P/REFERENCES OF DESIGN

XR_CODESTO: ANALYSIS OF EXTENDED REALITY COLLABORATIVE DESIGN TOOLS.

Flora Gaetani*[a], Federica Caruso[a]

a Politecnico di Milano, Design Department, Italy
* flora.gaetani@polimi.it

DOI: 10.63442/GVJR1179

KEYWORDS | EXTENDED REALITY, COLLABORATIVE DESIGN, DESIGN PROCESS, MAPPING, PRODUCT DESIGN VISUALISATION

ABSTRACT | The paper investigates Extended Reality (XR) advanced representation application paradigms in collaborative product design sessions. The research stems from the pressing need for innovative solutions to address the challenges posed by the global pandemic, particularly the necessity for collaborative telepresence due to enforced social distancing. In this scenario, XR and similar technologies as Virtual Reality (VR) have opened new design possibilities.

Therefore, the primary objective of the research is to investigate how XR technology, as an advanced representation system, can effectively contribute to industrial design, particularly in its collaborative phases. This study examines the technology landscape of XR in terms of challenges encountered by tools on a practical basis for industrial design.

This research addresses a central question: Can XR enhance "triggered" design practices by facilitating collaboration when sharing an unfeasible physical space?

The methodology includes a case study analysis conducted as exploratory studies, blue-sky research, and a thorough examination of academic and commercial XR applications. Each case study is categorised based on pertinent variables, focusing on collaboration and technological accessibility criteria. The outcomes offer a map that aligns case studies within the design process.

The map summarises the main results of the research. While not claiming to be exhaustive, its purpose is to provide an assessment framework and stimulate reflection on incorporating case studies into the design process. The map includes information on the strengths and weaknesses of current technologies and available resources serving as inspiration for future implementations.

1. Introduction

1.1 Background and Context

This research intends to explore and verify the possibilities of using eXtended Reality (XR) tools in collaborative design sessions. The study is based on a pressing need for innovative solutions to deal with global pandemic challenges, in particular, the necessity of collaborative telepresence due to enforced social distancing where Virtual Reality (VR) and similar technologies have opened new design possibilities (Strand, 2020; Vi et al., 2019). This requirement is thought to tackle challenges arising from the pandemic while generating lasting possibilities, such as improving remote collaboration and lessening the environmental impact of travel fields. Even beyond the immediate pandemic emergency, exploring this research area remains opportune, as it addresses workplace flexibility and enables design teams to simulate an in-person experience regardless of their location (Li et al., 2023).

Furthermore, there is a growing focus on exploring the collaborative aspect, particularly as co-design gains significance in addressing complex technological, social, and educational situations. An alternative approach becomes essential when no person has all the knowledge and skills to understand and solve these complexities (Zamenopoulos & Alexiou, 2018). In this paper, the collaborative session is to be taken as when stakeholders with different skills and capabilities work together towards a common goal to solve the design challenge, particularly during brainstorming sessions to define the brief, review sessions during project development, final refinement and testing and product presentation.

The future of XR technologies is envisioned as a collaborative and distributed infrastructure. As anticipated, users and specialists will interact and organise activities on a global scale through mediated environments (Nguyen & Bednarz, 2020). XR technologies integrated into collaborative user interfaces improve communication, facilitating seamless functional and cognitive workflows among users (Billinghurst & Kato, 1999) and augmenting the sense of co-presence. Schroeder (2002) summarised that co-presence refers to "*being there together*" and engaging with other users concurrently.

The Research XR_CODESTO (eXtended Reality Collaborative Design Tools) aims to explore and define new ways advanced representation systems, such as XR technology, can be effectively utilised in industrial design, mainly in its work-sharing phases. Given the evolution of technologies, this exploratory research, which still needs to be completed, aims to address the challenges XR technology faces in finding practical applications within the industrial design field. This would help designers and stakeholders overcome geographical limitations, achieve working continuity, and enhance the overall design experience (Ratcliffe et al., 2021). Additionally, the research aimed to contribute towards bridging the gap in knowledge and understanding of XR technology by providing insights into its practical implementation and benefits within the industrial design field and its related didactics.

Furthermore, the research aimed to contribute to the dissemination of XR technology and identify future research needs relating to pedagogical integration, digital skills, and digital infrastructure. Overall, the research aimed to explore and demonstrate the potential of XR technology in industrial design, address challenges posed by globalisation crises, establish XR as a valuable and widely used tool in the industrial design process, and contribute to the standardisation and future development of XR technology.
The subsequent paragraph aims to provide a concise theoretical overview of the primary subjects investigated in the research: Extended Reality and Collaborative Design session.

1.2 Extended Reality

Extended Reality (XR) is an overarching term that encompasses a broad spectrum of immersive technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Using the Reality-Virtuality Continuum is imperative to clarify the Extended Reality concept, engaging with the framework posited by Milgram et al. (1994). The continuum concept is a critical analytical tool, facilitating a nuanced comprehension of AR, MR, and VR while elucidating the intricate interrelations that link these technologies.

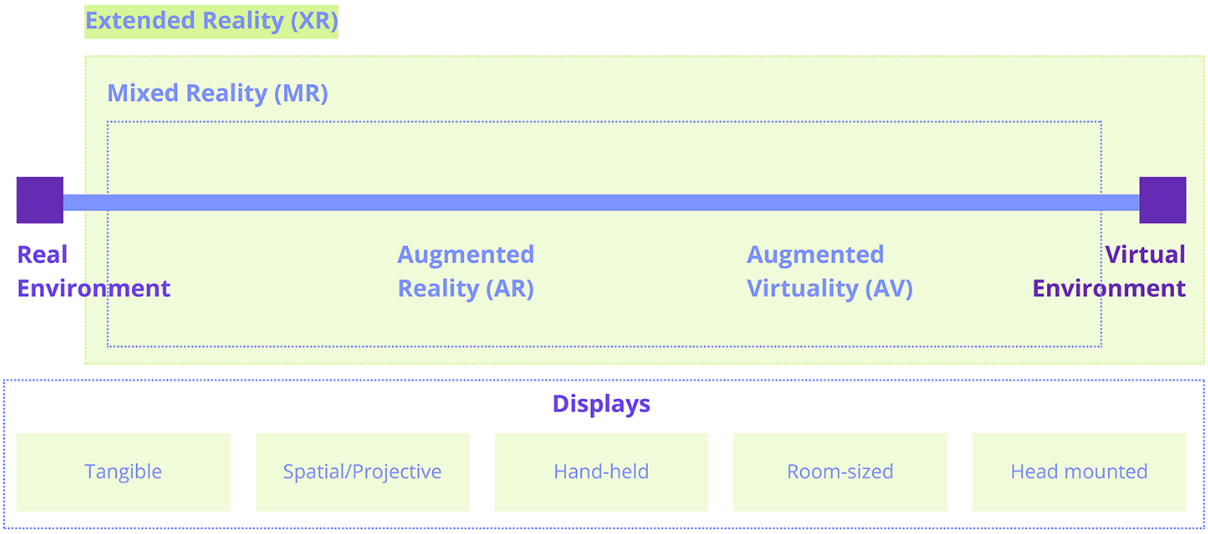

Figure 1. Diagram describing Milgram et al. (1994) Reality-Virtuality Continuum and adding the definition of the set of XR displays (Milgram & Kishino, 1994).

The Reality-Virtuality Continuum is articulated through two polar extremes: on one end, the not-changed real-world environment, and on the opposite end, a wholly virtual environment representative of VR. The intermediate space, which diverges from these extremes, is categorically delineated as Mixed Reality (Speicher et al., 2019). MR manifests in many forms within this intermediate domain, each uniquely characterised by varying degrees of immersion and the interplay between virtual elements and the natural environment. This diverse categorisation encompasses technologies such as Augmented Reality - wherein a predominantly real-world context is enhanced with virtual elements; Augmented Virtuality - a scenario that predominantly exists within a virtual realm yet incorporates elements of the real world to varying extents; Mediated Reality (Mann et al., 2018) (encompassing technologies like XY-R, designed to alter the perception of reality for specific purposes, such as augmenting the colour perception for individuals with colour blindness, thereby affording them a more accurate representation of their environment); and Diminished Reality (Cheng et al., 2022), which involves the technological elimination or reduction of real-world elements from the user's perception.

The delineation of XR has evolved in contemporary years, now being conceptualised as an amalgamation of Virtual Reality and all technologies that fall within the ambit of Mixed Reality. This broadened definition underscores XR's fluidity and expansive nature as a field, highlighting its capacity to integrate and synergise various immersive experiences. By encompassing a wide array of technologies that straddle the continuum from the entirely real to the fully virtual, Extended Reality stands at the forefront of technological innovation, pushing the boundaries of how digital and physical realities can converge to create novel and enriching experiences.

1.3 Collaboration in the Design Session

For this research, collaborative sessions are strategically integrated throughout the phases of the product design process, exhibiting variability in their type and frequency, contingent upon the intrinsic characteristics of the design process, its inherent complexity, and the phase of implementation. Individuals are engaged, assuming various roles, and may participate across different design project levels and stages. In line with the model of the Double Diamond (DD) (Design Council, 2005; Kochanowska et al., 2022) proposed by the Design Thinking approach, engagement in design starts with the "discovery" of nascent needs or opportunities within a specific context, proceeds with the "definition" of particular interest or challenge to be addressed, the "development" of viable ideas capable of addressing such situations, and culminates in the "delivery" of a (prototyped) solution to a distinct problem or opportunity.

This iterative process, characteristically non-linear and frequently recursive, shows varied ways of interaction influenced by the participants involved and the degree of detail attained. Aligning the DD model with collaborative practices (Figure 2), we can see that at the beginning, collaborative sessions mainly focus on defining or analysing the project brief, using low-tech tools to facilitate meetings, image exchange and brainstorming activities. These meetings serve to outline the inspirations and define the project constraints. During the intermediary phases, as the concept idea advances towards materialisation, the nature of collaborative sessions switches to design reviews.

This phase aims to advance towards a more refined articulation of the project, demanding the involvement of a broader spectrum of stakeholders and ensuring that the fidelity of representations incrementally aligns more closely with reality.

The final phases are dedicated to prototyping and testing. Herein, collaborative sessions are convened with a focus on the iterative refinement of the project, aiming to rectify any discrepancies before transitioning towards actual production. In the last phase, the testing is better done with the final users to verify whether the project result meets their needs, and the collaboration becomes even more complex. To conclude, the crucial role of collaboration at every stage is facilitating a holistic and iterative design process that optimises outcomes and enhances the feasibility of the final product (El-Jarn & Southern, 2020).

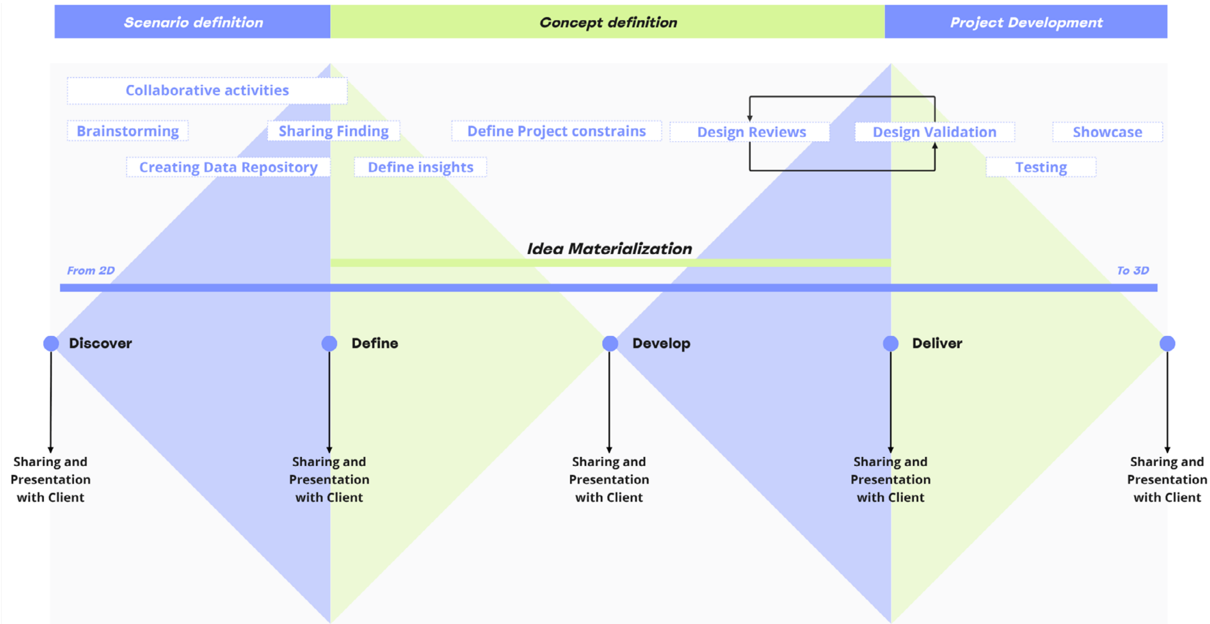

Figure 2. Collaborative session applied to the DD model, authors reinterpretation.

1.4 Representation Techniques

The methodologies and techniques employed in articulating ideas and concepts throughout the various phases of the design process are tailored to meet the unique requirements of each distinct phase within the process (Novoa Munoz et al., 2022). In the incipient stages of a project, representation is predominantly delegated to techniques of a fundamentally two-dimensional nature. This encompasses freehand sketches, which facilitate the exploration of initial ideas alongside reference images and mood boards. These tools are instrumental in delineating the project's conceptual framework and aesthetic ethos, providing a foundational visual vocabulary upon which subsequent development is predicated (Purcell & Gero, 1998).

As the design process advances, there is an evolution in the representation methods, which progressively embrace complexity since it is moving towards a three-dimensional perspective. This transition is exemplified by adopting a study maquette, which helps stimulate a tangible understanding of spatial dynamics and shape or provides volumetric three-dimensional constructs and a more realistic representation of the project. These instruments are pivotal, not merely for enhancing the visualisation of spatial relations and integrating elements but also for facilitating a simulation of the project with its context (Bellini, 2019).

In the final stages of the design process, the focus shifts towards generating lifelike models. These representations, often the product of modelling and rendering technologies, enable a precise visualisation of the project, meticulously accounting for variables such as lighting, materiality, and construction specifics. Thus, they accurately portray the anticipated outcome, significantly augmenting the dialogue among designers, clients, and stakeholders. This, in turn, allows for a comprehensive evaluation of the project's aesthetic and functional alternatives before its materialisation, ensuring a confluence of vision and execution that is both coherent and anticipatory of the project's intended impact (Kuys et al., 2023).

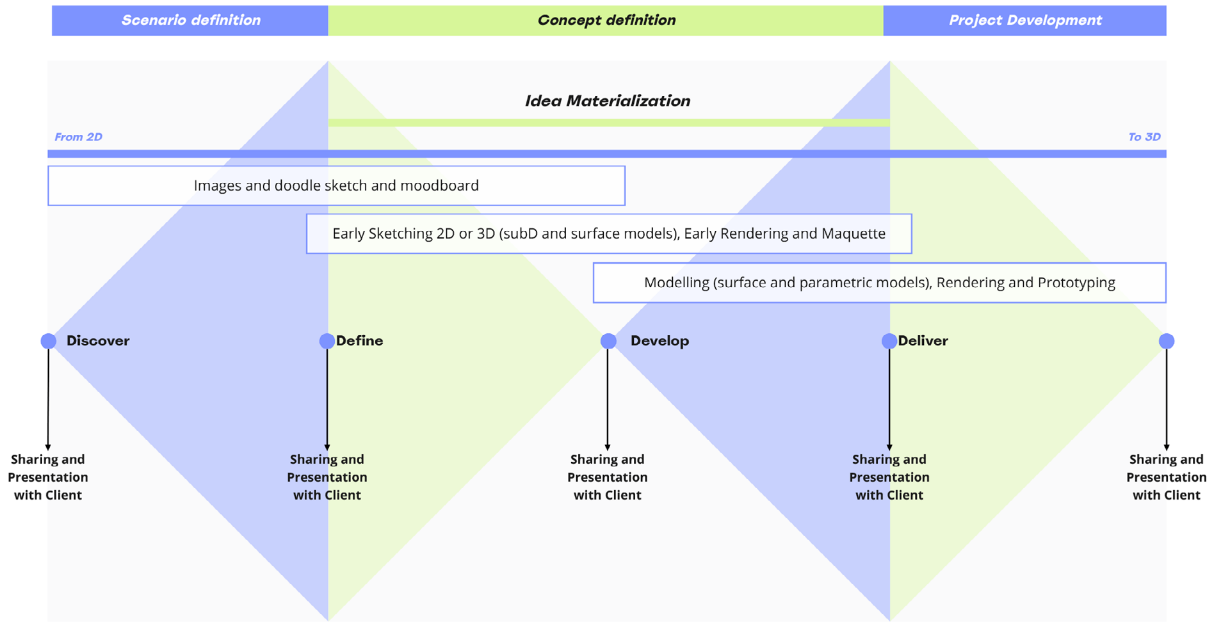

Figure 3. Methods and techniques of representation applied to the DD model, authors reinterpretation.

2. Methodology

Starting from a framework defined with the preliminary literature review, a qualitative research method was chosen for this research to explore the topic better. Qualitative research methodologies, encompassing case studies and best practices, are applied to explore the research question. Employing a mapping process, the research assesses diverse XR tools applied in design processes, specifically emphasising those supportive of co-design sessions.

This phase has been researched on state-of-the-art technology, emerging market trends and reports, and the implementations already in progress identified as opportunities. In this step, the team explores XR's possibilities by identifying interesting case studies and best practices.

The research process unfolds through four principal phases explored in the following paragraphs.

Table 1. Summary of activities, results achieved, and people involved.

Phase	People	Role	Type of activities	Outputs
Preliminary Exploratory	4	1 Research Fellow in Representation 2 Research Fellow in Design 1 PhD Student in Design	Analysis of the latest advancements in technology. Identifying and interpreting emerging trends within the marketplace.	**Collecting Data**
Collaborative Co-design Workshop	7	1 Research Fellow in Representation 2 Research Fellow in Design 1 PhD Student in Design 3 Students of MSc in Design	Understand the previously selected case studies, examine them, and define evaluation criteria.	**Case Studies Selection** **Case study "cards"**
Final Synthesis	5	1 Research Fellow in Representation 2 Research Fellow in Design 1 PhD Student in Design 1 Students of MSc in Design	Distil the information derived from the case study analysis into clusters, and to pinpoint the various connections within the design process.	**Case Studies Mapping**
Didactical Application	95	60 students of BSc in Product Design 15 students of Specializing Master TAD 20 students of an Elective course for MSc in engineering and design	Dissemination of the research findings and use as a didactical tool aimed to equip future professionals with the knowledge and skills to leverage XR technologies.	**Implementing tools for education**

2.1 Preliminary Exploratory Phase

In the Preliminary Exploratory Phase of the research, the initial objective was to examine and understand the contemporary XR technological landscape. This included an analysis of the latest advancements in technology, identifying and interpreting emerging trends within the marketplace, and recognising existing implementations that were deemed to hold potential for opportunity. This phase serves as a foundation for further investigation, aimed at collecting data and then analysing and synthesising it during the second phase.

At this stage, the team started with an exploratory literature review, examining the fundamental aspects of XR reality, with the methodology developed by Milgram et al. (1994) as a guide for the work. The focus was identifying research addressing design principles and illustrating practical applications through case studies. Simultaneously, the team engaged in an online XR MOOC (Nebeling, 2020) introductory course to understand XR technologies necessary for subsequent analytical phases. A trend analysis was also conducted using the Hype Cycle for Emerging Technologies, referencing reports from 2017 to 2022 (Gartner, 2017; 2018; 2019; 2020; 2021; 2022). The team selected emerging technologies relevant to their area of focus, using these trends to inform their commercial analysis. This involved thorough desk research to identify device systems and tools suitable for integration into the design process.

The output of this initial investigative stage was selecting a collection of case studies. Each chosen case study was explicitly aligned with the research goal that had been previously established. The goal serves as a filter allowing a focused examination of the technological landscape, choosing a case study directly relevant to the research.

2.2 Collaborative Co-design Workshop

The preliminary exploration phase laid the groundwork for an in-depth exploration, setting the stage for the subsequent phases of the research. A collaborative Co-design workshop followed the first phase. During the Collaborative Co-design Workshop, the primary goal was to understand the previously selected case studies, examine them, and define evaluation criteria. This phase was characterised by engagement, where participants were tasked with critically examining and classifying each case study.

The output of this workshop was case study cards that serve as a visual synthesis of each case study and related parameters. Despite the inherent diversity, these cards served as a pivotal output of this phase, offering a more precise and structured understanding of each case study.

Furthermore, this phase establishes the conceptual framework that allows us to bridge the theoretical underpinnings of XR with the design process.

2.3 Final Synthesis and Future Application

In the concluding phase of the research, the Final Synthesis and Future Applications, the effort was to amalgamate the insights into a coherent synthesis. The objective here was twofold: firstly, to distil the information derived from the case study analysis into clusters, and secondly, to pinpoint the various connections within the design process and understand where the technologies under consideration could be most effectively applied. Identifying these clusters was foundational to defining a conceptual framework for future explorations.

Equally important was the identification of specific steps within the design process where the technologies could be seamlessly integrated. This required a thorough understanding of the design process, including its various phases, requirements, and outcomes. The goal was to ensure that technology integration was not additive but transformative, enhancing the design process in meaningful and sustainable ways. The research aimed to provide actionable insights that could be directly applied to design challenges.
The output of this final stage was a comprehensive synthesis that mapped the case studies within the identified clusters and delineated the potential pathways for the future application of the technologies.

2.4 Didactical Application

This phase primarily focused on disseminating the research findings and fostering the professional adoption of XR technologies. This stage was essential in translating the theoretical insights and analytical conclusions drawn from the research into actionable knowledge and practices that could be readily applied within professional and educational settings. A strategy was employed to integrate the research outcomes into professional development and academic instruction to achieve this. The research serves as a groundwork to inspire various educational initiatives designed to cater to a diverse audience, ranging from industry professionals to students within the higher education sector.

The research findings were integrated into professional master's programmes, specifically within the automotive sector. Allowing the students to select among the case studies the ones that better fit their needs during the design process. Moreover, the conceptual framework will be used as an evolving tool to understand the technologies on the market and open up possible XR implementations and experiments. In this way, the integration aimed to equip future professionals with the knowledge and skills to leverage XR technologies to advance automotive design.

Furthermore, an elective course for master's degrees was also developed. This course was designed to foster interdisciplinary collaboration and innovation, enabling students from diverse academic backgrounds to explore the synergies between technological advancements and design principles through the lens of XR technologies. Additionally, the conceptualisation of a virtual laboratory represented a significant advancement in the educational application of the research findings.

Through these diverse educational initiatives, the Didactical Application phase sought to disseminate research findings and inspire and facilitate the widespread adoption of XR technologies. By embedding these technologies within the curricula of professional and academic programmes, the phase aimed to cultivate a new generation of professionals and scholars well-versed in applying XR technologies, thereby contributing to advancing the field and realising its full potential across various domains.

3. Collaborative XR Case Studies

3.1 Case Studies Selection

The case study method has been chosen because it is beneficial for understanding and generating explanations for complex phenomena (Anderson, 1993; Yin, 2009). Also, it provides the opportunity to investigate every case/project in depth. Therefore, the case study method could analyse the scenario through different design paradigms.

The first step to starting a case study is to draw the boundaries of the cases. Yin (2009) stated that more significant heterogeneity among cases could increase generalisations. Instead, the homogeneity might support internal validity.

According to these assumptions, the selected cases were chosen among XR devices/systems/tools that could be used in collaborative design processes. Then, these cases were examined regarding their availability and readiness to the market, their collaborative qualities, accessibility, and cross-integration between different platforms. Defined indicators have been applied to select and filter the first results according to the scope of this research, such as:

- Year of publication and date when the case study was conducted. Due to the growth rate of the rapid technological improvement of XR instruments and the depreciation of older ones, it must be considered that this type of technology undergoes a very rapid obelise. The release date is an essential indicator when looking at case studies;
- Field of application. As stated above, the research is focused on design-related industries that require the almost simultaneous use of XR tools among several stakeholders remotely, attending the session in the same physical space or a combination of them. For this reason, most research released in our selected timeframe regarding medical, military, and other external fields in which the interaction described is only human to machine or vice versa has been avoided;
- The level of interaction and collaboration such tools could offer to end users. It underscores the emphasis on collaborative aspects within the solutions being explored in the research. More interaction among more than two users is seen as having increased significance in the study context. Tools that, per se, were not designed for collaboration were not excluded because, when put into the system, they could still be of interest to the study.

The case collection and selection process in this research involved two distinct phases. Initially, cases were selected based on preliminary criteria and later refined during a co-design session. Consequently, the initial selection underwent a secondary review. During the first phase, 20 case studies were gathered via web-scraping by predetermined criteria. A subsequent screening process was conducted to exclude cases based on relevance to design collaboration, the quality of technology representation, and redundancy. When faced with similar cases, only the one best suited to the research requirements was retained. This approach resulted in the exclusion of 7 case studies.

Here is the list and a brief description of the selected case studies after the selection phase.

1. Gravity Sketch with LandingPad (Gravity Sketch, 2021): 3D design platform for cross-disciplinary teams to create and collaborate in virtual reality;
2. Spatial IO (Meta Quest, 2020): Customizable virtual space for meetups, NFT art exhibitions, and live events;
3. Campfire (https://campfire3d.com): A system consists of a headset and software for design collaboration in a remote world;
4. XR with Unity3D (https://www.khronos.org/openxr/): Cross-platform for designing and developing AR/VR/XR Experience;

5. 3DFrames for Webex (Grandis, 2022): A metaverse app for Webex. It helps teams meet virtually to conceptualise plans and present products;
6. Spark project (O'Hare et al., 2020): A tool that applies augmented reality in co-creative design sessions by projecting texture on 3D objects;
7. CAVE (Virtual Environments Group, 2013): A cubic room with projection screens aims to create a virtual environment. In which users wear eyewear to interact with visual stimuli;
8. Realtime VR projection(https://www.nuformer.com): Real-time projection on the environment's external surfaces while the user performs in virtual reality;
9. Tesla Suite & Tesla Glove (https://teslasuit.io): A full-body haptic feedback system provides the user with haptic feedback. Also, it captures the user's motion and biometrical data;
10. Sense glove (https://www.senseglove.com): Force-feedback glove that can be integrated with the VR system, allowing the user to gain a sensorial experience from the virtual environment;
11. Logitech VR Ink Stylus (https://www.logitech.com/en-eu/promo/vr-ink.html): VR stylus allows designers to create geometries in two-dimensional physical surfaces or three-dimensional room-scale space;
12. Touchable hologram (Baraiuk, 2014): System that uses sound waves to project “haptic holograms” into mid-air –letting the user touch 3D virtual objects with his bare hands;
13. InterHaptics (https://www.interhaptics.com): 3D design software for building interaction 'design hand tracking' and composing haptics for AR/VR applications for cross-disciplinary teams to create and collaborate in virtual reality.

3.2 Case Studies "Cards"

Upon selecting the case studies, the co-design workshop was convened to establish indicators that encapsulate the characteristics inherent to each case. This workshop was planned as a co-design activity to foster exhaustive comprehension among six participants. It saw the research team's collaboration with two young designers and was methodically organised, drawing upon insights from preceding research.

The activities conducted within this workshop were directly inspired by the selected case studies, engaging participants in a collective effort to review and refine the evaluation parameters.
The workshop served as a debate for exchanging perspectives and facilitating open discussions. The discourse that ensued was instrumental in refining the evaluation criteria for the case studies, culminating in the creation of evaluative cards summarising each case study's findings (Figure 4). These cards function as a comparative matrix, enabling a consistent comparison of case studies through the visual representation of parameters, enhancing clarity and comprehension.

This categorisation encompassed the following parameters:

- Device/System/Tool: This dimension delineates whether the case study is classified as a device (a tangible instrument such as a viewer), a system (a complex amalgamation of infrastructure, device, and software), or a tool (software developed to facilitate the use of XR);
- Academic/Industry R&D: This categorises the case studies based on their origin, differentiating between those emerging from academic research projects and those developed within industrial research and development contexts;
- Stand-alone/Add-on: This classifies the case studies based on their operational independence or requirement to use other devices, systems, or tools.
- Black/White box: This distinction is related to the potential for customisation the case study offers, primarily regarding software.

After this preliminary classification, the evaluative cards were enriched, adding other evaluation criteria. In this case, a value from 1 to 5 was given:

- Specific Equipment Required: This criterion assesses the extent of specific equipment necessity;

- Ready to Market: This evaluates the market readiness of the case study, awarding the highest score to those already available on the market;
- Collaborative: This measures the degree to which the case study facilitates collaborative efforts;
- Accessibility: This assesses the accessibility of the case study in terms of the requisite skills for users;
- Cross Integration: This evaluates how the case study can be integrated with other Devices, Systems, or Tools.

These evaluative metrics and classifications provided a structured approach to understanding the diverse case studies, facilitating a systematic analysis informing the subsequent research and application phases.

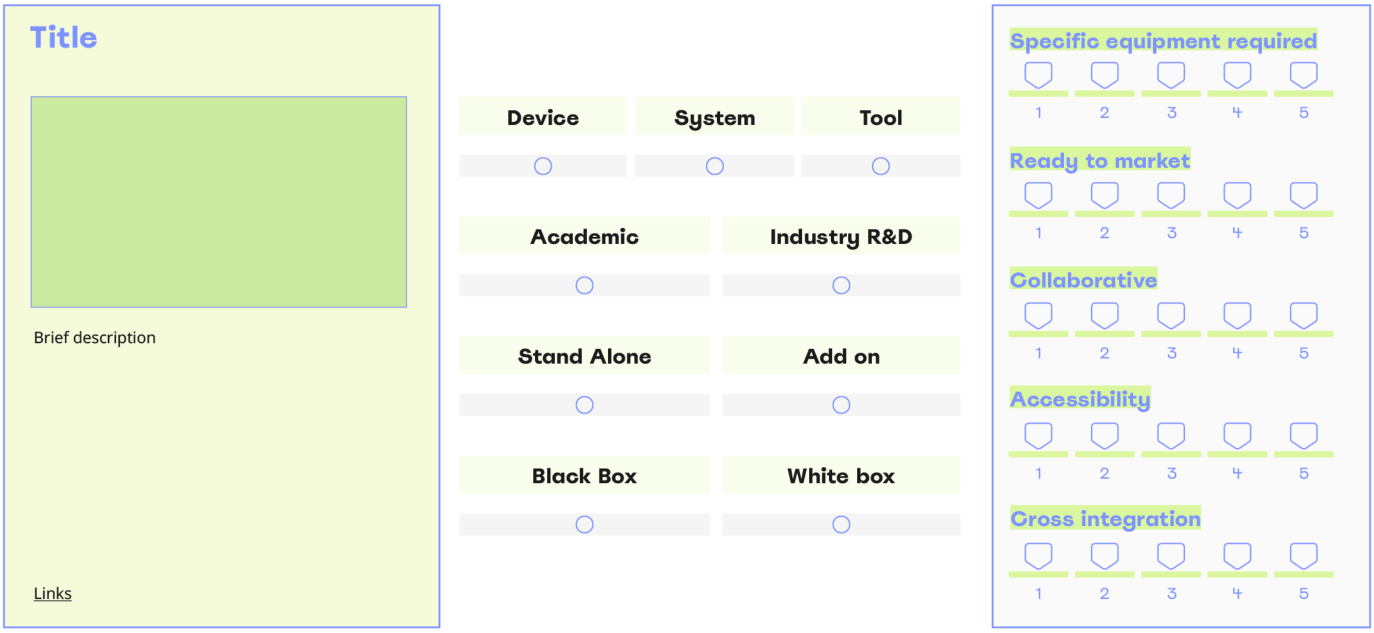

Figure 4. The case study evaluation grid.

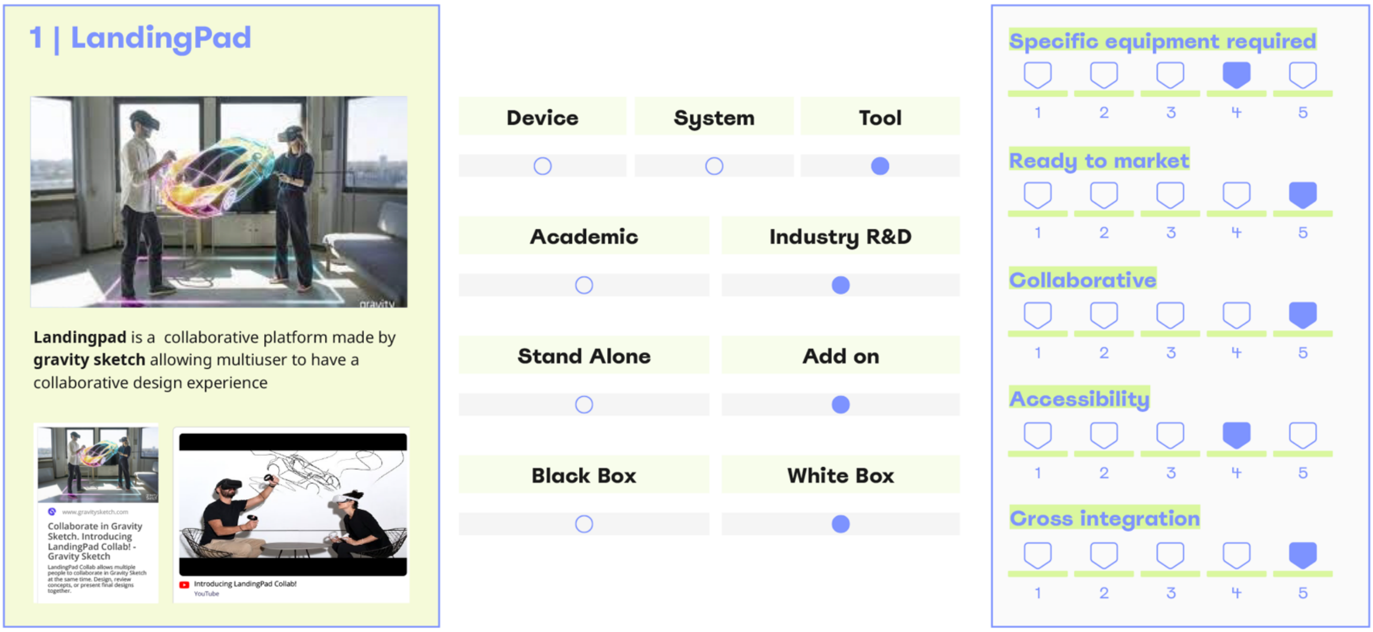

Figure 5. The case study evaluation grid, applied to a case study.

3.3 Case Studies Mapping

After this refinement and categorisation, the research established an additional evaluative stratum. This phase was characterised by creating a conceptual framework (Figure 5) that signifies an integration of two foundational models: the Double Diamond model, which delineates the structured phases of the design process, and the Milgram continuum, which represents the spectrum of reality-virtuality integration. The primary ambition behind this framework was to merge the Double Diamond model with the reality-virtuality continuum proposed by Milgram to combine the two concepts under inquiry. This phase produces a map that facilitates the strategic positioning of case studies concerning their congruence with the distinct phases of the design process, as well as their placement within the reality-virtuality spectrum. Consequently, the horizontal axis of the map delineates the alignment of case studies with the Double Diamond model's mapping of the design process, considering that a single case study may bear relevance to multiple stages of design, so it cannot have a single place but more than one. Meanwhile, the vertical axis categorises case studies according to their positioning within the Milgram continuum, from a fully real environment (bottom) to a fully virtual environment (top).

This map serves as a visual summarisation of the principal findings of the research. While it does not claim to be an exhaustive representation, especially considering the rapid evolution with which these technologies advance, its construction is intended to offer a structured framework for subsequent evaluation. Its objective is to catalyse reflection on the potential integration of the examined case studies into the design process. It provides a novel lens to consider the intersection of design methodology and the reality-virtuality continuum. Additionally, the map provides insights into the strengths and weaknesses of current technologies, thereby serving as a source of inspiration for future implementations. This evaluative tool facilitates a deeper understanding of the landscape of technology application within design, encouraging a vision of how emerging technologies might be harnessed to enrich and expand the boundaries of design practice.

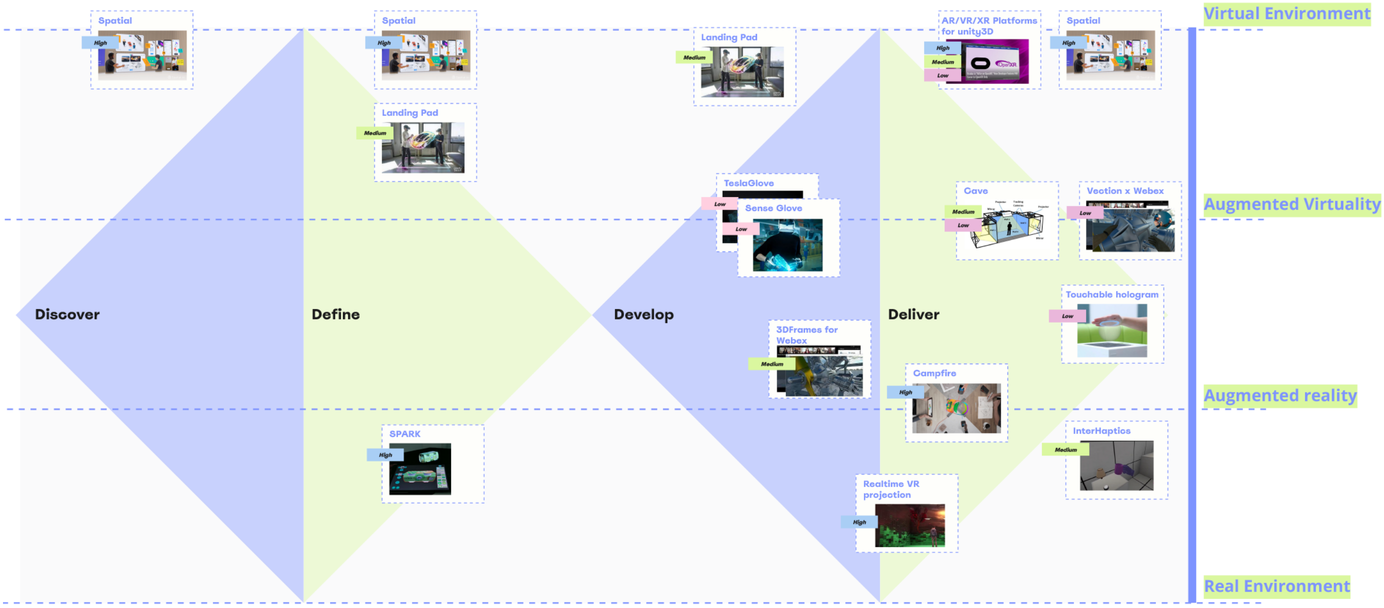

Figure 6. The mapping of the case studies on the double diamond model. The vertical distribution of the case studies is determined by their position within the Milgram continuum (ordered to the right of the diagram). The coloured flag indicates the level of possible collaboration: high blue, medium green, and low pink.

3.4 Implementing XR Tools for Education

Reflecting upon the utility of the most user-centric tools, the research team endeavoured to incorporate specific tools and devices into the academic curriculum, focusing on integrating XR within the educational sphere. This initiative aimed to devise and implement strategic action plans to discern the potential roles of XR in enhancing pedagogical practices. The investigative foray included conducting experiments with a second-year undergraduate cohort from the Product Design programme. AR visualisation software was introduced during the concluding phases of a Digital Representation Studio, categorised within the Showcase cluster. Additionally, students enrolled in the Specializing Master course in Transportation & Automobile Design (Poli.design, n.d.), were engaged in trials involving immersive Virtual Reality VR tools for the evaluative assessment of car interiors, alongside AR tools for the examination of car exteriors, aligning with the Review Together Cluster.

The insights garnered from this project have helped establish an elective course for Master of Science (MSc) degrees in engineering and design. This course is meticulously designed to equip students with an in-depth understanding and practical competencies in XR methodologies and tools. It aims to empower students to create virtual replicas of design solutions for industrial products throughout the various stages of the product development process.

Particular emphasis is placed on XR technologies that are particularly efficacious in representing design solutions during the conceptual and embodiment design phases, thereby fostering the creative process. In mid-2023, the project expanded its horizon by creating a small Virtual Lab. This laboratory is specifically tailored for students pursuing the Industrial Engineering-Design and Architectural Design degree at the XJTU-POLIMI Joint School of Design and Innovation (Polimi, n.d.). This venture represents a significant stride towards embedding XR technologies within the academic framework, facilitating hands-on learning and experimentation.

The forthcoming phase entails the structured evaluation of devices available within collaborative design sessions. Acknowledging the limitations inherent to these devices, conducting tests with designers in an organised setting is anticipated to yield direct feedback from end-users and validate the research findings. Such collaborative testing sessions, conducted within a virtual environment, are poised to delineate the boundaries and unveil XR's opportunities, thereby contributing to refining XR applications in design education and practice.

4. Results

The mapping exercises undertaken within this research have produced insights into the predominant tools that facilitate collaboration across various phases of the design process. An in-depth examination of the interplay between the analysed XR case studies and the principal tools employed during these collaborative stages has led to conclusions concerning the potential for the widespread integration of these tools into collaborative practices.

Recent advances in XR, which encapsulates VR, AR, and MR, have significantly increased the capacity for intuitive multi-user interactions within both co-located and remote settings. This growing technology affords a more enriched social presence through multimodal communication channels, elevating collaborative experiences and augmenting the quality of user experience and task-specific performance.

The analytical synthesis and consequent mapping of the case studies have facilitated their classification into four distinct clusters, each representing an application of XR technologies within collaborative contexts in the product design field:

1. Augmented Meeting. This cluster encapsulates virtual environments designed to enhance the immersive attributes of meetings, wherein participants can be partially or fully immersed. This category underscores the role of XR in transforming traditional meeting spaces into more engaging and interactive spaces. This cluster of XR technologies can be activated during all phases of the design process (Discover, Define, Develop, and Deliver);

2. Design Together. This category is characterised by a shared virtual experience accessible simultaneously to multiple users. It has proven especially effective in the collaborative design and modelling of complex products, demonstrating the profound impact of XR on facilitating collective creativity and problem-solving. This cluster of XR technologies can be activated during the central phases of the design process (Define and Develop), during the concept definition;

3. Review Together. Concentrating on the collaborative presentation of ideas, this cluster facilitates a unified user perspective, enabling the collective review and feedback process. It exemplifies the utility of XR in streamlining communication and enhancing the coherence of collaborative review sessions. Within this cluster, case studies in AR or VR can be found. This cluster of XR technologies can be activated during the final phases of the design process (Develop and Deliver);

4. Showcase. While this dimension may exhibit collaborative elements, it primarily functions as a platform for showcasing outcomes during the delivery phase or displaying products throughout the testing phase. This cluster illustrates the versatility of XR as a tool for demonstrating achievements and facilitating stakeholder engagement. Within this cluster, case studies in AR or VR can be found.

These insights explain the multifaceted applications of XR technologies within collaborative scenarios, highlighting their transformative potential across various dimensions of stakeholder interaction and project evolution. The emergent classification not only offers an understanding of the scope and efficacy of XR in enhancing collaborative activities but also lays the groundwork for future explorations into integrating these technologies within the broader landscape of design and development processes.

5. Discussion

While exploring the XR technologies, it becomes imperative to critically assess the landscape, particularly to demystify the overstatement that often surrounds emerging technologies. A discerning analysis reveals several aspects that deserve consideration (Ashtari et al., 2020).

Firstly, there is a noticeable trend within the domain of XR technology wherein new terminologies are frequently introduced to describe what essentially amounts to the same underlying technology. This proliferation of terminologies and the launch of new devices that exhibit only minor enhancements over their predecessors contribute to a landscape marked by confusion and redundancy. Such a scenario often complicates distinguishing genuine innovation from mere incremental updates (Nebeling, 2020).

Furthermore, promotional materials associated with XR technologies frequently suffer from a tendency towards over-promising. Videos and advertisements showcasing these technologies often portray capabilities and experiences beyond the reach of current implementations. This practice sets unrealistic expectations and obscures these technologies' progress and potential limitations.

Among the critical factors that significantly impact the efficacy and immersion of XR experiences are the display resolution and the field of view. These elements are paramount in defining the quality of the virtual or augmented reality experience, influencing the user's sense of presence and immersion within the digital environment. While many technical aspects of XR technologies are witnessing rapid advancements, these fundamental features continue to serve as benchmarks for assessing the maturity and capability of XR devices (Poulin et al., 2024).

Advancements in user interaction modalities, particularly hand, finger, and eye tracking, have reached a level that is now considered standard and performs quite effectively. These developments have greatly enhanced the intuitiveness and responsiveness of XR systems, allowing for more natural and engaging user experiences.

Despite these advancements, it is crucial to acknowledge that XR technologies are still subject to significant technical and design limitations. These constraints often manifest as less-than-optimal user interfaces, limited content availability, and challenges integrating virtual elements with the physical world (Speicher et al., 2019).

Moreover, the capability for environmental understanding, a critical component for creating convincing and interactive augmented reality experiences, remains relatively rudimentary. Current systems often struggle to interpret and respond to complex physical environments accurately, limiting AR applications' scope and realism.

In conclusion, while XR is expanding with potential, understanding its current state reveals a mix of rapid advancements and persistent challenges. This interplay of progress and limitation defines the current frontier of XR technology, highlighting the importance of tempered expectations and continuous innovation in overcoming the hurdles that lie ahead.

Only in some technologies or devices, which may be the case with the new Apple Visor Pro (Apple, 2023), released in June 2023, does the technology leap forward. In the case of Apple, in addition to improvements on the "visor" system by inserting various features already in use on other devices, the most significant new paradigm is represented by the possibility of gradually varying the immersion of the virtual environment between fully immersive or augmented.

6. Conclusion

This research has provided valuable insights into the potential applications and challenges of integrating such technologies into the design process, demonstrating that XR technologies offer promising solutions for remote collaboration, enhanced communication, and enriched design experiences.

This research has highlighted the transformative potential of XR in redefining collaborative design practices. The classification of XR case studies into distinct clusters, including Augmented Meeting, Design Together, Review Together, and Showcase, underscores the versatility and efficacy of XR tools across various phases of the design process. The findings of this research serve as a foundation for future exploration and innovation in integrating XR technologies within design education and practice. By fostering interdisciplinary collaboration, facilitating hands-on learning experiences, and addressing the evolving needs of design professionals and students, XR technologies promise to revolutionise how designers conceive, create, and collaborate on design projects.

While this research has provided valuable insights into integrating XR technologies in collaborative design sessions, it is essential to acknowledge several limitations. One limitation is the technology evolution: XR technologies are rapidly evolving, with new devices, platforms, and applications continually being developed. This research may become outdated as newer technologies emerge, potentially impacting the relevance and applicability of its findings over time. The findings of this research may be specific to the context in which the study was conducted.

Also, methodological limitations should be considered. The research methods employed, such as case studies, workshops, and literature reviews, may have inherent limitations, such as sampling biases or subjectivity in data interpretation. Future studies may address these limitations by broadening the investigation scope and considering the technology's long-term implications. Thus, the long-term impact of integrating XR technologies into design education and practice remains to be determined and solved by research. It is still being determined how these technologies will evolve, how practitioners and educators will adopt them, and their lasting effects on design processes and outcomes. Nevertheless, this research provides a valuable starting point for further exploration and advancement in the field of XR technologies in collaborative design sessions by providing points for reflection and analysis that provide insights for future research.

References

Anderson, J. R. (1993). Problem solving and learning. *American Psychologist, 48*(1), 35–44. https://doi.org/10.1037/0003-066X.48.1.35

Apple. (2023). Introducing Apple Vision Pro: Apple's first spatial computer. *Apple Newsroom*. Retrieved June 25, 2023, from https://www.apple.com/newsroom/2023/06/introducing-apple-vision-pro/

Ashtari, N., Bunt, A., McGrenere, J., Nebeling, M., & Chilana, P. K. (2020). Creating augmented and virtual reality applications: Current practices, challenges, and opportunities. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1–13). Association for Computing Machinery. https://doi.org/10.1145/3313831.3376722

Baraniuk, C. (2014, December 1). Haptic holograms let you touch the void in VR. *New Scientist*. https://www.newscientist.com/article/dn26640-haptic-holograms-let-you-touch-the-void-in-vr/

Bellini, M. (2019). Architettura, design e altro. *Diségno*, 4, 9–19.

Billinghurst, M., & Kato, H. (1999). Collaborative mixed reality. In *Proceedings of the First International Symposium on Mixed Reality (ISMR)* (pp. 261–284). https://doi.org/10.1007/978-3-642-87512-0_15

Cheng, Y., Yin, H., Yan, Y., Gugenheimer, J., & Lindlbauer, D. (2022). Towards understanding diminished reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. ACM. https://doi.org/10.1145/3491102.3517452

Design Council. (2005). *Framework for innovation*. The Design Council. https://www.designcouncil.org.uk/our-resources/framework-for-innovation/

El-Jarn, H., & Southern, G. (2020). Can co-creation in extended reality technologies facilitate the design process? *Journal of Work-Applied Management, 12*(2), 191–205. https://doi.org/10.1108/JWAM-04-2020-0022

Gartner. (2017, July 21). *Hype cycle for emerging technologies, 2017*. Retrieved June 17, 2022, from https://www.gartner.com/en/documents/3768572

Gartner. (2018, August 6). *Hype cycle for emerging technologies, 2018*. Retrieved June 17, 2022, from https://www.gartner.com/en/documents/3885468

Gartner. (2019, August 6). *Hype cycle for emerging technologies, 2019*. Retrieved June 17, 2022, from https://www.gartner.com/en/documents/3956015

Gartner. (2020, July 21). *Hype cycle for emerging technologies, 2020*. Retrieved June 17, 2022, from https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020

Gartner. (2021, August 11). *Hype cycle for emerging technologies, 2021*. Retrieved June 17, 2022, from https://www.gartner.com/en/documents/4004623

Gartner. (2022, July 25). *Hype cycle for emerging technologies, 2022*. Retrieved September 17, 2022, from https://www.gartner.com/en/documents/4016848

Grandis, D. (2022, June 13). Vection Technologies' 3DFrame: Build your 3D/VR metaverse in Webex meetings. *Webex Blog*. https://blog.webex.com/hybrid-work/vection-metaverse/

Gravity Sketch. (2021, November 5). Collaborate in Gravity Sketch: Introducing LandingPad Collab! https://www.gravitysketch.com/blog/updates/collaborate-in-gravity-sketch-introducing-landingpad-collab/

Kochanowska, M., & Gagliardi, W. R., with reference to Jonathan Ball. (2022). The Double Diamond Model: In pursuit of simplicity and flexibility. In D. Raposo, J. Neves, & J. Silva (Eds.), *Perspectives on Design II* (pp. 23–45). Springer. https://doi.org/10.1007/978-3-030-79879-6_2

Kuys, B., Ranscombe, C., & Zhang, W. (2023). Visualising product concepts to engage manufacturers with little or no industrial design capability. *Design Studies, 87*, 1–29. https://doi.org/10.1016/j.destud.2023.101188

Li, M., Houwing, D., Albayrak, A., Shidujaman, M., & van Eijk, D. (2023). Mapping XR platforms: Analyzing immersion from the designer's perspective. In M. Kurosu & A. Hashizume (Eds.), *Human-Computer Interaction* (Vol. 14013, pp. 32–49). Springer. https://doi.org/10.1007/978-3-031-35602-5_32

Mann, S., Furness, T. A., Yuan, Y., Iorio, J., & Wang, Z. (2018). All reality: Virtual, augmented, mixed (X), mediated (X, Y), and multimediated reality. *ArXiv*, abs/1804.08386.

Meta Quest. (2020, September 20). Spatial | Oculus Quest [Video]. YouTube. https://youtu.be/0JD6F9XYrMQ?si=VT846ZtNhujnxf6v

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented reality: A class of displays on the reality-virtuality continuum. In *Proceedings of SPIE - The International Society for Optical Engineering, 2351*, 282–292. https://doi.org/10.1117/12.197321

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Trans. Information and Systems, 77*(12), 1321–1329.

Nebeling, M. (2020, December 14). XR Mooc. *Information Interaction Lab, University of Michigan*. https://www.mi2lab.com/xrmooc/

Novoa Munoz, M., Howell, B. F., Hoftijzer, J. W., Rodríguez Díaz, J. M., Zhang, W., & Kramer, N. (2022). New collaborative workflows: Immersive co-design from sketching to 3D CAD and production. In E. Bohemia, L. Buck, & H. Grierson (Eds.), *Proceedings of the 24th International Conference on Engineering and Product Design Education* (pp. 425–436). https://doi.org/10.35199/EPDE.2022.64

Nguyen, H., & Bednarz, T. (2020). User experience in collaborative extended reality: Overview study. In P. Bourdot, V. Interrante, R. Kopper, A.-H. Olivier, H. Saito, & G. Zachmann (Eds.), *Virtual reality and augmented reality* (pp. 41–70). Springer. https://doi.org/10.1007/978-3-030-62655-6_3

O'Hare, J., Dekoninck, E., Mombeshora, M., Martens, P., Becattini, N., & Boujut, J. F. (2020). Defining requirements for an augmented reality system to overcome the challenges of creating and using design representations in co-design sessions. *CoDesign, 16*(2), 111–134. https://doi.org/10.1080/15710882.2018.1546319

Poli.design. (n.d.). Transportation & automobile design. Retrieved April 3, 2024, from https://www.polidesign.net/en/formazione/interior-design-and-architecture/master--transportation-automobile-design/

Polimi. (n.d.). XJTU-POLIMI Joint School. Retrieved April 3, 2024, from https://www.xjtu.polimi.it/?lang=en

Poulin, M., Masclet, C., & Boujut, J.-F. (2024). Investigating the effects of spatial augmented reality on user participation in co-design sessions: A case study. *Computers in Industry, 154*. https://doi.org/10.1016/j.compind.2023.104023

Purcell, A. T., & Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies, 19*(4), 389–430. https://doi.org/10.1016/S0142-694X(98)00015-5

Ratcliffe, R., Soave, F., Bryan-Kinns, N., Tokarchuk, L., & Farkhatdinov, I. (2021). Extended reality (XR) remote research: A survey of drawbacks and opportunities. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 527, 1–13). Association for Computing Machinery. https://doi.org/10.1145/3411764.3445170

Schroeder, R. (2002). Social interaction in virtual environments: Key issues, common themes, and a framework for research. In R. Schroeder (Ed.), *The social life of avatars* (pp. 1–20). Springer. https://doi.org/10.1007/978-1-4471-0277-9_1

Speicher, M., Hall, B. D., & Nebeling, M. (2019). What is mixed reality? In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 537, 1–15). Association for Computing Machinery. https://doi.org/10.1145/3290605.3300767

Strand, I. (2020). Virtual reality in design processes: A literature review of benefits, challenges, and potentials. *FormAkademisk, 13*(6). https://doi.org/10.7577/formakademisk.3874

Vi, S., Da Silva, T. S., & Maurer, F. (2019). User experience guidelines for designing HMD extended reality applications. In D. Lamas, F. Loizides, L. Nacke, H. Petrie, M. Winckler, & P. Zaphiris (Eds.), *Human-Computer Interaction - INTERACT 2019* (pp. 319–341). Springer. https://doi.org/10.1007/978-3-030-29390-1_18

Virtual Environments Group. (2013, June 4). Implementing Kanban in a virtual reality CAVE [Video]. YouTube. https://youtu.be/wompfASioZw?si=KRiEui96hyxxSP6t

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Sage.

Zamenopoulos, T., & Alexiou, K. (2018). *Co-design as collaborative research*. Bristol University/AHRC Connected Communities Programme. https://doi.org/10.9935528-3-0

About the Authors:

Flora Gaetani, with a PhD in Industrial Design and Multimedia Communication, is a research fellow focusing on advanced representation techniques in product design. She teaches design, collaborates with Xi'an Jiaotong University, and has professionally applied her design skills for numerous companies.

Federica Caruso is a UX/Product designer and PhD candidate; her research focuses on integrating Inclusive Design approaches into Meta-Design. She coordinates the Experience Design Academy and collaborates with the COmeta Laboratory, emphasising social impact, particularly in autism.

Acknowledgements: The present paper is the result of research and results obtained by all the authors together. However, Flora Gaetani wrote the Methodology (2), the Case Study Mapping (3.3), the Results (4), the Discussion (5) and the Conclusion (6), and Federica Caruso wrote the Introduction (1) and the Collaborative XR Case Studies (3.1, 3.2, 3.4). The authors would like to thank Andrea Ascani, Ammer Mahmoud Ahmed Fahmy Harb, Arianna Pasqualone and Ahmed Abdelmoneim Abdellatif Ali Hegazy for participating in the project.

P/REFERENCES OF DESIGN

This contribution was presented at Cumulus Budapest 2024: P/References of Design conference, hosted by the Moholy-Nagy University of Art and Design Budapest, Hungary between May 15-17, 2024.

Conference Website
cumulusbudapest2024.mome.hu

Conference Tracks
Centres and Peripheries
Converging Bodies of Knowledge
Redefining Data Boundaries
Bridging Design and Economics
Speculative Perspectives
The Power of Immersion
The Future of Well-being
Taming Entropy: Systems Design for Climate and Change
Ways of Living Together
Cumulus PhD Network

Full Conference Proceedings
https://cumulusbudapest2024.mome.hu/proceedings

ISBN Volume 1: 978-952-7549-02-5 (PDF)
ISBN Volume 2: 978-952-7549-03-2 (PDF)

DOI Volume 1: https://doi.org/10.63442/IZUP8898
DOI Volume 2: https://doi.org/10.63442/TADX4016

Conference Organisers
Moholy-Nagy University of Art and Design Budapest (MOME)
mome.hu
Cumulus Association
cumulusassociation.org