Towards a Systematic Mapping of Evidence-based UX Guidelines for Room-scale User Interfaces in Extended Reality

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User experience (UX) guidelines help designers with many challenges and opportunities when creating XR applications. However, guidelines that can be found from research and industry that offer insights and ideas surrounding UX for XR room-scale User Interfaces (UIs) are often opinions from experts, developers and designers. To validate experts' stated beliefs, those guidelines should be based on concrete empirical evidence. In this paper, we present a systematic review based on an analysis of 408 peer-reviewed papers determine the state of the art of empirical evidence for guidelines for room-scale UIs. Our study shows that out of these 408 publications, only 26 were empirical studies. We found 9 studies focusing on room-scale UIs where all of these 9 publications created guidelines from an empirical study instead of using an empirical study to evaluate guidelines.

1 INTRODUCTION

Advances in Extended Reality (XR), including Augmented Reality (AR) and Virtual Reality (VR), have drastically altered the human-computer interactions enabled through computers and wearable devices [27]. While XR opens up new possibilities for engaging with digital data, it's necessary to realize that these developments need a widening of our current guidelines of user experience design [37]. Most of the existing guidelines are based on applications running on a 2D screen and do not take into account the possibilities of placing UI elements is the space/room around the user. In addition, among publications that considered 3D interaction, none collected evidence to evaluate guidelines. Designers will likely find challenges unlocking the full potential of these technologies unless established design principles are updated to reflect opportunities created by room-scale interfaces. Moreover, as extended reality becomes more and more mainstream, designers and developers are starting to build techniques and processes to make XR environments and experiences fun, believable, practical and seamless. In our study, we conducted a systematic mapping of the existing XR literature. We show the lack of empirical evidence-based guidelines for room-scale UIs.

2 BACKGROUND

This section describes and defines the paper's fundamental terminology, as well as past relevant research of the two main topics combined in this paper: room-scale XR and UX guidelines. Bringing these topics together allows us to show the empirical gap for supporting design guidelines for room-scale UIs in XR applications.

2.1 Room-Scale Extended Reality

Extended Reality (XR) is a term referring to Virtual Reality (VR) and Mixed Reality (MR) (Augmented Reality (AR) and Augmented Virtuality) within the Milgram's reality-virtuality continuum [24]. Cross Reality (CR) is a term used to describe a set of developing technologies such as virtual reality (VR), augmented reality (AR), and virtual worlds (VWs) that employ 3D models/simulations across physical, virtual, and immersive platforms [40]. Designing for Cross reality applications therefore require unique solutions to various interaction design challenges, adapting tools to VR and AR applications [38]. On the other hand, while the UI in the one version (e.g., VR) act like a barrier for design, the other (e.g., AR) can bring support for the design challenge [38]. In recent years, "room-scale" XR has gained popularity, in which the user utilizes her surroundings (aka a room) for interacting with a software system. This setup usually requires calibration of a physical area using sensors that track the location of a head-mounted display (HMD) and and often

uses portable motion-tracked controllers as input devices. This setup allows the user to move in a virtual space within a XR application by moving their physical body in a physical room[19]. An example of room-scale VR technology would be the HTC Vive while a MS HoloLens 2 is an example of room-scale AR technology. As VR technology has developed rapidly in recent years [39] and is rapidly approaching a much more mature stage, research has sufficiently studied VR and most work so far is focused on VR (e.g., [36]), while this paper's goal focused on XR. Current room-scale XR design guidelines and best practises have been discussed in a number of industry speeches and lectures presented at major development conferences (e.g. [13, 21]). However, room-scale XR should be distinguished from the more well-established seated XR paradigm as traditional XR technology has mostly focused on a fixed and sitting experience [3]. Nonetheless, we believe that traditional VR research may be applied to room-scale XR. Bowman and Hodges [5], for example, characterise VR interaction approaches as "viewpoint motion control" of the camera and "selection and manipulation" of objects [5], both of which are still used in XR today.

2.2 User Experience Guidelines

The term "user experience" (UX) has multiple different connotations [9]. According to Nielsen's definition of UX, "User experience" comprises all elements of the end user's contact with the firm, its services, and its goods [29]. The International Organization for Standardization (ISO) defines UX as a user's perception and response as a result of using or anticipating using a product, a system, or a service. Furthermore, UX encompasses the users' beliefs, emotions, perceptions, preferences, bodily, and psychological responses, as well as their behaviour and performance before, during, and after usage. In addition, there are three major aspects that influence the UX: the user, the system, and the usage situation [12]. UX is the result of a user's internal state (predispositions, expectations, needs, motivation, mood, etc.), the characteristics of the designed system (e.g. complexity, purpose, usability, functionality, etc.), and the context (or environment) in which the interaction occurs (e.g. organizational/social setting, meaningfulness of the activity, voluntariness of use, etc.). Usability of a product is an important factor in ensuring a high-quality user experience [10]. Usability is defined as "the extent to which a product can be used by specified users to achieve given goals with effectiveness, efficiency, and satisfaction in a specified context of usage," according to the International Organization for Standardization. Many papers used efficiency and effectiveness [2], however, efficiency and effectiveness are insufficient to satisfy users, as they also want emotional fulfilment [35], which is an essential aspect of the UX [10]. The emotional effect is the aspect of the user experience that has an affect on the user's emotions. Deeper emotional variables such as self-expression and self-identity, ownership pride, and a sense of contribution to the world can all be included. [11] emphasise the importance of pleasure, stating, "The most basic rationale for addressing the joy of use is the humanistic idea that happiness is important to existence".

To create XR experiences engaging, convincing, practical, and seamless, designers and developers are starting to include different aspects of UX into their general design choices [6]. Google[1], IBM[2] and Oculus have a set of guidelines for VR/AR UX designers[37]. As in the grey literature that provided UX guidelines, most work focused on VR, [14, 33] are UX guidelines for VR environment and [6, 20, 26] are for room-scale VR environment. In addition, several authors have stated that it is necessary to investigate on different aspect of UX to provide better guidelines [37]. For example, in [17], the authors conclude that the existing usability guidelines were too general to be applicable for evaluating the usability of mobile map applications. Thus, it is necessary to have a new set that has been evaluated by empirical study. We believe a similar argument can now be made for room-scale UX.

[1]https://www.google.com/
[2]https://www.ibm.com/

3 RESEARCH METHOD OVERVIEW

The importance of adopting an empirical approach to generate an effective and efficient collection of heuristics has been established in previous work on the design of guidelines [31]. The design of a small-scale experiment to solve a very particular, low-level issue is frequently documented in research publications (e.g. [4, 8, 18, 28]) and there is usually minimal reflection on evidence-based experiment and how to evaluate design guidelines through these experiments.

Our study summarizes the empirical evidence on UX guidelines for room-scale UIs in XR systems. So far, we have conducted a preliminary analysis of the research publications in the multidisciplinary domain of XR and UX. We used Scopus[3] and Google Scholar[4] to provide a comprehensive list of peer-reviewed papers. As our goal was to summarize empirical evidence supporting UX of room-scale interfaces, we focused on the academic literature, omitting grey literature sources (which tend to be mostly anecdotal experience reports and expert opinions). We defined a search string to reflect the scope of the research. Any paper that contains at least one of related keywords from all three category of 'Extended reality', 'User experience' and 'Design guidelines', is picked without any limitation on published year or subject area. Keywords for each category are listed as follows:

- Extended reality: 'virtual reality', 'augmented reality', 'mixed reality', '3d interaction', 'immersion (virtual reality)', 'virtual learning environment', AR, XR, MR, VR.
- User experience: usability, 'user experience design', 'user modeling', 'user-centered design', 'quality of experience', 'human factors and ergonomics'.
- Design guidelines: 'design heuristic', 'design principle', 'design guideline', 'task-centered design', 'usage-centered design', 'participatory design'.

Therefore, we searched the literature in the Scopus and Google Scholar, based on the string ('virtual reality', 'augmented reality' OR 'mixed reality' OR '3d interaction' OR 'immersion (virtual reality)' OR 'virtual learning environment' OR AR OR XR OR MR OR VR) AND (usability OR 'user experience design' OR 'user modeling' OR 'user-centered design' OR 'quality of experience' OR 'human factors and ergonomics') AND ('design heuristic' OR 'design principle' OR 'design guideline' OR 'task-centered design' OR 'usage-centered design' OR 'participatory design') in January 2022. The search string was then applied to search title, abstract, and keywords in Scopus and all combinations has been searched separately in Google Scholar.

After refining and iterating through search strings, we found 485 (69 Scopus, 416 Google Scholar) studies, which were reviewed in three iterations: on title, abstract, and full paper. In each iteration, papers were excluded that (1) were duplicate, (2) did not apply extended reality, (2) did not have implications for design or (3) focused on very specific population (e.g., older adults). Thus, through screening these 485 papers, 77 papers that were either duplicate or irrelevant to the study were excluded, resulting in 408 unique and relevant papers. To find papers with empirical studies, we then added the string of '*("Evidence based" OR empirical)*' to the final string which brought our total to 32 (4 Scopus, 28 Google Scholar). Since by screening all 408 papers to avoid missing empirical studies, we found one additional empirical study [7] , we additionally investigated references of and citations to retained papers and continued exploring references of each additional suitable paper. Overall, we ended up with 27 studies that presented empirical studies on UX guidelines. As the focus of our work is on room-scale UIs, we identified 9 relevant papers that focused on room-scale interfaces in their experiments [7, 15, 16, 22, 23, 25, 30, 32, 34]. Two authors (AUTHOR2 and AUTHOR1) independently validated the mapping and list of papers. The final set of papers is given in Table 1.

[3]https://www.scopus.com/
[4]https://scholar.google.com/

Table 1. Overview of 9 Empirical Studies on UX guidelines for Room-scale User Interfaces in Extended Reality, as Included in the Literature Review

Authors	Application domain	Type of VR	Research Method
[7] Economou et al. 2017	Social VR	Kinect-depth sensing cameras	Action research
[15] Jin et al. 2022	Narrative in AR	HoloLens Clicker, HMD devices	Experimental study + Interviews
[16] Kharoub et al. 2019	Generic	HTC Vive, Leap Motion controller	Experimental evaluation + Observations, Interviews
[22] Marsh et al. 2001	film-making	HMD VR system	Review study
[23] Mayor et al. 2019	Generic	HTC Vive VR HMD	Experimental evaluation
[25] Minocha et al. 2011	Wayfinding	Second Life navigational aid Camera and Sensors	Observations + Semi-structured interviews
[30] Paes et al. 2018	Generic	Oculus Rift DK2, HMD devices	User testing + Heuristics evaluation
[32] Radianti et al. 2020	Education	Google Cardboard, Samsung Gear, Oculus Rift, HTC Vive HMDs	Review study
[34] Schjerlund et al. 2018	Generic	HTC Vive	Experimental evaluation

4 RESULT SUMMARY

Four of these 9 papers derived design guidelines from an empirical study [15, 23, 25, 34]. [34] derive five design principles from an experiment in a room-scale VR setup through interviewing participant about their experiences, [15] proposed ten guidelines based on qualitative feedback from a survey and interviews. [25] has derived heuristics and guidelines for the design of 3D virtual spaces to facilitate navigation. [23] provided guidelines for interaction and locomotion in virtual reality. [16] and [32] provided a review on UI Design elements and usability for immersive VR. [7] evaluates the effectiveness of the proposed system, through the lens of a set of design guidelines generated by previous extensive user-centred research. [22] proposed evaluation guidelines for the design of experience. In [30], expert designers performed tasks in the virtual environment and then answered objective and subjective questions about their understanding of the virtual representation, their overall experience with the platform, and their personal assessment of heuristics.

5 DISCUSSION

The door to mass-market extended reality is poised to break open. According to Oculus VR user interface guideline[5] [1], designers face many challenges and opportunities when creating XR applications, as there are limited guideline especially for room-scale UIs. Moreover, existing guidelines are often opinions from experts, developers and designers. In our opinion, guidelines should be drawn from concrete empirical studies that are designed specifically for evaluating the guideline. In this paper, we reviewed 408 peer-reviewed papers, that offer insights and ideas surrounding user experience (UX) for XR applications, to summarize the literature for empirical evidence on guidelines for room-scale UIs. The most relevant publications derived guidelines from an empirical study instead of using an empirical study to evaluate guidelines. This clearly demonstrates a substantial gap in the field: researchers should conduct experiments to provide empirical evidence as a basis for UX design guidelines for room-scale user interfaces. We hope that systems designed based on such guidelines will result in a high-quality user experiences.

[5]https://developer.oculus.com/documentation/native/pc/dg-performance-guidelines/

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