Space Renovation in Virtual Reality

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Figure 1: An example of renovating a Nordic studio apartment in virtual reality. The virtual space includes, for example, overlapping areas that leverage the same physical components to serve different purposes, a program-controlled study companion to simulate co-working experiences, and natural scenery with sunlight adjusted according to working hours to mitigate long darkness in winter.

ABSTRACT

Virtual reality (VR) space renovation considers designing co-located virtual spaces while accounting for constraints imposed by the physical space. Such design presents distinctive challenges and differs from designing for a physical space, as physical items may manifest in various forms in the virtual realm. Furthermore, designers may seek to incorporate unrealistic elements to optimize specific objectives, such as efficiency or comfort, considering the activities involved in the space. This research explores a framework for VR space renovation to offer a systematic guide to such designs. The framework examines physical and virtual spaces across various dimensions regarding space layouts and boundaries, activities and interactions, characters, and other dynamics. Furthermore, we implement a design example of renovating a Nordic studio apartment in VR and discuss insights that could inform and inspire future research. For instance, we illustrate how architecture and physical building components may convey different meanings in VR.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**.

KEYWORDS

Adaptive space, architecture, interior design, metaverse, space design, virtual space, 3D reconstruction

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1 INTRODUCTION

Virtual reality (VR) can immerse users into entirely distinct virtual environments, detached from their co-located physical spaces. For instance, users can lounge on a virtual beach, basking in the simulated sunlight, while physically reclining on their home sofa. They can even find themselves drifting through the galaxy, all within the confines of the exact same physical setting. However, designing such an experience is non-trivial because of three reasons.

Firstly, such design should not be approached as simply placing the user into another location. VR has the ability to generate compelling illusions, such as altering the perception of time and space [6], and introduce fantastical elements, like a conversational puppy, to create immersive experiences that transcend our physical reality.

Secondly, elements utilized in the design of physical spaces, such as those found in landscape, architecture, and interior design, may convey different meanings when translated into the virtual space. For instance, walls in the physical world are often employed to establish boundaries and to isolate sound and temperature, whereas in the virtual environment, they may serve the purpose of concealing an adaptive virtual environment.

Thirdly, such design also distinguishes itself from 3D game scene development, which does not need to consider physical constraints. Importantly, current VR users remain limited by the parameters of the physical world [10]. For example, they can bump into other objects or people in the physical space, which can break the immersive experience.

We call such design *VR space renovation*, as designers want to introduce (potentially unrealistic) virtual elements to enhance user experience while crafting a seamless blend between the virtual and physical realms. The concept is not entirely new, with scattered research efforts on this topic. For instance, various studies have explored adaptive spaces, aiming to establish congruence between physical and virtual worlds [8, 14]. Endeavors have also been made to introduce beyond-real spaces and interactions [2, 3], such as the collocating giant figures with small buildings. Furthermore, research has been directed towards optimizing layouts of virtual contents [5] and concealing objects within the physical environment (known as diminished reality [12]).

In this work, we attempt to consolidate a unified framework to assist designers in systematically approaching VR space renovation. The framework encompasses various design dimensions, such as boundaries, layouts, activities, and dynamics, addressing them in both physical and virtual spaces. Guided by the framework, we delve into a design example of renovating a studio apartment in VR. Lastly, we reflect on the lessons learnt from this work, including the reinterpretation of physical design elements in the virtual space, and discuss implications to inspire future endeavors.

2 DESIGN FRAMEWORK

We formulate a design framework through several discussions among the authors, including architects and VR interaction designers. The formulation process starts with brainstorming sessions followed by further consolidations of the design space. The framework delineates essential design dimensions related to VR space renovation, providing a reference guide for researchers and designers (see Table 1).

The primary consideration of VR space renovation is the overlapping nature of the physical and virtual space. Users reside in the physical space, interacting with it through haptic sensations, while the virtual space dictates their visual experiences. In the virtual space, users may choose to utilize (e.g., tools) or avoid specific elements (e.g., boundaries, fragile items) from the physical space. Furthermore, events and dynamics occurring in the physical world should be accurately represented or selectively obscured within the virtual realm. Therefore, the design framework introduces all the design dimensions in terms of both physical and virtual spaces.

The nine design dimensions of the framework delve into various aspects of VR space renovation. *Theme* serves as the guiding principle for VR renovation, influencing the overarching concepts of the virtual space, which may enhance, contrast, or transcend the design of the physical space. *Background*, *boundary*, and *layout* focus on the design of the general environment and interaction space. *Activity* and *interaction* address the activities users will engage in and the methods by which they will do so. *Character* and *Dynamics* emphasize the potential changes that may occur in both spaces. Lastly, *decoration* elevates the design theme. These dimensions are detailed in Table 1.

3 A DESIGN EXAMPLE: RENOVATING A STUDIO APARTMENT IN VR

3.1 Case

The example concerns with renovating a studio apartment in VR for Ida, who is a student in a Nordic country. Ida's apartment is around 30-square-meter filled with essential furniture and equipment (see Figure 1 for the floor plan). During the winter days shrouded in darkness, Ida prefers studying at home to avoid snow and strong winds. However, she encounters reduced efficiency and misses the inspiring atmosphere of her school library. She also yearns for the warmth of sunlight to brighten her mornings and kick-start her day. Moreover, Ida wishes for a dedicated recreational area to enjoy movies with her friends remotely.

3.2 Design Solution

While we have used the framework as a "checklist" to determine the design of each dimension, we here highlight several key features in the final design outcome for better readability.

3.2.1 *Three virtual spaces (theme, boundary, and layout).*

We divide the physical studio space into three virtual spaces that serve different functional requirements: a study area designed in a library style for working (marked as red in Figure 1), a cinema space for enjoying movies with friends on the sofa (marked in yellow), and a morning tea zone for a refreshing start to the day (marked in blue). The cinema area and the tea zone share the middle space with a table and chair for enjoying either breakfasts or snacks while watching a movie. The virtual areas can be accessed through portals that appears when the user approaches their respective boundaries. The user will exit VR mode (e.g., by enabling passthrough) when they step outside the designated virtual spaces.

Dimension	**Physical Space**	**Virtual Space**
Theme	The unifying concepts that synthesize the existing physical space, include aesthetic aspects (e.g., from existing decorations) and functional (e.g., workspace and home space).	The design concepts of the virtual space. They could *augment* (color or texture changes), *contrast* (e.g., a messy room to minimalist design), or *transcend* (e.g., fictional) the physical space.
Background	Environments that are outside of the immediate reach (e.g., scenes outside of windows)	Skybox: a texture that represents the distant background to save computation.
Boundary	Primarily walls and other surfaces (e.g., furniture, windows, sliding doors) that create distinct areas of a physical space.	Virtual boundaries, primarily visual boundaries (e.g., illusory walls, play area boundaries), that separate areas in the virtual space.
Layout	The arrangement and organization of boundaries and items (e.g., chair, table, bed) in the physical space. The items could serve a functional purpose in the virtual environment (e.g., aligning a virtual seat for users to sit on) or could be prevented from accessing through boundaries.	The configuration of the virtual space, given the constraints of the physical space. It could be: *1-to-1* physical to virtual mapping, *overlapping spaces* (i.e., multiple virtual spaces sharing proportions of a physical space), and *1-to-multiple* physical to virtual mapping. If multiple spaces are considered, the transition between them should also be designed.
Activity	The activity that will be carried out in the physical space. Some activities may not be suitable in VR (e.g., cooking).	The activity that will be conducted in VR. A key consideration is how to optimize the activity (e.g., for better efficiency and comfortableness).
Interaction	The method of interaction during the activity. The interaction could be based on bare hands or tools (e.g., pens, keyboards).	The interaction mapped from physical to virtual. It could be based on virtual hands, pointing, or virtual tools (e.g., virtual screen and keyboard without physical ones). The movement can also be redirected (i.e., alter perceived movements).
Character	Physical living beings (e.g., people, pets) that may enter the space. They should be mapped in the virtual space to avoid collision.	VR may introduce virtual characters for specific purposes (e.g., a conversational puppy to remind the user of to-dos).
Dynamics	*Time dynamics* (e.g., sun movement across a day) or *event dynamics* (e.g., a knock on the door) that happen in the physical world.	Virtual space may map the dynamics in the physical space or create new ones (e.g., the sun position is fixed to blur time sensation).
Decoration	Ornaments in the physical space that users in the virtual space may be restricted from interacting with (e.g., protected by virtual boundaries).	Virtual ornaments are utilized to elevate the design theme in the virtual space. They can be either interactive or static elements.

Table 1: The design framework of VR space renovation that considers both physical and virtual worlds.

3.2.2 Virtual study buddy (activity and character). Due to the user's struggle with low efficiency working from home, we introduce a virtual study companion controlled by the program. This study buddy will quietly work alongside the user to create a co-working environment, occasionally prompting the user to take breaks and stretch for a healthier work routine. In the cinema area, the user's friend will appear as an avatar when connecting to the system.

3.2.3 Time illusion (dynamics). Given the prolonged darkness during winter days in the region, we adjust the virtual sun in the space to synchronize with the user's work routine (e.g., the sun dims as the workday concludes). Moreover, the sun in the morning tea zone will always be bright, ensuring a vibrant start to the day.

3.2.4 Reality-based interaction (Interaction). Interaction within the study area and morning tea zone mirrors real-life activities for familiarity (e.g., utilizing a pair of physical keyboard and mouse to navigate the virtual screen). In the cinema area, users can employ gestures to point and remotely control the movie screen.

3.2.5 Nature-based design style (theme, background, and decoration). The study area and morning tea zone are enriched with abundant natural elements, such as trees and mountains. Simple decorations like bookshelves and lamps complement the natural scenery. This aligns with the vibe of the Nordic region but in a different season.

4 DISCUSSION AND FUTURE OUTLOOK

We have delved into the concept of VR space renovation by creating a design framework and implementing a design example. Through this exploration, we have identified several noteworthy issues that merit further discussion.

4.1 Architecture and Physical Building Components in VR

Architecture, such as buildings, and its components, like walls, doors and stairs, are commonly observed in many off-the-shelf VR applications, including those that create multiplayer virtual worlds like *VRChat* and *Horizon Worlds* [1, 13]. However, at the beginning of the project, our initial question was about the necessity of implementing such architecture within the virtual space. For example, in the physical world, buildings offer shelter to protect people; walls block sound and isolate temperature; doors grant access only to those with keys. Conversely, in the virtual realm, a user could mute the noise or remove unwanted participants through system control. As a result, many physical functionalities of architectural elements and building components are not retained in VR; maybe virtual screens and a method to interact with them are all that is needed in the space [7].

On the other hand, many of the architectural designs and building components are incorporated for aesthetic purposes, serving as decorations to enhance the theme. For instance, cyberpunk-like architectures have been integrated into the virtual space to evoke a a futuristic ambiance. Furthermore, these elements provide a sense of security and familiarity. For example, doors typically offer people access to new places. Thus, when Doraemon opens The Anywhere Door [1], it wouldn't appear surprising if it grants access to various wired spaces. Since people have established meanings associated with these objects, the same principle of affordance can be applied in VR.

Another interesting observation we made during the design process was the utilization of walls. They can effectively conceal the spaces behind them, making overlapping of the spaces possible. In the design example, the cinema space and the morning tea zone occupy the same area with a table and a chair, yet they manifest as entirely distinct virtual spaces based on the user's entry point. Achieving this manipulation of shared space can be challenging without visually occluding the user with boundaries. In other words, these walls create ambiguities between the space boundaries because of the adaptive nature of a virtual space, which is different from fixed walls in the physical space. Overall, exploring new meanings of building components in the virtual world and re-evaluating their necessity in VR presents an intriguing avenue for exploration.

4.2 The influence of VR space design on physical space

Throughout the design process, our focus frequently turned to the possibility of adjusting the physical layout to incorporate additional functionalities. For example, by condensing the study area with the cinema space and morning tea zone, since these activities typically involves minimal movement, we can create a larger central space within the studio. The user could then use this expanded area to do some exercise. Hence, when designing virtual spaces, it could alter our approach to arranging (or "renovating") the physical spaces. The iterative design process based on both spaces is quite distinctive from other types of space design. We consider the adaptation of physical spaces can be accomplished either during the early planning phase or through the utilization of shape-changing interfaces (e.g., [16]).

[1]Doraemon, created by Fujiko Fujio in a fictional comic series, has The Anywhere Door, which opens portals to any desired location.

4.3 Envisioning the Deployment

Blending virtual spaces seamlessly into physical environments demands both design innovation and technological progress. VR headsets must become more context-aware and comfortable for prolonged wear to achieve this vision. For example, the VR device must possess the capability to reconstruct the surrounding physical environment at various complexities, preferably in real-time (e.g., [4, 9, 14, 15]). Ethical concerns and the long-term effects of VR (such as prolonged exposure to simulated lights) should also be taken into account (e.g., [11]).

The construction and deployment of such virtual spaces may differ form physical spaces, which often require dedicated designers (e.g., interior designers) to be involved in the whole process. In VR space renovation, users can easily customize and personalize their spaces using pre-set templates of 3D models. Therefore, perhaps design efforts should prioritize developing ideas that can be easily transformed into templates (either room templates or individual components similar to those in *Mozilla Hubs*). Notably, the room templates should exhibit a certain degree of adaptability to enable real-time (re-)construction based on various physical space settings.

4.4 Concluding Remarks

In conclusion, our paper highlights the promising potential of renovating new spaces in virtual reality to enhance everyday experiences. While seamlessly integrating virtual and physical spaces is complex, our framework serves as early steps in this journey for researchers and designers to expand upon. Crucially, we highlight the importance of reinterpreting the meaning of architecture and building components in VR. Future work could apply the framework in diverse physical space settings, such as a complex home space filled with furniture, educational environments, and large public spaces, to assess its versatility and adaptability. Furthermore, establishing suitable evaluation metrics for renovated virtual spaces could ensure the usefulness of such solutions.

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