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DESIGN FOR EXTENDED REALITY (DFXR) – EXPLORING ENGINEERING AND PRODUCT DESIGN EDUCATION IN XR

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ABSTRACT
With the rapid development and increasing utilisation of eXtended Reality (XR), sustainability considerations have become an important factor in the design process. Despite the many advantages of XR, existing studies covering design education research show a fragmented early phase application use primarily focusing on local use-cases rather than global interconnected alternatives. While many universities are developing their digital capabilities using XR for various educational purposes, few examples exist of interceded activities using multiple variations of XR (i.e., VR, AR, or MR). Establishing a more interconnected set of use-cases is important to fully realise the potential of this technology. Past methodological considerations have been presented through guided design steps when working with elements of XR. However, to position early attempts to work on design imperatives using XR this paper presents a literature review and content analysis to examine the current state of design principles for XR. By utilizing the Design Society's knowledge repository, it employs a categorization process and charts valuable insights of existing XR pedagogical practices. Ultimately, this paper highlights the importance of considering sustainability in digitally enabled prototyping steps and practices using XR and its relevance for the E&PDE community. It also emphasises the need for more research and attention on how XR is practised and how it can be used to advance sustainability efforts.

Keywords: Design, extended reality, XR, augmented reality, AR, virtual reality, VR, mixed reality, MR

1 INTRODUCTION
Design for extended reality (XR) refers to the creation of digital experiences that blend the physical and virtual worlds. XR includes virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies that allow users to interact with digital content in real-world environments. XR has the potential to revolutionise design education, particularly in the context of sustainability. With the use of XR technology, design educators can create immersive and interactive experiences that allow students to explore sustainable design principles, materials, and techniques. In this way, XR technology can promote a deeper understanding of sustainability and help students develop skills and knowledge to design sustainable solutions that meet the UN's sustainability goals [1]. Designing for XR involves creating immersive experiences integrating the user's surroundings and providing a sense of presence and interactivity that can accelerate the product development cycle [2]. The design process of XR is a multidisciplinary approach that combines the principles of architecture, spatial design, interaction design, visual design, audio design, and user experience design [3].
XR design typically involves the following key elements:

1. Spatial design: XR is inherently spatial, designing experiences require careful consideration of physical space and how the virtual content is situated within it. Designers must consider the user's movement and ensure that the experience remains comfortable and safe in the virtual environment, this includes the placement of objects, scale, and movement [4].
2. Interaction design: XR experiences require intuitive interaction mechanisms that enable users to interact with digital content in natural and intuitive ways. This may involve using gestures, voice commands, or physical objects as input [5]

3. Audio design: Sound plays a crucial role in XR experiences, helping to create a sense of presence and immersiveness. Audio design for XR may involve creating 3D soundscapes that change as the user moves through the environment [6].
4. User experience design: XR experiences require a seamless user experience that is easy to navigate and understand. User experience design in XR requires designers to create interfaces that are easy to use in a 3D environment and ensure that the experience is accessible to users with different levels of experience and abilities [7].
5. Visual design: XR experiences require high-quality visuals that can immerse users in the digital environment by creating high-quality 3D models, textures, and lighting that are optimised for XR displays. Designers should balance visual fidelity with the need for efficient rendering, user comfort and consider the colour temperature, contrast, and saturation when designing interfaces [8].

XR design involves creating immersive experiences that seamlessly blend physical and virtual environments to create new forms of interaction and engagement, incorporating spatial design, interaction design, visual design, audio design, and user experience design principles. XR user interfaces used in engineering design have frequently reported deficiencies that create interruptions or gaps in the user's workflow [9]. Despite the potential benefits of using XR in the design process, there are still several obstacles that must be addressed in order to ensure an efficient and effective design process [10]. To minimise errors and enhance the quality of XR design, this paper introduces the acronym DfXR, which stands for Design for XR. By using this acronym, the paper aims to promote and standardise the use of this term within the XR design community. DfXR should be considered as crucial as other well-established methodologies such as Design for Manufacturing (DfM) for ensuring efficiency, speed, and high production rates. The design process must be structured to produce efficient outputs, as research suggests that more than 70% of manufacturing costs result from design choices made during the early design phases, including material selection and manufacturing methods [11, 12]. Therefore, it is imperative for companies to focus on improving their design processes to reduce costs and enhance the quality of their products. By incorporating DfXR principles, designers and ultimately companies can minimise errors and ensure that their XR designs meet the requirements of users and stakeholders [2]. Therefore, the dual purpose of this paper is to explore; i) the relevance for XR for engineering and design education, and ii) to find out key considerations that are necessary for a successful DfXR approach.

2 BACKGROUNDS

Design is a complex, high-order cognitive activity that relates to multiple cognitive processes such as visual processing and reasoning, decision-making, emotions and problem solving [13]. By adopting and preparing for an integration of XR [14], a crucial step in the design process becomes to establish authenticity and realism. Realism in XR applications refers to the degree to which the virtual environment mimics the physical world, and this affects the user's sense of presence and immersion in the environment. Achieving high levels of realism in XR applications can enhance the user experience, increase the user's sense of presence in the virtual environment, and reduce cybersickness [15]. When designing an XR application, it is essential to consider both input and output devices, regardless of the hardware being used. Input devices refer to the mechanisms through which users interact with the virtual environment, such as controllers, hand gestures, or voice commands, while output devices refer to the mechanisms that deliver visual and auditory feedback to the user. Designers must consider the type and compatibility of input and output devices when designing XR applications to ensure that they are safe, accessible and easy to use [16]. The inclusiveness of XR has become increasingly apparent in recent years with the attempt to merge augmented reality's benefit of immersiveness applied to VR [15] where we today see many XR devices, with integrated features like hand tracking as a built-in input option, e.g., HoloLens 2. This underlines that spatial design is reaching new heights with refinements to the optical hand and finger tracking where natural interaction schemes mimic how we operate in the real world [17]. This technology is the only option that offers direct interactions with the hologram, without any additional devices or markers and therefore brings no interruption to the classic workflow [9]. Haptics play an important role for visual interactive representation resulting in attempts to use ultrasonic sound and vibrations to be applied for haptic feedback [18]. By automating the detection process, designers can focus on creating immersive experiences without worrying about technical constraints. Several studies have demonstrated the effectiveness of using AI and Machine Learning (ML) algorithms in the design process [19, 20]. The strength of an AI-based approach for predicting e.g., user preferences in immersive environments opens for deep learning algorithms to analyse a broaden pattern of user behaviour.

3 RELEVANCE OF DFXR TO THE FUTURE OF DESIGN EDUCATION

Known as Metaverse, a virtual reality space allowing people and digital objects to interact in a shared environment presents an opening for testbed activities as AI, ML algorithms and deep learning architectures, which are expected to play an important role in development of new learning environments [20]. The successful implementation of XR in higher education requires the consideration of multiple areas and stakeholders. Still, little focus has been given to study the product design education can process and capture XR without presenting specific technology features or case experiences [21]. XR has the potential to enhance teaching and learning by breaking down the boundaries of traditional classrooms, establishing playful gamification scenarios [11]. Facing new types of immersive environments for presenting and delivering instructional content [22], XR enables unique learning experiences, and develops communities of inquiry and practice [10, 23]. An integration of emerging technologies such as XR provides opportunities for increased understanding in design and engineering disciplines, while not jeopardising cognitive loads. It is crucial for educators, designers, and technology experts to collaborate and prototype iterative ways for co-designing [24], in the potential design of a XR-enhanced gamified learning experience [10]. Therefore, design considerations should match the needs and goals of learners, the appropriate use of technology, and the alignment of XR activities with learning outcomes [25]. By doing so, higher education institutions can optimise the use of XR transforming teaching and learning embedding interdisciplinarity by incorporating AI and ML as part of a more immersive design education.

4 METHODOLOGIES

This is a position paper that draws on an extensive literature review on the application of design principles for XR and potential implications on existing practices. By looking at trends and potential gaps in current research and providing insights into effective XR pedagogical practices. The Design Society's rich knowledge repository was analysed using both descriptive and content analysis. Tracing relevant past experiences, identifying relevant studies based on the inclusion criteria and keywords 'extended+reality', and source 'paper'. Papers were thereafter categorised based on content screening with inspiration from open coding [26]. Due to page limitation the E&PDE* reference list and the categorising process have been drastically shortened.

5 FINDINGS

To elicit key characteristics of selected papers, an initial abstract review was conducted to validate the relevance of the papers and limiting the total of 220 papers initially found, to 56 out of 1619 in the E&PDE series. The last decade presented a short list of 46 papers, which after screening went down to 25 papers that all bring attention to XR in the last decade within the E&PDE community. Notably, only one paper from 2008 showed any initial relevance. Descriptions that could be attached to the different papers showed multiple aspects of XR (e.g., immersive teaching, design tool, STEM skills, spatial abilities, frameworks, learning modality, role). The papers are mainly exploratory approaching functionalities in different use-case scenarios and in combination with other aspects of design e.g., drawing to overcome transferability and communication, scalability and safety in work practices. The papers also highlight the necessity for new digitalized skills, including XR from a user-centric perspective. The collection of papers provides evidence of good practices and successes of immersive XR experiences rather than solely focusing on the design principles behind these explorations.

Table 1. E&PDE series, last decade on Extended Reality*

Year(s): 10	Number after keyword search: 46	Number based on relevance and scope: 25
2022	8	8, immersive teaching, gamification, onboarding, co-design, additive manufacturing, design tool, learning modality
2021	12 (-6 after screening)	6, STEM skills, spatial abilities, remote VR prototyping,

		creativity using VR tools, XR platform
2020	2	2, VR in design education, educational role, multimodal drawing framework
2019	7 (-4 a.s.)	3, VR as teaching tool, lab, challenges
2018	4 (-3 a.s.)	1, AR familiarity
2017	4 (-3 a.s.)	1, new design paradigm
2016	3 (-3 a.s.)	0
2015	1	1, industrial design AR
2014	4 (-2 a.s.)	2, emotion assessment, educational role
2013	1	1, evaluation, early design concepts

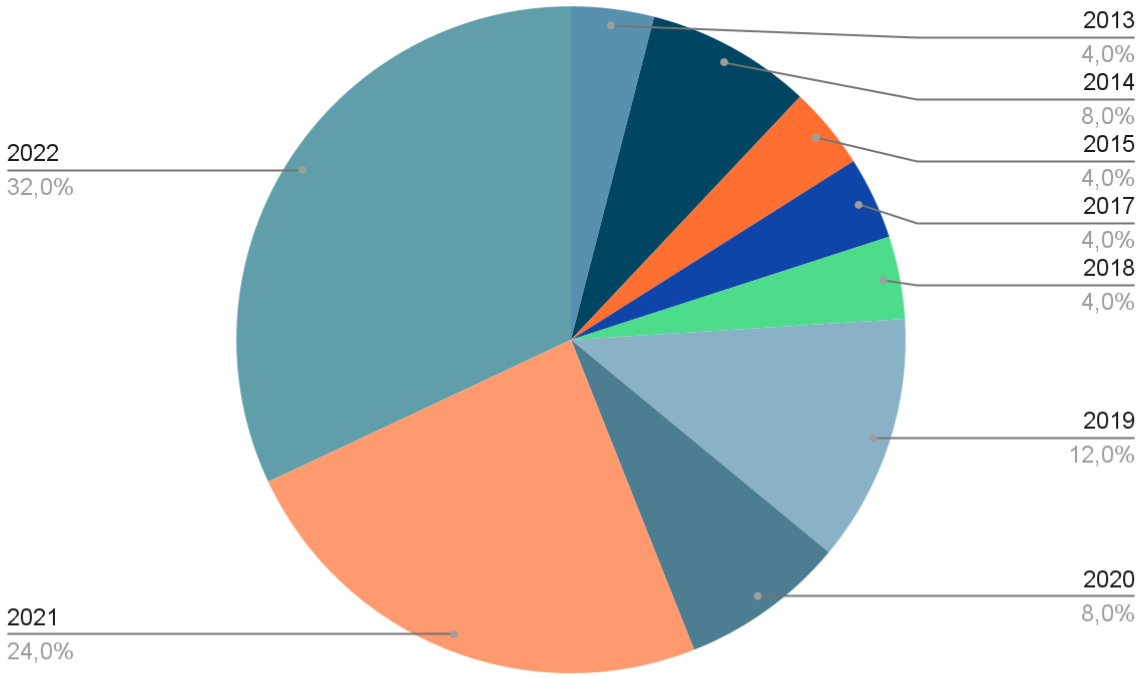

Figure 1. Annual distribution of XR 2013-2022

6 DISCUSSIONS

XR is gaining significant momentum and attracting growing interest within the engineering and product design education community. Its research scope is expanding exponentially, reflecting the increasing recognition of its potential. As a theme is emerging there is still little attention shared on how to develop XR using robust and sustainable design principles. Indications are similar across a multitude of other places, e.g., society, business, healthcare, research and education. This poses implications that necessitate a deeper consideration of how to design sustainable efforts for the long-term benefit of XR. Additionally, this paper also presents the relevance and the essential factors for effectively implementing a DfXR approach. The ratio of produced material covering XR for design education is rapidly increasing, presenting the advantages of cross-platform interlinkage [9], establishing new ways of critical learning [21]. The need for a seamless design interaction put emphasis on an iterative prototyping process where digital alterations enrich materialised cognitions [22]. XR applications, particularly those focused on VR for engineering design, commonly present gaps in the user's workflow, such as data-gaps [9]. Once modifications are made to the data, the complexity of data conversion is causing problems, the second gap relates to the potential of a hardware-gap, where most modern immersive devices, such as head-mounted displays and hand-held controllers, require the user to wear a headset or visit a specific area to switch from classical to immersive workflows. What is referred to the Open XR runtime standards are currently extending the possibilities between hardware and software interoperability, which can potentially increase XR sustainability by making the technology more accessible. By identifying and exploring remote design processes, collaborations that utilise a mix of technological platforms are looked at and how interaction of XR practices and processes affect aspects like internationalisation and interconnectedness. With a growing number of students, professional workers and companies utilising new remote-working norms, a better understanding is needed to support distributed and sustained XR collaboration. The study proposes features for DfXR by building upon past immersive XR user experiences [6, 10, 22, 24]. To address the complexity of the design approach and its impact on virtual product development, the integration of AI and ML algorithms can automatically detect essential constraints [18, 19]. DfXR is a design approach that seeks to optimise user experience by involving the creation of virtual products that are immersive, interactive, and responsive to user input. However, DfXR is often challenging due to the complexity of creating immersive experiences that meet the user's expectations. To address this challenge, AI and ML algorithms have made their way into the design process. Using algorithms essential constraints can be detected in immersive design features, such as motion tracking, object interaction, and visual fidelity. Integrating AI and ML algorithms into the design process can help overcome the deficiencies in immersive extensions of key design features for DfXR, aimed at enhancing immersive user experiences. These algorithms can automatically detect essential constraints, allowing designers to focus on creating immersive experiences.

7 CONCLUSIONS

This paper provides overall design guidance and highlight the community's increasing interest in XR. The rapid growth of XR and the interest for XR design principles are providing space for greater solutions to be made. This research presents that the design education discipline has shown an escalated interest in how to use and develop meaningful learnings with XR. To pursue such design efforts XR applications need to consider various criteria, including realism, spatial design, input and output devices, cognitive and emotional factors, and privacy and security. These design criteria are essential in ensuring that XR applications provide an immersive, engaging, and accessible user experience. Still, additional research is needed to further investigate effects and implications of design approaches of XR. Understanding the sustained impact of these design practices can contribute to the development of more effective and responsible XR experiences that transcend disciplinary boundaries and extend across diverse domains.

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