DESIGNING A FRAMEWORK FOR METAVERSE ARCHITECTURE

A preliminary framework for mixing holographic and physical architectural elements

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Abstract. Metaverse, which was first interpreted as an isolated virtual universe, is now evolving into a multiverse, where virtual worlds superimpose on the real one. Spaces, people, and activities in both physical and virtual formats are going to be seamlessly integrated. Architecture is seen as a container of spaces, people, and activities. Architectural elements are arranged to define spaces guiding people to conduct required activities. The emerging duality of the metaverse will change not only the architectural requirements but also the nature of architecture in terms of form and function. While holograms are becoming a new kind of architectural material, envisioning a potential framework to guide future exploration of metaverse architecture is the goal. In this paper, we conduct a qualitative user study to collect users' needs, identify architectural requirements, and build a preliminary framework for metaverse architecture. This framework provides strategies for mixing holographic and physical architectural elements to fulfill the users' needs of the metaverse. It could further lead to a potential way of reducing the production and consumption of carbon to contribute to the post-carbon framework.

Keywords. Metaverse; Mixed Reality; Hologram; Metaverse Architectural Framework; SDG 11.

1. Introduction and Goal

Metaverse, first coined in Neal Stephenson's 1992 science fiction book "Snow Crash," is interpreted as a virtual universe separate from the real one (Stephenson, 1992). It is a simulated world where people go to escape from their daily lives (Cline, 2011). In the metaverse, people can interact with each other to create, socialize, play, and trade via custom avatars (Ball, 2020). With the advancement of wearable optical see-through display technology (Bimber and Raskar, 2005), the metaverse is no longer an isolated virtual world but a digital multiverse where virtual worlds superimpose on the physical one. Spaces, people, and activities in physical and virtual formats will be seamlessly integrated (Microsoft, 2019; Microsoft, 2021).

POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2022, Volume 2, 445-454.

Architecture is a container of spaces, people, and activities. Architectural elements, such as horizontal and vertical elements, closures, and openings, are arranged to define spaces and guide people to conduct required activities (Alexander et al., 1977). However, the metaverse, where virtual and physical worlds coexist and collocate, creates a dual representation of spaces, people, and activities. The emerging duality of metaverse will change not only architectural requirements but also the very nature of architecture in terms of form and function.

Computational technologies currently serve as architectural design tools that assist with design thinking (Menges and Ahlquist, 2011), design communication, and construction management (Eastman et al., 2008). However, mixed reality technology, which was mostly adopted to enhance design visualization and simulation (Bertol, 1997), means they can no longer be viewed solely as design tools but must now be seen as architectural materials. Holograms can be used in the same way as wood, glass, concrete, and steel to create brand new architectural elements, reshaping the way people interact with architecture in the metaverse.

Hence, the goal of this research is to envision a potential architectural framework for guiding future exploration of metaverse architecture by answering two key questions:

- What are the new architectural requirements that would serve the emerging needs of metaverse?
- What are the design strategies guiding designers to explore ways of mixing physical and virtual architectural elements to fulfill those requirements?

2. Methodology and Steps

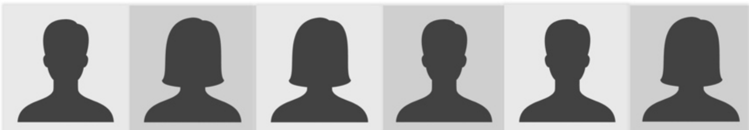
A four-step research and design plan is developed and executed in this study to answer the proposed research questions. First, six potential metaverse early adopters are interviewed to collect qualitative data on user needs. Second, architectural requirements are identified based on the users' needs. Third, a preliminary framework of metaverse architecture is generated consisting of strategies and goals for mixing physical and virtual architectural elements. Lastly, the framework is explained with a design example.

3. Qualitative Interviews

This qualitative research study conducted a series of interviews with six early adopters of the metaverse. As the metaverse is still a developing concept, there are currently no actual products providing metaverse experiences. Hence, early adopters are defined as subjects who with experience using Mixed Reality (MR) devices, including Microsoft HoloLens 2 (Microsoft, 2019) and Oculus Quest 2 (Meta, 2020), with at least two of the chosen 3D remote collaboration and social applications, including Microsoft Mesh (Microsoft, 2021), Spatial (Spatial, 2021), AltspaceVR (Microsoft, 2017), Rec Room (Rec Room, 2016), and Horizon Workrooms (Meta, 2021). These devices and applications are recognized as products offering pioneer experiences in the metaverse. The minimum experience of participants using the above-mentioned MR products should be more than one hour.

Five key questions are used to guide subjects' think-aloud processes. Subjects are asked to answer the questions based on their personal experiences with using MR products, materials related to MR, and metaverse concepts they have seen and heard, as well as their own expectations of MR and the metaverse. The five key questions are:

- What is MR/metaverse based on your understanding?
- What kinds of experiences with MR/metaverse have you tried?
- What benefits of MR/metaverse have you noticed?
- What pain points of MR/metaverse have you encountered?
- Are there any missing features/functions you would like to include in future MR/metaverse products?



Subject	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
Age	26	36	30	22	40	25
Occupation	Grad Student	Professor	SW Engineer	College Student	3D Content Creator	Project Manager
Metaverse HWs	HoloLens 2 Oculus Quest 2	HoloLens 2 Oculus Quest 2	Oculus Quest 2	Oculus Quest 2	HoloLens 2 Oculus Quest 2	HoloLens 2
Metaverse SWs	Mesh Spatial	Mesh Rec Room	Spatial Horizon Workroom	Altspace VR	Mesh Spatial	Mesh Spatial
SW Experiences	~ 1 hour	4 ~ 8 hours	2 ~ 4 hours	1 ~ 2 hours	> 8 hour	1~ 2 hours

Figure 1. Subject recruitment criteria

4. User Needs

After interviewing the six subjects, the results were grouped and summarized into four categories: spaces, activities, people, and objects. Within each category, the benefits and pain points that subjects articulated are listed off and discussed. To make the findings more concise and focused, opinions were only considered if they came from more than two subjects.

4.1. SPACES

- **[Benefit]Metaverse offers a three-dimensional (3D) spatial experience.** Virtual world experience is no longer bounded by screen real estate. For example, a user can participate in a 3D virtual remote meeting via a headset, providing full-body interaction instead of a computer monitor constrained by finger and touch screen.
- **[Benefit] Metaverse shows virtual and real spaces at the same time.** Users can perceive, interact with, and be guided by virtual and physical spaces overlaid on top of each other. For example, a user can have a 3D virtual meeting room placed in his real living room.

- **[Benefit] Metaverse makes virtual spaces persistent**. Users can revisit or retrieve the virtual spaces according to physical context. For example, a 3D virtual meeting room previously placed in a living room can be set to auto-launch when a user visits the living room again at the planned meeting time.
- **[Pain Point] Forms of virtual and physical spaces are conflicted.** Physical and virtual spaces overlaid on physical spaces should be further integrated by embedding simulated physics or correlation rules to avoid conflicts. For example, when placing a virtual meeting room in a real living room, the metaverse system should avoid placing a virtual wall and a physical chair in the same location.
- **[Pain Point] Functions of virtual and physical spaces are mismatched.** Physical and virtual spaces that are overlaid should be further merged into a new space that can host two different functions simultaneously. For example, a living room could be divided into two subspaces to host TV watching in the physical space and a virtual meeting in the metaverse simultaneously.

4.2. ACTIVITY

- **[Benefits] Activities in metaverse are not bounded by geolocation.** Activities happening at the same time in different locations are overlaid for users to join in simultaneously. For example, a user can participate in a 3D remote meeting in New York while at home in Taipei.
- **[Benefit] Activities in the metaverse are not affected by time zones.** Activities happening asynchronously are 3D recorded for users to review later. For example, a user can replay a recorded 3D virtual meeting that happened in New York from his home in Taipei.
- **[Pain Point] Virtual activities are constrained by physical boundaries.** Virtual and physical activities should be integrated to adapt to physical contexts. For example, activities in a medium-sized 3D virtual meeting room should be reconfigured to fit into a small-sized physical living room so that remote users are not being obstructed by physical walls.
- **[Pain Point] Physical and virtual activities interfere with each other.** Virtual and physical activities should be considered to prevent interference. For example, a 3D virtual meeting room is placed away from a TV in the living room to avoid interference.

4.3. PEOPLE

- **[Benefit] Users can select avatars to represent themselves.** Avatars and real people can be overlaid in the same viewport. For example, a user can see collocated colleagues and avatars of their remote coworkers in a 3D mixed meeting room.
- **[Benefit] Users can use real-time, 3D-captured representations as their presences.** 3D-captured human representation enables high fidelity and photorealistic communications. For example, a user’s appearance, body and hand gestures, and facial expressions can be captured to better communicate with remote

coworkers.

- **[Pain Point] Remote users cannot substantially interact with onsite users.** Both physical and virtual human representations should be integrated to provide interactive feedback, such as hand touch and body touch. For example, a user can use a physical hand to touch the avatar hand of a remote coworker to give them a high-five.
- **[Pain Point] Physical and virtual appearances are separated.** Merging physical and virtual body representations to create a partially real and partially virtual one. For example, a user can wear a physical jacket with virtual decorations augmented on it.

4.4. OBJECT

- **[Benefit] Users can manipulate physical and virtual objects at the same time.** Physical and virtual objects are overlaid to enable users to continue their physical tasks while remaining in the metaverse. For example, a user can drink water from a physical glass and sketch on a virtual whiteboard of a 3D virtual meeting room simultaneously.
- **[Benefit] Digital properties can be augmented on physical objects.** Physical and virtual objects are merged to gain new object-leveraging advantages from both physical and virtual properties. For example, a physical cup can have virtually augmented textures, colors, and even parts.
- **[Pain Point] Physical objects have no correlation with virtual ones.** Physical and virtual objects should be integrated into a physical simulation to make interaction perceptually seamless. For example, using a physical cup to hit a virtual one moves the virtual cup and generates sound feedback.
- [Pain Point] Physical objects cannot be seen by remote participants. Physical objects could be scanned to share with remote users. For example, a user could scan a physical cup to make the cup visible and interactable with remote coworkers.

5. Architectural Requirements

Based on the feedback collected on user needs, four requirements of metaverse architecture emerged.

- Metaverse architecture consists of virtual and physical elements, which are persistent, shareable, and integrated, providing continuous 3D spatial experiences.
- Metaverse architecture integrates distant and present elements to conduct both synchronous and asynchronous remote collaborative activities.
- Metaverse architecture hosts real and avatar participants, who can interact with each other via intuitive and natural communication channels.
- Metaverse architecture provides hybrid artifacts which leverage the advantages of physical and digital properties for users to manipulate.

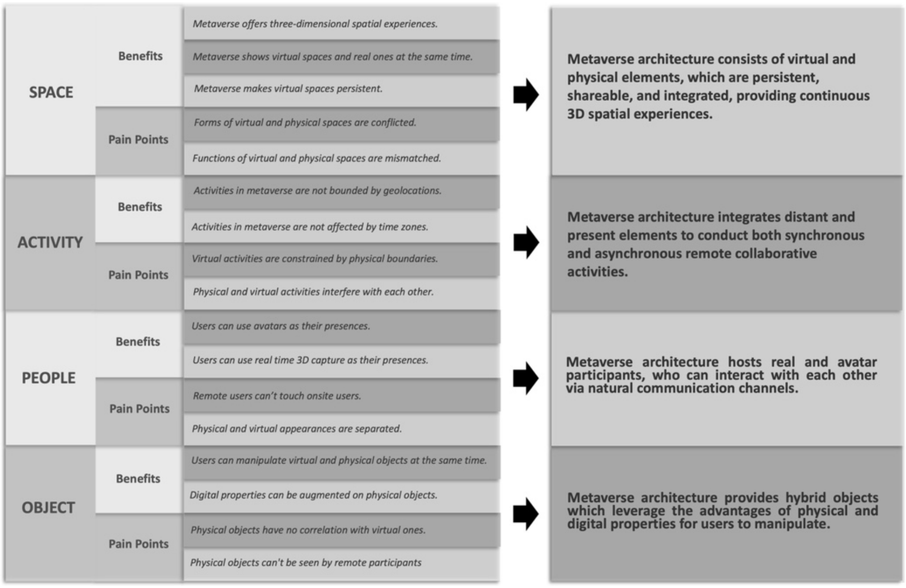


Figure 2. User needs and architectural requirements

6. Strategies and Framework

Based on the requirements of the metaverse architecture we identify, we figure out that mixing virtual and physical entities, including architectural elements, human presences, and artifact properties, to host hybrid and dynamic activities is the core of designing metaverse architecture. In order to create a framework to guide future design explorations, we come up with four strategies tackling different levels of the mixture, including transform, collocate, correlate and stitch. These strategies further form a framework for designing metaverse architecture.

- Transform forms to duplicate functions. Physical forms are transformed into virtual ones via 3D scanning. The goals of this transformation are to capture shapes of architectural elements, store contextual information, and duplicate the functions of the elements.
- Collocate forms to overlay functions. Physical and virtual forms are collocated without any connection or relationship. Users can perceive and interact with physical and virtual forms without causing any functional chain reactions.
- Correlate forms to integrate functions. Physical and virtual forms are correlated by embedding connections and relationships among them. Interacting with one form would cause functional chain reactions of another.
- Stitch forms to merge functions. Physical and virtual forms are stitched together to create a new function. A merged form leverages the advantages of the physical and virtual to provide advanced functions.

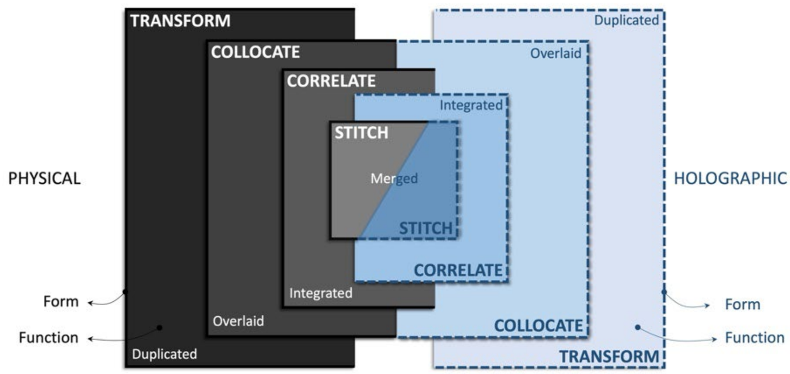


Figure 3. A preliminary metaverse architecture framework

7. Design Example

To make the preliminary framework more understandable, an example is used to demonstrate the applications of the proposed strategies. The scenario has two locations with both architectural and non-architectural elements within them. In location A, elements include a space shaped by two walls and a ground, a regular chair, and a male. In location B, the elements include a space shaped by five columns and a ground, a long chair, and a woman.

- Transform: All elements are duplicated (in blue wireframe). Spaces are mapped, people are 3D captured, chairs are scanned.
- Collocate: All elements from one location are duplicated and teleported to the other location with their original orientations. As shown in the diagram, all teleported elements of one location are overlaid on elements in the other location. The positions of the elements from one location are overlapped with the second location, which may cause conflicts.
- Correlate: All elements of one location are teleported to the other location with rotations and displacements to prevent conflict. For the man, his space is reshaped by five holographic columns, making the east and north sides semi-open. For the woman, her space is also reshaped by two solid walls, making the east and north sides visually blocked. For both the man and the woman, they can see how their own space is seamlessly integrated with the other.
- Stitch: All elements of one location are teleported to the other location with rotations and displacements. The man's north wall is overlapped with the woman's west columns. With the overlapped architectural elements, the two spaces seem to be stitched together to merge into a new space with a different sense of openness.

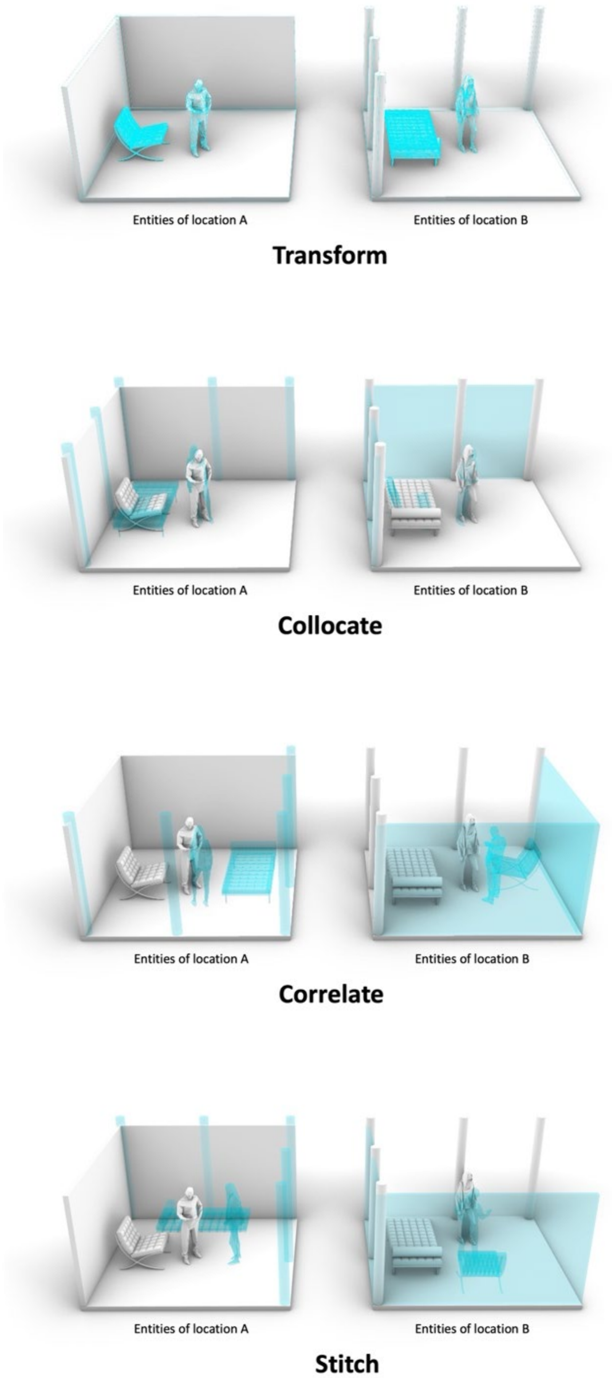


Figure 4. Design examples

8. Conclusion and Future Work

In this research study, a preliminary framework for metaverse architecture was generated based on findings from qualitative user interviews. The framework represents strategies for mixing physical and virtual architectural forms and functions. This framework could be further used to explore potential metaverse architectural patterns. The authors plan to conduct further research to validate the usefulness of this framework.

This study only focused on evolving the framework for architectural elements. However, the gathered data reflected similar findings from other categories of user needs, such as people, activities, and objects. The authors believe this framework could be extended to other design fields, such as avatar design, service design, and industrial design for the metaverse in future work.

Although the findings of this study offer a clearer understanding of potential user needs, a six-subject user study is still not representative enough. Future research could employ a larger sample size to determine if the framework developed here should be expanded or modified.

This preliminary framework also reveals that architectural elements no longer need to be physical, solid, and static. They can be virtual, holographic, and dynamic. It would be even more powerful to merge physical and digital properties to create hybrid architectural elements. We believe such a Holo-physical architectural material could lead to a potential way of reducing the production and consumption of carbon and further contribute to the post-carbon framework.

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