Classification of Augmented Reality Design Recommendations on User Experience Dimensions: Preliminary Study Results

Stefan Graser[1] [a], Jessica Kollmorgen[2] [b], Martin Schrepp[3] [c], María José Escalona[4] [d] and Stephan Böhm[1] [e]

[1] *CAEBUS Center for Advanced E-Business Studies, RheinMain University of Applied Sciences, Wiesbaden, Germany*
[2] *University of Applied Sciences Emden/Leer, Emden, Germany*
[3] *SAP SE, Walldorf, Germany*
[4] *University of Seville, Seville, Spain*

Keywords: Augmented Reality (AR), Corporate Training (CT), AR Design Recommendations, AR Guidelines, User Experience (UX), UXARcis.

Abstract: Augmented Reality (AR) in Corporate Training (CT) enables immersive and interactive learning scenarios, resulting in a new user experience (UX). Within software development, UX is a crucial success factor. While numerous AR-specific design recommendations exist, it remains unclear how these contribute to the actual user experience perceived by learners. This misalignment between intended and actual UX highlights the challenge for AR authors. Concerning UX evaluation, questionnaires can be used to collect data from target groups and produce reliable quantitative data describing UX quality. However, a questionnaire should not include too many items to capture the UX impression of users to avoid being too time-consuming. Since UX questionnaires typically capture only high-level impressions, their results often do not provide clear suggestions for designers or developers on how to improve an application. Linking design recommendations to questionnaire scales would help connect UX evaluation results more directly to design changes that are likely to improve users' UX impressions. We describe a study establishing such a mapping for the application domain of AR in corporate training. Preliminary results provide an initial classification of AR design recommendations across relevant UX dimensions.

1 INTRODUCTION

Augmented Reality (AR) supplements the real world with virtual content (Azuma, 1997). Digital information (for example, directions, labels, or 3D models) integrates into the user's view of the real world through smart glasses or smartphone displays. This enables a new way of conducting and experiencing tasks across various application domains, such as education, training, or cultural heritage. The field of Corporate Training (CT), in particular, shows great potential for applying AR as the technology enables interactive and immersive learning scenarios. As a result, various aspects, such as training engagement, motivation, and effectiveness, can be improved (Billinghurst and Duenser, 2012; Chang et al., 2020; Criollo-C et al., 2021).

AR introduces new learning formats differing from classical methods, resulting in a distinct user experience (UX) for learners. In the software development process, UX is a key factor for the acceptance, use, and success of digital systems (Hinderks et al., 2019). Thus, it is essential to ensure a positive UX (Rauschenberger et al., 2013). Therefore, product designers and developers typically apply design recommendations as standards and best practices for system design and development, intending to achieve a good UX by designing the product features in accordance with the respective guidelines (Hassenzahl, 2004). Regarding AR, a large number of AR-specific design recommendations exist in the literature (Fu et al., 2016; Krauß et al., 2021a; Krauß et al., 2021b).

[a] https://orcid.org/0000-0002-5221-2959
[b] https://orcid.org/0000-0003-0649-3750
[c] https://orcid.org/0000-0001-7855-2524
[d] https://orcid.org/0000-0002-6435-1497
[e] https://orcid.org/0000-0003-3580-1038

Graser, S., Kollmorgen, J., Schrepp, M., Escalona, M. J. and Böhm, S.
Classification of Augmented Reality Design Recommendations on User Experience Dimensions: Preliminary Study Results.
DOI: 10.5220/0013778000003985

In *Proceedings of the 21st International Conference on Web Information Systems and Technologies (WEBIST 2025)*, pages 511-520
ISBN: 978-989-758-772-6; ISSN: 2184-3252

However, the actual UX perceived by the users may differ significantly from the designer's intention (Hassenzahl, 2004). Understanding and gathering insights into the actual experience, therefore, requires applying methods of UX measurement. However, current research highlights different challenges in integrating UX into the software development process (Pettersson et al., 2018; Kashfi et al., 2019; Kollmorgen et al., 2025).

Various methods for measuring and quantifying the UX exist in literature (Albert and Tullis, 2022). Standardized UX questionnaires are the most commonly applied. These, however, often lack context specificity. As the relevant UX dimensions differ depending on the product, it is crucial to apply context-specific methods. Only a limited number of AR-specific UX measurement methods are available, differing in structure and focus (Graser et al., 2024a; Graser et al., 2025c). Moreover, empirical findings from UX evaluation methods are often challenging to interpret and translate into actionable design improvements. Quantitative results, which are usually based on concise and time-efficient questionnaires, often capture only high-level impressions and may indicate dissatisfaction without revealing underlying causes. On the other hand, qualitative data is often too general and lacks clear references to specific system weaknesses. This highlights a fundamental misalignment: While designers rely on design recommendations to develop AR applications, it remains unclear whether these recommendations actually enhance the UX, as they often lack the tools to validate this. In turn, there is a lack of understanding of the application of empirical measurement methods and the interpretation of their results (Pettersson et al., 2018; Kashfi et al., 2019).

To sum up, even with domain-specific questionnaires, it often remains unclear how measured weaknesses and problems can be specifically remedied. There is often an insufficient connection between empirical UX measurement and concrete design measures. Although numerous design recommendations exist, their impact on specific UX dimensions has not been proven, making it challenging for designers and software developers to select the most suitable recommendation for the respective UX weakness. Mapping design recommendations to UX dimensions is, therefore, useful and necessary. To our knowledge, no approach exists combining development recommendations with measurement scales in research. This study addresses this gap in the specific context of AR in CT. We aim to bridge the gap between AR authors and users. Therefore, our objective is to provide an initial setup for a bidirectional, more evidence-based way to develop AR applications in CT while fostering a positive UX. We classify AR-specific design recommendations based on empirically validated, relevant UX dimensions. By empirically mapping AR design recommendations to UX dimensions, we aim to provide actionable insights supporting both the development and evaluation of AR applications in CT. We present preliminary findings from a quantitative online survey. Based on this, we propose a structured approach for linking design improvements to measured UX deficiencies. Thus, this research contributes to closing the gap between AR design theory and practical UX evaluation in the domain of Corporate Training. Moreover, this contributes to the innovative development of user-centric, interactive systems within the field of Human-Computer Interaction (HCI). This article is based on our previous research (Graser et al., 2025a; Graser et al., 2025c). Against this background, we address the following research question:

RQ: Which relationships exist between AR design recommendations and the relevant UX dimensions?

The article is structured as follows: Section 2 introduces the related work regarding our previous research relevant for this study. Section 3 describes the methodological approach of this study. Preliminary study results are presented in Section 4. Section 5 provides the discussion. Section 6 concludes including insights for future work.

2 RELATED RESEARCH

This section presents an overview of the related research, providing the basis of this pre-study. We introduce UX evaluation in 2.1. Based on this, we present the UXARcis questionnaire in 2.2. Moreover, we illustrate existing design recommendations for AR in CT (see 2.3).

2.1 Quantifying UX

UX is defined as the "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service" (ISO9241-210, 2020). Thus, UX does not describe objective quality criteria, but rather the individual subjective impressions of users, including emotions and beliefs, resulting from their interaction with an application. Users have corresponding expectations for interaction with systems, which raises the question of how individual UX can be continuously evaluated in iterative software development and how generalizable conclusions can be drawn (Kollmorgen et al., 2024).

UX questionnaires are an established evaluation method for this purpose. They enable systematic evaluation to identify weaknesses, strengths, and potential improvements, and to design user-centered development (Lohse, 2011). The evaluation is carried out using so-called UX dimensions or scales. These are one-dimensional constructs that can positively or negatively influence the user's perception of the product (Provost and Robert, 2013).

Depending on the system and use case, various UX dimensions may be relevant. For example, while users of online banking tools place a high value on dimensions such as trust and dependability, stimulation and novelty are more relevant for online games (Kollmorgen et al., 2024). UX questionnaires such as the UEQ+, therefore, allow the relevant dimensions to be individually compiled and queried depending on the system (Schrepp and Thomaschewski, 2019). Over the years, different dimensions have been added, such as those specifically related to voice user interfaces (Klein et al., 2020). Attempts have also been made to develop domain-specific questionnaires, such as for virtual reality (Tcha-Tokey et al., 2016). Research highlights the necessity of domain-specific measurement approaches (Pettersson et al., 2018). The advantage lies in quantitatively evaluating perception-related and system-related UX dimensions and making them comparable at the same time (Mortazavi et al., 2024).

2.2 UXARcis Questionnaire

Only a limited number of AR-specific questionnaires exist in research, also differing in structure and focus (Graser et al., 2024a). Against this background, we identified the relevant UX dimensions for AR in CT. Based on the UX model by (Hassenzahl, 2004), we follow the understanding of breaking the UX dimensions down into **product features** and **product character**. Regarding the product features, the ARcis criteria by (Krüger et al., 2019; Krüger, 2023) represent the relevant system characteristics of AR in relation to the display of information (Azuma, 1997) re-framed from a user's perspective. Concerning the product character, we followed the approach by (Schrepp et al., 2023) describing UX with a set of UX Quality Aspects (UX-QA). We evaluated the importance of the UX-QA in relation to AR in CT and identified five relevant UX-QAs (Graser et al., 2024c; Graser et al., 2024b). The descriptions of the UX dimensions are shown in the following:

- **Contextuality *(Con)*:** Integrated presentation of virtual and physical elements.
- **Spatiality *(Spa)*:** Assignment of unique spatial properties to virtual elements by positioning them within the physical environment.
- **Interactivity *(Int)*:** Modification and manipulation of virtual components by interacting with physical objects.
- **Perspicuity *(PE)*:** The user easily gets familiar with the product and to learn how to use it.
- **Efficiency *(EF)*:** The user can solve their tasks without unnecessary effort. The product reacts fast.
- **Dependability *(DE)*:** The user feels in control of the interaction. The product reacts predictably and consistently to user commands.
- **Usefulness *(US)*:** Using the product brings advantages to the user. Using the product saves time and effort.
- **Clarity *(CL)*:** The user interface of the product looks ordered, tidy, and clear.

Both product features and character were combined, resulting in an adjusted UX model for AR in CT (Graser and Böhm, 2025) (see Figure 1).

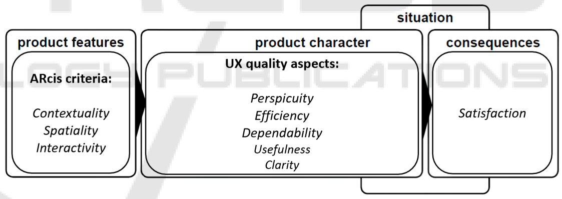


Figure 1: Adjusted UX model for AR in CT (Graser and Böhm, 2025).

Based on this, the **UXARcis** questionnaire represents a context-specific UX questionnaire for AR in CT, measuring both product features and character (Graser et al., 2025c).

2.3 AR Design Recommendations

AR authoring as part of software engineering refers to the development of AR applications. Within the software engineering process, requirements engineering is an initial step in the development process (Brooks, 1987; Hull et al., 2011; Pacheco et al., 2018; de Almeida Pacheco et al., 2019). Over time, design practices and lessons learned emerge based on experience gained during the development of the respective technology. This results in so-called design recommendations (sometimes referred to as ”guidelines” or even "heuristics"), which serve as orientation and standards for designers and developers. Similar to the UX evaluation, it is necessary to apply context-specific design recommendations to avoid neglecting the specifics of a particular technology (Krauß et al., 2021a; Krauß et al., 2021b).

In the context of AR, various design recommendations exist. (Krauß et al., 2021b) identified a comprehensive set of recommendations regarding mixed reality applications. They classified all design recommendations into thematically similar topics. However, due to technological development, AR is developing rapidly, resulting in new design practices and recommendations. We applied the dataset by (Krauß et al., 2021b) as a foundation. Based on a multi-method approach, we identified new design recommendations regarding AR published since 2020. We further classified them into thematically similar topics. For this, we applied an NLP approach, measuring the semantic textural similarity between the statements. Moreover, all resulting topics were evaluated based on the importance of AR in CT. This results in a total of 32 relevant topics. Lastly, for all topics and the corresponding design recommendations, we added summarizing descriptions to make them communicable (Graser et al., 2025a). The comprehensive data set, including all topic descriptions, is available online (See (Graser et al., 2025b)).

3 METHODOLOGICAL APPROACH

This article presents a preliminary study based on our prior research (Graser et al., 2025a; Graser et al., 2025c). We aim to identify the relationships between the identified AR design recommendation topics (see 2.3, (Graser et al., 2025a; Graser et al., 2025b)) and the UX dimensions of the UXARcis (2.2, (Graser et al., 2025c)). In particular, AR authors with experience in developing and designing AR applications evaluate the influence of the design recommendation topics on the UX dimensions when applied.

We conducted a quantitative online survey using Unipark. To gather participants, we shared the survey on LinkedIn within our professional environment, including different international AR-related development groups. To ensure that only AR authors with expertise in developing and designing AR applications were eligible to participate, we filtered based on their experience with AR. We ensured this by asking two filter questions. We considered whether the participant had already developed an AR application, followed by the question of how long participants have worked in the field of AR authoring. Participants who had not yet created an application and therefore had no experience were excluded. Moreover, participants were asked to specify their role within the authoring process, and we examined the specific AR application domain. Afterwards, the participants were automatically divided into two groups. The assignment was performed randomly. Each group was shown 16 topic descriptions *(Group 1: Topic descriptions 1–16; Group 2: Topic descriptions 17–32)* to be evaluated in terms of their influence on the UX dimensions. In particular, the participants could select the four options: (1) product features (ARcis), (2) product character (UX quality aspects), (3) both product features and product character, or (4) none. Option (1) means that the application of the respective topic only impacts the ARcis criteria, whereas option (2) indicates an influence solely on the UX quality aspects. Option (3) implies an influence on both. Choosing option (4) means that the topic has no influence on any UX dimension and, thus, is irrelevant. An illustrative example from the survey is shown in the Appendix. A quality assurance question was included in the middle of each group after the eighth topic. The group division was performed to reduce the survey duration and, thus, the abandonment rate. Finally, demographics regarding the age group, level of education, and employment relationship were considered.

As the survey is still ongoing to collect more data, we will present a preliminary empirically derived classification between design recommendation topics and related UX dimensions.

4 STUDY RESULTS

This section presents the preliminary results of this study. We illustrate demographics and information regarding the study participants in Section 4.1. Moreover, we provide the initial classification of the topics on the UX dimensions in Section 4.2.

The results were collected between June 18 and June 30, 2025. In summary, 207 people started the questionnaire, and 138 submitted it. We conducted data cleaning by dropping all participants who failed to answer the filter and quality question correctly. This results in a final sample size of 106. These are divided into 56 participants for group 1 (N1) and 50 participants for group 2 (N2).

4.1 Demographics & Experience

The age distribution, based on the 95 that provided an answer for this question in the total sample (N=106), highlights a focus on the so-called "Generation Y," which was born between 1981 and 1996 and thus ranges in age from 29 to 44. Two respondents belonged to "Generation Z" (aged 18-28), while nine participants belonged to "Generation X" (aged 45-60). No person of the "Baby Boomer" generation (61-79) was represented.

In terms of educational attainment, the majority of respondents had an academic degree. No participant stated that a high school diploma was their highest level of education. Thirteen people had completed an apprenticeship. The majority of the sample had a bachelor's degree (76 participants), followed by 15 participants with a master's degree. Two people had a doctorate.

There was also a wide range of professional backgrounds. 23 participants were employed in small or medium-sized companies, 28 in corporations, and another 28 in (media) agencies. Forty respondents worked at research institutions, and eight at public institutions, such as universities. Two people were self-employed.

We further examined the participants' experience as AR authors. It should be noted that multiple assignments were possible, as many participants take on several roles in AR projects. For this, we followed the classification into four roles by (Krauß et al., 2021a):

- Concept developers: They create the first concepts and drafts of an application. In some cases, they manage to ignore technical limitations and focus on the problem to be solved. 52 participants (49.06%) assigned themselves to this role.
- Interaction designers: They focus on the mechanics and interactivity of the application, with an emphasis usually on the conceptual level. Their tasks include conceiving mechanisms for locomotion, navigation, and input and output, as well as designing the interaction between the various modalities used in AR systems. With 66 mentions (62.26%), this was the most frequently chosen role.
- Content author: They focus on the creation of animations, 3D models, visualizations, and elements such as shadows, textures, color schemes, or sound design. 33 participants (31.13%) chose this option.
- Technical developer: They do not focus exclusively on the production of code and the development of functions, but are usually also involved in the technical feasibility and practicality of concepts. This role was chosen by 29 people (27.36%).

With regard to experience in developing AR applications, the distribution was as follows: the majority of respondents (n = 42; 39.62%) had one to two years of experience. Eighteen people reported two to three years of experience, while 15 participants had three to four years of professional experience. Another 17 authors had four to five years of experience, and 14 reported more than five years of experience in developing AR applications. Overall, the distribution of authors with more than two years of experience is relatively balanced.

There was a wide range of application contexts in which the participants implemented AR projects: 42 people were active in academic teaching, 38 in the context of cultural heritage (e.g., museums), 43 in the field of games, 48 in industry and business, 32 in corporate training, 34 in marketing and entertainment, three people in the field of medicine, and a few mentions in the field of "digital twins" (other). This again underscores the diversity of application fields in the sample.

The broad range of professional backgrounds, roles, and areas of application of the participants provides a comprehensive picture of the requirements and challenges involved in designing AR applications. This diversity increases the validity of the following classification, as different perspectives and experiences have been incorporated into the evaluation of the design recommendations. Building on this basis, the next section presents the preliminary assignment of the design recommendations to the UX dimensions.

4.2 Preliminary Classification

In the following, we present a preliminary classification. Figure 2 illustrates the distribution of evaluation results by the authors, exemplarily for topic (1). This indicates that AR authors assume that the topic (1) *Appropriate interplay of virtual content and physical environments* mainly influences the product features (ARcis criteria) of AR applications.

Table 1 presents a comprehensive classification of all topics in relation to the UX dimensions. We highlighted the category with the most ratings in **bold**. In summary, five topics were evaluated to influence the product features (ARcis criteria), whereas 13 topics refer to the product character (UX Quality Aspects, *short: UX-QA*). Moreover, 13 topics were assigned to both product features and character. Topic (31) *Head-locked content* has the same number of ratings (n = 16) concerning product features and character, similar to topic (15) *Encourage to explore*, which has a rating of 19 each. Thus, we chose both. In this case,

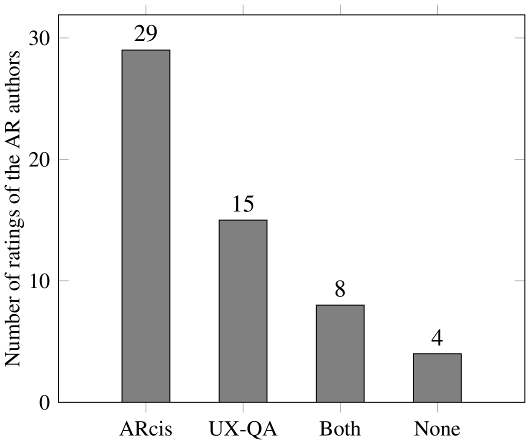


Figure 2: Distribution of classification by AR authors for topic (1) *Appropriate interplay of virtual content and physical environments*.

a chi-square test would be necessary to reject the assumption of a random distribution. Figure 3 shows the topic distribution among the UX dimensions. A comprehensive classification, including topic names, is presented in the Appendix.

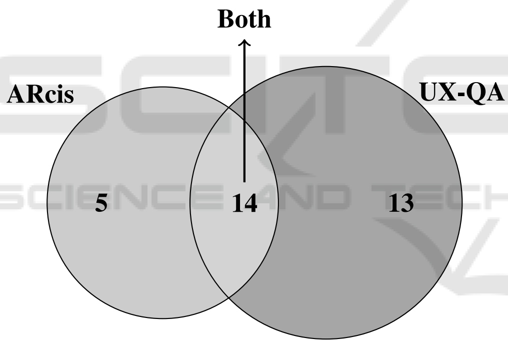


Figure 3: Classification of the 32 AR design recommendation topics to the UX dimensions.

Table 1: Overview of the classification of the AR design recommendation topics to the UX dimensions. The numbers represent the number of authors rated for this classification option.

AR Design Recommendation Topics	**ARcis**	**UX-QA**	**Both**	**None**
(1) Appropriate interplay of virtual content and physical environments	**29**	15	8	4
(2) Attention directors	12	20	**21**	3
(3) Instructions	15	17	**18**	6
(4) Onboarding	19	14	**21**	2
(5) Hand & finger gestures	**19**	17	16	4
(6) Textures – Visual Realism and Appearance of Objects	**19**	14	17	6
(7) Occlusion	18	16	**18**	4
(8) Image detection	17	16	**19**	4
(9) Handling Interruptions / Relocalization	15	**20**	19	2
(10) Surface Detection	14	18	**22**	2
(11) Affordance	14	16	**23**	3
(12) Visual cues for object manipulation	17	**18**	16	5
(13) Object Placement	15	**21**	17	3
(14) Object Manipulation	17	17	**20**	2
(15) Encourage to explore	19	19	**18**	0
(16) Keep the focus on AR experience, but use 2D-UI On-Screen elements when needed	15	19	**20**	2
(17) Error prevention & recovery	**22**	16	10	2
(18) Consider and show User's required Effort	**16**	15	12	7
(19) Law of practice	13	**21**	13	3
(20) Inform about Waiting Time	11	14	**20**	5
(21) Text / Font	11	**16**	14	9
(22) Accessibility (visuals)	14	**15**	14	7
(23) Ergonomics (avoid muscle fatigue)	16	**18**	16	0
(24) Ergonomics (avoid head & neck fatigue)	14	**19**	11	6
(25) Pause / Breaks	8	**21**	17	4
(26) Performance	15	**19**	11	5
(27) Audio Feedback	13	15	**17**	5
(28) Feedback	16	**18**	12	4
(29) FOV	11	**18**	14	7
(30) Content Placement	15	**20**	14	1
(31) Headlocked content	16	16	**12**	6
(32) Anchored UI	14	16	**17**	3

5 DISCUSSION

The refinement and practical applicability of the identified relationships to improve the UX must be tested in case studies involving AR authors. Design recommendations naturally align with various UX criteria. Thus, if we want to improve a dedicated UX scale, a checklist of potential design improvements will result. If this checklist is manageable and interpretable, allowing for clear design decisions, and if AR authors are comfortable with the method, it can be effectively applied in practical applications.

We currently have only a limited number of responses. This will be enhanced by further data collection. Moreover, our study focuses on the application domain of AR in CT. However, applications from this domain are not so different from other learning applications (for example, AR applications that support learning in museums or exhibitions). Thus, it is promising to investigate whether this approach can also be applied to other AR domains. Even if this may not always be possible, the developed method can be used to provide a similar mapping. Moreover, we did not consider the classification results in relation to the different roles of AR authors or the professional experience. This could also provide interesting differences.

5.1 Implications

From a practical perspective, this further enables a bidirectional application: On the one hand, it becomes evident how specific design recommendations and their implementation affect the resulting UX. This provides AR authors with concrete starting points for enhancing the UX. On the other hand, when UX deficits are identified, AR authors can trace them back to associated design recommendations and adapt their AR applications accordingly. This contributes to a more evidence-based development, design, and evaluation process of AR applications. The internal communication within the team among all participants is facilitated, as the relationship between weaknesses and approaches for improvement becomes transparent and clear.

In terms of interpretation, we want to illustrate a concrete example by revisiting the topic *(1) Appropriate interplay of virtual content and physical environments*. Concerning the first classification, topic (1) refers to the product features of AR applications. If the UX evaluation revealed a deficit in the ARcis criteria, one approach would be to consider the respective guidelines for this topic. In particular, practitioners should check whether the scenes and objects are natural, realistic, and simple in design. In this way, the classification can serve as a basis for iterative product improvement, and even when resources are scarce, it can be utilized in a way that positively impacts the UX. This can be applied to all topics and their classification (see Appendix for the comprehensive results). Thus, this provides an initial understanding of which topics are relevant for which UX dimensions. Moreover, mapping the UX evaluation to the design recommendations facilitates communication within the team, as the relationship between the weakness and the solution is made transparent.

From a research perspective, this can serve as a sound empirical basis for future studies on the interplay between UX evaluation and design practices as well as the development of new methods. The mapping enables researchers to systematically investigate the effectiveness of individual design recommendations in improving specific UX dimensions, for instance, through correlation or regression analyses. Moreover, the results allow for the derivation of new hypotheses regarding the impact of design decisions on UX, such as the comparison of topic (1) to topic *(15) Encourage to explore*. In this context, the respective design recommendations can be applied to an AR application and thus systematically modified. Furthermore, a UX evaluation can be conducted. Based on the evaluation results, the hypotheses could be tested. Thus, the impact of the design recommendations on the UX could be verified. Moreover, this could be useful in identifying interdependencies between both aspects.

5.2 Limitations

Some limitations of this work should also be mentioned. During classification, potential overlaps may exist between individual UX dimensions or multiple assignments, making interpretation difficult. However, this was addressed by explicitly allowing multiple assignments and making them transparent in order to reflect the complexity of the design in practice.

6 CONCLUSION & FUTURE WORK

This article is a pre-study extending our previous research on AR design recommendations and context-specific UX evaluation of AR in CT. We aimed to classify AR design recommendations on relevant UX dimensions. In particular, we conducted a quantitative online survey. AR authors were asked to evaluate the influence of the design recommendation topics on the UX dimensions. As preliminary results, we provide an initial classification. Thus, mapping design recommendations to UX dimensions bridges the gap between research and practice, as the findings of UX evaluation become actionable. This closes the existing gap in research regarding the UX integration in software development.

As this is a pre-study, we aim to further enhance this approach by gathering additional data within the online survey regarding the classification. This is the first step in a multi-method approach. Based on this, we aim to map the design recommendation topics to the eight specific UX dimensions related to product features and character in a second step. This allows us to achieve a more specific differentiation. In the third step, we aim to evaluate the classified design recommendation topics in terms of their importance for each respective UX dimension. By doing so, we will obtain a prioritized, fine-grained mapping of AR design recommendation topics to the structure of the UXARcis. This will enable AR authors to identify which design aspects are most critical for achieving and improving a positive UX based on identified UX deficits. Thus, this framework supports strategic and effective design decisions, fostering the development of AR applications that are both user-centered and empirically grounded.

REFERENCES

Albert, W. B. and Tullis, T. T. (2022). *Measuring the User Experience. Collecting, Analyzing, and Presenting UX Metrics*. Morgan Kaufmann.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, 6:355–385.

Billinghurst, M. and Duenser, A. (2012). Augmented Reality in the Classroom. *Computer*, 45(7):56–63.

Brooks (1987). No silver bullet essence and accidents of software engineering. *Computer*, 20(4):10–19.

Chang, Y.-S., Hu, K.-J., Chiang, C.-W., and Lugmayr, A. (2020). Applying Mobile Augmented Reality (AR) to Teach Interior Design Students in Layout Plans: Evaluation of Learning Effectiveness Based on the ARCS Model of Learning Motivation Theory. *Sensors*, 20(1):105.

Criollo-C, S., Abad-Vásquez, D., Martic-Nieto, M., Velásquez-G, F. A., Pérez-Medina, J.-L., and Luján-Mora, S. (2021). Towards a New Learning Experience through a Mobile Application with Augmented Reality in Engineering Education. *Applied Sciences*, 11(11):4921.

de Almeida Pacheco, B., Guimarães, M., Correa, A. G., and Farinazzo Martins, V. (2019). Usability evaluation of learning objects with augmented reality for smartphones: A reinterpretation of nielsen heuristics. In Agredo-Delgado, V. and Ruiz, P. H., editors, *Human-Computer Interaction*, pages 214–228, Cham. Springer International Publishing.

Fu, K. K., Yang, M. C., and Wood, K. L. (2016). Design principles: Literature review, analysis, and future directions. *Journal of Mechanical Design*, 138(10):101103.

Graser, S. and Böhm, S. (2025). The influence of system characteristics on the user experience of augmented reality applications: An experimental approach in corporate training. In *Proceedings of the 2025 9th International Conference on Virtual and Augmented Reality Simulations*, ICVARS '25, New York, NY, USA. Association for Computing Machinery. [Unpublished manuscript, accepted for publication].

Graser, S., Kirschenlohr, F., and Böhm, S. (2024a). User experience evaluation of augmented reality: A systematic literature review. *CENTRIC 2024, The Seventeenth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services*.

Graser, S., Schrepp, M., and Böhm, S. (2024b). Construction of the UXAR-CT – A User eXperience Questionnaire for Augmented Reality in Corporate Training. *CENTRIC 2024, The Seventeenth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services*.

Graser, S., Schrepp, M., and Böhm, S. (2024c). UXAR-CT – An Approach for Measuring UX for Mobile Augmented Reality Applications in Corporate Training. In Wei, J. and Margetis, G., editors, *Human-Centered Design, Operation and Evaluation of Mobile Communications*, pages 211–234, Cham. Springer Nature Switzerland.

Graser, S., Schrepp, M., and Böhm, S. (2025a). Identification of design recommendations for augmented reality authors in corporate training. arXiv. https://arxiv.org/abs/2507.21722.

Graser, S., Schrepp, M., Kollmorgen, J., Escalona, M. J., and Böhm, S. (2025b). Classification of ar design recommendations on ux dimensions: Preliminary study results: Research report & data. 10.13140/RG.2.2.28124.71047.

Graser, S., Schrepp, M., Krüger, J. M., and Böhm, S. (2025c). Development of an innovative ux measurement approach for augmented reality in corporate training. [Unpublished manuscript, accepted for publication in the HCII 2025 - Late Breaking Papers Springer LNCS volumes of the Proceedings.

Hassenzahl, M. (2004). *The Thing and I: Understanding the Relationship Between User and Product*, pages 31–42. Springer Netherlands, Dordrecht.

Hinderks, A., Winter, D., Schrepp, M., and Thomaschewski, J. (2019). Applicability of user experience and usability questionnaires. *Journal of Universal Computer Science*, 254(13):1717–1735.

Hull, E., Jackson, K., and Dick, J. (2011). *Requirements Engineering*. Springer-Verlag, Berlin Heidelberg, 3 edition.

ISO9241-210 (2020). Ergonomics of human-system interaction - part 210: Human-centred design for interactive systems.

Kashfi, P., Feldt, R., and Nilsson, A. (2019). Integrating ux principles and practices into software development organizations: A case study of influencing events. *Journal of Systems and Software*, 154:37–58.

Klein, A. M., Hinderks, A., Schrepp, M., and Thomaschewski, J. (2020). Construction of ueq+ scales for voice quality: measuring user experience quality of voice interaction. In *Proceedings of Mensch Und Computer 2020*, MuC '20, page 1–5, New York, NY, USA. Association for Computing Machinery.

Kollmorgen, J., Hinderks, A., and Thomaschewski, J. (2024). Selecting the Appropriate User Experience Questionnaire and Guidance for Interpretation: The UEQ Family. *International Journal of Interactive Multimedia and Artificial Intelligence*, pages 1–14.

Kollmorgen, J., Pilz, J., Silva da Silva, T., Thomaschewski, J., and Schön, E.-M. (2025). Reframing challenges in agile and ux: A new categorization approach. In Schrepp, M., editor, *Design, User Experience, and Usability*, pages 101–111, Cham. Springer Nature Switzerland.

Krauß, V., Boden, A., Oppermann, L., and Reiners, R. (2021a). Current Practices, Challenges, and Design Implications for Collaborative AR/VR Application Development. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, CHI '21, pages 1–15, New York, NY, USA. Association for Computing Machinery.

Krauß, V., Jasche, F., Saßmannshausen, S. M., Ludwig, T., and Boden, A. (2021b). Research and practice recommendations for mixed reality design – different perspectives from the community. In *Proceedings of the 27th ACM Symposium on Virtual Reality Software and Technology*, VRST '21, New York, NY, USA. Association for Computing Machinery.

Krüger, J. M. (2023). *Augmented Reality for Learning - The Role of Contextuality, Interactivity, and Spatiality for AR-based Learning Experiences*. Doctoral dissertation, University of Duisburg-Essen.

Krüger, J. M., Buchholz, A., and Bodemer, D. (2019). Augmented reality in education: Three unique characteristics from a user's perspective. In Chang, M., So, H.-J., Wong, L.-H., Yu, F.-Y., and Shih, J. L., editors, *Proceedings of the 27th International Conference on Computers in Education*, pages 412–422, Taiwan. Asia-Pacific Society for Computers in Education.

Lohse, M. (2011). Bridging the gap between users' expectations and system evaluations. In *2011 RO-MAN 20th IEEE International Symposium on Robot and Human Interactive Communication*, pages 485–490.

Mortazavi, E., Doyon-Poulin, P., Imbeau, D., Taraghi, M., and Robert, J.-M. (2024). Exploring the landscape of ux subjective evaluation tools and ux dimensions: A systematic literature review (2010–2021). *Interacting with Computers*, 36(4):255–278.

Pacheco, C., García, I., and Reyes, M. (2018). Requirements elicitation techniques: a systematic literature review based on the maturity of the techniques. *IET Software*, 12(4):365–378.

Pettersson, I., Lachner, F., Frison, A.-K., Riener, A., and Butz, A. (2018). A Bermuda Triangle? A Review of Method Application and Triangulation in User Experience Evaluation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, page 1–16, New York, NY, USA. Association for Computing Machinery.

Provost, G. and Robert, J.-M. (2013). The dimensions of positive and negative user experiences with interactive products. In Marcus, A., editor, *Design, User Experience, and Usability. Design Philosophy, Methods, and Tools*, pages 399–408, Berlin, Heidelberg. Springer Berlin Heidelberg.

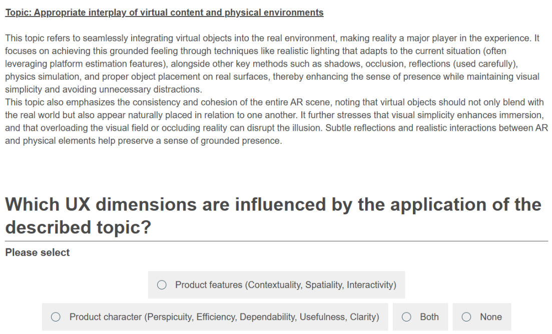
Rauschenberger, M., Schrepp, M., Cota, M. P., Olschner, S., and Thomaschewski, J. (2013). Efficient measurement of the user experience of interactive products. how to use the user experience questionnaire (ueq).example: Spanish language version. *Int. J. Interact. Multim. Artif. Intell.*, 2:39–45.

Schrepp, M., Kollmorgen, J., Meiners, A.-L., Hinderks, A., Winter, D., Santoso, H., and Thomaschewski, J. (2023). On the Importance of UX Quality Aspects for Different Product Categories. *International Journal of Interactive Multimedia and Artificial Intelligence*, 8:1.

Schrepp, M. and Thomaschewski, J. (2019). Design and validation of a framework for the creation of user experience questionnaires. *International Journal of Interactive Multimedia and Artificial Intelligence*, 5(7).

Tcha-Tokey, K., Loup-Escande, E., Christmann, O., and Richir, S. (2016). A questionnaire to measure the user experience in immersive virtual environments. In *Proceedings of the 2016 Virtual Reality International Conference*, VRIC '16, New York, NY, USA. Association for Computing Machinery.

APPENDIX



Topic: Appropriate interplay of virtual content and physical environments

This topic refers to seamlessly integrating virtual objects into the real environment, making reality a major player in the experience. It focuses on achieving this grounded feeling through techniques like realistic lighting that adapts to the current situation (often leveraging platform estimation features), alongside other key methods such as shadows, occlusion, reflections (used carefully), physics simulation, and proper object placement on real surfaces, thereby enhancing the sense of presence while maintaining visual simplicity and avoiding unnecessary distractions.
This topic also emphasizes the consistency and cohesion of the entire AR scene, noting that virtual objects should not only blend with the real world but also appear naturally placed in relation to one another. It further stresses that visual simplicity enhances immersion, and that overloading the visual field or occluding reality can disrupt the illusion. Subtle reflections and realistic interactions between AR and physical elements help preserve a sense of grounded presence.

Which UX dimensions are influenced by the application of the described topic?

Please select

Product features (Contextuality, Spatiality, Interactivity)

Product character (Perspicuity, Efficiency, Dependability, Usefulness, Clarity)

Both

None

Exemplary excerpt from the survey. AR design recommendation topics were presented to the participants, followed by the classification question. At the end of each questionnaire page, the UX dimensions and their descriptions were listed, allowing participants to refer back to them as needed.

Product features (ARcis):
(1) Appropriate interplay of virtual content and physical environments
(5) Hand & finger gestures
(6) Textures – Visual Realism and Appearance of Objects
(17) Error prevention & recovery
(18) Consider and show User's required Effort

Product character (UX Quality Aspects):
(9) Handling Interruptions / Relocalization
(12) Visual cues for object manipulation
(13) Object Placement
(19) Law of practice
(21) Text / Font
(22) Accessibility (visuals)
(23) Ergonomics (avoid muscle fatigue)
(24) Ergonomics (avoid head & neck fatigue)
(25) Pause / Breaks
(26) Performance
(28) Feedback
(29) FOV
(30) Content Placement

Product features and character (Both):
(2) Attention directors
(3) Instructions
(4) Onboarding
(7) Occlusion
(8) Image detection
(10) Surface Detection
(11) Affordance
(14) Object Manipulation
(15) Encourage to explore
(16) Keep the focus on AR experience, but use 2D-UI On-Screen elements when needed
(20) Inform about Waiting Time
(27) Audio Feedback
(31) Headlocked content
(32) Anchored UI