2020). Despite the growing popularity of immersive technology and its influence on business and society (Huang & Liao, 2015), little research has been carried out to understand better what is known about immersive technology and, especially, how users experience these technologies (Suh & Prophet, 2018). Understanding immersion is a difficult task, albeit an important and urgent one (Zhang, 2020). The emergence of interactive technological products is accompanied by very explicit attention to UX (Rebelo et al., 2012), which has been introduced to emphasize the importance of the feelings that users experience as they interact with technological artifacts (Jokinen, 2015). Assessing the quality of immersive experiences has become a trending topic (Zhang, 2020).

To show the importance of UX in an immersive context, we can cite practical works of UX evaluation. For example, Shin (Shin, 2019) conducted a study to investigate how users experience the interaction with an immersive screen. For this, he investigated the relationship of some UX dimensions, such as engagement, immersion, flow, and presence, in the context of Ultra-high-definition television (UHDTV). Shin (Shin, 2019) proposes a model based on UX dimensions that impact the intention to use. The study indicates that UX can be significantly influenced by immersion.

Lee et al. (Lee et al., 2020) carried out a study to investigate the impact of absorptive experiences (e.g., education and entertainment experiences) on immersion, overall VR (Virtual Reality) museum experience, and intention to visit a museum. They collected data from 269 participants through a questionnaire. The results show that absorptive experiences greatly influence immersive experiences, VR museum experiences, and physical intention to visit the museum.

The importance of UX differs according to the type of product as well as its intended use (Rebelo et al., 2012). Measuring users' feelings while interacting with a product, system, or service is a significant challenge in UX evaluation (Nur et al., 2021). Due to the subjective nature of UX, the characteristics of current technological scenarios, such as the invisibility of devices and the lack of conscious interaction, among others, the UX evaluation becomes even more complex (Brennand et al., 2019).

To support these new systems, the quality evaluation should take into account new characteristics, such as context-awareness and mobility, to evaluate the interaction between the user and the system (Santos et al., 2013). In this sense, some attempts to identify what is essential to assess in the immersive context have been made, however, with different focuses and, sometimes, without a systematic approach.

Gonçalves et al. (Gonçalves et al., 2022) performed a systematic review of comparative studies aiming to investigate the impact of realism in immersive virtual experiences. From an initial set of 1300 papers, they selected 79 papers that met the eligibility criteria. Overall, most of the studies reported that higher realism has a positive impact on user experience. As their research interest was focused on the sense of realism, they did not do a comprehensive investigation into other dimensions of UX that impact the immersive experience. While this is not a limitation of the work, realism alone is not enough to have a holistic understanding of how we can evaluate UX in an immersive context.

Suh and Prophet (Suh & Prophet, 2018) conducted a literature analysis to investigate the state of immersive technology research. They collected 926 papers from the Scopus database. After applying the inclusion and exclusion criteria, they defined a set of 56 papers. The literature review reveals that immersion is a key construct representing users' cognitive reaction to immersive technology use. Besides, the findings indicate that the number of immersive technology studies is increasing. The focus of this work was not on the UX dimensions. Therefore, one of the points in which our work differs from the literature analysis made by Suh and Prophet is our focus on collecting UX dimensions in the context in which immersive technologies are used.

Tcha-Tokey et al. (Tcha-Tokey et al., 2018) propose a conceptual model of the UX in Immersive Virtual Environments (IVE) named User eXperience in Immersive Virtual Environment Model (UXIVE Model). They focused on the edutainment field and based the UXIVE on the four UX models referenced in the literature. They collected some UX dimensions and established relationships among them. After assessing the Model with Structural Equation Modelling (SEM) analysis, the results do not validate the proposed model. Then, they proposed a modified UXIVE Model with new UX dimensions relationships. Indeed, the modified model states that flow and engagement are the two components influencing presence; engagement is the unique component influencing immersion and others. Despite being based on four models from the literature, the UXIVE model lacks a systematic approach to support it. A systematic approach is important for providing grounded evidence when creating a model. Furthermore, the authors argue that the model needs to be validated in other contexts. We present in our work results related to UX dimensions collected based on a well-defined protocol and a systematic approach.

Although UX has received growing attention in immersive contexts, little research has been conducted to better understand what we know and need to know about how users experience these technologies, and immersive experiences (Suh & Prophet, 2018). Also, UX as a field seeks to offer a systematic approach to design and analysis of the user's holistic experience (Väänänen-Vainio-Mattila et al., 2015). Based on all these limitations, we conducted an SLM to characterize and identify which UX dimensions should be considered for evaluating immersive experiences.

3. Methodology for systematic mapping review

We followed a systematic methodology to conduct our SLM by defining a systematic mapping protocol to uphold the integrity of our SLM and provide a reproducible process. A protocol is an important document to ensure both the SLM's validity and conduction (Wohlin et al., 2012). We developed our protocol following the guidelines provided by Kitchenham et al. (Kitchenham et al., 2022) and Petersen et al. (Petersen et al., 2015).

3.1. Goal

In this SLM, our goal is to characterize how UX evaluation has been carried out when it comes to immersive experiences, identifying:

- The technologies used to enable immersive experiences.
- The primary UX dimensions used to define a good immersive experience.
- The instruments used to collect data for UX evaluation.
- The kind of immersive experiences that are reported in the collected publications.

Defining it helped us guide our SLM procedure and focused the search only on primary studies pertinent to our goal. Additionally, we defined some research questions. Following the guidelines by Kitchenham et al. (Kitchenham et al., 2022) and Petersen et al. (Petersen et al., 2015) to perform our SLM, we present our research questions, the search for primary studies strategy, and study selection process in the following subsections.

3.2. Research questions

This SLM review aims to offer insights that help us grasp the field's current state and how UX evaluations have been carried out within immersive experiences. In this regard, our goal is to gather data that empirically addresses the following high-level research question (RQ):

- RQ - What is evaluated and taken into account in UX assessments when examining the context of immersive experiences?

With this RQ, we aim to provide an overview of UX assessment in an immersive context, considering all the essential aspects, such as methods, tools, frameworks, approaches, and UX dimensions. We will define which approaches are most used to support UX assessments of immersive experiences and how they are used for data collection. We will refer to UX methods, techniques, frameworks, and approaches as technologies used to support UX assessment. This term "technology" has already been used by Rivero and Conte (Rivero & Conte, 2017) in another systematic mapping study related to UX.

To answer our high-level RQ, it is essential to understand what has been accomplished so far with UX evaluation regarding immersive experiences. Therefore, to obtain data on each selected publication and answer our RQ in a more structured way, we further refined it in a set of research sub-questions (RSQs). We provide our complete set of sub-questions below:

- **RSQ1** - *What are the technologies used in the UX assessment?* We aim to identify the most employed UX assessment technologies (e.g., techniques, frameworks, approaches, and others) in the context of immersive experiences.
- **RSQ2** - *What are the UX dimensions evaluated?* Our goal is to identify which UX dimensions are most analyzed in UX assessments considering immersive experiences. UX Dimensions are those that have an impact on the user experience (e.g., Emotion) (Zarour & Alharbi, 2017).
- **RSQ3** - *How are UX dimensions collected?* This sub-research question aims to identify the most common ways of collecting the data regarding the dimension.

Table 1. GQS papers.

ID	Publication title	Authors	Year	Terms for search string
1	Keeping Users in the Flow: Mapping System Responsiveness with User Experience	Rina A. Doherty and Paul Sorenson Intel	2015	immersive experience, flow, framework
2	Experiencing immersive virtual reality in museums	Hyunae Lee, Timothy Hyungsoo Jung, M. Claudia tom Dieck and Namho Chung	2020	absorptive experience, immersive experiences
3	How do users experience the interaction with an immersive screen?	Donghee Shin	2019	immersive experience, flow, presence, immersive technologies
4	Comparative Reality: Measuring User Experience and Emotion in Immersive Virtual Environments	Adam Greenfeld, Artur Lugmayr and Wesley Lamont	2018	immersive applications

- **RSQ4** - *What kind of immersive experience is evaluated?* We aim to identify which immersive experiences are most investigated in the scientific context, considering UX assessments.

The following subsections detail how the papers were collected and what we did at each step.

3.3. Searching for primary studies

In the first step in our methodology, we searched for primary studies that would adequately address the RQs. We began the search process by defining a known set of papers that we used as an oracle to validate the results of our search string. The results of search strings are heavily dependent on their quality (Wohlin, 2014; Zhang et al., 2011). One of the approaches to improving the search string's quality is the Quasi-Gold Standard (QGS), defined by Zhang et al. (Zhang et al., 2011). The QGS is a set of known studies of related venues, such as domain-specific conferences and journals, recognized by the community in a given field of research. We can define a search string based on the QGS in two ways: (i) subjectively and further evaluated (with possible refinement) based on the QGS; (ii) objectively by extracting keywords from the QGS. To establish a well-defined string, we followed an intermediate approach. First, we defined our search string subjectively (with terms related to the search context and validated by specialists), and then we refined the string based on the QGS keywords. Extracting keywords from a set of known papers is also recommended by Petersen et al. (Petersen et al., 2015). The QGS papers can be consulted in Table 1.

We selected only publications written in English, considering that most international conferences and journals adopt it as their primary language. Furthermore, English is the dominant language for global communication, making it possible for other researchers to replicate and/or expand this systematic mapping study.

Once we established GQS, we developed a search string to query three electronic databases to identify relevant studies. We searched for scientific publications of our SLM in the IEEE Xplore, ACM, and Scopus digital libraries. Scopus is a meta-library that indexes publications from several well-known publishers (e.g., Springer, Elsevier, and Taylor & Francis). ACM and IEEE are two of the leading digital libraries in Computer Science. We chose these databases because previous systematic literature reviews recommended them as appropriate and relevant for use (Dyba et al., 2007; Mendes et al., 2020; Petersen et al., 2015). At the end of the refinement, we created a generic string that we adapted for each electronic database, considering the syntax of each library. The generic string can be consulted in Table 2.

3.4. Selection criteria

We defined a set of inclusion and exclusion criteria to select publications related to the objective of this SML, that is, publications that present ways of evaluating UX in immersive contexts. The selection of studies in this SML consisted of two steps: (1) reading the title and abstract (abstract) – called the first filter, and (2) reading the entire publication – called the second filter. We developed two sets of inclusion and exclusion criteria. One set for the first filter and one for the second filter (see Table 3). In the first filter, one of the exclusion criteria (EC2) refers to excluding publications related to the context of games. We excluded those publications because the gaming context has many particularities that may not generally apply to other entertainment. For instance, it is common to consider difficulty or a feeling of fear as a positive aspect of some types of games, which is not true for other types of entertainment. These peculiar characteristics of games highlight the need for particular investigations in this context, including having a specific term called Player eXperience (PX) (Wiemeyer et al., 2016).

We performed this SML involving two other researchers to avoid single-researcher bias. Before performing the first and second filters, the researchers independently classified, according to the inclusion and exclusion criteria, a sample of 15 randomly selected publications. Then, we assessed the level of agreement between researchers applying Cohen's Kappa (Cohen, 1960) to ensure that the criteria were well-defined and understood. The result indicated a substantial agreement between researchers ($k = 0.70$), according to the interpretation of Landis and Koch (Landis & Koch, 1977) described in Table 4. Based on this level of agreement, the first author of this research classified the rest of the papers, including a consensus with other researchers when necessary.

In this SML, conducting a quality assessment of the returned publications was unnecessary, as it is not part of this SLM to assess the quality of existing work (Kitchenham et al., 2015). This can happen in the case of tertiary studies that investigate the methodology used in systematic reviews, which is not the objective of this SML.

3.4.1. Snowballing

Since a keyword-based search might omit relevant studies, we performed a snowballing-based search to complement our results. The snowballing strategy was adopted to obtain the best possible coverage of the relevant literature to this research. We performed backward snowballing, using the reference list of selected publications from digital libraries, to identify new publications and include them in the final selected publications (Wohlin, 2014). We got 1265 publications through backward snowballing (see Figure 1 in Results Section).

3.5. Extraction data strategy

After selecting the publications, we performed the data extraction process. We created an extraction form to answer the RSQ1-RSQ4 and our high-level RQ, defined in Section 3.2. The extraction form (see Table 5) defines the data extracted and the procedures to perform the data extraction. The data will include details of each publication (Kitchenham et al., 2015).

4. Results

4.1. Selected publications

The search string returned 1883 publications, of which 678 were from the Scopus, 92 from the IEEE, and 1113 from the ACM. Of the total publications returned, 310 were duplicated between libraries, 15 from Scopus, 26 from IEEE, and 269 from ACM, resulting in 1573 unique publications. In the first filter (reading the title and abstract), 1409 publications did not meet the inclusion criteria (see Table 3), and we excluded them from the selection process. The remaining 164 publications were entered into the second filter to be read in full and submitted to the inclusion and exclusion criteria established for the second filter. In the second filter, 123 publications did not meet the inclusion criteria. We excluded them, resulting in 41 publications accepted in the second filter and further extraction.

We collected 1449 references regarding the backward snowballing process from the 41 selected SLM publications. Of these, 7 were duplicates, resulting in 1442 unique publications submitted to the same inclusion and exclusion criteria defined in Table 3. At the end of the process, 13 publications passed the first and second filters and were added to the extraction step. All publications selected in the SML can be consulted in Appendix A.

Table 2. Generic search string.

(″immersive experience″ OR ″immersive environment″ OR ″absorptive experience″ OR ″immersive app″
OR ″immersive apps″ OR ″immersive application*″ OR ″immersive technology″)
AND
(″framework″ OR ″method″ OR ″tool″ OR ″technique″)
AND
(″user experience″ OR ″ux″ OR ″flow″ OR ″engagement″ OR ″presence″)
AND
(″entertainment″)

4.2. Publication's overview

The selected publications were published between 2003 and 2023. The graph in Figure 2 shows that the number of publications has grown since the first publication was identified in 2003 (there was no initial time limit on the search). Considering that we carried out the publications' collection of this systematic mapping study in October 2023, data for this year may be incomplete.

Most publications were published in conference proceedings, totaling 31 publications. Fifteen publications were published in periodicals, and another four were presented at conference workshops. Figure 2 shows the distribution of publications by venue. Table 6 lists all the venues where the papers were published.

4.3. RSQ1: What are the technologies used in the UX assessment?

This research question aims to identify the most used techniques, methods, frameworks, approaches, and others to carry out a UX assessment in the context of immersive experiences. Figure 3 shows the most used technologies in UX assessments. As in other literature surveys on UX evaluations, without considering the immersive context, questionnaires and interviews are the most used forms of UX evaluation (Pettersson et al., 2018; Vermeeren et al., 2010).

Table 4. Agreement strength associated with kappa statistics.

Cohen's Kappa	Strength of agreement
< 0.00	No agreement
0.00 – 0.20	Slight agreement
0.21 – 0.40	Fair agreement
0.41 – 0.60	Moderate agreement
0.61 – 0.80	Substantial agreement
0.81 – 1.00	Almost perfect agreement

Table 3. Inclusion (IC) and exclusion criteria (EC).

ID	Description	Filter
IC01	The title and/or abstract indicate using some technology to evaluate the UX in immersive experiences.	1
IC02	The publication discusses ways to evaluate the UX of immersive experiences.	2
IC03	The publication discusses aspects to be considered in immersive experiences.	2
EC01	The publication does not meet the inclusion criteria.	1, 2
EC02	The publication is related to the gaming context.	1
EC03	The publication is not accessible in full-text online.	2
EC04	The publication is a duplicate or a previous version of another selected paper.	1, 2
EC05	The publication is not written in English.	1, 2
EC06	The study is published as a book or gray literature.	2
EC07	The publication is a secondary study (Systematic Review or Mapping Study).	1, 2

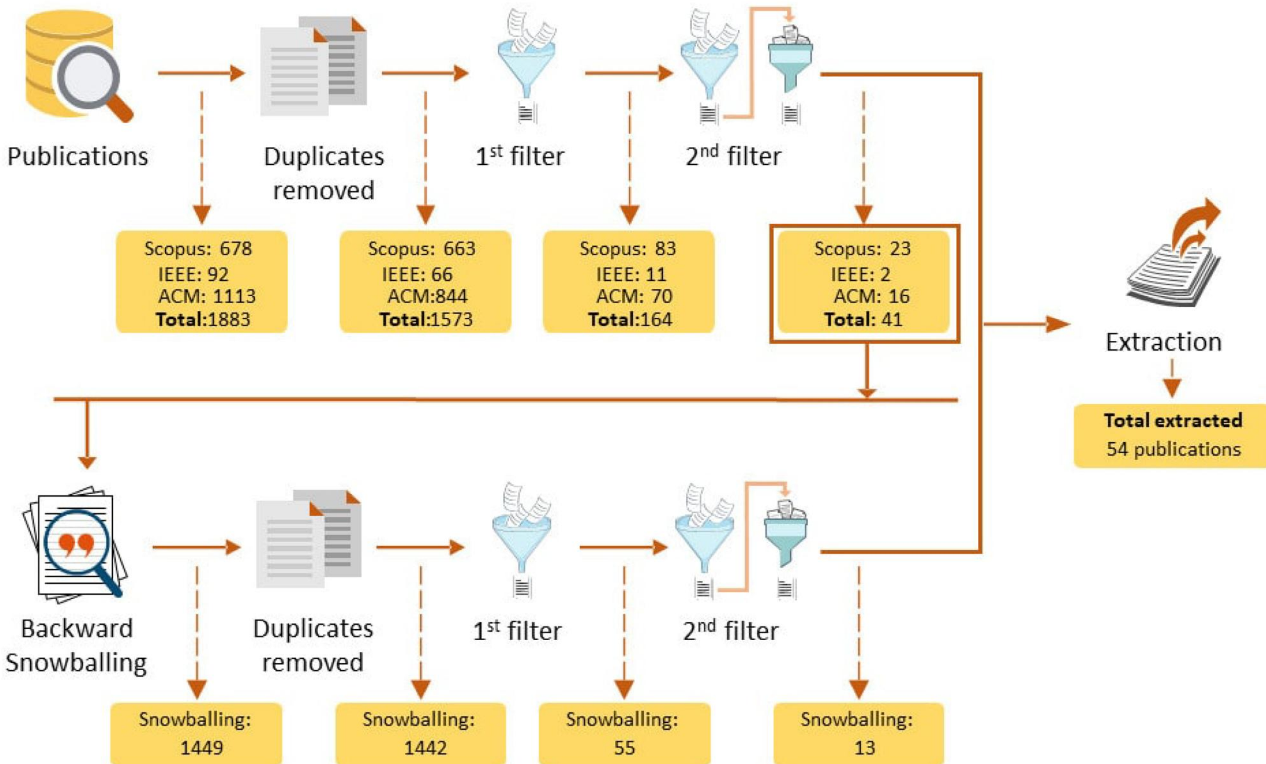

Figure 1. Search and selection results.

Table 5. Extraction form.

General Information	Question for extraction
Publication overview	What is the purpose of the publication? What is the motivation?
Publication's summary from the researcher's point of view	The overview of the publication focused on the interests of the research question.
Does the publication deal directly with UX?	() Yes () No
RSQs	Question for extraction
RSQ1 Technology	What are the technologies used in the UX assessment?
RSQ2 UX dimensions	What are the UX dimensions evaluated?
RSQ3 How to evaluate UX dimensions	How are UX dimensions evaluated/collected?
RSQ4 Immersive experience	What kind of immersive experience is evaluated?

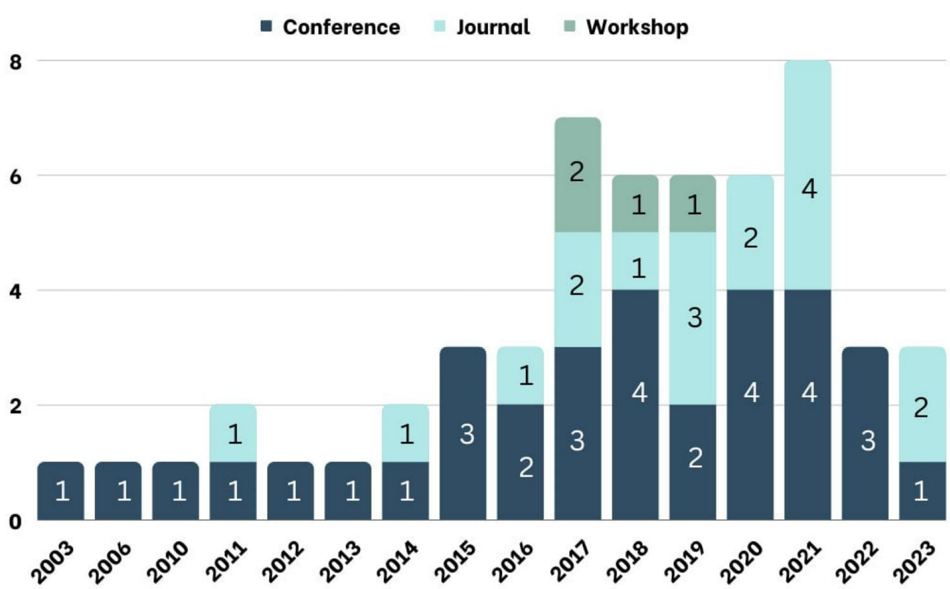

Figure 2. Publications per year and venue.

Figure 3 shows the techniques used in each technology category (limited to the five most used technologies). We noted that within the Questionnaire category, the most used technique was the Likert scale. In addition, there are two intensity scale occurrences and two Absolute Category Rating (ACR). The second most used technology was the Interview. Of 18 interviews carried out in the investigated studies, 6 were Semi-structured interviews, and 4 were open-ended interviews, i.e., the interviewer left the interviewee free to express himself about the experience. In addition, there were two structured interviews, where the interviewee limited himself to the interview questions, and one was a contextual interview.

The observation techniques totaled seven correspondences, among which, in six publications, the adopted observation process was not clearly described. Among the other occurrences is shadowing, which consists of an evaluator acting as a person's" shadow" during the experience and taking notes. In addition, an ethnographic approach and in-situ observation were used.

The log is another way used to evaluate immersive experiences. In some publications, there is only an indication that the log-based approach was used, but it is unclear which data was collected from the logs. On the other hand, cameras, time, cards with user data, and records of interactivity and behavior were data used as logs in other publications.

Physiological measures are also widely used in UX assessments in the immersive context. Most of the measurements collected refer to heart rate. There was an occurrence of a device for collecting physiological measurements called Hexoskin.

4.4. RSQ2: What are the UX dimensions evaluated?

Figure 4 presents the twelve most evaluated UX dimensions in the primary studies investigated in this SLM. Presence is the most recurrent dimension in UX assessments in the immersive context, followed by immersion and engagement. These dimensions have been understood as the main dimensions of UX, both inside and outside the immersive context (Alves et al., 2021; Marques et al., 2020; Oyedele et al., 2018; O'Brien et al., 2018). For instance, if a product or an experience is not engaging, users will quickly abandon it (Oyedele et al., 2018).

Usability, Flow, Enjoyment, Emotion, and Satisfaction are the other dimensions most investigated in the immersive

Table 6. Top venues.

Venue	# Citations	Papers (Appendix A)
Conference on Human Factors in Computing Systems (CHI)	5	S15, S32, S42, S43, S48
ACM International Conference on Interactive Media Experiences	3	S41, S44, S50
Computers in Human Behavior	3	S02, S19, S37
Multimedia Tools and Applications	2	S21, S23
ACM Transactions on Multimedia Computing, Communications, and Applications	2	S22, S24
Brazilian Symposium on Human Factors in Computing Systems (IHC)	2	S35, S45
International Conference on Applied Human Factors and Ergonomics (AHFE)	1	S01
Information & Management	1	S03
IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)	1	S04
NORDICHI	1	S05
Advances in Computer Entertainment Technology Conference	1	S06
Australia Conference on Computer-Human Interaction	1	S07
UbiComp	1	S08
IEEE International Workshop on Multimedia Signal Processing	1	S09
Spring Simulation Multiconference	1	S10
Multimodal Technologies and Interaction	1	S11
International Conference on Serious Games and Applications for Health	1	S12
International Conference on Human-Computer Interaction (HCII)	1	S13
Eurographics Workshop on Graphics and Cultural Heritage	1	S14
Symposium on Virtual Reality Software and Technology	1	S16
International Conference on Cyberworlds	1	S17
International Workshop on Multimedia Alternate Realities	1	S18
International Conference on Digital Arts	1	S20
Conference on Italian SIGCHI Chapter	1	S25
New Media & Society	1	S27
Virtual Reality International Conference	1	S28
INTERACT	1	S30
Conference of the European Association of Cognitive Ergonomics	1	S29
Advances in Human-Computer Interaction	1	S31
International Conference on Quality of Multime dia Experience (QoMEX)	1	S33
Thematic Workshops of ACM Multimedia	1	S26
IEEE Transactions on multimedia	1	S34
International Conference on Research into Design	1	S36
Computer Graphics International Conference	1	S38
Behaviour & Information Technology	1	S39
International Journal of Human Computer Studies	1	S40
Symmetry MDPI	1	S46
Australasian Journal of Information Systems	1	S47
ACM Symposium on Virtual Reality Software and Technology	1	S49
Cyberpsychology, Behavior, and Social Networking	1	S51
International Conference on Intelligent User Interfaces (IUI)	1	S52
ACM Journal on Computing and Cultural Heritage	1	S53
ACM Multimedia Systems Conference	1	S54

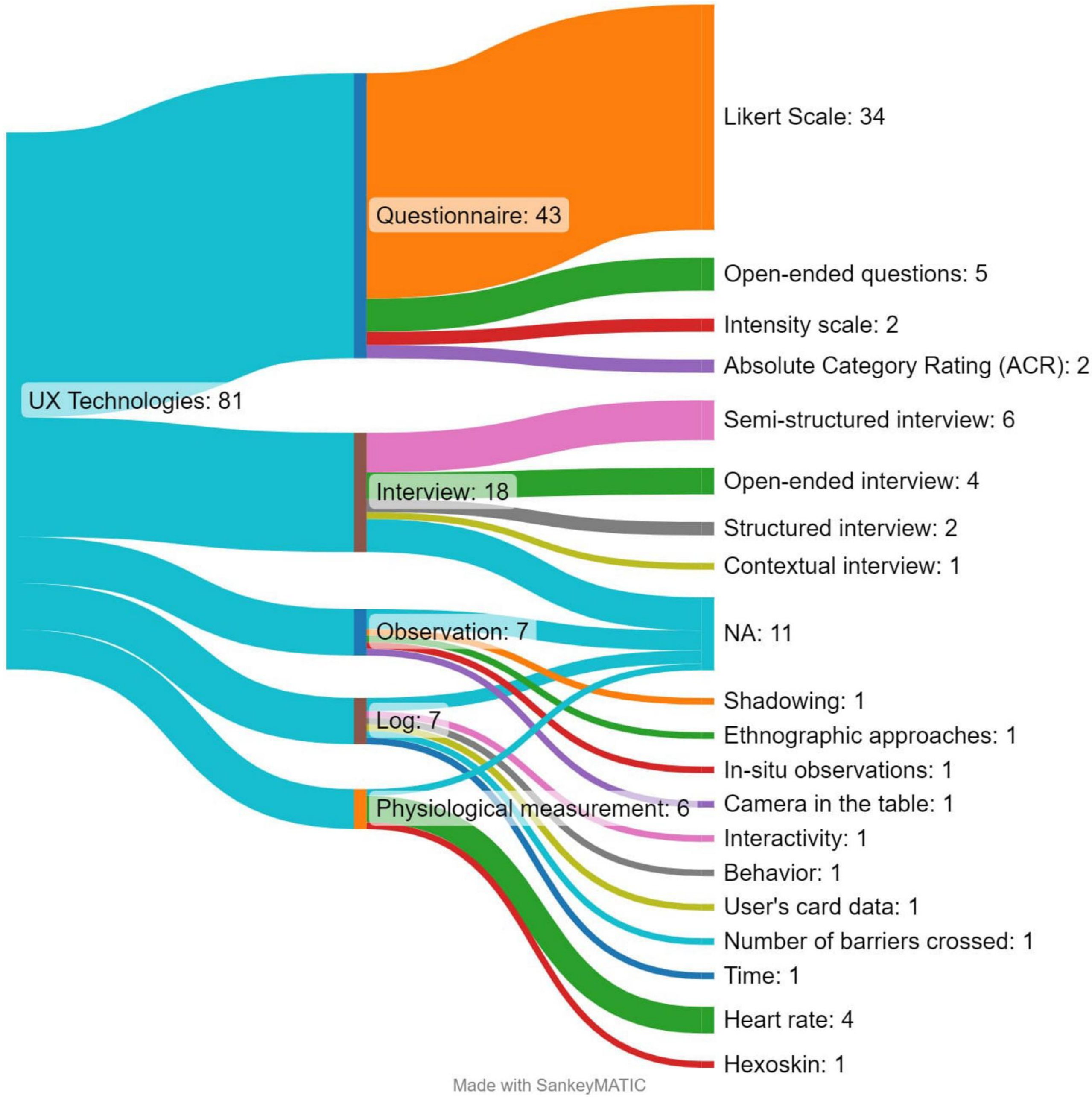

Figure 3. Techniques used in each technology.

context. We highlight the main occurrences of UX dimensions, classifying which dimensions are most used in UX assessments from the five occurrences. This finding shows which dimensions most impact the user experience when experiencing immersive entertainment and, consequently, are the most important to consider in a UX assessment. Therefore, a UX evaluation approach for immersive context must consider some or all of these dimensions in its construct.

4.5. RSQ3: How are UX dimensions collected?

The way the investigated UX dimensions in immersive contexts are collected varies greatly. Perhaps this variation results from the fact that there is still no widely used and accepted approach as an assessment standard. Consequently, the most common ways of collecting data regarding the UX dimensions are replicated in evaluations of immersive experiences, as shown in Figure 3.

Likert scales are always highlighted in any literature survey on assessing UX (Pettersson et al., 2018; Rivero & Conte, 2017; Vermeeren et al., 2010). It can be explained by the low cost of using them and their ease of employability. It is not a technique requiring much cognitive load from users or difficulty pointing out how their experience was (Marques et al., 2018). We discovered that most of the scales used in the analyzed works are not standardized, i.e., they were self-developed for a specific assessment interest, such as immersion. This finding regarding self-developed scales is also made in other UX reviews (Pettersson et al., 2018; Vermeeren et al., 2010). The fact that UX is multidisciplinary and contextual contributes to these results (Zarour & Alharbi, 2017).

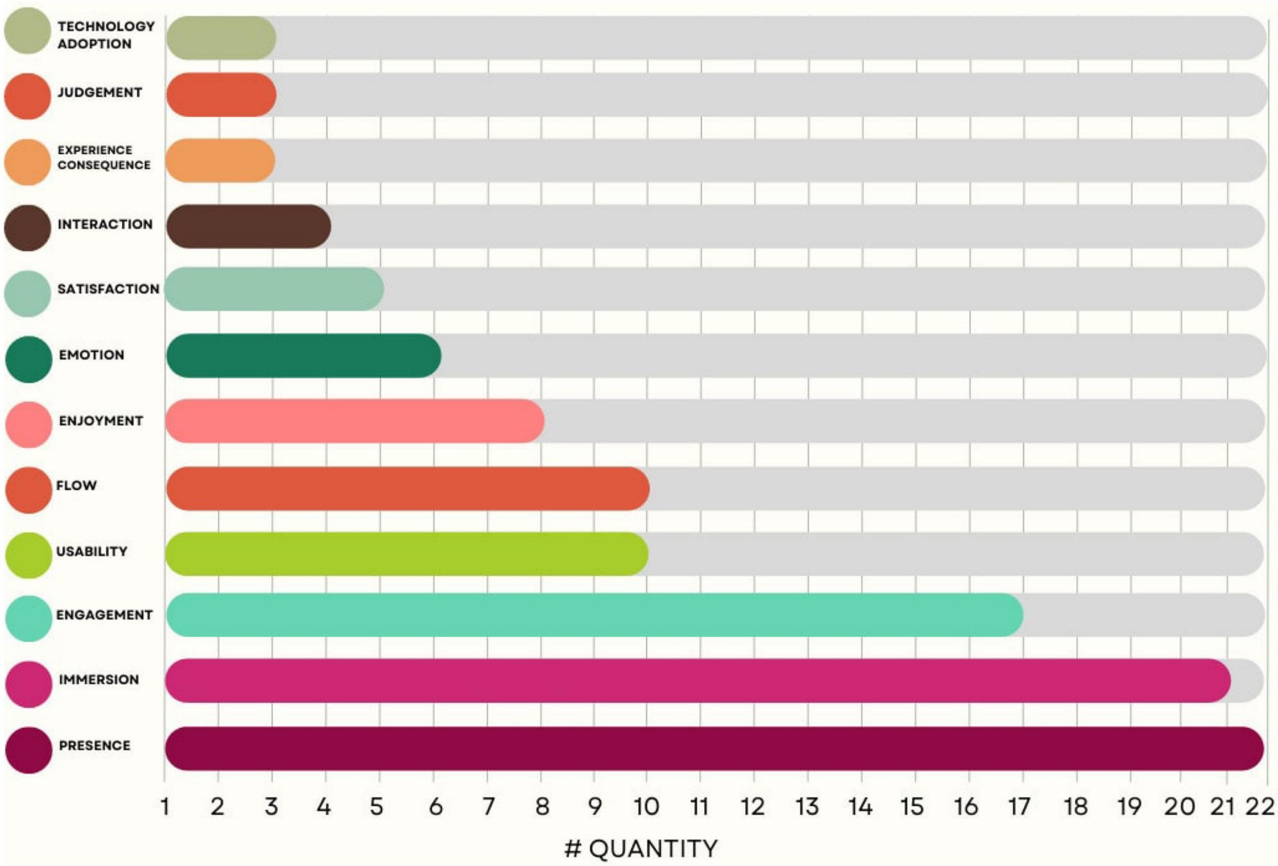

Figure 4. UX dimensions most evaluated.

Table 7. Top entertainment.

Entertainment	# citations
Immersive Virtual Reality	8
360-degree video	6
Head-Mounted Display (HMDs)	4
Interactive Installations	2
Museum - Virtual experience	2
Virtual Environments	2
Interactive Artwork	1
Immersive Journalism	1
Interactive Multimedia Installations	1
Interactive Films	1
Multisensory VR experience	1
Immersive Film	1
Art Installation	1
Social Virtual World	1
Map exploration	1
VR Video	1
Virtual Dome System using HMDs	1
VR service Journeys	1
3D learning environment	1
Fun Park	1
Tangible 3D Tabletop	1
Museum	1
Living History Museum	1
Immersive UHDTV	1

4.6. RSQ4: What kind of immersive experience is evaluated?

In Table 7, it is possible to see the types of immersive experiences most investigated in the literature. We noted that Immersive Virtual Reality is the most common experience in the immersive context. The fact that immersive virtual reality is the type of experience most reported in publications can be explained by the fact that it is the simplest (and perhaps most economical) way to set up an immersive environment. Videos watched through Virtual Reality (VR) glasses (360-degree video) are the second most common experience in the immersive context. The increase in the consumption of immersive videos is due to the broad access to mobile devices used in conjunction with Virtual Reality Glasses (Head-Mounted Displays - HMD) (Torres et al., 2020). In addition to HMDs, VR is one of the most common ways to deliver immersive experiences. Its potential has been considered since the early days of technology (Gonçalves et al., 2020), and research has been carried out in different contexts in which VR can be used.

4.7. Group analysis

The group analysis presented here is based on the principles of cluster analysis. Cluster analysis is an analytical tool that classifies data into meaningful groups based on similarities between the data (Balijepally et al., 2011). From the data collected in this SLM, we created four groups following the similarity criterion (Balijepally et al., 2011), which forms the grouping based on the similarity of the data. Although cluster analysis is widely used in the context of Machine Learning (ML), using powerful algorithms to define clusters, in our group analysis, we only used the clustering principle of cluster analysis since the clustering process performed was manual and not based on algorithms. However, two senior researchers reviewed the grouping process. The similarity data we use to define the groups is unique and presented in each group (the groups are independent). Furthermore, the data collected in each group is also different, as the data depends on the characteristics present in each group and in each paper. We present the Museum, 360-degree Video, Log, and Immersive Virtual Reality groups in the following subsections.

4.7.1. Museum group

We identified the Museum group based on data similarity regarding the evaluation context. We grouped five publications (S03, S05, S07, S20, and S32 – see Appendix A) relating the immersive experience to museums. For each publication in this group, we collected information about the paper's primary purpose, how the experience was evaluated, whether the papers featured a study, whether the study was carried out in a real context (i.e., in a museum) or a simulated/controlled environment and the main result of the paper. As a summary of the results, we can point out the following conclusions:

- Immersion is not just about virtual environments and can be achieved without VR/AR (Augmented Reality) technologies (S05). In publication S05, the authors use dated objects, such as an antique bed, to heighten Immersion during a museum visit. There are different types of immersive experiences that are not necessarily linked to VR/AR.
- The paper S32 offers a way to design an interactive artwork (e.g., create artwork by interacting with objects) to provide a more appropriate experience where the user can interact and help create an artwork, showing an example of immersion where the user is immersed through active participation without using VR.
- In the museum context, content plays an important role in engaging people. Considering that engagement is one of the most evaluated UX dimensions in immersive experiences, knowing what promotes engagement in a given context is important to provide a good experience.

4.7.2. 360-Degree video group

We identified the second group based on the similarity of the type of immersive experience promoted. The group of 360-degree videos is composed of five references collected in this SML (S09, S12, S14, S15, and S21 – see Appendix A). In this set of publications, the immersive experience was directly linked to the consumption of immersive videos through Head-Mounted Displays (HMDs). For each publication, we collected information concerning the purpose of each publication, how the experience was carried out, and how the data used in the UX assessment was collected. We also collected whether the paper presents a study, which technologies were used to provide the immersive experience, the reported experiences, and the main result. We present a summary of the results below:

- Overall, the HMD helps to improve the sense of presence, engagement, and immersion.
- HMD was the most used technology to provide an immersive 360° video experience.
- Sensory effects can increase the presence in a 360° experience (publications S09, S12, S14 and S21).
- Engagement and presence increase when interactive elements are added to the 360° video experience (such as scents or real elements related to the experience) (S09).
- Almost all studies used a questionnaire to evaluate the experience. In addition, the assessments were mainly after the experience (S09, S12, S15 and S21).
- The studies were carried out in a controlled environment.

An issue raised in the analysis of this group refers to the forms of UX evaluation. Most of the evaluations were carried out using questionnaires, and consequently, after the experience, since it is not feasible to interrupt the user during the immersive experience to question them about their experience. This interruption would significantly affect their experience (Marques et al., 2020). Is it not more feasible to evaluate the UX in these experiences based on data collected during the experience? For instance, engagement should be better measured based on what the user interacted with during the experience rather than after the experience itself. The question may be answered with the analysis of the next group.

4.7.3. Log group

We defined the Log group based on the similarity of how data was collected in the UX assessment. The Log group consists of eight references (S07, S19, S25, S30, S35, S38, and S41 – see Appendix A). The main characteristic of this group is that the data used to perform the UX assessment was based on log collection.

For each publication, we extracted information on how the logs were collected and analyzed, what data was recorded, and whether the paper correlated the data collected with any UX dimension. Also, we extracted whether the paper presented a study and whether the UX assessment was based only on log data or in conjunction with some other technology (such as questionnaires). The results are summarized below:

- In general, logs are associated with some UX dimensions, such as engagement (S07, S30) or behavior (S25). There was one occurrence of log associated with immersion (S19).
- In general, logs are used to triangulate data with other methods. In the selected papers, there was a correlation of log data with questionnaires (S19 and S25), interviews (S07, S25, and S30), observation (S07, S25, and S30), and video analysis (S25 and S30).
- There is no formal definition of the log. There is usually only an indication of what is collected. Some papers formally define what the log is and its measures. For example, paper S19 indicates that space exploration and

social engagement (measures related to the paper's context) were recorded in the log and that space exploration is related to the total barriers crossed by study participants. Social engagement refers to the duration of interaction between two users (represented by an avatar in the context of the paper's immersive experience) (S19). There was an occurrence in which it was not mentioned how the log was collected or analyzed. The authors only present the results, saying they were based on log collection (S30).
- In all papers, there were studies reported where data were collected in interactive installations (S07), Virtual Environments (S19), events (S25), and public spaces (S30).
- The logs were not analyzed automatically. When the paper describes the log analysis, the experts analyzed the log data to extract some information (such as behavior, immersion, and engagement).

The main result of this group refers to the possibility of collecting data that can be used to carry out a UX assessment within the immersive context. In the group of 360-degree videos, we noted the need to collect data without interrupting the immersive experience and that they were representative data of what the user did during the experience. In this sense, logs are an interesting alternative in this scenario, as they allow data collection on user interaction without interrupting their experience.

4.7.4. Immersive virtual reality group (UXIVE model)

We identified this group based on the similarity of the UX assessment context. This group comprises three references identified through snowballing (S28, S29, and S31 – see Appendix A). The main characteristic of this group is related to the proposal of the papers. The authors of the papers are the same (therefore we named the group with the same name as the model proposed by the authors of the references), and the intention is to develop a way to evaluate UX in immersive virtual environments (IVEs).

For each publication, we collected information such as the paper's primary purpose, the context of the proposal, the year of publication, the main contribution, and whether the papers presented a study. A summary of the results is presented below, showing the details of the authors' UX assessment proposal for a context of immersive experiences (IVEs):

- The questionnaire proposed in paper S28 is quite extensive, with many items (87 items). This questionnaire is based on several other questionnaires in the literature that assess a UX dimension in isolation. For example, they rely on the Presence Questionnaire (PQ) to measure Presence and The Immersive Tendency Questionnaire (ITP) to measure Immersion. The final questionnaire comprises parts of several questionnaires, which helps explain its extension.
- In paper S29, they define a metric to measure the interaction system (faster interaction between two IVEs, the CAVE and HMD), called completion time. In this paper, we noted an underexplored approach in UX context, by using metrics to collect data from users.
- The analysis carried out in the S31 paper presents a different result, focusing on showing which UX dimensions influence the other. The main results indicate that Engagement influences Presence, Immersion, and adoption of specific technology, and Flow influences emotion and Presence.

There is an example of a metric definition used to investigate what kind of immersive technology provides a faster interaction among the results obtained. This example of metric definition can be used in conjunction with the log group results, defining log-based metrics for collecting data that can indicate the user experience. The main proposal of the set of papers in this group refers to elaborating a UX evaluation questionnaire aimed at the context of immersive experience. Specifically, the UXIVE questionnaire aims at immersive experiences in virtual environments. This questionnaire shows that the attempt to develop a form of UX evaluation based on scales is considered a good alternative, especially considering its positive points such as ease of use, low implementation cost, and low cognitive load spent on the evaluation (Marques et al., 2018). However, to consider several dimensions of UX in the immersive context, the questionnaire proposal presented in paper S28 was quite extensive, which can directly interfere with the question of the user's cognitive load during the evaluation.

5. Towards a UX dimension model

In the previous sections, we summarized the findings of this SLM. As we pointed out at the end of Section 2, there is a lack of a systematic approach that allows the identification of UX dimensions that should be considered in a UX assessment of immersive experiences. Our SLM findings showed that some UX dimensions are evaluated more than others (e.g., presence in papers S09, S27, and many others). From the knowledge of the dimensions reported in the literature and the establishment of relationships between these dimensions, we present a theoretical model of UX dimensions as the primary research result of this SLM. Our model can be helpful for many purposes, such as studying the UX dimensions relations, establishing UX dimensions that should be considered in UX evaluations, and as a base for developing new UX evaluation techniques focused on evaluating immersive experiences. We present our theoretical model in Figure 5. In the following subsections, we discuss the hypotheses developed from the analysis of the papers and how we performed the analysis to arrive at the hypotheses defined in the model.

5.1. Dimension confidence level

In this section, we explain the process we followed to establish the hypothesis that constitutes our model. First, we identified the dimensions from the extracted papers in this SLM. We considered both the papers from digital databases and the backward snowballing. As we want to define a model that helps characterize the UX dimensions in the immersive context, we only use dimensions with at least five occurrences, and we find relationships from the papers analyzed in this SLM.

To synthesize the dimensions, we performed a definition analysis. We first counted the occurrence of each one of them in the publications, and then we performed an analysis based on their respective definitions. We aimed to investigate the consistency with which different dimensions are assessed and whether different publications conceptualized the dimensions relatedly. For example, publications S02 and S31 assess the immersion dimension and define it correlatedly, indicating that the understanding of immersion converges in both works.

As in the extracted papers, authors can either define the concept of one dimension, for example, immersion, or use the concept of another work that defines immersion. We analyzed these definitions at two levels. First, we checked if the papers we extracted in SLM defined the dimensions used. Otherwise, we analyzed the referenced concept. As the referenced paper could be making another reference, we decided to stop the analysis until the second level. Otherwise, we could get into a multilevel quest.

After collecting all the definitions up to the second level, we held a meeting to discuss the concepts and relationships that could be derived from the collected definitions. This meeting involved two UX experts and the first author of this research.

The dimensions were analyzed until some hypotheses could be elaborated to define the relationships between the UX dimensions evaluated in the immersive context. These hypotheses are further discussed in the following subsection and visually presented in Figure 5, where we organized the hypotheses in tuple format. Each tuple consists of (i) the hypothesis, (ii) the reference that indicates the paper in which we extracted the hypothesis, and (iii) the immersive context defined in the paper. Considering that there may be more than one paper corroborating the hypothesis and, consequently, different contexts in the papers, there may be both a list of publications and contexts (organized in brackets) in a given tuple (for example, in H1 in Figure 5).

5.2. Discussing the hypotheses

In the following subsections, we present the dimensions, their correlations, and the hypotheses derived from the definitional analysis.

5.2.1. Engagement, immersion, presence, and emotion dimensions

Immersion is recognized as the "illusion" that "the technology replaces the user's sensory" [S28]. It is considered an experience that occurs at one moment in time (Teng, 2010). Immersion is being considered a key aspect of UX in emerging technologies, such as those that provide immersive experience (Shin, 2019). According to paper S13 from our extracted papers (see Appendix A), Immersion has been defined in many ways. For instance, in our second level analysis (explained in section 5.1, we identified that Immersion was often conceptualized as a three-level construct composed of Engagement, Engrossment and Total Immersion (Brown & Cairns, 2004).

According to Brown and Cairns (Brown & Cairns, 2004), Engagement is the lowest level of involvement and must occur before Engrossment and Total Immersion. Therefore, Engagement is the first step to reaching Immersion. In paper S02 (from our selected papers), we can understand Immersion as becoming a part of the experience physically

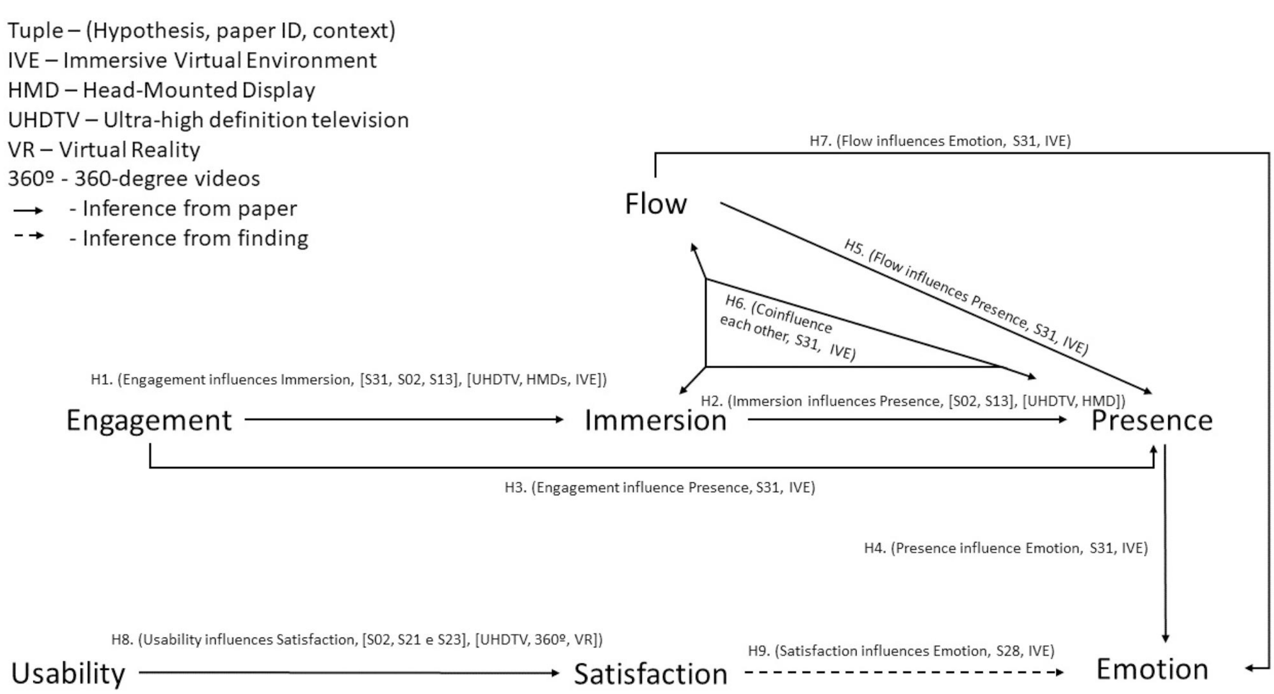

Figure 5. UX dimensions theoretical model.

or virtually. In this sense, a person first engages in an immersive experience, taking the first steps to start interacting to achieve Immersion. From Engagement, the user may be able to become further involved with the experience and become Engrossed, which means there is a high level of emotional investment. If the experience does not fail to continue to attract the participant's interest, the participant tends to move towards Total Immersion, and Total Immersion is Presence (Brown & Cairns, 2004).

Engagement generally means offering increased opportunities to interact fully with the experience. This idea is supported by many papers in our SLM (S04, S07, S25, S29 and S31). Presence refers to the extent to which two people interacting via a technological medium feel as if they are together (Nicovich et al., 2005). In other words, Presence is defined as the feeling of "being there," the sense that a person has been transported to another place (Slater, 2003).

If a user's sense of Presence is high, it means that the immersive experience is able to produce an environment that deludes users into thinking that what they are experiencing is real [S21], causing several different emotions. In this sense, Presence is one dimension that influences Emotion.

Since Engagement is the first step of Immersion, and achieving a high level of Immersion (Total Immersion) means achieving Presence and Presence influences Emotion, we derived three hypotheses:

- H1. Engagement influences Immersion.
- H2. Immersion influences Presence.
- H3. Engagement influences Presence.
- H4. Presence influences Emotion.

5.2.2. The Flow and emotion dimensions

According to paper S02, when people are in the Flow, they shift into a common mode of experience when they have become absorbed in their activity. The authors in the paper S51 also agree with this idea, defining Flow as a mental state of absolute absorption and involvement. This mode is characterized by a narrowed awareness that results in irrelevant perceptions and thoughts being filtered out by a loss of self-consciousness, responsiveness to clear goals, unambiguous feedback, and a sense of control over the environment. The concept of Flow as the state of being fully absorbed in activity was credited to psychology professor Mihaly Csikszentmihalyi (Csikszentmihalyi, 1990). Based on the characteristics described above, we can relate the state of being fully absorbed with a high level of involvement, which means being immersed and achieving Presence. Shin et al. (Shin et al., 2013) had already indicated that Flow, Immersion, and Presence influence each other, and Guertin-Lahoud et al. [S51] reinforce this argument, indicating that when Presence and Immersion are optimal, Flow is more likely to emerge. In addition, in paper S31, Flow is defined as "an enjoyable experience in which a participant feels an important level of behavioral control, happiness, and enjoyment." This way, when the user enters the Flow state, it means achieving control, happiness, and enjoyment, i.e., subjective feelings that define Emotion [S31]. Therefore, H5, H6, and H7 are hypothesized as follows:

- H5. Flow influences Presence.
- H6. Flow, Immersion, and Presence coinfluence each other.
- H7. Flow influences Emotion.

5.2.3. The usability and satisfaction dimensions

Usability and Satisfaction are two strongly related dimensions in many definitions. The ISO definition of usability indicates that Satisfaction is one of the dimensions that must be met to obtain good usability. In paper S02, the authors argue that it has been widely proven that user satisfaction is significantly impacted by usability. Satisfaction as a psychological effect is related to and resulting from a cognitive appraisal of the expectation-performance discrepancy (Shin, 2011). We derived the following hypotheses:

- H8. Satisfaction is influenced by Usability.
- H9. Satisfaction influences Emotion.

6. Limitations from the systematic mapping study

We made extensive efforts to identify a comprehensive set of relevant publications to mitigate the threat of not including relevant papers. We achieved this by utilizing a metasearch engine encompassing key search engines, conferences, and journals pertinent to the topic, such as IEEE Xplore, Scopus, and the ACM Digital Library. Furthermore, we adopted the quasi-gold standard (GQS) approach, which suggests a relatively rigorous approach for search performance evaluation regarding sensitivity and precision. After verifying the returned papers by applying our search string, the initial set of papers used to develop our search string was cross-verified. To capture as many papers as possible, we used snowballing as the complementary search to reduce the possibility of missing relevant papers.

To preemptively mitigate selection bias, we defined our research question in advance, performed a multi-stage process, and meticulously documented all inclusions and exclusions. We critically examined the review protocol and conducted the Kohen's Kappa statistical test to minimize any inherent researcher bias.

The integrity of the data extraction results could have been compromised by the potential bias introduced by the researcher responsible for extracting the data. Such data extraction bias can lead to inaccurate recorded data items. We mitigated this bias by discussing the extracted data and comparing such data with our research goals in meetings involving at least three researchers.

7. Conclusion and future work

The immersive experiences landscape has brought new interaction paradigms, challenging the mainstream UX evaluation techniques and demanding new considerations regarding what we must consider when evaluating immersive experiences. The rapid development of immersive technologies allows a delay in developing both the theories regarding immersive experience and its practical measurements. We surveyed scientific publications through an SLM related to the context of immersive experiences that presented a UX assessment or guidelines of what should be considered to assess the quality of immersive experiences.

Going back to our high-level research question, we defined the leading technologies used to evaluate UX in immersive experiences and how they are applied. Despite a set of different technologies used in UX evaluation in the immersive context, there is a predominance of technologies based on questionnaires and interviews, emphasizing techniques based on the Likert scale and semi-structured interviews. Furthermore, we identified the types of immersive experiences most investigated in the literature, emphasizing Immersive Virtual Reality, 360-degree video, and the use of HMDs. A significant finding of our study is related to the main dimensions of UX that are considered when evaluating immersive experiences. Based on the dimensions mentioned at least five times in the extracted papers, we can point out that the main UX dimensions in the immersive context are Presence, Immersion, Engagement, Usability, Flow, Enjoyment, Emotion, and Satisfaction, thus answering the research sub-questions.

Based on these results, we defined a theoretical model of UX dimensions and some relationships between these evaluations from the extracted papers. Since UX is a multifaceted concept, i.e., context-sensitive, one of the primary investigations is defining and considering UX evaluations in a given context. Therefore, as we highlighted in the introduction, our model can be helpful for many purposes, such as studying the UX dimensions relations and establishing UX dimensions that should be considered in UX evaluations. We emphasize that the main contribution of this SLM is to serve as a basis for developing new UX evaluation techniques focused on evaluating immersive experiences.

In future work, we intend to use the theoretical basis built in this SLM to develop UX evaluation techniques focused on the specific context of immersive experiences. Our goal is to provide different approaches that help evaluate UX, considering the particularities of the immersive context. For instance, we can define a way of collecting data during the experience through automatically-collected records and define a set of metrics that can be applied to the records to extract information about how the experience was. In addition, it is possible to develop specific questionnaires for the immersive context and apply them to carry out a UX assessment when a more specific approach is not possible.

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Appendix A

List of publications selected in the systematic mapping

S01 - Doherty, R. A., & Sorenson, P. (2015). Keeping users in the flow: Mapping system responsiveness with user experience. *Procedia Manufacturing*, *3*, 4384–4391. https://doi.org/10.1016/j.promfg.2015.07.436

S02 - Shin, D. (2019). How do users experience the interaction with an immersive screen? *Computers in Human Behavior*, *98*, 302–310. https://doi.org/10.1016/j.chb.2018.11.010

S03 - Lee, H., Jung, T. H., Tom Dieck, M. C., & Chung, N. (2020). Experiencing immersive virtual reality in museums. *Information & Management*, *57*(5), 103229. https://doi.org/10.1016/j.im.2019.103229

S04 - Greenfeld, A., Lugmayr, A., & Lamont, W. (2018). *Comparative reality: Measuring user experience and emotion in immersive virtual environments* [Paper presentation]. 2018 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR) (pp. 204–209). IEEE. https://doi.org/10.1109/AIVR.2018.00048

S05 - Ciolfi, L., & McLoughlin, M. (2012). Designing for meaningful visitor engagement at a living history museum. In *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense through Design* (pp. 69–78). https://doi.org/10.1145/2399016.2399028

S06 - Halskov, K., Dalsgaard, P., & Stolze, L. B. (2014). Analysing engaging experiences with a tangible 3D tabletop. In Proceedings of the *11th Conference on Advances in Computer Entertainment Technology* (pp. 1–10). https://doi.org/10.1145/2663806.2663831

S07 - Hornecker, E., & Stifter, M. (2006). Learning from interactive museum installations about interaction design for public settings. In *Proceedings of the 18th Australia Conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments* (pp. 135–142). https://doi.org/10.1145/1228175.1228201

S08 - Gallacher, S., Golsteijn, C., Wall, L., Koeman, L., Andberg, S., Capra, L., & Rogers, Y. (2015). Getting quizzical about physical: Observing experiences with a tangible questionnaire. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (pp. 263–273).

S09 - Guedes, A. L., Azevedo, R. G. D. A., Frossard, P., Colcher, S., & Barbosa, S. D. J. (2019). Subjective evaluation of 360-degree sensory experiences. In *2019 IEEE 21st International Workshop on Multimedia Signal Processing (MMSP)* (pp. 1–6). IEEE. https://doi.org/10.1109/MMSP.2019.8901743

S10 - Cooper, K. (2010). Go with the flow: Engagement factors for learning in Second Life. In *Proceedings of the 2010 Spring Simulation Multiconference* (pp. 1–9).

S11 - Boletsis, C. (2018). Virtual reality for prototyping service journeys. *Multimodal Technologies and Interaction*, *2*(2), 14. https://doi.org/10.3390/mti2020014

S12 - Torres, A., Carmichael, C., Wang, W., Paraskevakos, M., Uribe-Quevedo, A., Giles, P., & Yawney, J. L. (2020). A 360 video editor framework for interactive training. In *2020 IEEE 8th International Conference on Serious Games and Applications for Health (SeGAH)* (pp. 1–7). IEEE.

S13 - Liu, Y., Liu, Z., & Jin, Y. (2019, July 26–31). *Virtual dome system using HMDs: An alternative to the expensive and less accessible physical domes* [Paper presentation]. In Virtual, Augmented and Mixed Reality. Applications and Case Studies: 11th International Conference, VAMR 2019, Orlando, FL, USA, Held as Part of the 21st HCI International Conference, HCII 2019 Proceedings, Part II 21 (pp. 312–328). Springer International Publishing.

S14 - Selmanovic, E., Rizvic, S., Harvey, C., Boskovic, D., Hulusic, V., Chahin, M., & Sljivo, S. (2018). VR video storytelling for intangible cultural heritage preservation.

S15 - Bindman, S. W., Castaneda, L. M., Scanlon, M., & Cechony, A. (2018). Am I a bunny? The impact of high and low immersion platforms and viewers' perceptions of role on presence, narrative engagement, and empathy during an animated 360° video. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (pp. 1–11).

S16 - Jo, D., Kim, K., Welch, G. F., Jeon, W., Kim, Y., Kim, K. H., & Kim, G. J. (2017). The impact of avatar-owner visual similarity on body ownership in immersive virtual reality. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology* (pp. 1–2). https://doi.org/10.1145/3139131.3141214

S17 - Fabroyir, H., Teng, W. C., Wang, S. L., & Tara, R. Y. (2013). Mapxplorer handy: An immersive map exploration system using handheld device. In *2013 International Conference on Cyberworlds* (pp. 101–107). IEEE.

S18 - Egan, D., Keighrey, C., Barrett, J., Qiao, Y., Brennan, S., Timmerer, C., & Murray, N. (2017). Subjective evaluation of an olfaction enhanced immersive virtual reality environment. In *Proceedings of the 2nd International Workshop on Multimedia Alternate Realities* (pp. 15–18). https://doi.org/10.1145/3132361.3132363

S19 - Grinberg, A. M., Careaga, J. S., Mehl, M. R., & O'Connor, M. F. (2014). Social engagement and user immersion in a socially based virtual world. *Computers in Human Behavior*, *36*, 479–486. https://doi.org/10.1016/j.chb.2014.04.008

S20 - Nisi, V., Dionísio, M., Bala, P., Gross, T., & Nunes, N. J. (2017). DreamScope: Evaluating interactive 360° virtual reality in a physical narrative art installation. In *Proceedings of the 8th International Conference on Digital Arts* (pp. 67–75).

S21 - Gonçalves, G., Melo, M., Vasconcelos-Raposo, J., & Bessa, M. (2020). A novel method to enhance the touristic 360 promotional video experience. *Multimedia Tools and Applications*, *79*(31-32), 22905–22927. https://doi.org/10.1007/s11042-020-09026-x

S22 - Karafotias, G., Teranishi, A., Korres, G., Eyssel, F., Copti, S., & Eid, M. (2017). Intensifying emotional reactions via tactile gestures in immersive films. *ACM Transactions on Multimedia Computing, Communications, and Applications*, *13*(3), 1–17. https://doi.org/10.1145/3092840

S23 - Coelho, H., Melo, M., Martins, J., & Bessa, M. (2019). Collaborative immersive authoring tool for real-time creation of multisensory VR experiences. *Multimedia Tools and Applications*, *78*(14), 19473–19493. https://doi.org/10.1007/s11042-019-7309-x

S24 - Verdugo, R., Nussbaum, M., Corro, P., Nuñnez, P., & Navarrete, P. (2011). Interactive films and coconstruction. *ACM Transactions on Multimedia Computing, Communications, and Applications*, *7*(4), 1–24. https://doi.org/10.1145/2043612.2043617

S25 - Morreale, F., & De Angeli, A. (2015). Evaluating visitor experiences with interactive art. In *Proceedings of the 11th Biannual Conference on Italian SIGCHI Chapter* (pp. 50–57). https://doi.org/10.1145/2808435.2808440

S26 - Keighrey, C., Flynn, R., Murray, S., Brennan, S., & Murray, N. (2017). Comparing user QoE via physiological and interaction measurements of immersive AR and VR speech and language therapy applications. In *Proceedings of the on Thematic Workshops of ACM Multimedia 2017* (pp. 485–492). https://doi.org/10.1145/3126686.3126747

S27 - Shin, D., & Biocca, F. (2018). Exploring immersive experience in journalism. *New Media & Society*, *20*(8), 2800–2823. https://doi.org/10.1177/1461444817733133

S28 - Tcha-Tokey, K., Loup-Escande, E., Christmann, O., & Richir, S. (2016). A questionnaire to measure the user experience in immersive virtual environments. In P. *Roceedings of the 2016 Virtual Reality International Conference* (pp. 1–5). https://doi.org/10.1145/2927929.2927955

S29 - Tcha-Tokey, K., Loup-Escande, E., Christmann, O., & Richir, S. (2017). Effects on user experience in an edutainment virtual environment: Comparison between CAVE and HMD. In *Proceedings of the European Conference on Cognitive Ergonomics* (pp. 1–8).

S30 - Dalsgaard, P., Dindler, C., & Halskov, K. (2011, September 5–9). Understanding the dynamics of engaging interaction in public spaces. In *Human-Computer Interaction–INTERACT 2011: 13th IFIP TC 13 International Conference*, Lisbon, Portugal. Proceedings, Part II 13 (pp. 212–229). Berlin: Springer.

S31 - Tcha-Tokey, K., Christmann, O., Loup-Escande, E., Loup, G., & Richir, S. (2018). Towards a model of user experience in immersive virtual environments. *Advances in Human-Computer Interaction*, *2018*, 1–10. https://doi.org/10.1155/2018/7827286

S32 - Höök, K., Sengers, P., & Andersson, G. (2003, April). Sense and sensibility: Evaluation and interactive art. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 241–248).

S33 - Egan, D., Brennan, S., Barrett, J., Qiao, Y., Timmerer, C., & Murray, N. (2016). *An evaluation of Heart Rate and ElectroDermal Activity as an objective QoE evaluation method for immersive virtual reality environments* [Paper presentation]. 2016 Eighth International Conference on Quality of Multimedia Experience (QoMEX) (pp. 1–6). IEEE. https://doi.org/10.1109/QoMEX.2016.7498964

S34 - Keighrey, C., Flynn, R., Murray, S., & Murray, N. (2021). A physiology-based QoE comparison of interactive augmented reality, virtual reality and tablet-based applications. *IEEE Transactions on Multimedia*, *23*, 333–341. https://doi.org/10.1109/TMM.2020.2982046

S35 - Marques, L., Amazonas, M., Castro, T., Assuncao, W., Zaina, L., Gadelha, B., & Conte, T. (2020). Ux trek: A post-interaction journey from immersive experience logs. In *Proceedings of the 19th Brazilian Symposium on Human Factors in Computing Systems* (pp. 1–6).

S36 - Kailas, G., & Tiwari, N. (2021). Design for immersive experience: Role of spatial audio in extended reality applications. In *Design for Tomorrow—Volume 2: Proceedings of ICoRD 2021* (pp. 853–863). Springer.

S37 - Verhulst, I., Woods, A., Whittaker, L., Bennett, J., & Dalton, P. (2021). Do VR and AR versions of an immersive cultural experience engender different user experiences? *Computers in Human Behavior*, *125*, 106951. https://doi.org/10.1016/j.chb.2021.106951

S38 - Cheiran, J. F., Torres, L. A., da Silva, A. A., de Souza, G. A., Nedel, L. P., Maciel, A., & Barone, D. A. (2020, October 20–23). Comparing physical and immersive VR prototypes for evaluation of an industrial system user interface. In *Advances in Computer Graphics: 37th Computer Graphics International Conference, CGI 2020*, Geneva, Switzerland. Proceedings 37 (pp. 3–15). Springer International Publishing.

S39 - Chessa, M., & Solari, F. (2021). The sense of being there during online classes: Analysis of usability and presence in web-conferencing systems and virtual reality social platforms. *Behaviour & Information Technology*, *40*(12), 1237–1249. https://doi.org/10.1080/0144929X.2021.1957017

S40 - Wu, H., Cai, T., Luo, D., Liu, Y., & Zhang, Z. (2021). Immersive virtual reality news: A study of user experience and media effects. *International Journal of Human-Computer Studies*, *147*, 102576. https://doi.org/10.1016/j.ijhcs.2020.102576

S41 - Pamparău, C., & Vatavu, R. D. (2022). *The user experience of journeys in the realm of augmented reality television* [Paper presentation]. ACM International Conference on Interactive Media Experiences (pp. 161–174). https://doi.org/10.1145/3505284.3529969

S42 - Branch, B., Efstratiou, C., Mirowski, P., Mathewson, K. W., & Allain, P. (2021). Tele-immersive improv: Effects of immersive visualisations on rehearsing and performing theatre online. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1–13).

S43 - Yan, S., Ge, S., Wang, J., & Shen, X. (2021). Performing with me: Enhancing audience-performer interaction in an immersive virtual play. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1–6).

S44 - Young, J., Thompson, S., Downer, H., Allen, B., Pantidi, N., Stoecklein, L., & Rhee, T. (2022). *TeleFest: Augmented virtual teleportation for live concerts* [Paper presentation]. ACM International Conference on Interactive Media Experiences (pp. 69–78). https://doi.org/10.1145/3505284.3529968

S45 - Martins, G., Gomes, G., Conceição, J. L., Marques, L., Silva, D. D., Castro, T., Gadelha, B., & de Freitas, R. (2020). Enhanced interaction: Audience engagement in entertainment events through the bumbometer app. In *Proceedings of the 19th Brazilian Symposium on Human Factors in Computing Systems* (pp. 1–9).

S46 - Park, W., Heo, H., Park, S., & Kim, J. (2019). A study on the presence of immersive user interface in collaborative virtual environments application. *Symmetry*, *11*(4), 476. https://doi.org/10.3390/sym11040476

S47 - North, M. M., & North, S. M. (2016). A comparative study of sense of presence of traditional virtual reality and immersive environments. *Australasian Journal of Information Systems*, *20* https://doi.org/10.3127/ajis.v20i0.1168

S48 - Schwind, V., Knierim, P., Haas, N., & Henze, N. (2019). Using presence questionnaires in virtual reality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1–12). https://doi.org/10.1145/3290605.3300590

S49 - He, L., Li, H., Xue, T., Sun, D., Zhu, S., & Ding, G. (2018). Am I in the theater? Usability study of live performance based virtual reality. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology* (pp. 1–11).

S50 - He, L., Li, H., Xue, T., Sun, D., Zhu, S., & Ding, G. (2018). Am I in the theater? Usability study of live performance based virtual reality. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology* (pp. 1–11).

S51 - Guertin-Lahoud, S., Coursaris, C. K., Sénécal, S., & Léger, P. M. (2023). User experience evaluation in shared interactive virtual reality. *Cyberpsychology, Behavior, and Social Networking*, *26*(4), 263–272. https://doi.org/10.1089/cyber.2022.0261

S52 - Cai, C., He, J., & Luo, T. (2023). *Using redirection to create a swimming experience in VR for the sitting position* [Paper presentation]. In Companion Proceedings of the 28th International Conference on Intelligent User Interfaces (pp. 68–71). https://doi.org/10.1145/3581754.3584134

S53 - Hulusic, V., Gusia, L., Luci, N., & Smith, M. (2023). Tangible user interfaces for enhancing user experience of virtual reality cultural heritage applications for utilization in educational environment. *Journal on Computing and Cultural Heritage*, *16*(2), 1–24. https://doi.org/10.1145/3593429

S54 - Salgado, D. P., Flynn, R., Naves, E. L. M., & Murray, N. (2022). A questionnaire-based and physiology-inspired quality of experience evaluation of an immersive multisensory wheelchair simulator. In *Proceedings of the 13th ACM Multimedia Systems Conference* (pp. 1–11). https://doi.org/10.1145/3524273.3528175