VR ANTHROPOCENE

— Spatial Composition Through Virtual Locomotion

ADAM Yuzhen Zhang

May 2021

B. Arch. Thesis

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With special thanks to

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Professor Henry Richardson for introducing me to the realm of Virtual Reality and inspiring me to see the value of VR design

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Thesis Advisors:
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Cornell University
Art, Architecture, and Planning
Department of Architecture

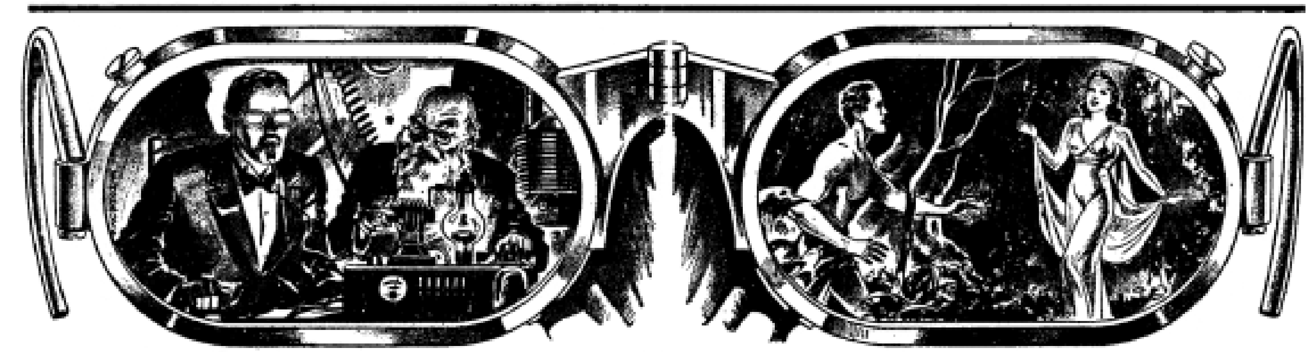
“A movie that gives one sight and sound [...] taste, smell, and touch. [...] You are in the story, you speak to the shadows (characters) and they reply, and instead of being on a screen, the story is all about you, and you are in it.”

Pygmalion’s Spectacles, Stanley Weinbaum, 1935

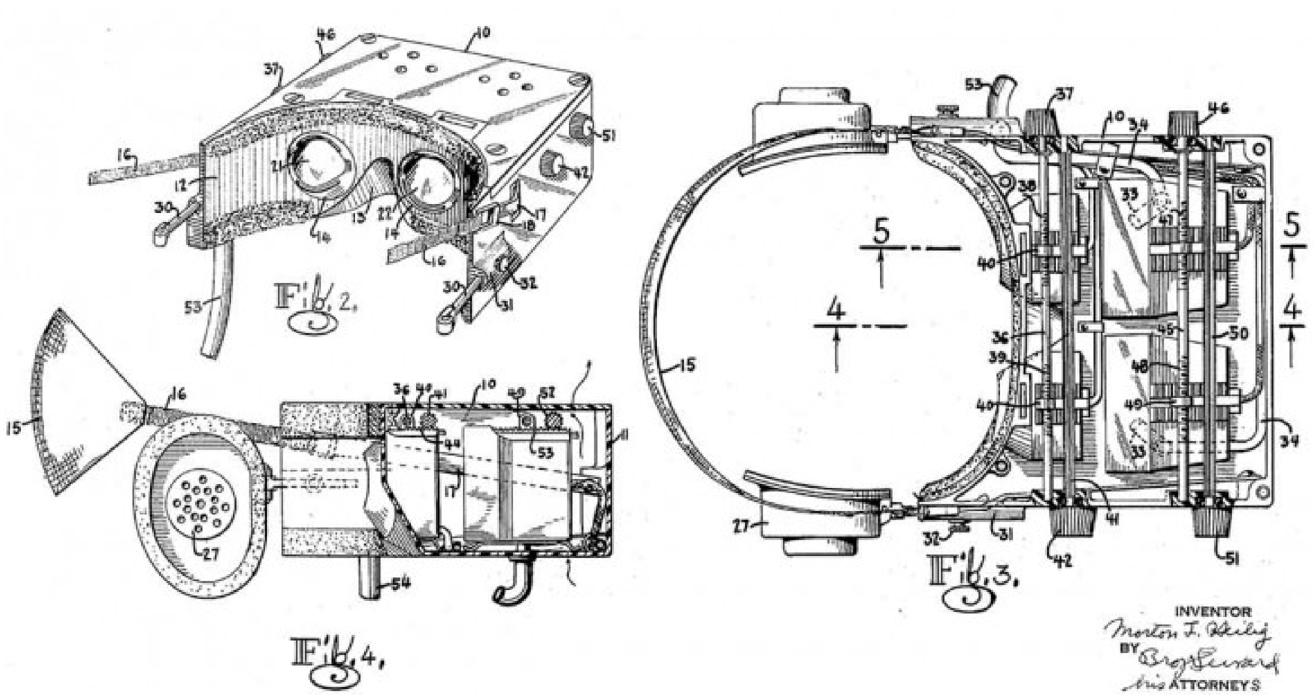
PYGMALION’S SPECTACLES

By STANLEY G. WEINBAUM

Author of “The Black Flame,” “A Martian Odyssey,” etc.



Unbelieving, still gripping the arms of that unseen chair, Dan was staring at a forest



Morton Heilig, The Telesphere Mask, 1960

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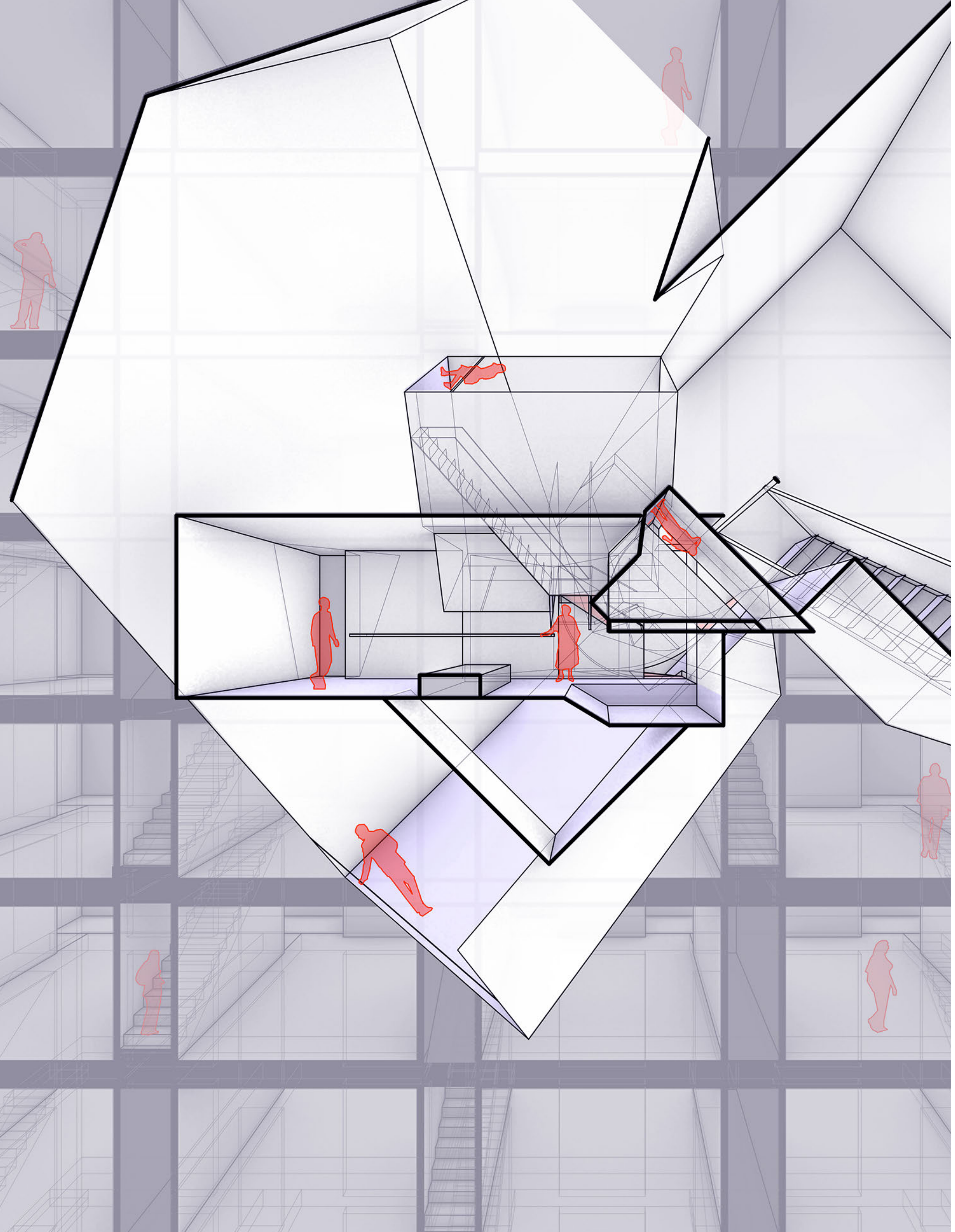
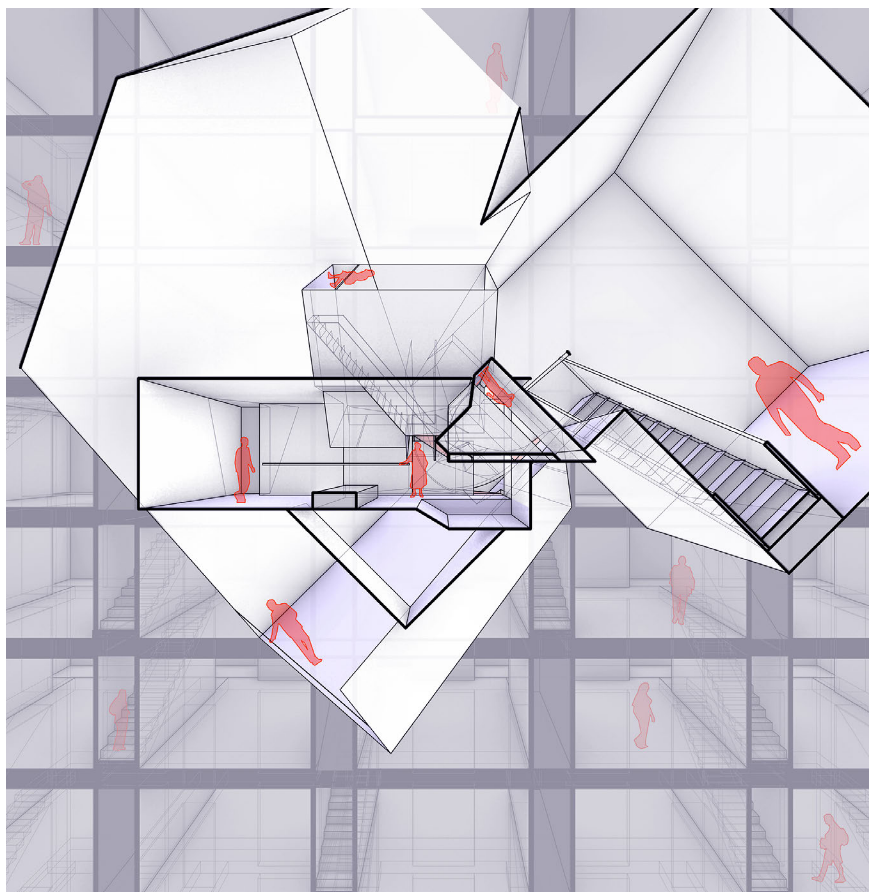


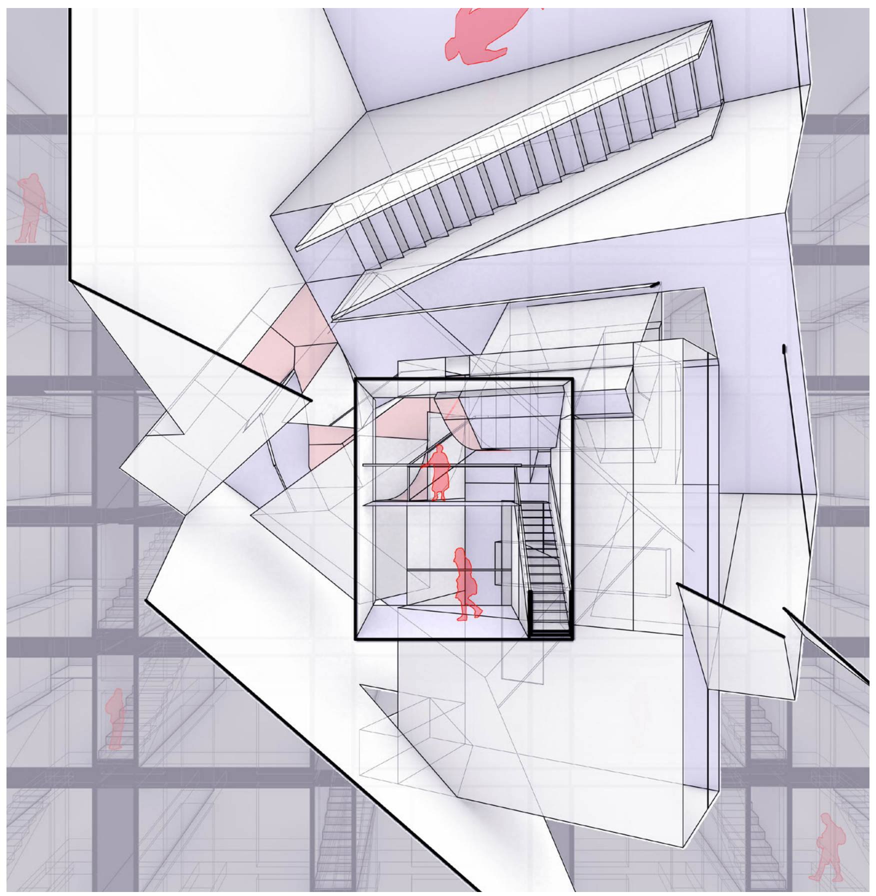
I. INTRODUCTION



INTRODUCTION
Abstract

The burgeoning Virtual Reality technology is creating a new anthropomorphic sphere in which traditional spatial relationships and experiences are reimagined. This is a technology that visualizes potentiality, adding extended layers of reality upon preexisting urban spheres.

Through designing, experiencing, and analyzing Redirected Walking, a deceptive locomotive technique within Virtual Reality, this thesis proposes spatial prototypes that unfold a physical space into a series of virtual vignettes. It also investigates the impact of virtual augmentation on an urban housing unit in which residents could cognitively experience a series of real and surreal spaces. It ultimately studies how such intersection reforms physical boundaries and redefines programs, generating a prototype for the future way of living.

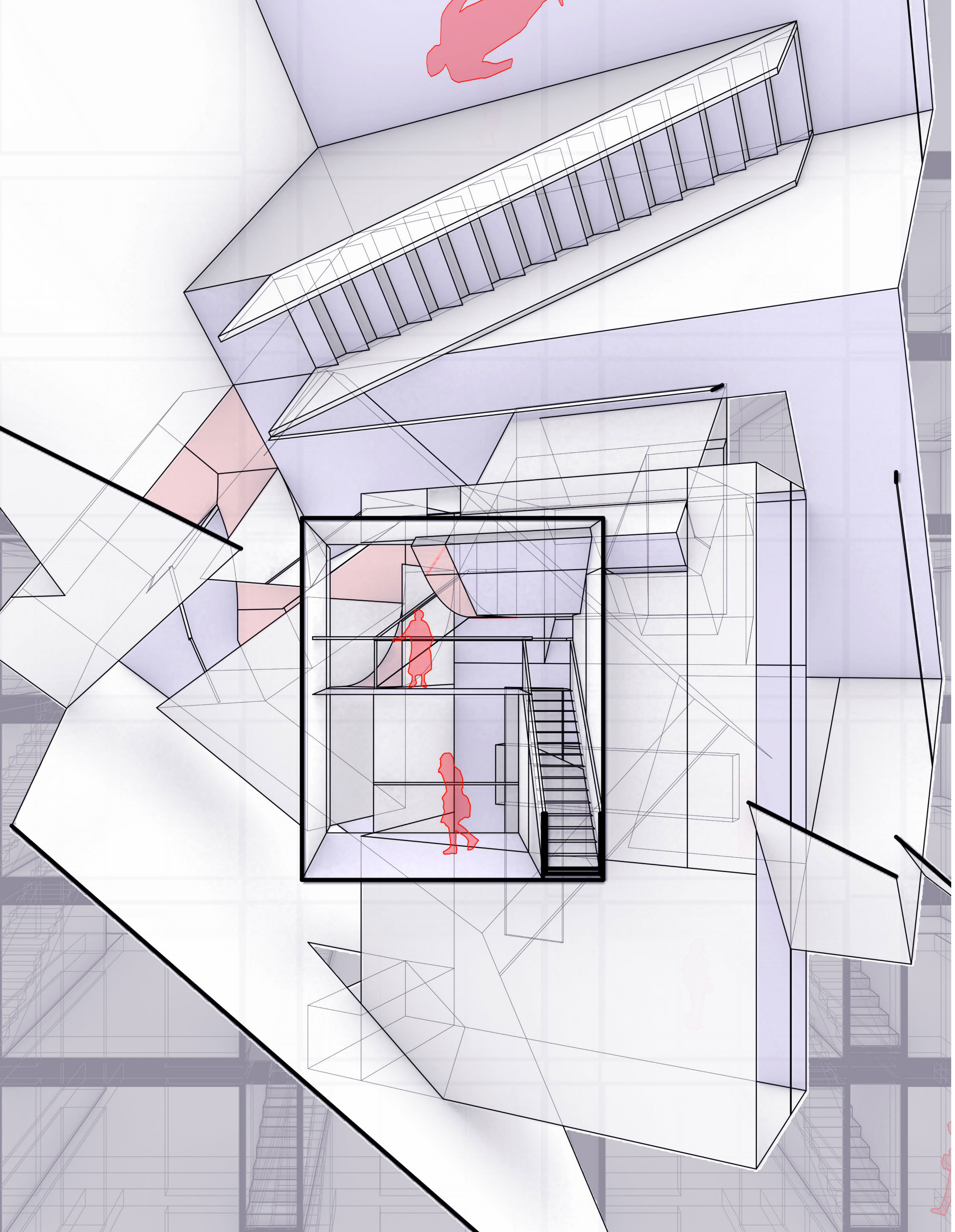


INTRODUCTION
Questions

Q1. How do people circulate through Virtual Spaces?

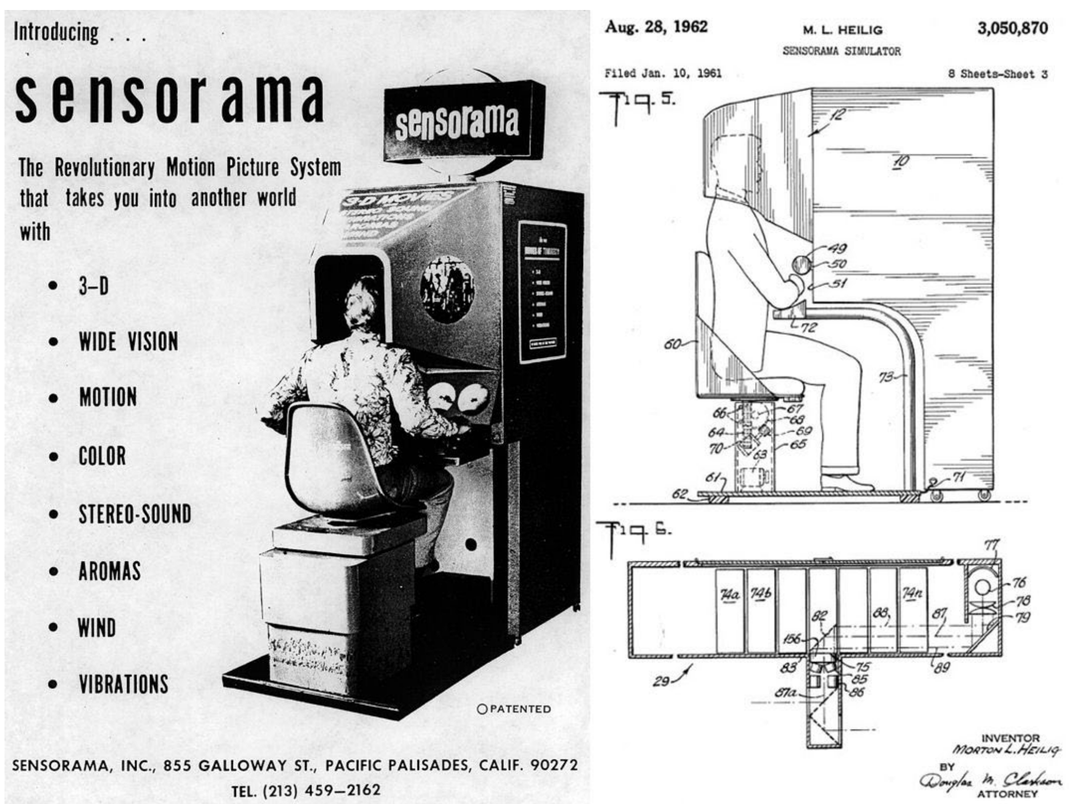
Q2. How do virtual locomotion techniques redefine the way spaces are constructed in the virtual realm?

Q3. How do physical spaces respond to virtual augmentation in a way that promotes concurrent living in the physical and virtual realms?



II. BACKGROUND

Ever since the first Wheatstone stereoscope was invented in 1838 to create a sense of depth and immersion via a pair of static photographs, the immersive technologies have been developed and improved continuously. From static views, pre-recorded films, to real time renderings, the virtual environment presented by new technologies has not only become more realistic, but also more mobile as interactions with the virtual world were made possible with motion tracking.



Morton Heilig, The Sensorama VR Machine, 1956

BACKGROUND

This responsive virtual world was gradually developed to replicate the physical world. Such concept of replication was raised by Ivan Sutherland in *the Ultimate Display* in 1965, in which he stated that:

“The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked.”

Such technological advancements mean a metamorphosis of reality that must be treated seriously and with caution. Living in a completely virtual replication of the physical world surely does not equal good living quality, and it may easily lead to an uncanny posthumanism. However, my thesis is that such technology means potentiality, opening up more alternatives to human’s constant mode of occupying space. It could mean bringing the world to homebound individuals, reconstructing and “awakening” historical cities or architecture that is lost in time, fulfilling some of our fantasies as well as desires for more experiences, and most importantly, saving up space in nature. Instead of investing in micro housing that would only further exploit the lower class and diminish their life qualities, this technology could be integrated into the design of large-scale and luxurious architecture. Some sections of such buildings that take up a large portion of space could be substituted with virtual spaces. As the head-mounted display becomes smaller and more powerful, soon people would be able to spend their daily lives in the virtual world in their contact lenses.

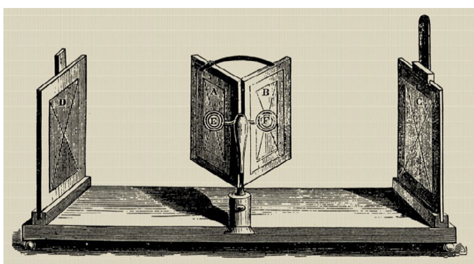
Therefore, this thesis project aims to study the architectural design inside the virtual world, which I would argue, will not be merely a replication of the physical world. The difference in architectural and physical concepts such as scale, materiality, gravity, and even time would bring lots of potentials to the virtual architecture. Before diving into the spatial design, the point of departure is defining the Extended Reality in my context, analyzing precedents of virtual spaces, and translating the physical architectural elements into the virtual realm.

BACKGROUND
Extended Reality

Prototype

1838
Stereoscope
Charles Wheatstone

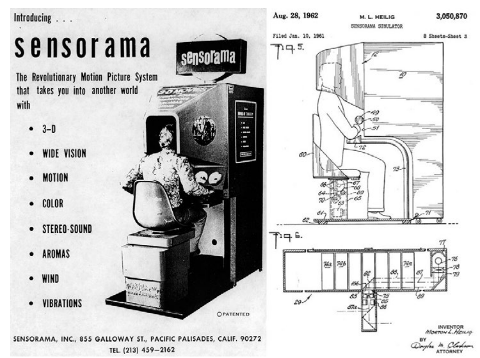
brain combines two photographs to have a sense of depth and immersion



Machine

1956
The Sensorama VR Machine
Morton Heilig

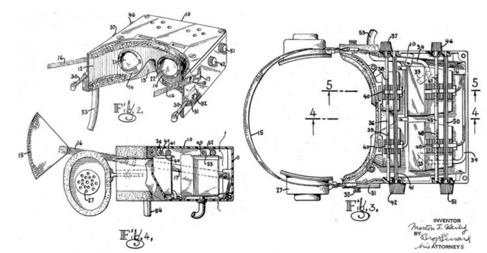
VR machine for watching immersive videos



Headset

1960
The Telesphere Mask
Morton Heilig

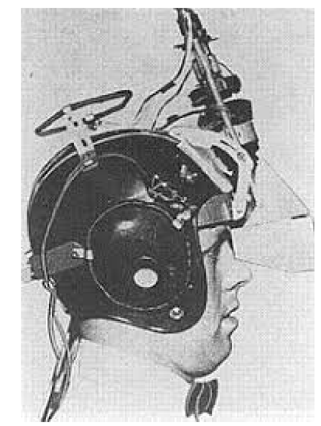
first head-mounted display (HMD)



Motion Tracking

1961
Headsight
Comeau and Bryan

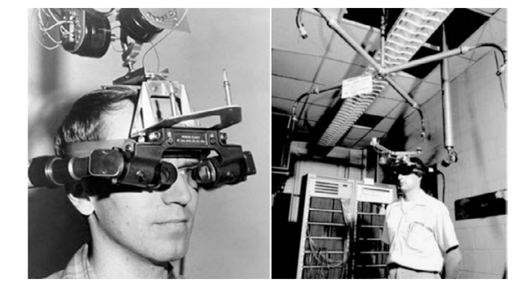
first motion tracking HMD



Rendering

1968
The Sword of Damocles
Ivan Sutherland

computer-generated graphics that enhance users' sensory perception of the world



Augmented Reality

1992
Virtual Fixtures
Louis Rosenburg

first fully functional AR system

Affordable and Portable

1995
Virtual Boy Console
Nintendo

affordable and portable home VR headsets

DIY

2014
Cardboard
Google

Low-cost and do-it-yourself stereoscopic viewer for smartphones

Standalone

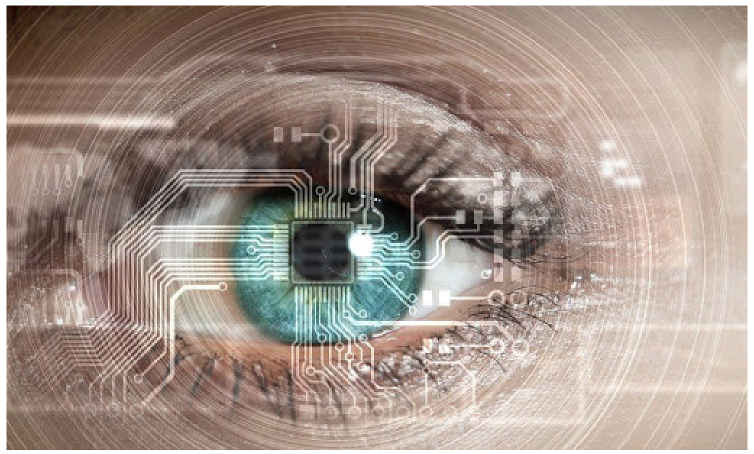
2019
Quest
Oculus

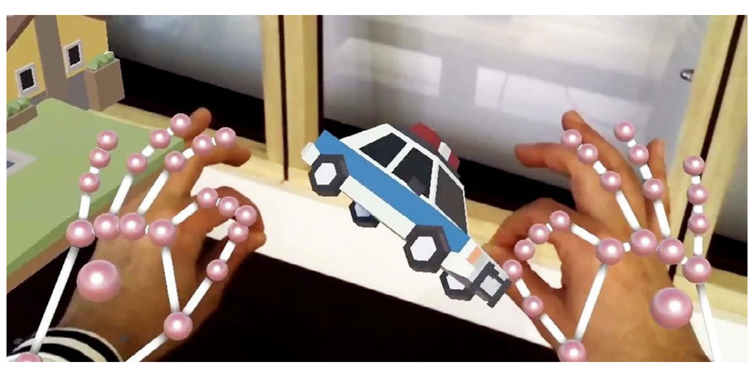
standalone headset with inside-out tracking

Contact Lenses

202-
Mojo Lens
Mojo

small wearables that augments vision





BACKGROUND
Extended Reality

Extended Reality (XR) refers to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. It includes representative forms such as Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR). The main difference between the augmented reality and the virtual reality is whether the physical space is completely hidden, and the recently released hardware such as the Oculus Quest 2 supports passthrough views to see the physical space within VR. Therefore, in the near future, the abovementioned representation forms will be merged into one set of extended reality system. My later design studies will be based on the XR technology satisfying the following 3 criterias:

Wearable

The hardware is small and affordable for daily uses

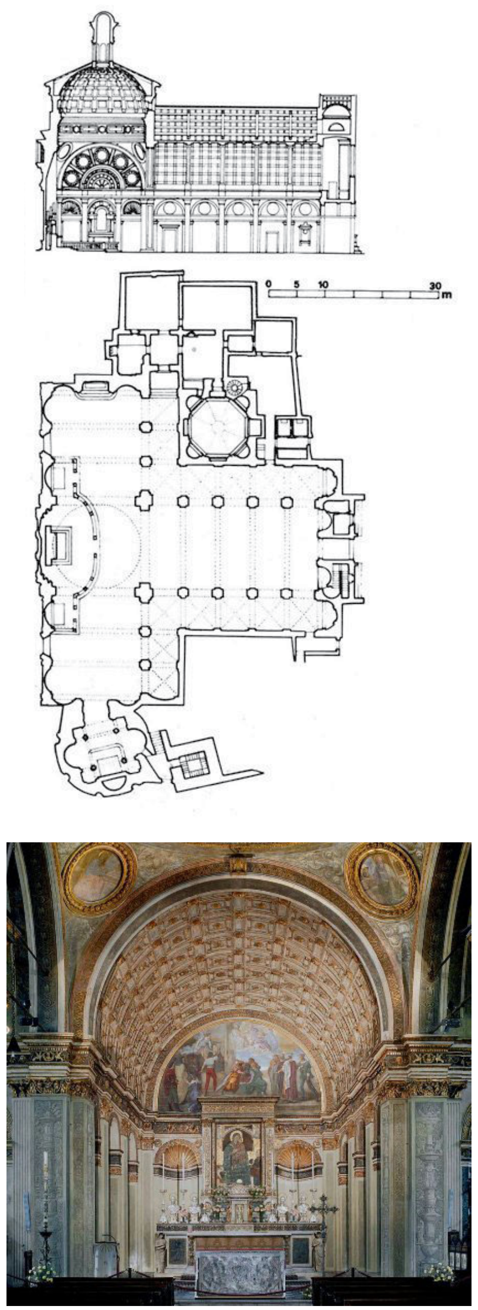
Immersive

The virtual scenes rendered by the hardware are realistic enough to fool users' senses

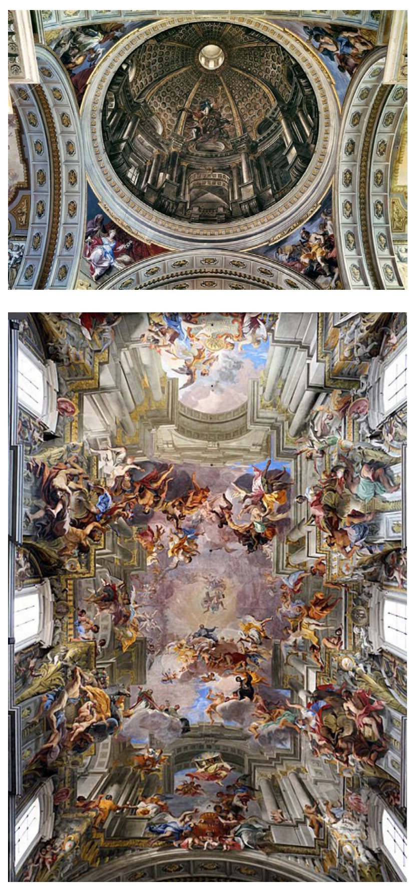
Interactable

The system allows motion tracking and physical input from users to allow interaction with virtual objects

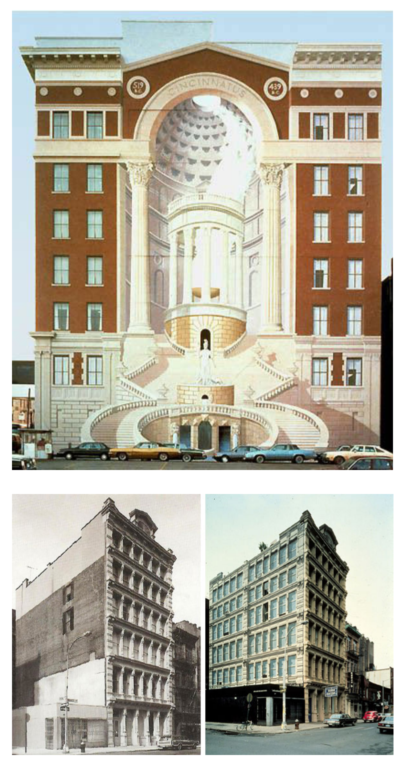
BACKGROUND
Virtual Spaces



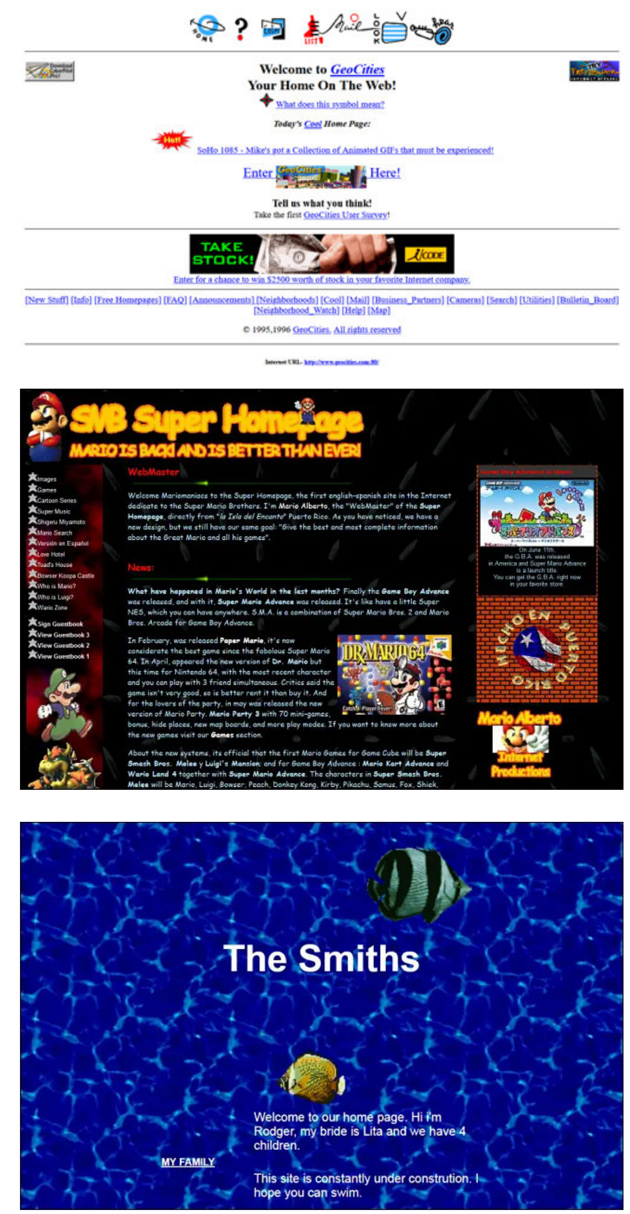
Santa Maria presso San Satiro
Bramante



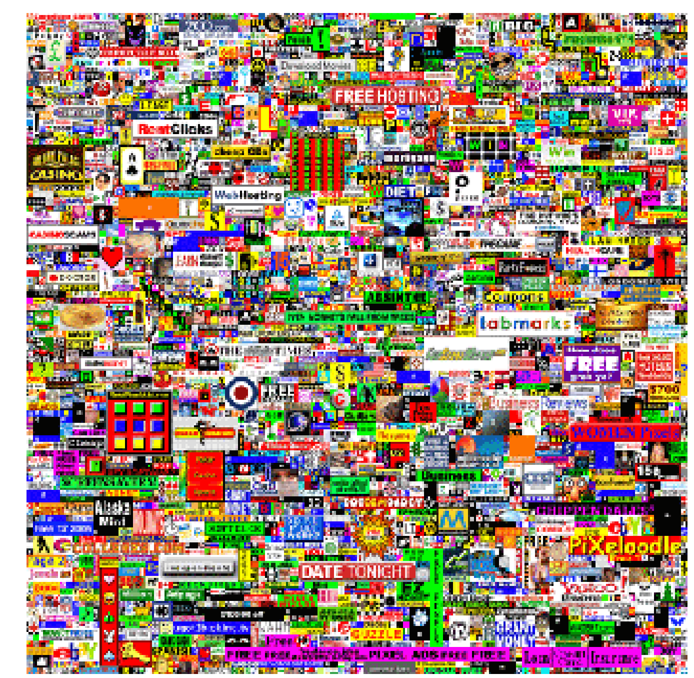
Sant'Ignazio
Andrea Pozzo



Murals
Richard Haas



Yahoo! GeoCities
David Bohnett, John Rezner
1994 - 2009

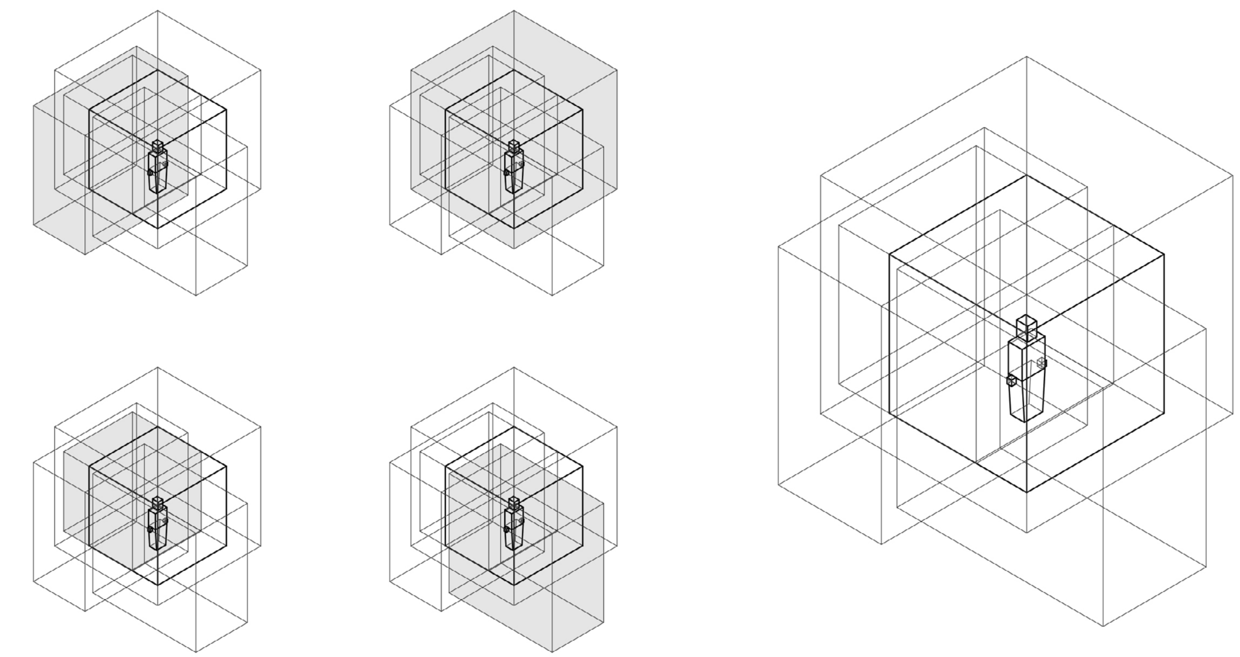


The Million Dollar Homepage
Alex Tew
2005 - Now

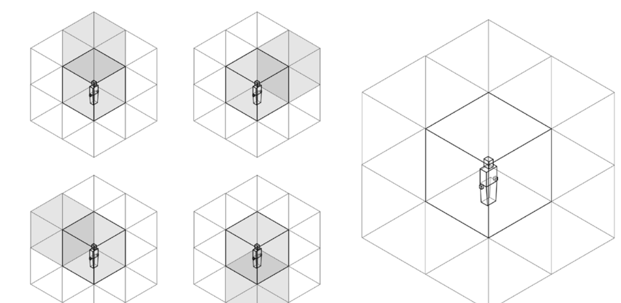
BACKGROUND
Virtual Spaces

Architects have been creating virtual spaces even before the advent of Extended Reality technologies. During the Renaissance, the prevalent trompe l'oeil perspective techniques were used to construct architectural spaces that can be visually perceived but cannot be physically occupied. Take Bramante's perspective of the choir in Santa Maria presso San Satiro as an example, physical limitation is overcome through optical illusions. The resulting virtual space overlaps with the area outside of the church and adds the fourth dimension to the 3D space. Such spaces are similar to those of the extended reality except for the lack of mobility. The virtual spaces are both visible and accessible.

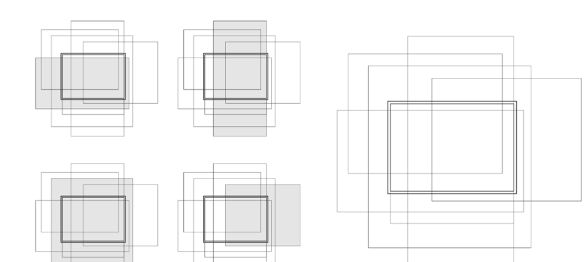
On the other hand, after the advent of the internet, digital worlds are constructed over the web where each personal webpage resembles a private space. Without the third dimension, such web spaces can be viewed as superposition of information in the 2D screen plane. Similarly, the three dimensional virtual spaces can also be viewed as superposition of digital locations in a 3D physical area that the viewer occupies. How to switch from one virtual space to another with spatial techniques rather than simply turning one off and the other on will be further studied in later sections.



Virtual Spaces
Superposition of information in a 3D space

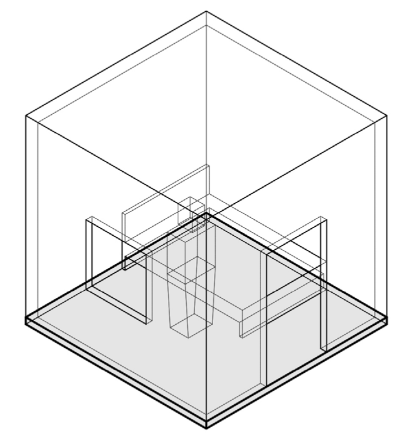


Trompe-l'œil
Architectural spaces that can be seen but not occupied

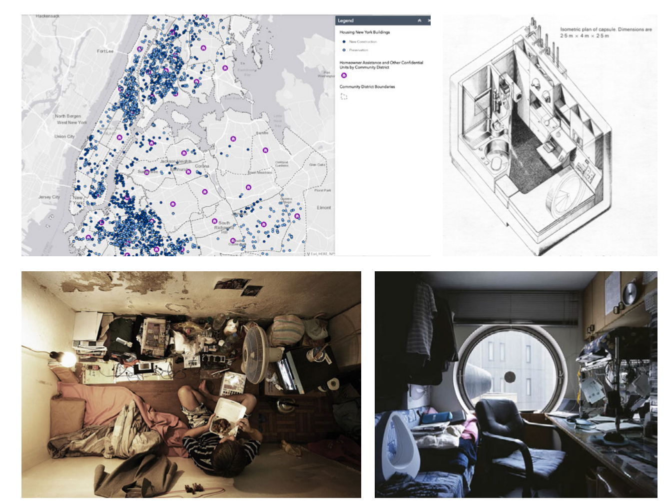


Digital World
Superposition of information in a 2D plane

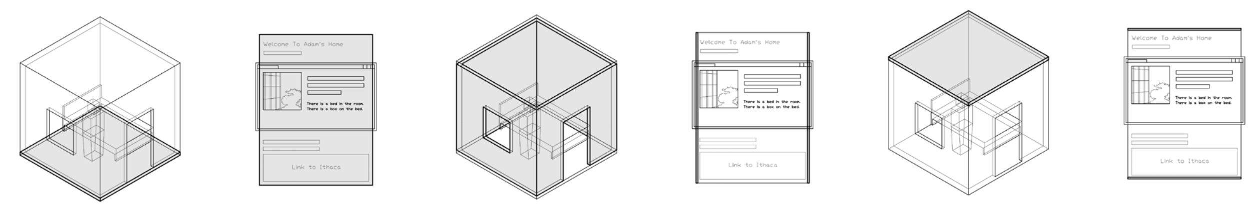
BACKGROUND
Spatial Translation



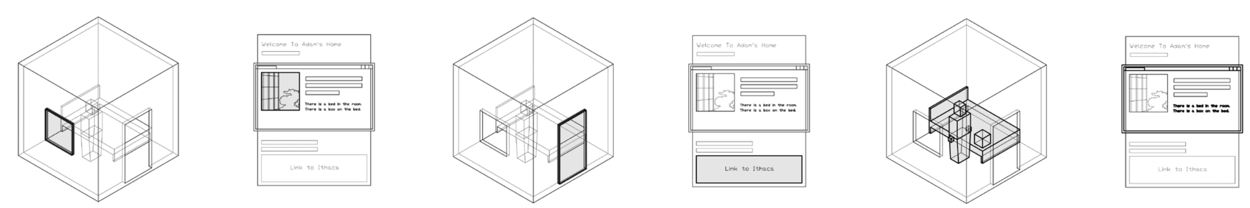
In order to translate physical architectural elements into the virtual realm, elements in a physical room space and a digital web space are compared and translated into virtual ones. In the virtual outcome, the ground planes no longer need to remain parallel to the ground, the views outside of the windows could be flatten into a trompe l'oeil, and the relativity of movements could be reversed, as the rotation relative to the space is identical to rotation of the space relative to the user.



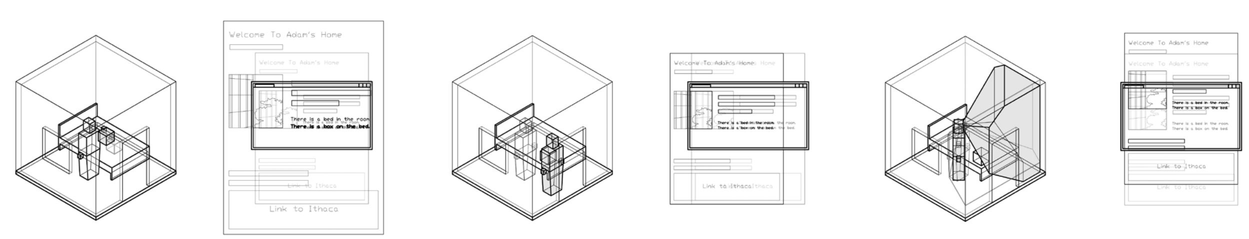
BACKGROUND
Spatial Translation



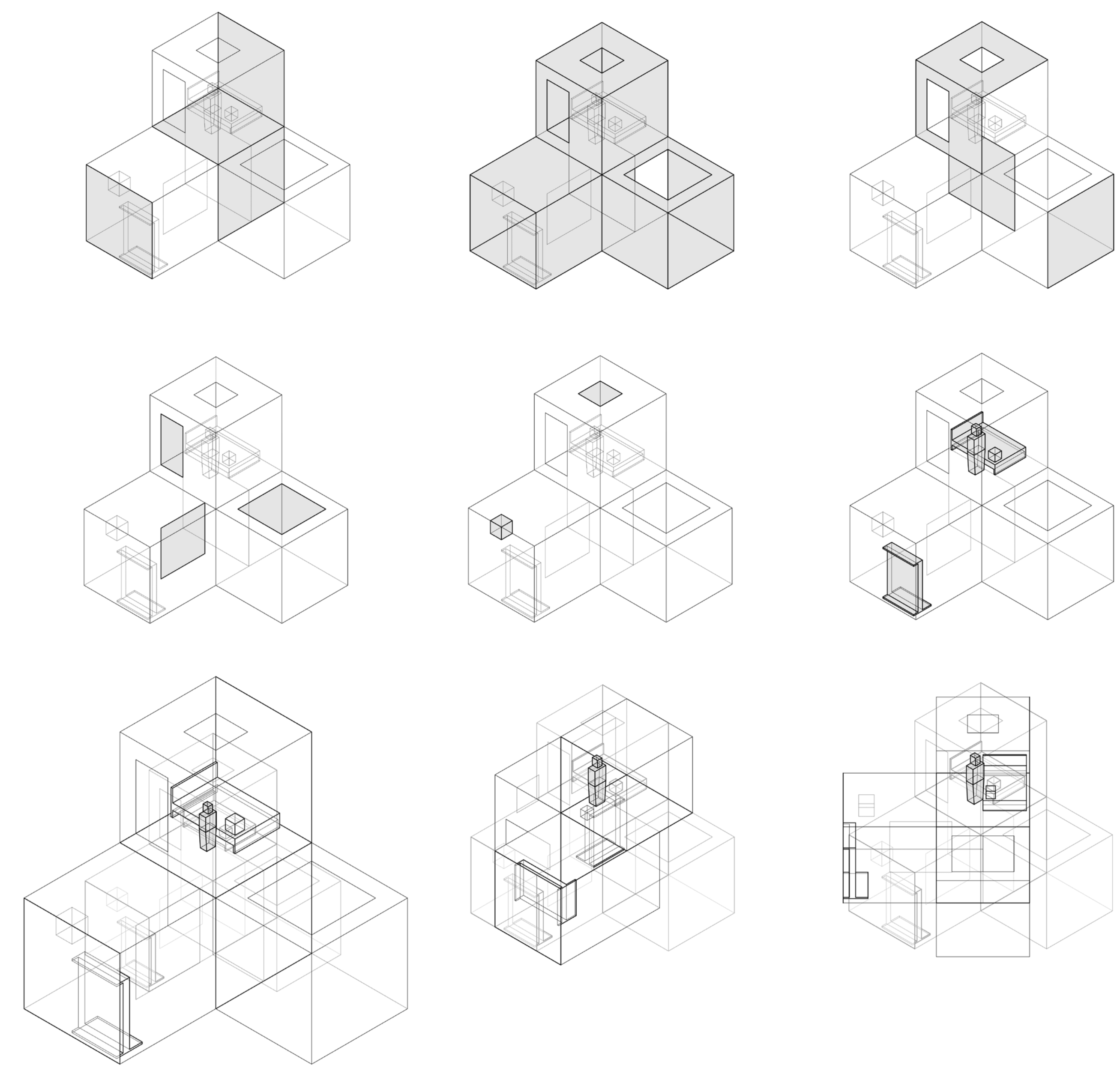
Floor Wall Ceiling

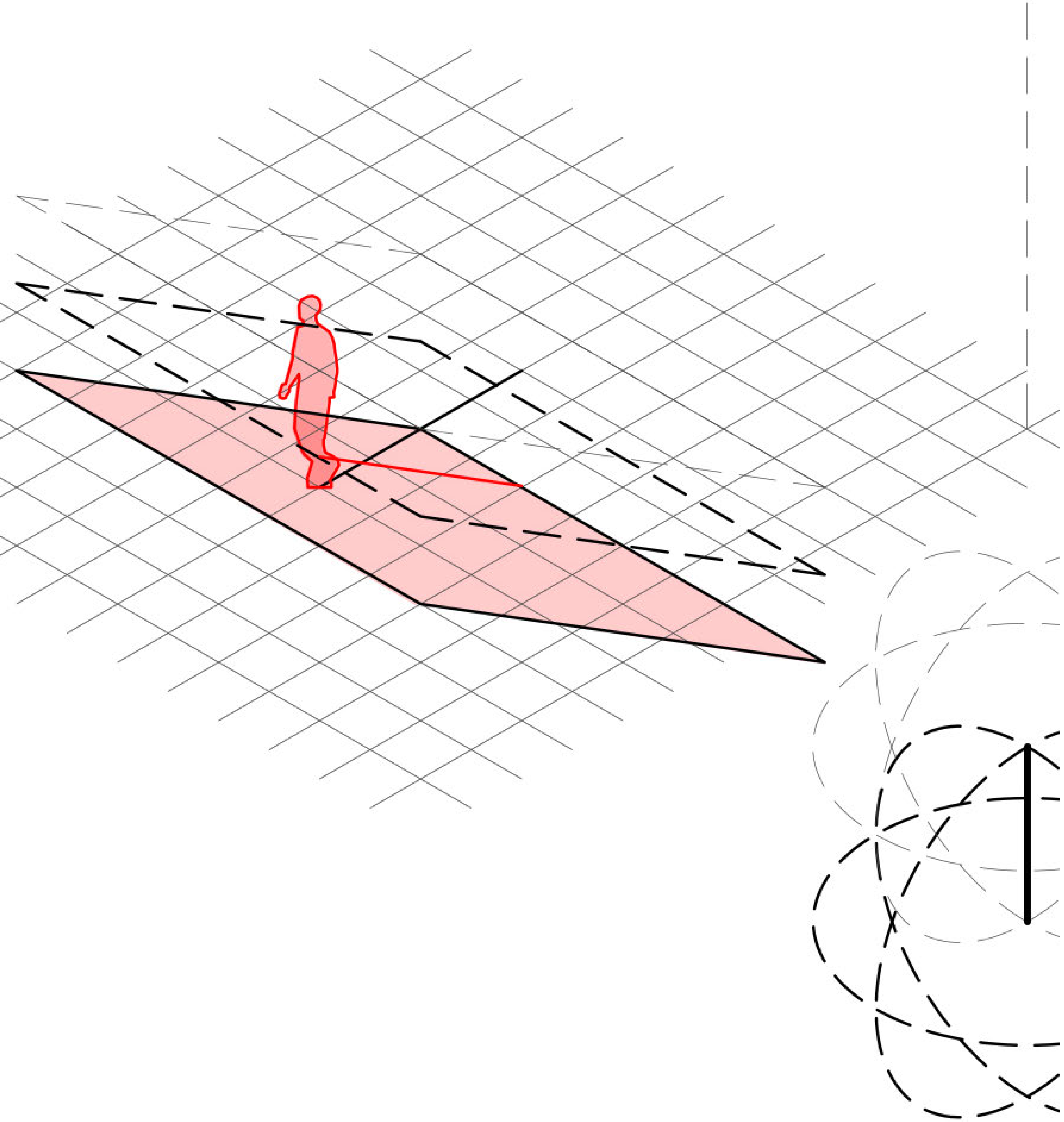


Window Door Objects



Grab Translate Rotate

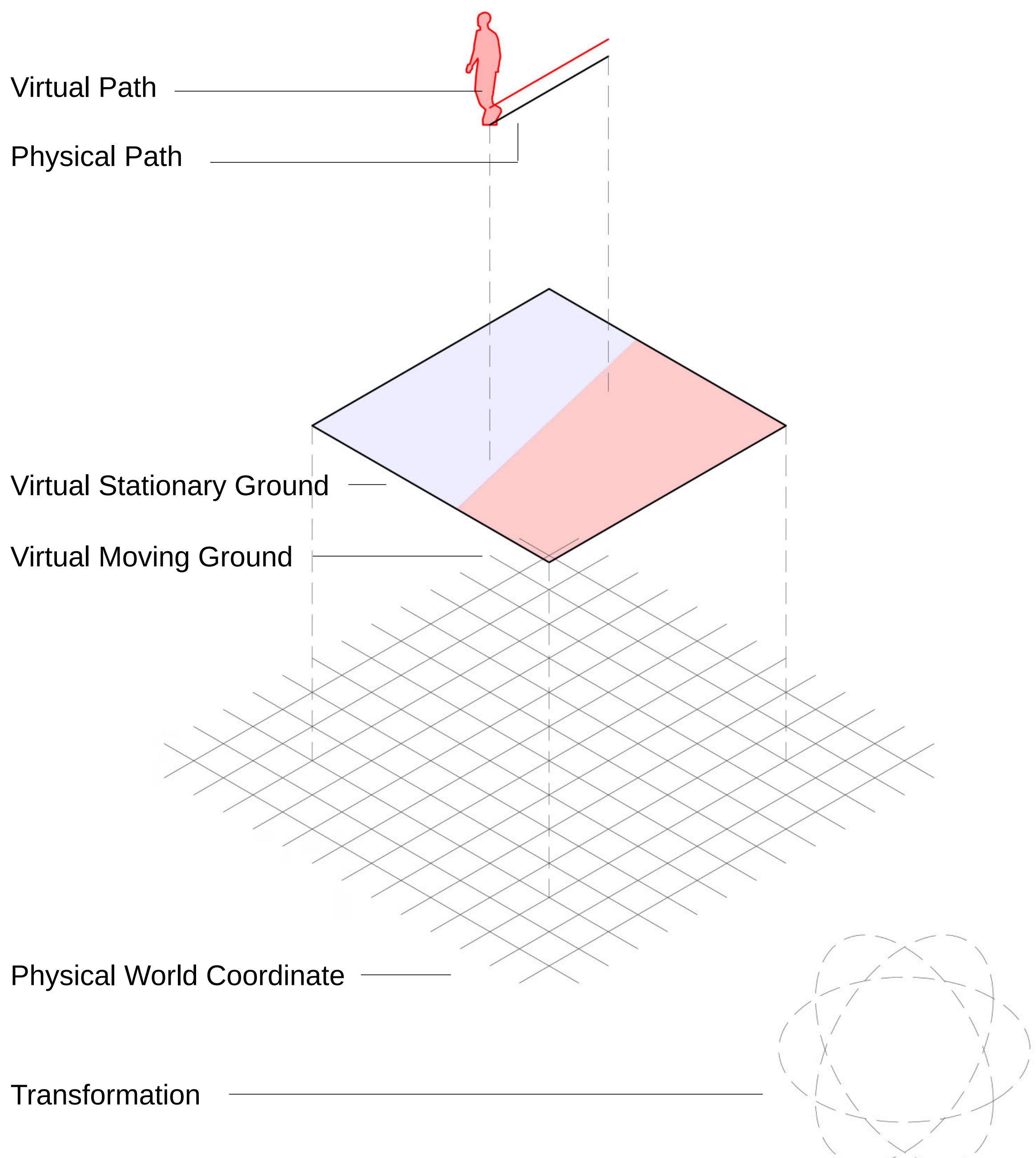




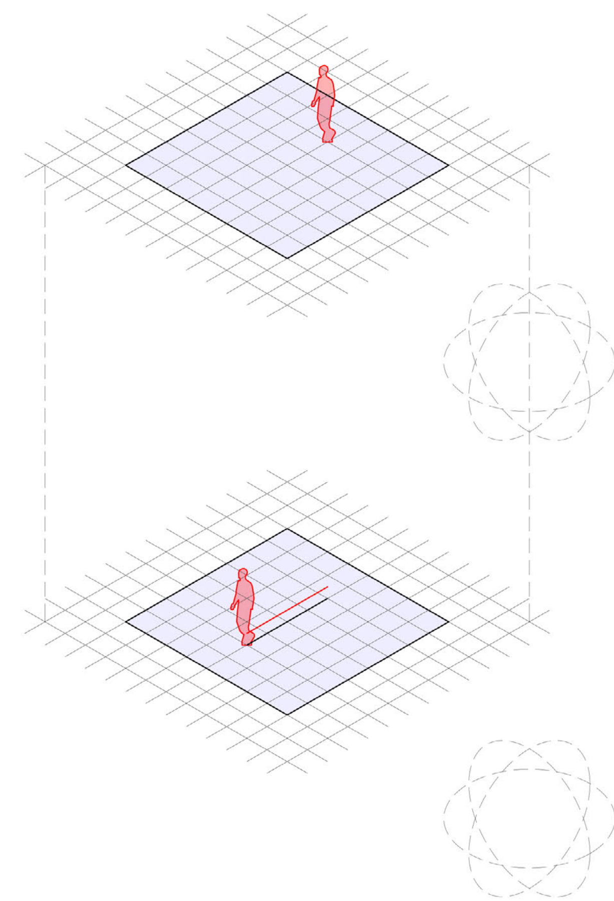
III. VIRTUAL LOCOMOTION

Q1. How do people circulate through Virtual Spaces?

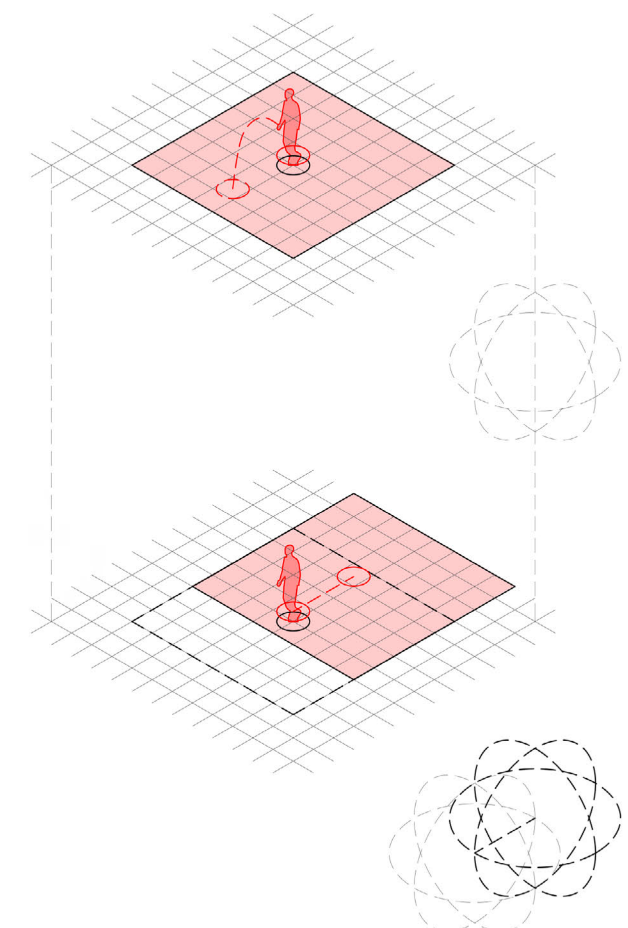
Walking and Teleportation are two common locomotion techniques used in Virtual Reality currently. The “normal” walking allows the virtual space to be stationary relative to the physical area it resides in, but the movement is also confined by the boundaries of the physical space. On the other hand, Teleportation creates the moving spaces, as the virtual world shifts back relative to the physical room when the user teleports forward. However, teleportation ruptures the continuity of virtual experience and reduces immersion.



VIRTUAL LOCOMOTION
Traditional Methods



Walk
Stationary Virtual Space



Teleportation
Moving Virtual Space

VIRTUAL LOCOMOTION
Stationary Spaces

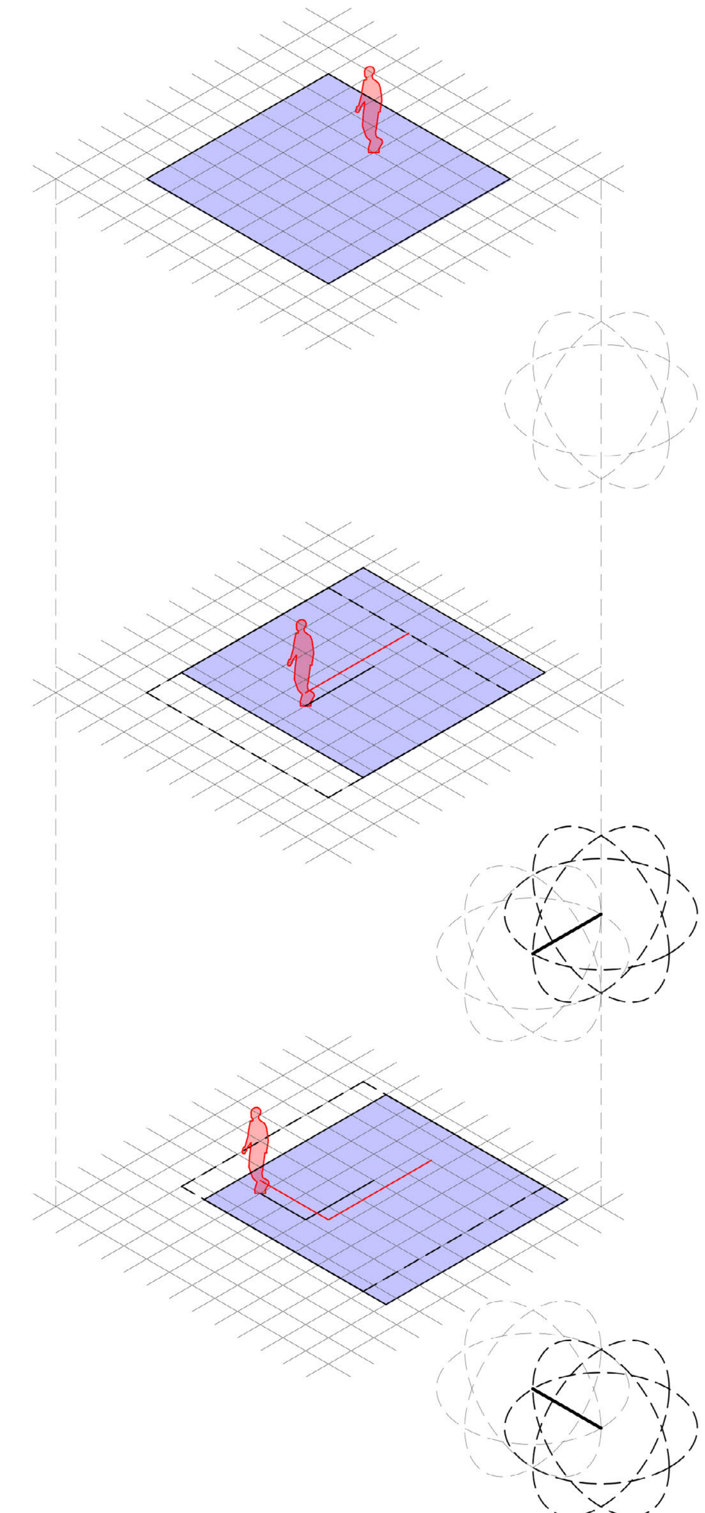
Therefore, can users explore a larger virtual world only through walking within a limited physical space? The answer is yes. Redirected Walking is introduced by researchers with three methods that subtly offsets and moves the virtual world relative to the physical space to fool users' senses, as according to studies in the field of perceptual psychology, vision often dominates proprioception and vestibular sensation when the senses disagree. When the offset is kept below a certain threshold, it can remain imperceptible to the user, thus allowing a larger virtual environment to be mapped to a confined physical area. Such effect can be achieved through the following three techniques:

Translation offset
Increasing or decreasing the speed of walking in the virtual environment to allow the user to move farther or shorter virtually.

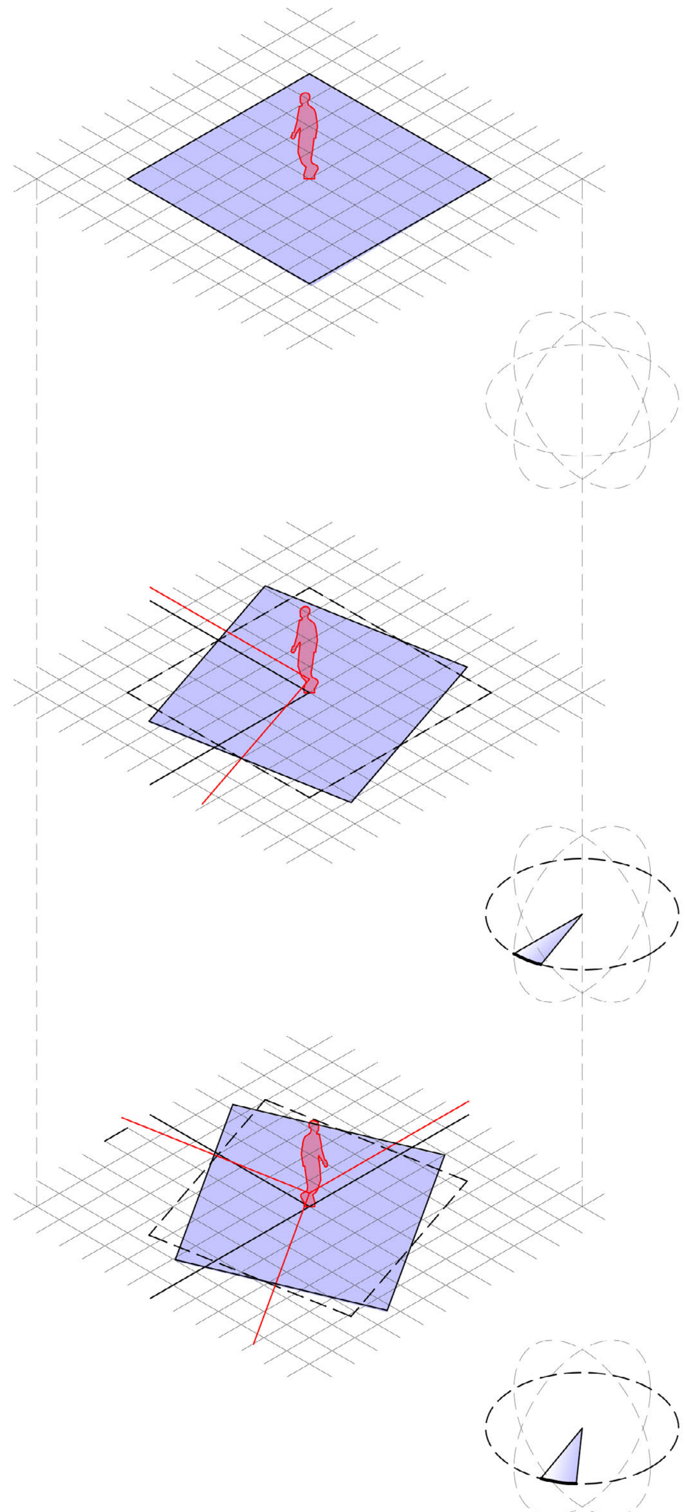
Rotation offset
Increasing or decreasing the rotation speed as the user rotates. Allowing the user to move to a different direction after rotation.

Curvature offset
Continuously rotating the virtual environment while the user moves. Walking in a straight line virtually would result in a curved physical path.

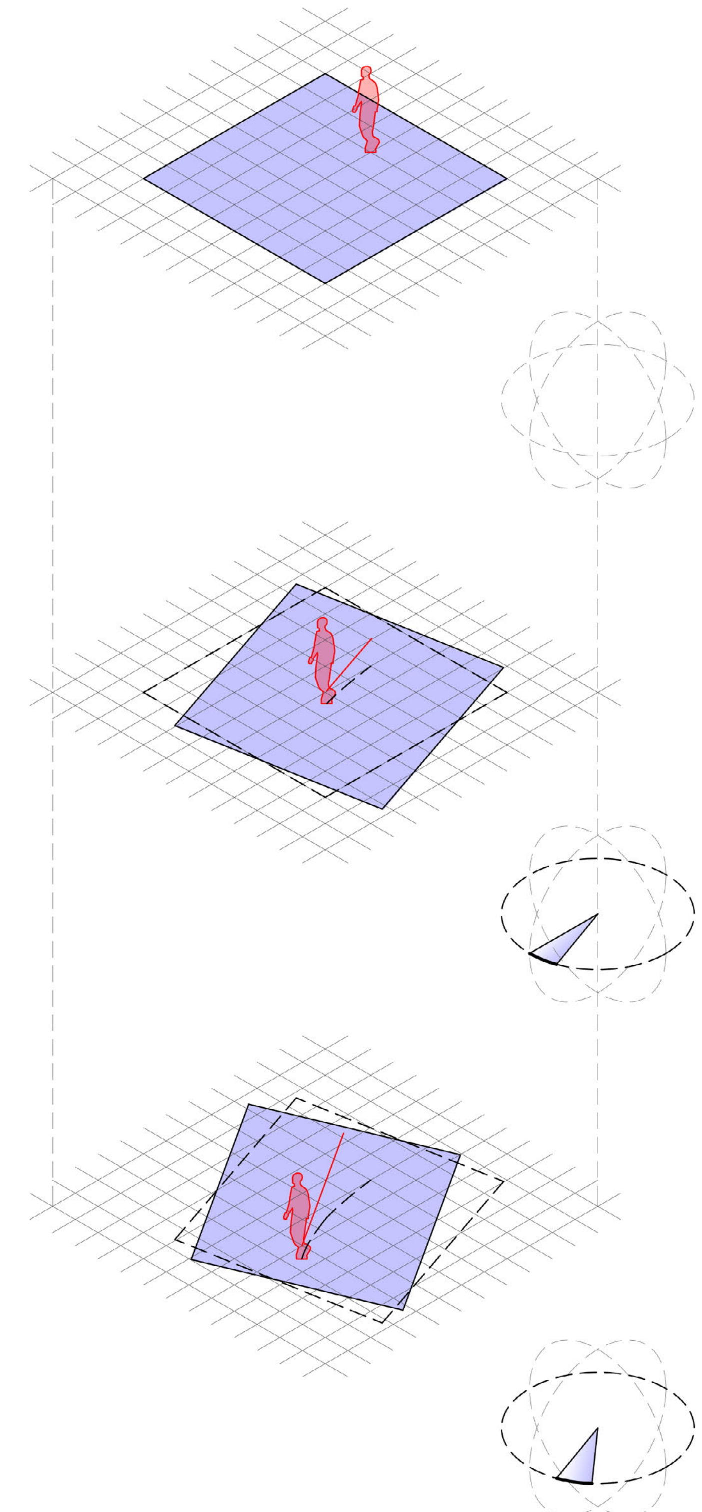
The thresholds of the offsets have been thoroughly analyzed by researchers. According to Steinicke et al. the offsets remain unnoticeable when the translation gain is kept between 0.86 and 1.26, rotation gains between 0.80 and 1.49, and curvature gains below 2.6°/m. Since the thresholds are defined by subjective analysis, I constructed a virtual space using the Unreal Engine 4 and experienced Redirected Walking techniques in Virtual Reality using Oculus Quest. Buttons are implemented to adjust the value of gains.



Translation
Translation Gain :=
Virtual Translation / Physical Translation



Rotation
Rotation Gain :=
Virtual Rotation / Physical Rotation



Curvature
Curvature Gain :=
(Physical Rotation - Virtual Rotation) / Physical Translation

VIRTUAL LOCOMOTION
Moving Spaces

Through the VR experience, I discovered that moving spaces, the virtual space whose offset is noticeable to the user but still does not cause motion sickness, can be achieved by pushing the gains beyond the threshold. Such spaces could drastically enlarge the virtual space and bring much more freedom to the design of the virtual space. Three additional techniques that create moving spaces and expand the movement on the ground plane to the third dimension are discovered and tested during this process.

Vertical translation offset

Shifting the virtual world up or down vertically as the user walks forward. Allowing the user to switch between ground levels while remaining in the same physical level.

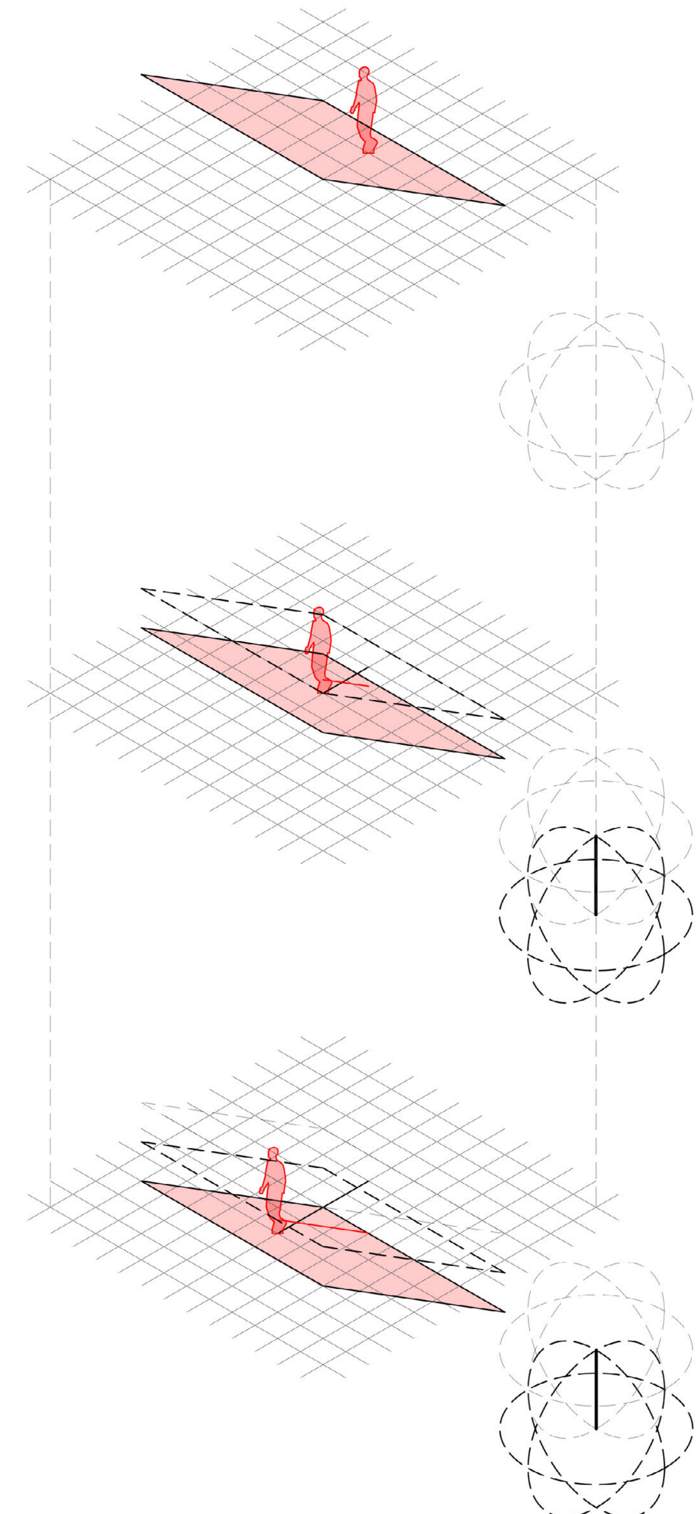
Scaling offset

Scaling the virtual world up or down as the user walks forward. Allowing the user to alter their relative scale and resulting in different perspectives and experiences at the same virtual space.

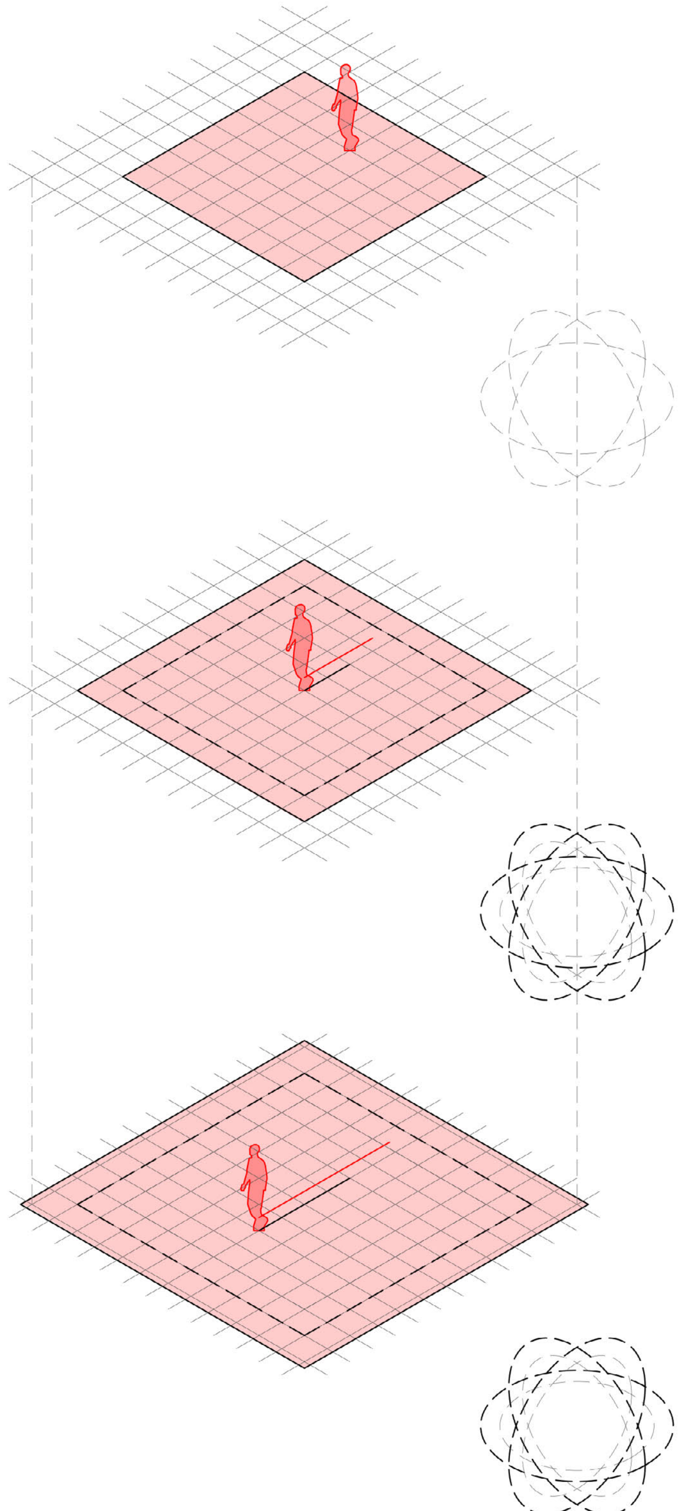
Ground shifting offset

Rotating the virtual world along the horizontal axis perpendicular to the user's moving direction. Blurring the boundaries between walls and floors and allowing the user to walk to planes at any angles.

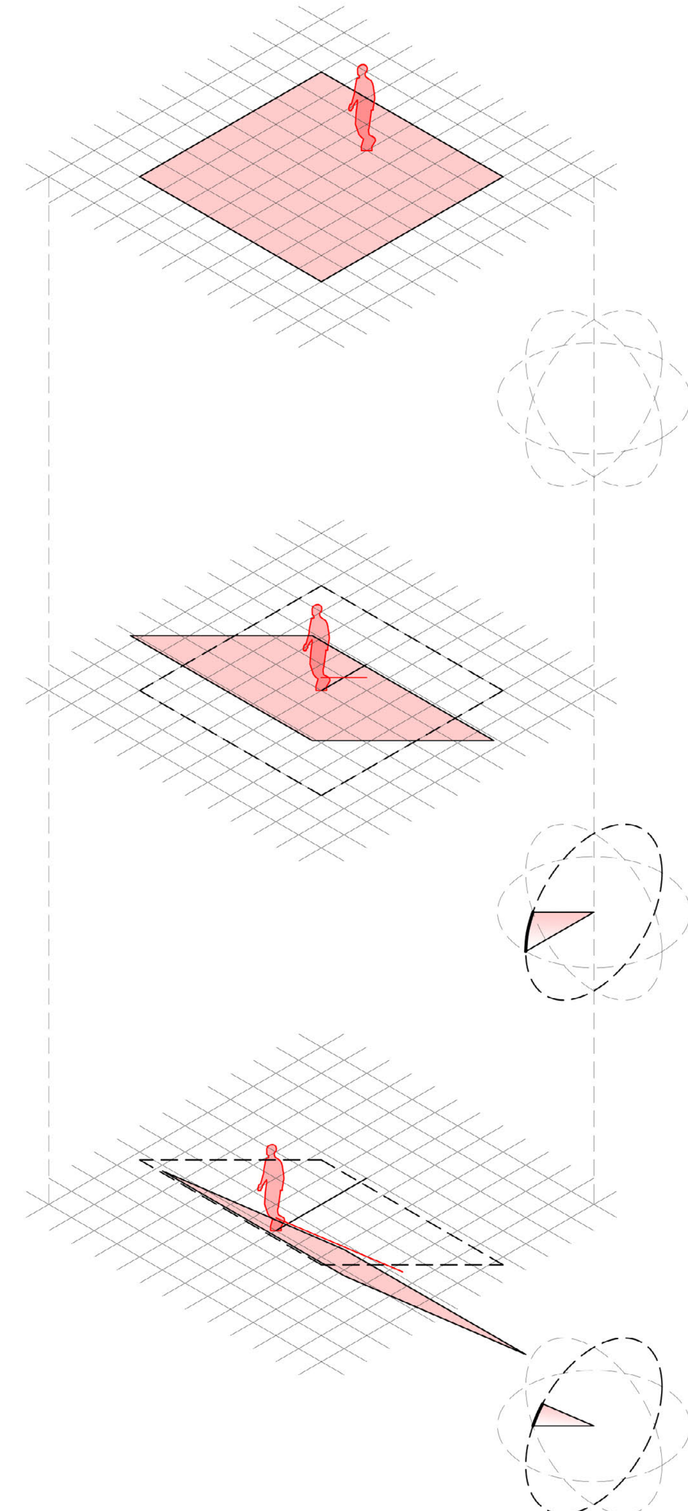
The abovementioned six techniques: translation, rotation, curvature, vertical translation, scaling, and ground shifting are used as the vocabulary for the generation of virtual spaces.



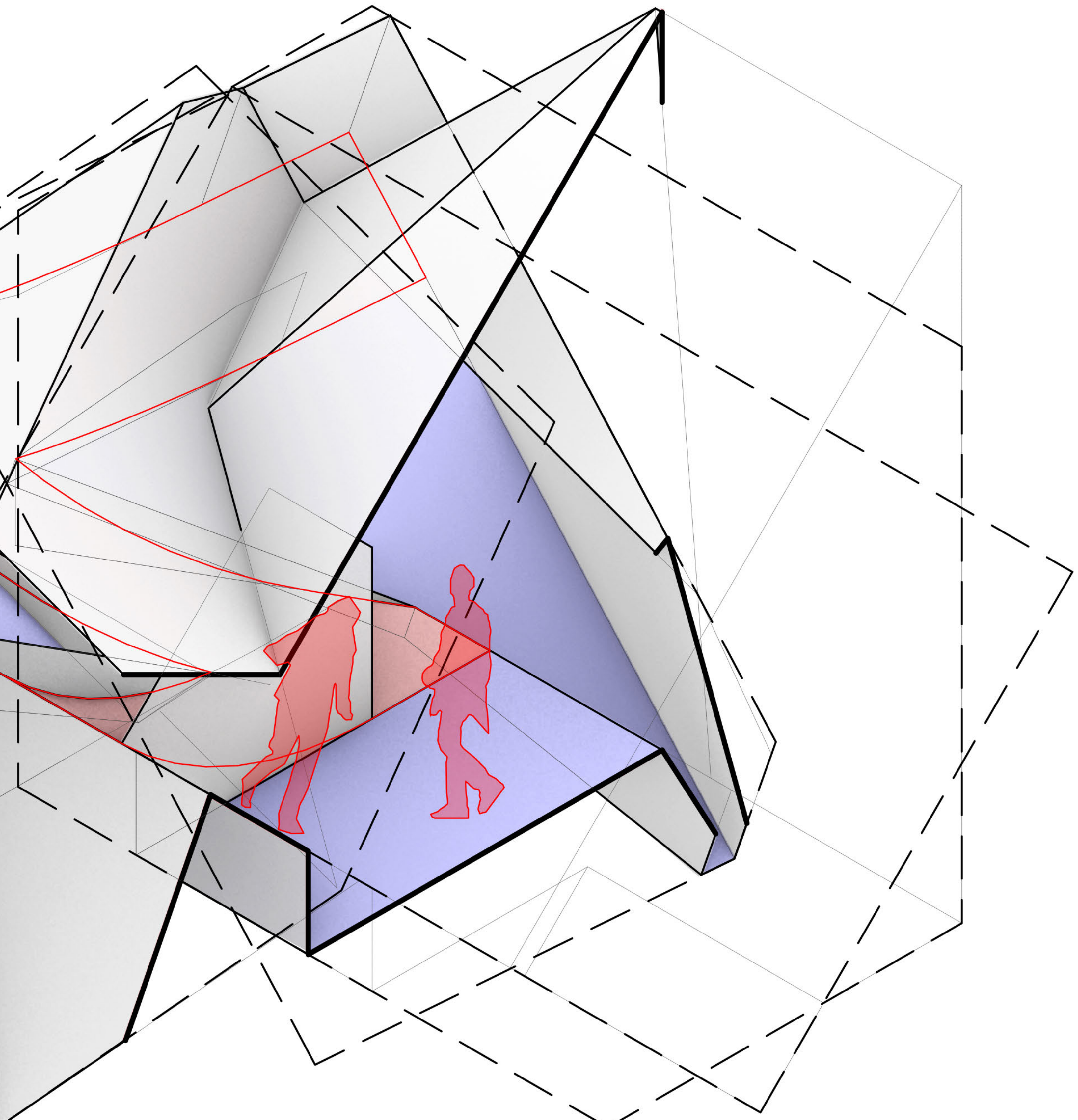
Vertical Translation
Vertical Gain :=
Vertical Translation / Horizontal Translation



Scale
Sclae Gain :=
Difference in Scale / Physical Translation



Ground Shifting
Shifting Gain :=
Ground Rotation / Physical Translation



IV. SPATIAL PROTOTYPES

Q2. How do virtual locomotion techniques redefine the way spaces are constructed in the virtual realm?

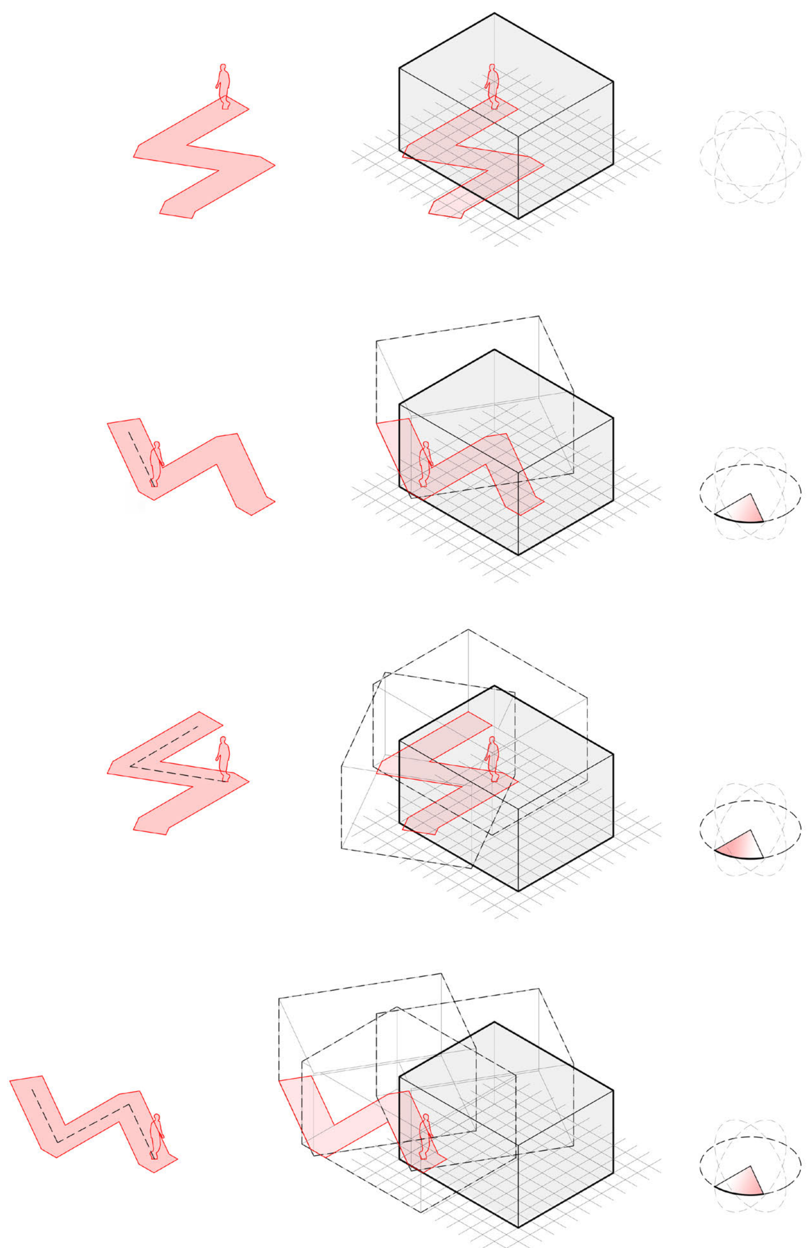
The circulation in virtual spaces is drastically different from that in the physical spaces as the new virtual locomotion techniques are introduced. Without the constraint of gravity, the limitation of space and the constant scale, users can now utilize the walls as the ground plane or turn a shoebox into a living room. The traditional spatial design is no longer compatible with the virtual sphere. Therefore, spatial prototypes are created to analyze the new methods of spatial design. The six virtual locomotion techniques that were previously analyzed are used as the vocabulary to create virtual paths, along which a series of virtual volumes is generated, resulting in the following spatial prototypes.

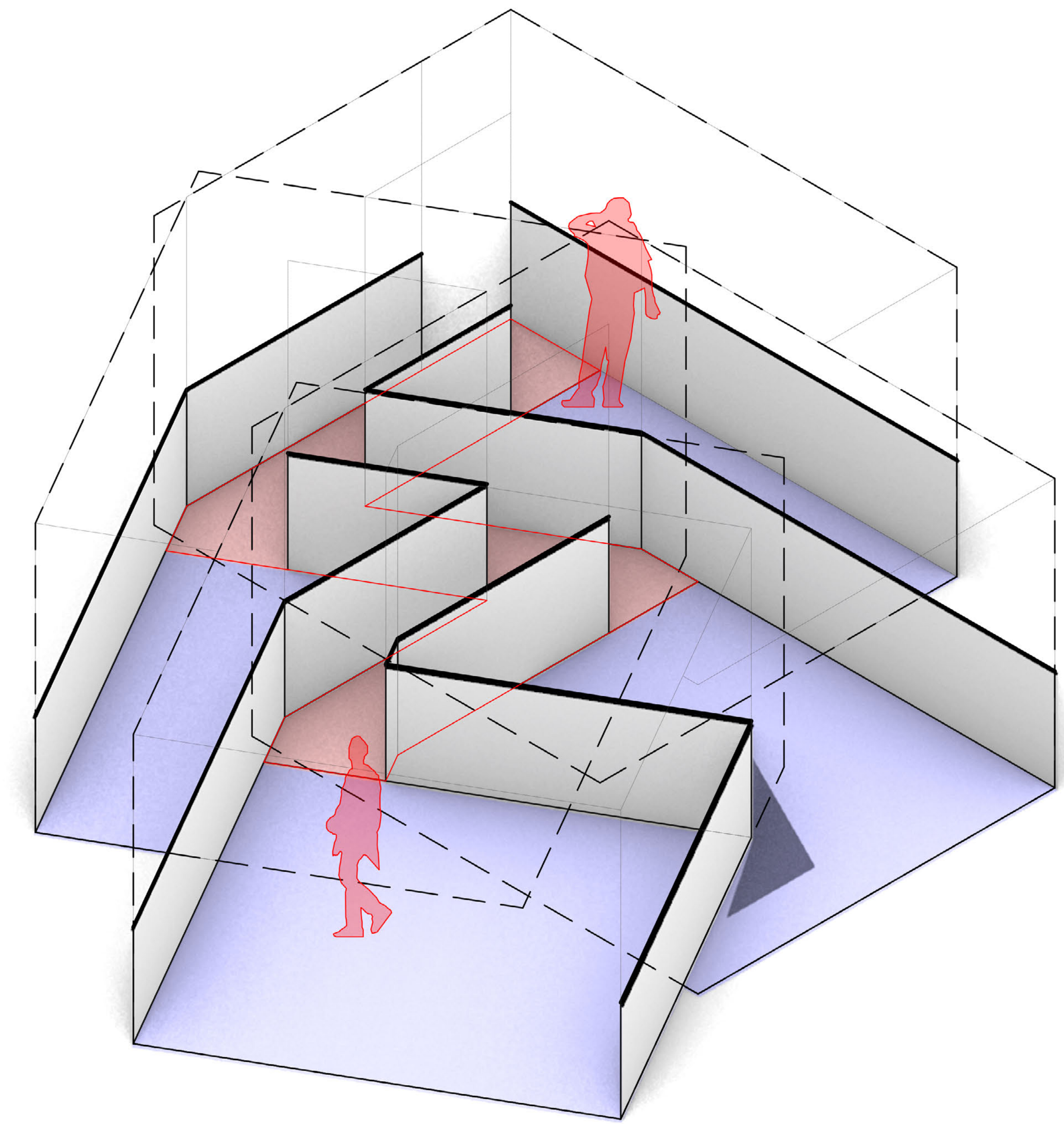
SPATIAL PROTOTYPES
Locomotion Techniques

01

Translation
Rotation
Curvature
Vertical Translation
Scale
Ground Shifting

The translation and rotation techniques of Redirected Walking transform the back and forth physical movement along a straight line into a zigzag virtual path. The translation technique allows the virtual rooms to be slightly larger than their physical counterparts, and the rotation technique creates a 60 degree offset as the user turns 180 degrees at the ends. After each turn, the virtual world is realigned with the physical coordinate, based on which a virtual space is generated. Then, the four inserted virtual spaces intersect with each other and form the first prototype.



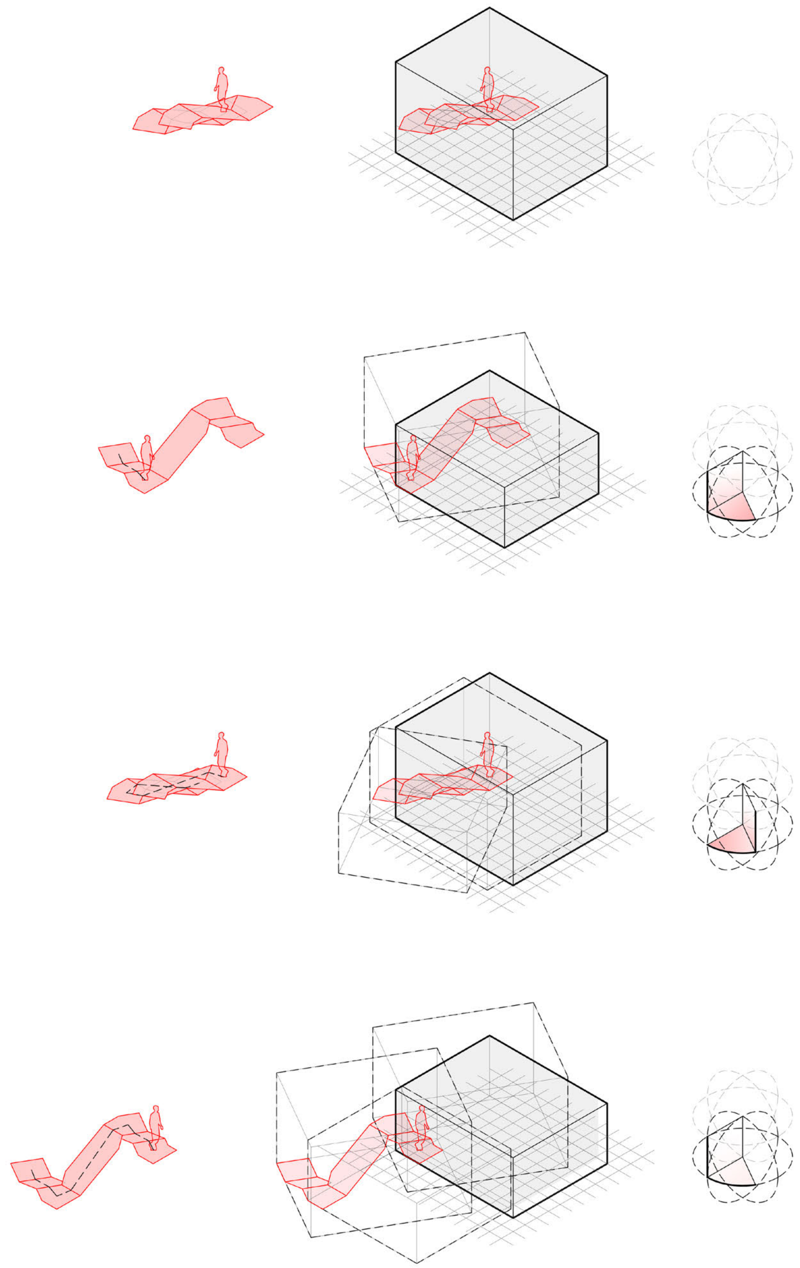


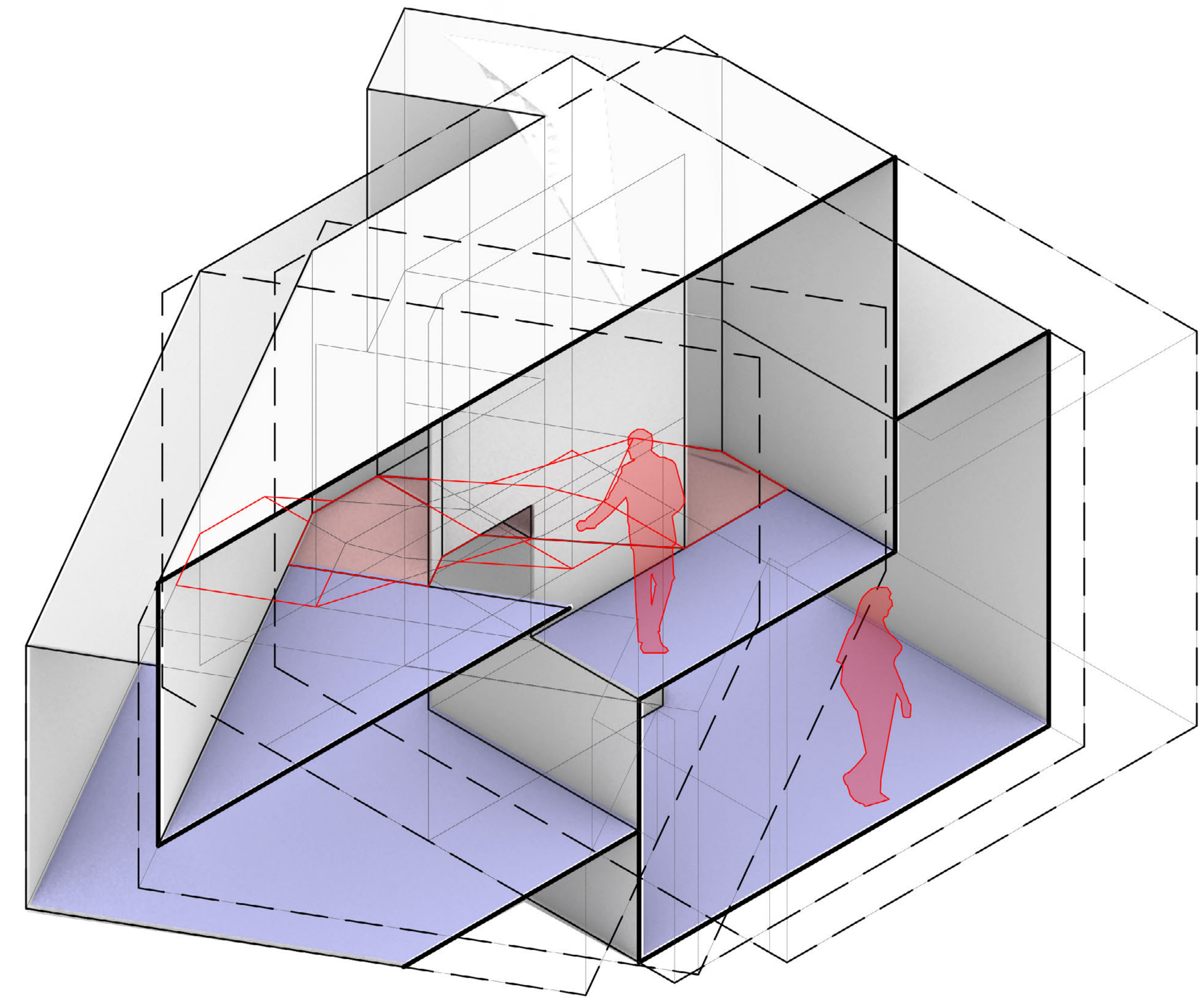
SPATIAL PROTOTYPES
Locomotion Techniques

02

Translation
Rotation
Curvature
Vertical Translation
Scale
Ground Shifting

Vertical translation applied to the straight paths allows the virtual world to shift vertically, resulting in the slanted virtual path. Therefore, the generated four virtual spaces are located at different heights, and when intersected with each other, openings that allow visual connection between spaces are created at the points of intersection. The virtual spaces could be larger than those in spatial prototype 01, as vertical areas are utilized.





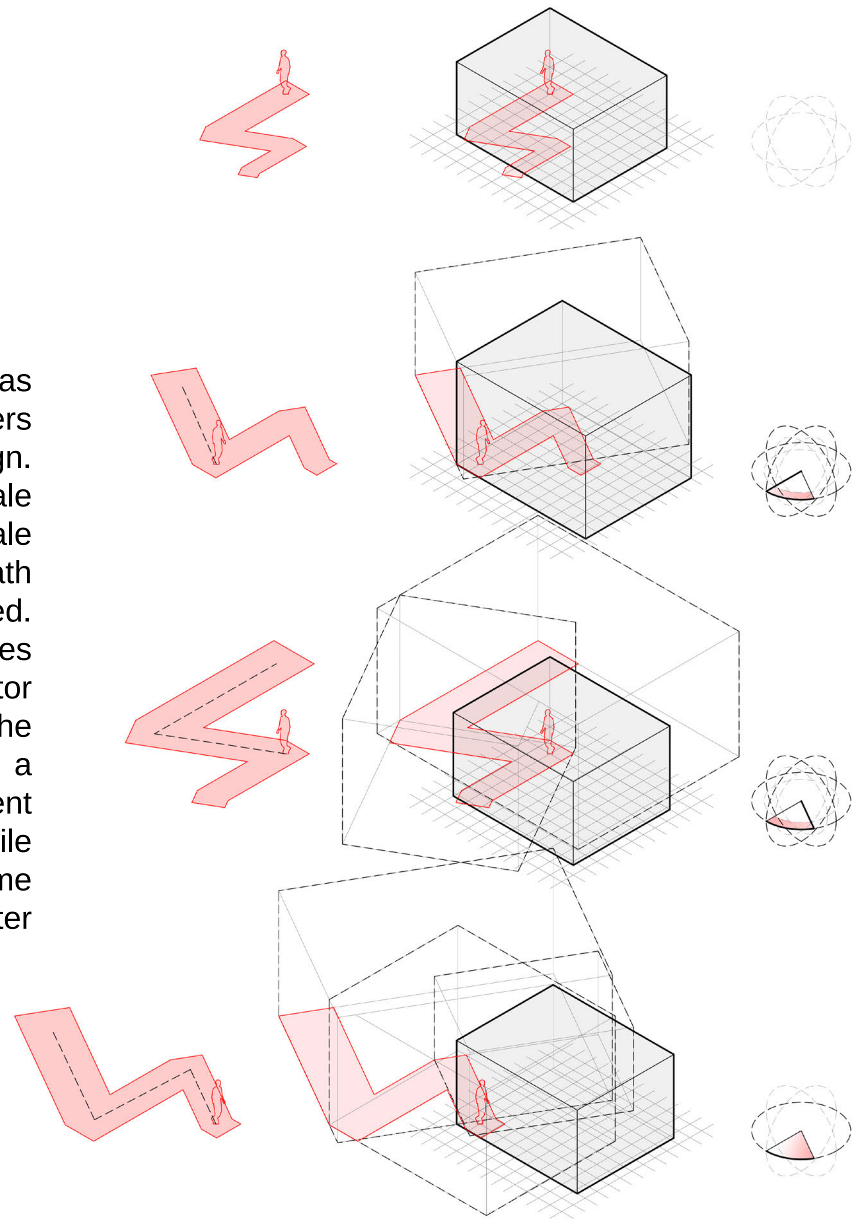
SPATIAL PROTOTYPES

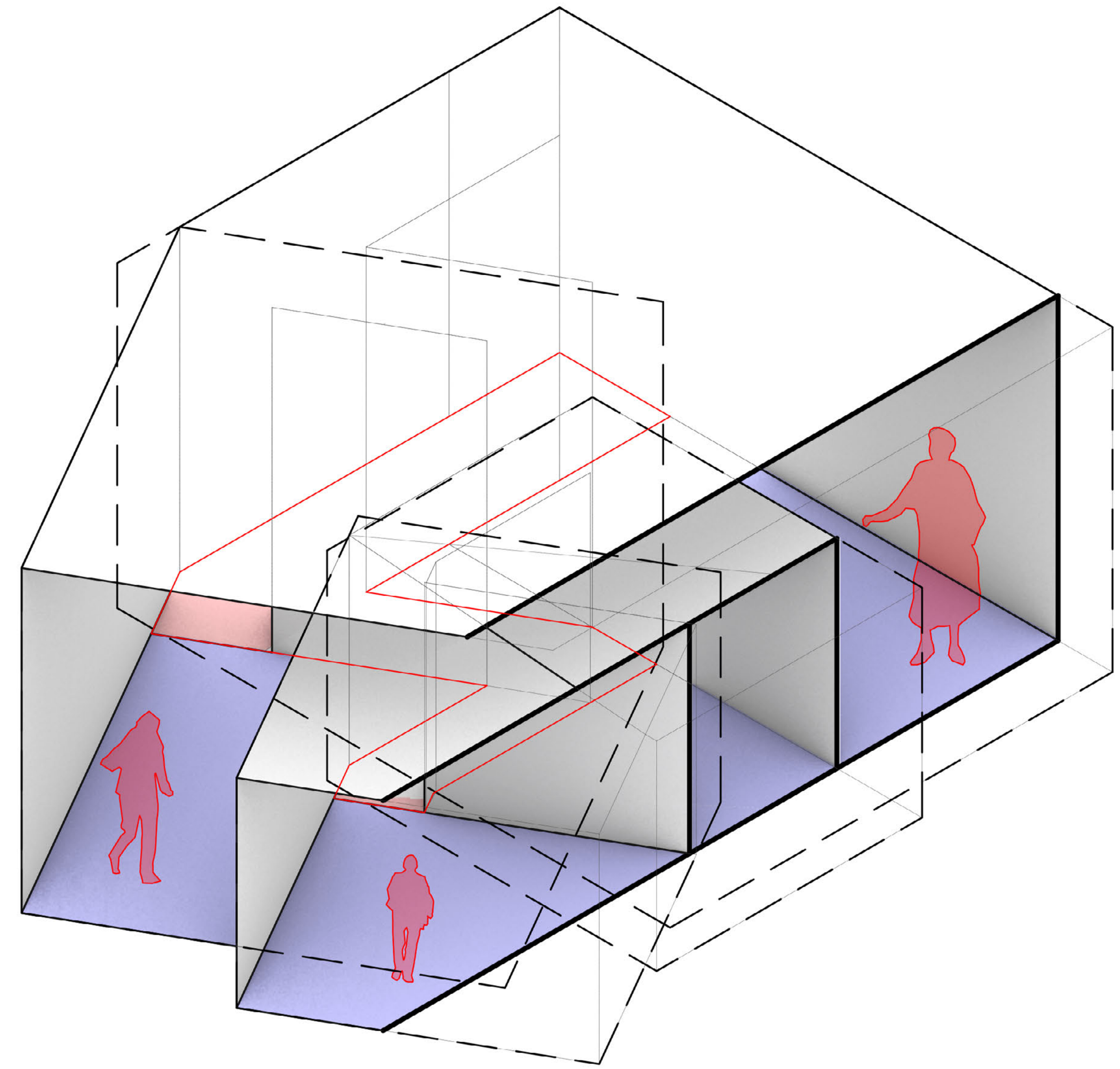
Locomotion Techniques

03

Translation
Rotation
Curvature
Vertical Translation
Scale
Ground Shifting

Scaling of the virtual world as the user walks through shatters the convention of spatial design. In this case, objects at any scale could be turned into a room scale space as long as a virtual path with gradual scaling is designed. In this prototype, nested spaces are created. If the scaling factor is pushed to an extreme, the outer spaces could become a building scale virtual environment enclosing the inner spaces, while the inner spaces could become a closet sitting inside the outer spaces.



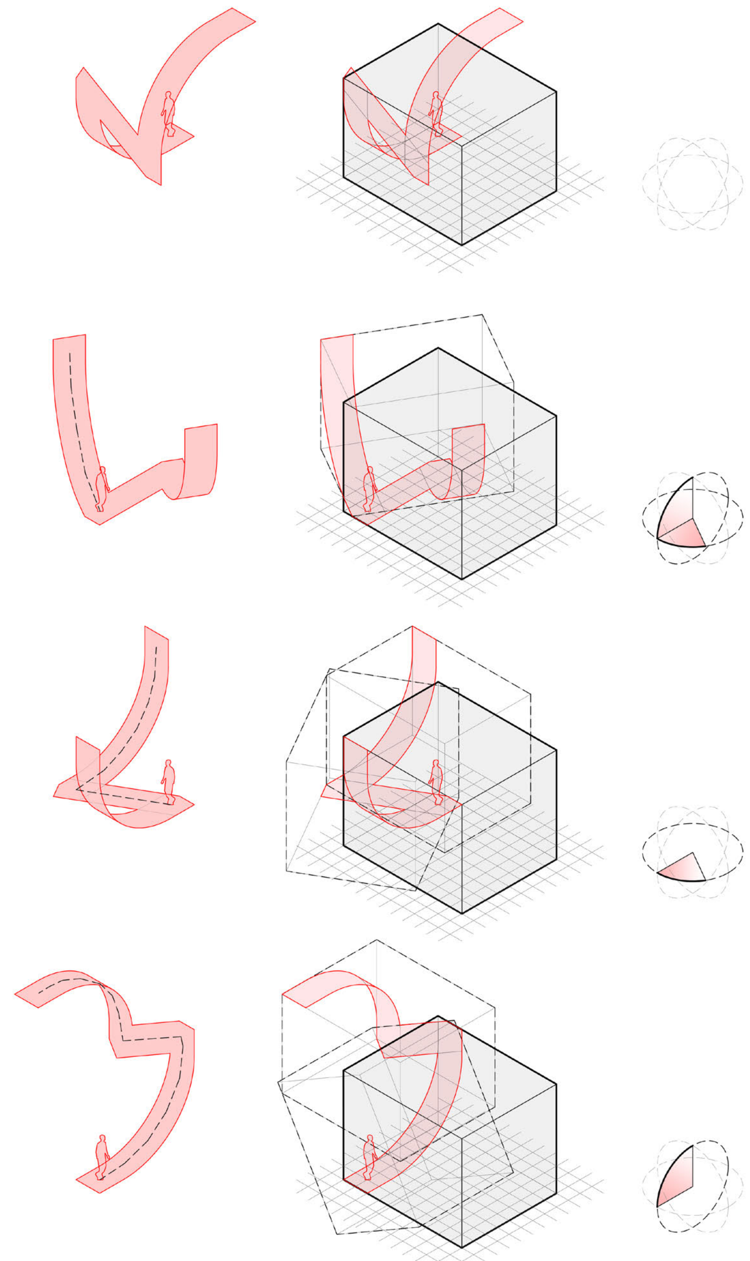


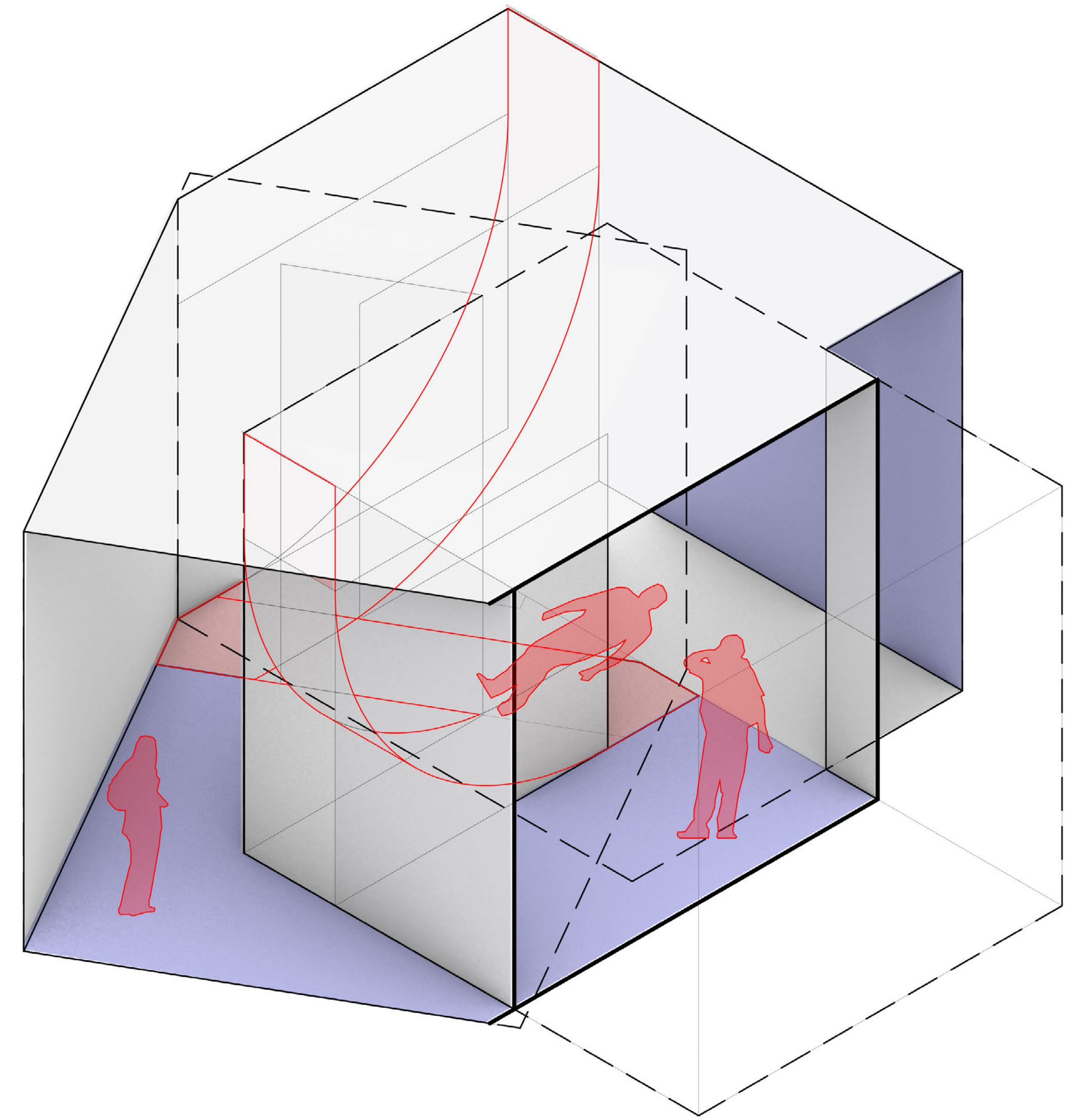
SPATIAL PROTOTYPES
Locomotion Techniques

04

Translation
Rotation
Curvature
Vertical Translation
Scale
Ground Shifting

The last technique, ground shifting generates supernatural spaces. With this technique, any plane in the virtual realm could become a ground plane and is accessible through walking in the physical area as long as it is linked by a virtual path. In this prototype, the virtual world rotates 90 degrees as the user moves along the straight line. The former walls now become grounds, and the same space could be experienced twice from different perspectives. The different ground planes are also visually connected to each other.



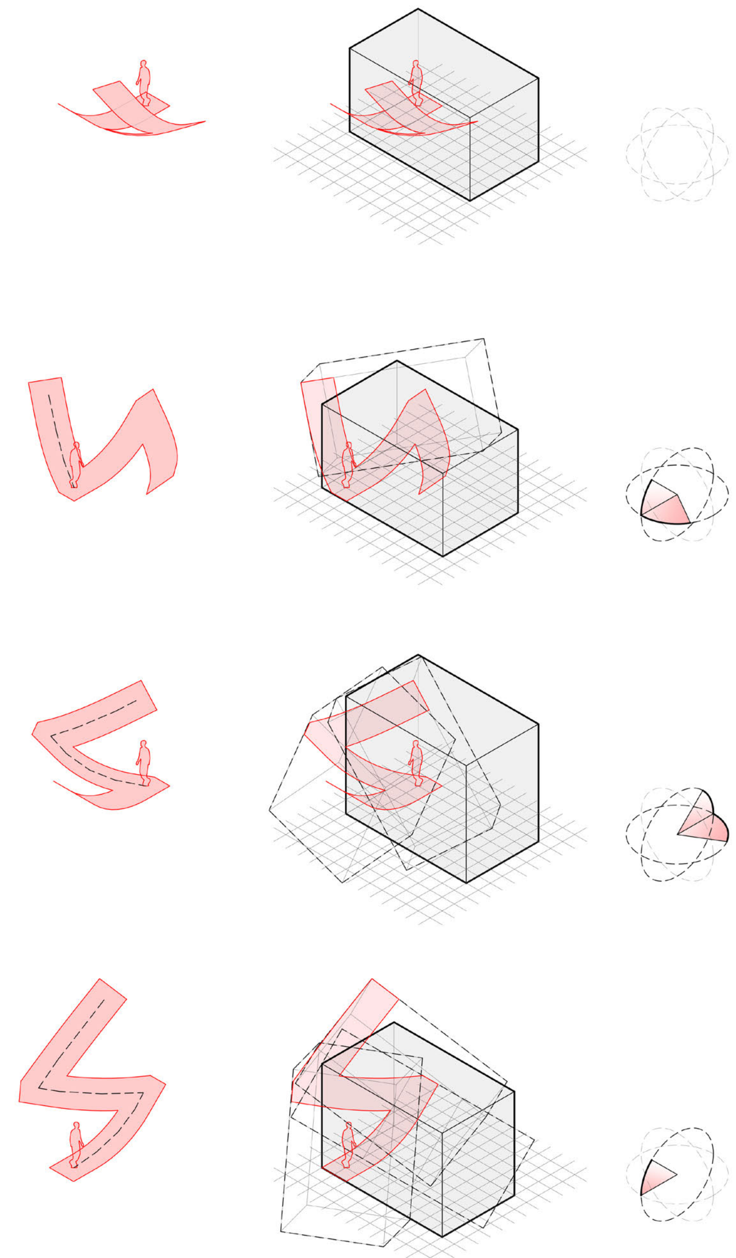


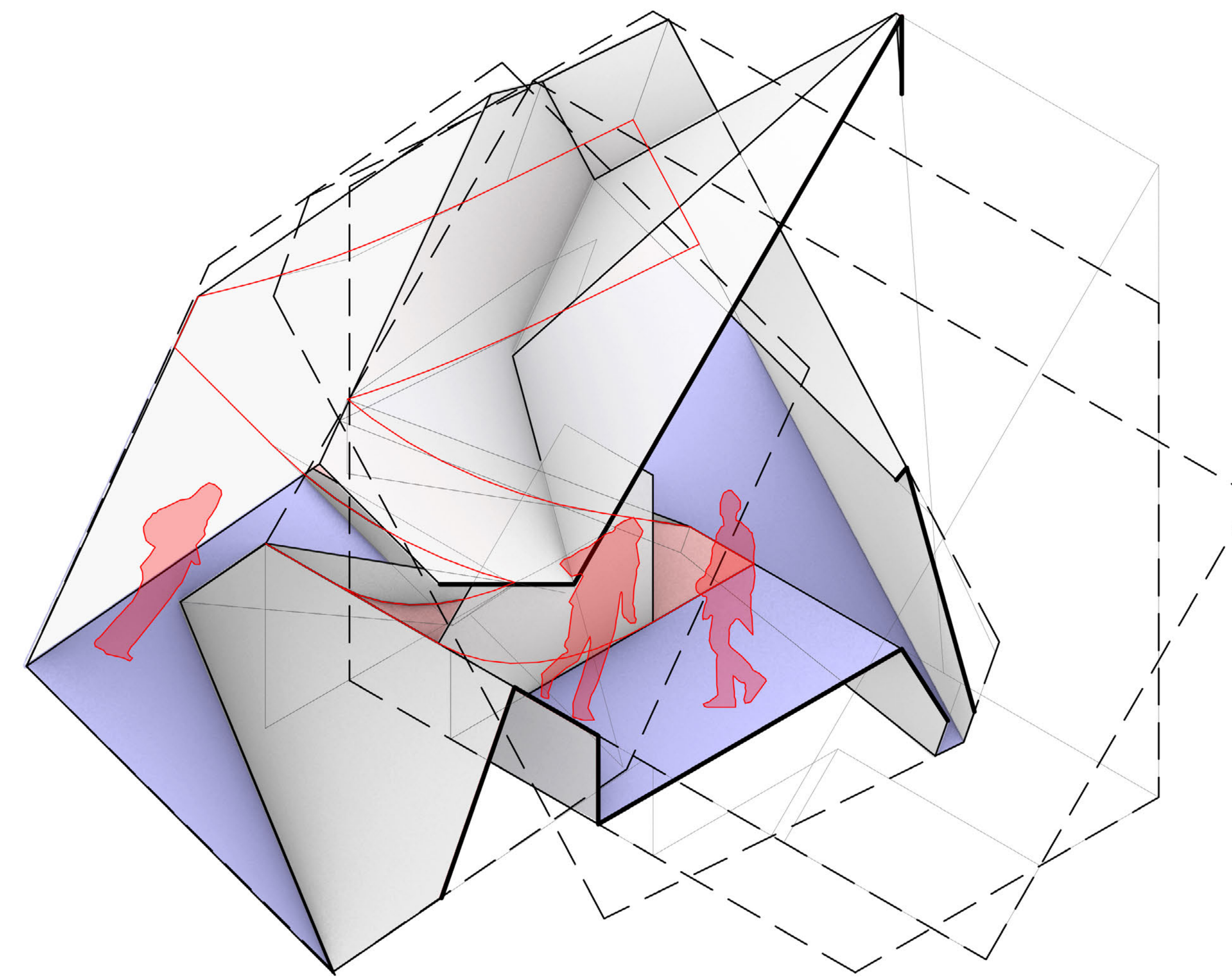
SPATIAL PROTOTYPES
Changing Parameters

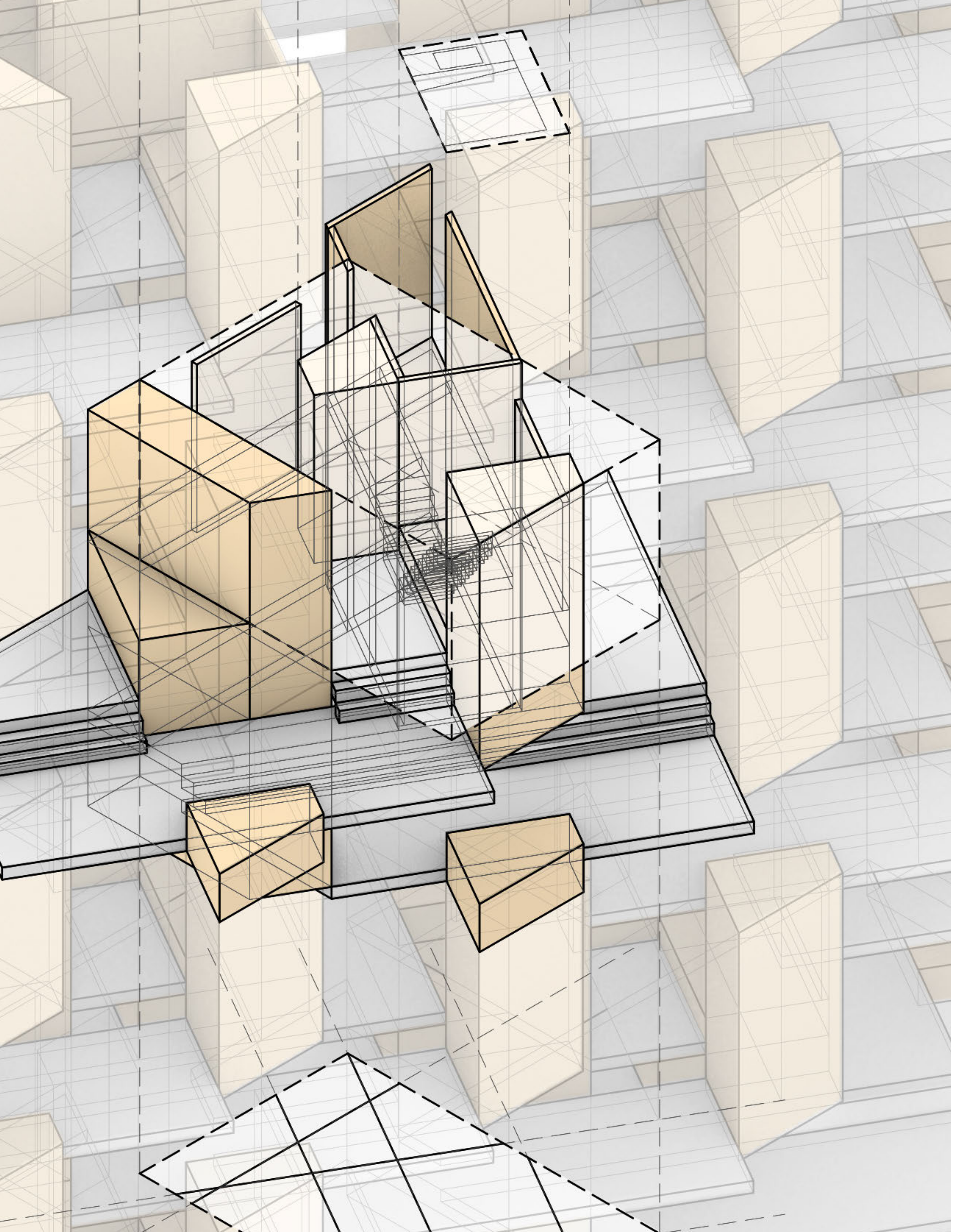
05

Translation
Rotation
Curvature
Vertical Translation
Scale
Ground Shifting

Different virtual locomotion effect gains could result in different spatial relations in the prototypes. The final prototype explores the changing of gains. The former orthogonal spaces are now oblique as the ground shifting gain is reduced by half. More intricate intersections result in openings at different scales and allow the virtual paths to be merged into the spaces. Surreal perspectives can be found in all spaces.







V. VIRTUAL HOUSING

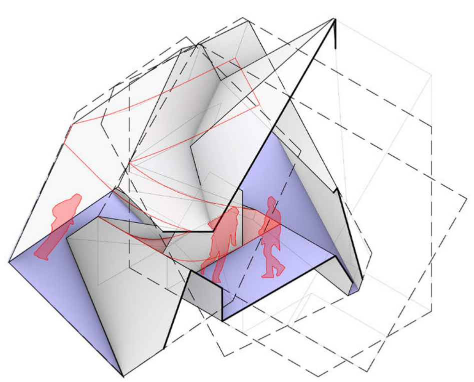
Q3. How do physical spaces respond to virtual spaces in a way that promotes concurrent living in the physical and virtual realms?

When the prevalent Extended Reality technologies enters our daily lives, virtual spaces would ultimately become an extended layer of the urban spheres, and architecture at that time, would be the integral of physical construction and its virtual counterpart. Architecture will be the intersection point between the physical and the virtual realms. Focusing on the design of future urban housing, the project overlaps the spatial prototypes with a physical space, and studies how such augmentation reforms physical boundaries and redefines programs, generating a prototype for the future way of living.

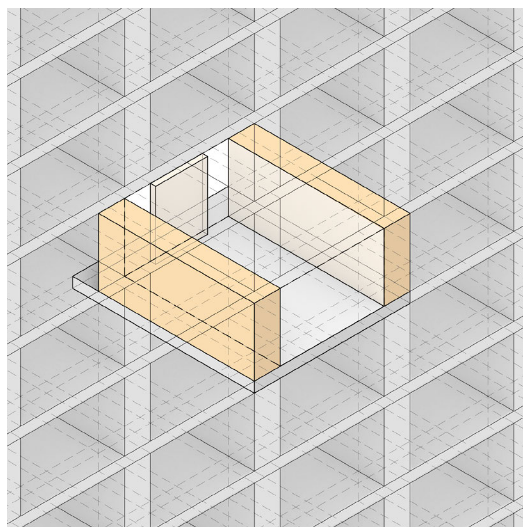
VIRTUAL HOUSING
Design Process

The design process of the virtual housing iterates between the virtual and the physical and continues, as the two parts evolve concurrently and adapt to each other, resulting in an interdependent system between the two.

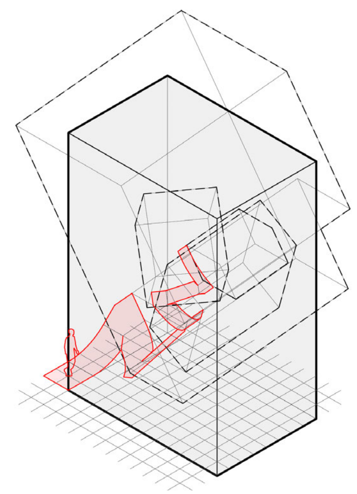
Virtual
Spatial compositions derived from locomotion techniques



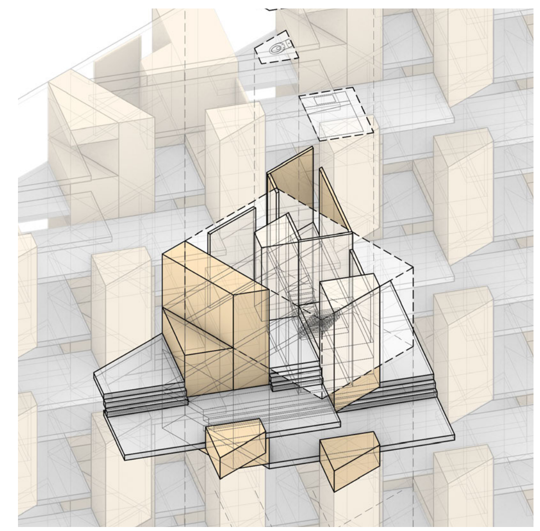
Physical
Shoebox unit generated from virtual compositions



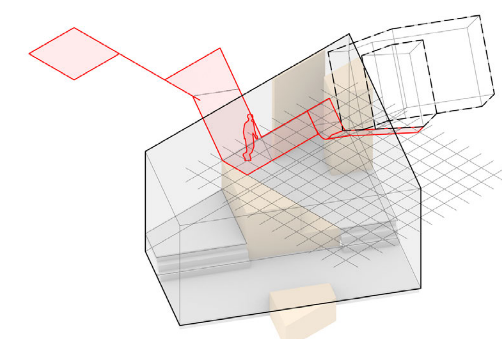
Virtual
Sequential experience based on physical units



Physical
Furnishing reconfigured by virtual datums

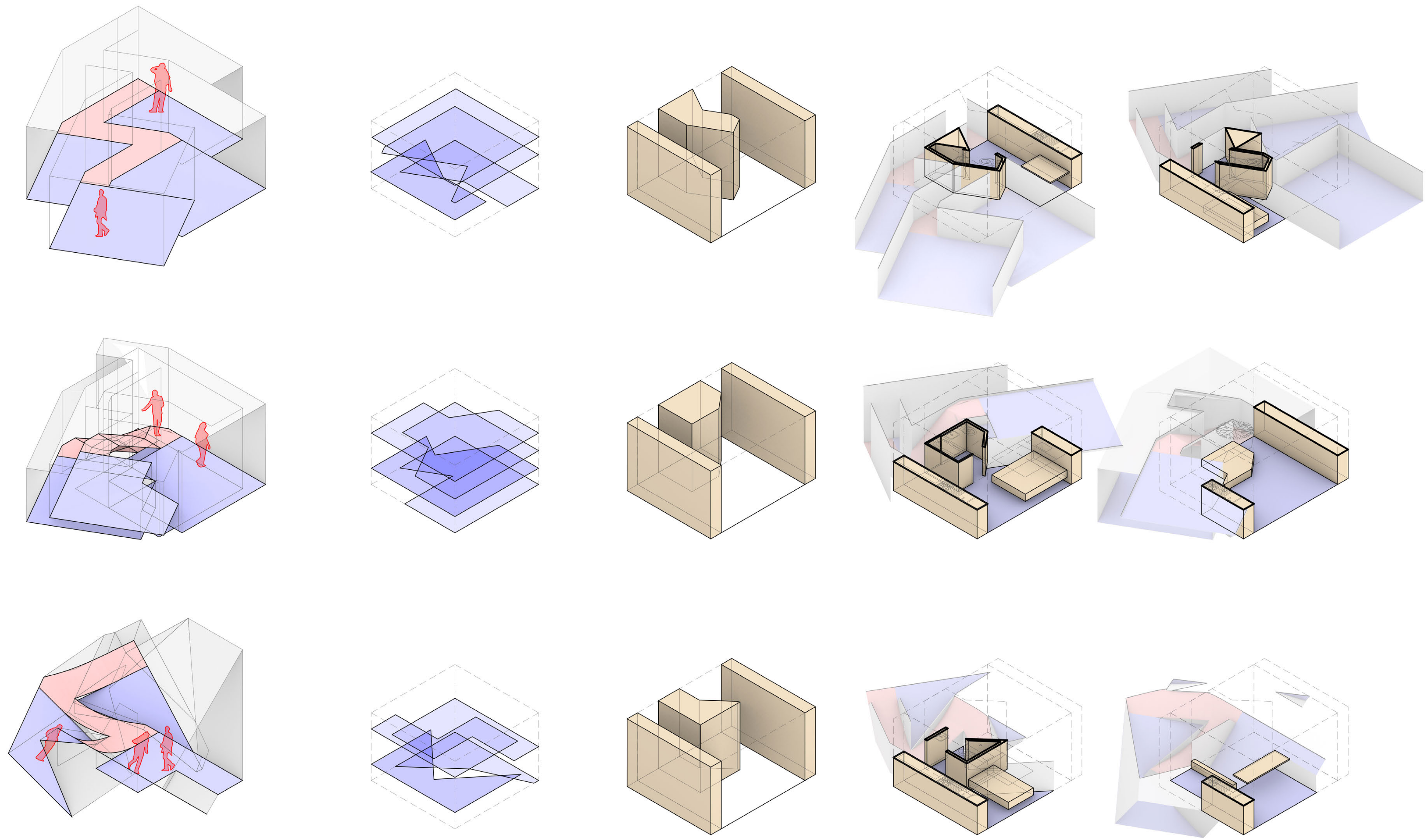


Virtual
Sequential experience based on physical furnishing



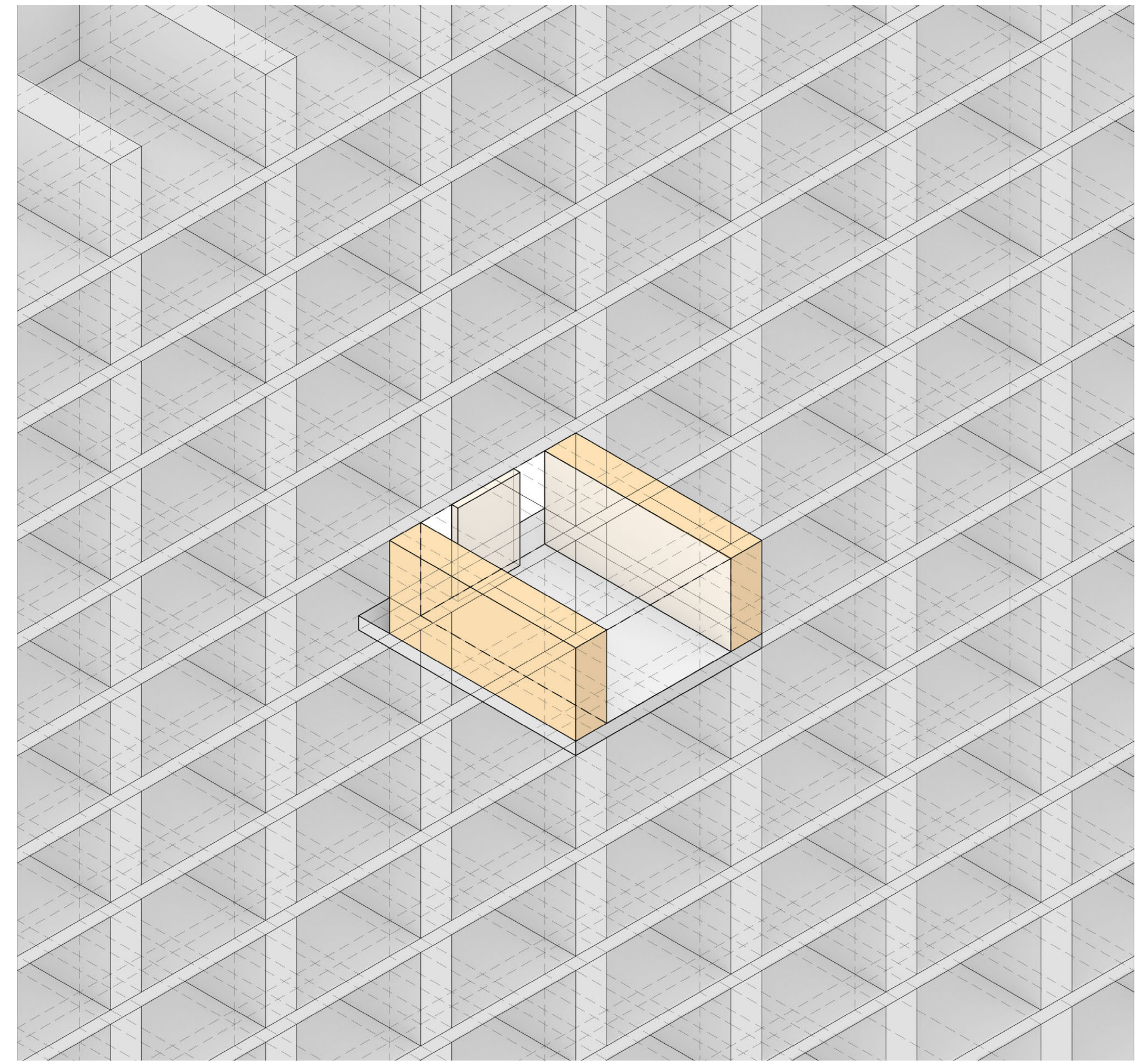
VIRTUAL HOUSING
Spatial Augmentation

Starting from the spatial prototypes, I overlapped their virtual floors and used them as guides. Three possible zones located along the walls and at the center can be found for physical insertion. With the ability to turn off physical elements by blocking certain areas with virtual renderings, the furnishing can be reconfigured based on different layouts of the virtual space to accommodate different programs.



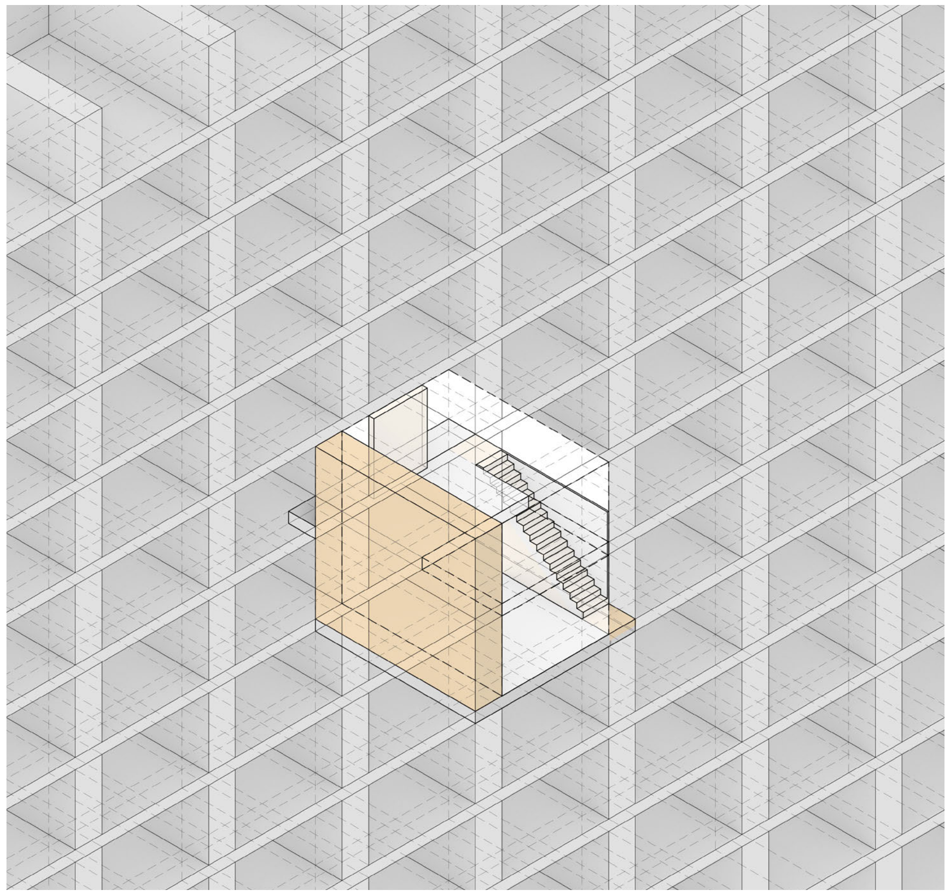
VIRTUAL HOUSING
Shoebox Unit

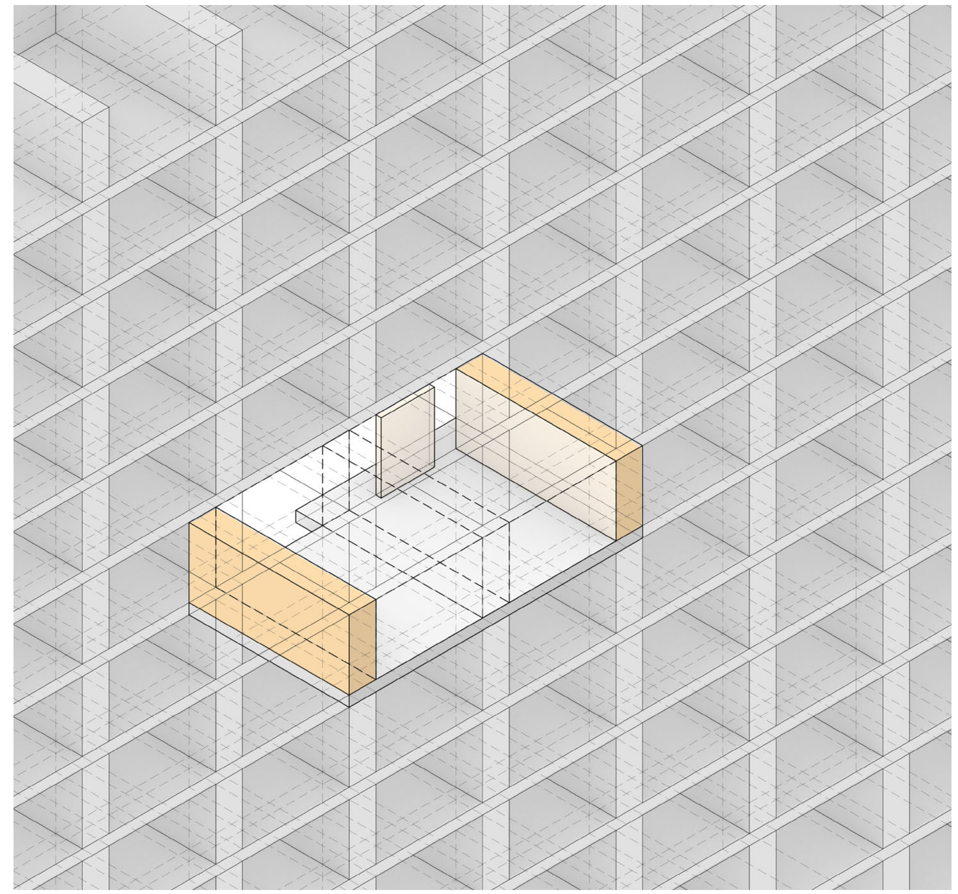
The step of spatial augmentation leads to the physical shoebox units bounded by reconfigurable wall furniture. The shoeboxes can aggregate into a vertical matrix of units.

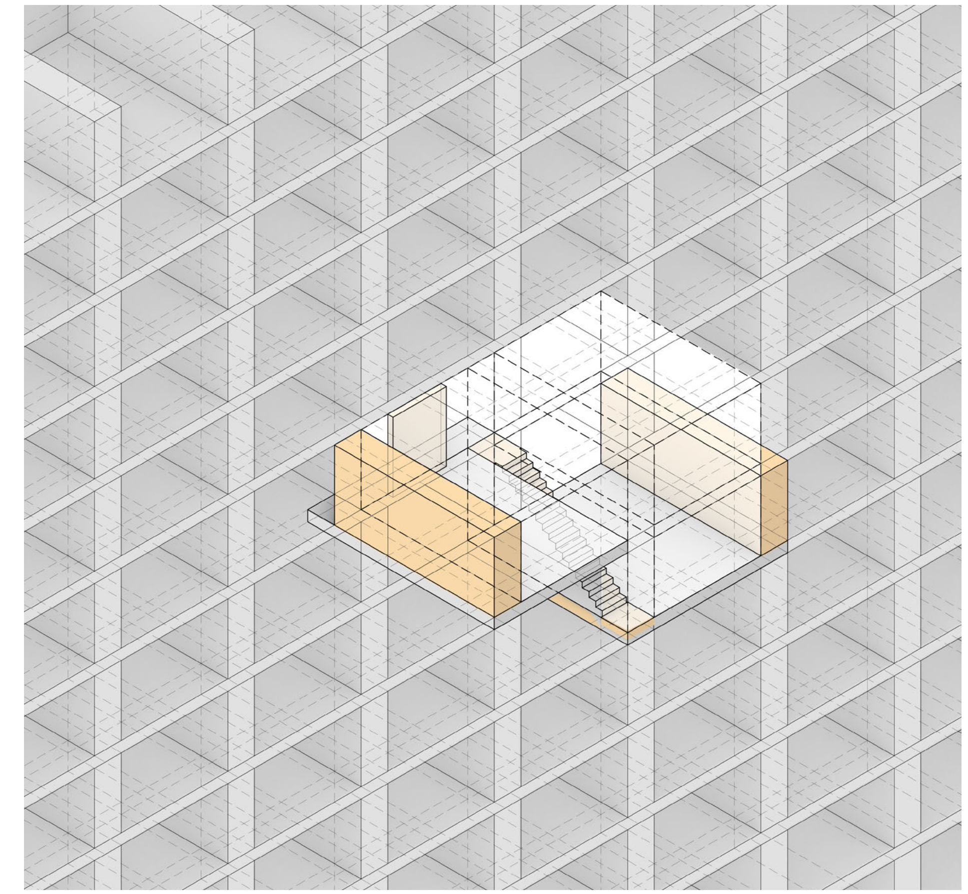


VIRTUAL HOUSING

Reforming Boundaries

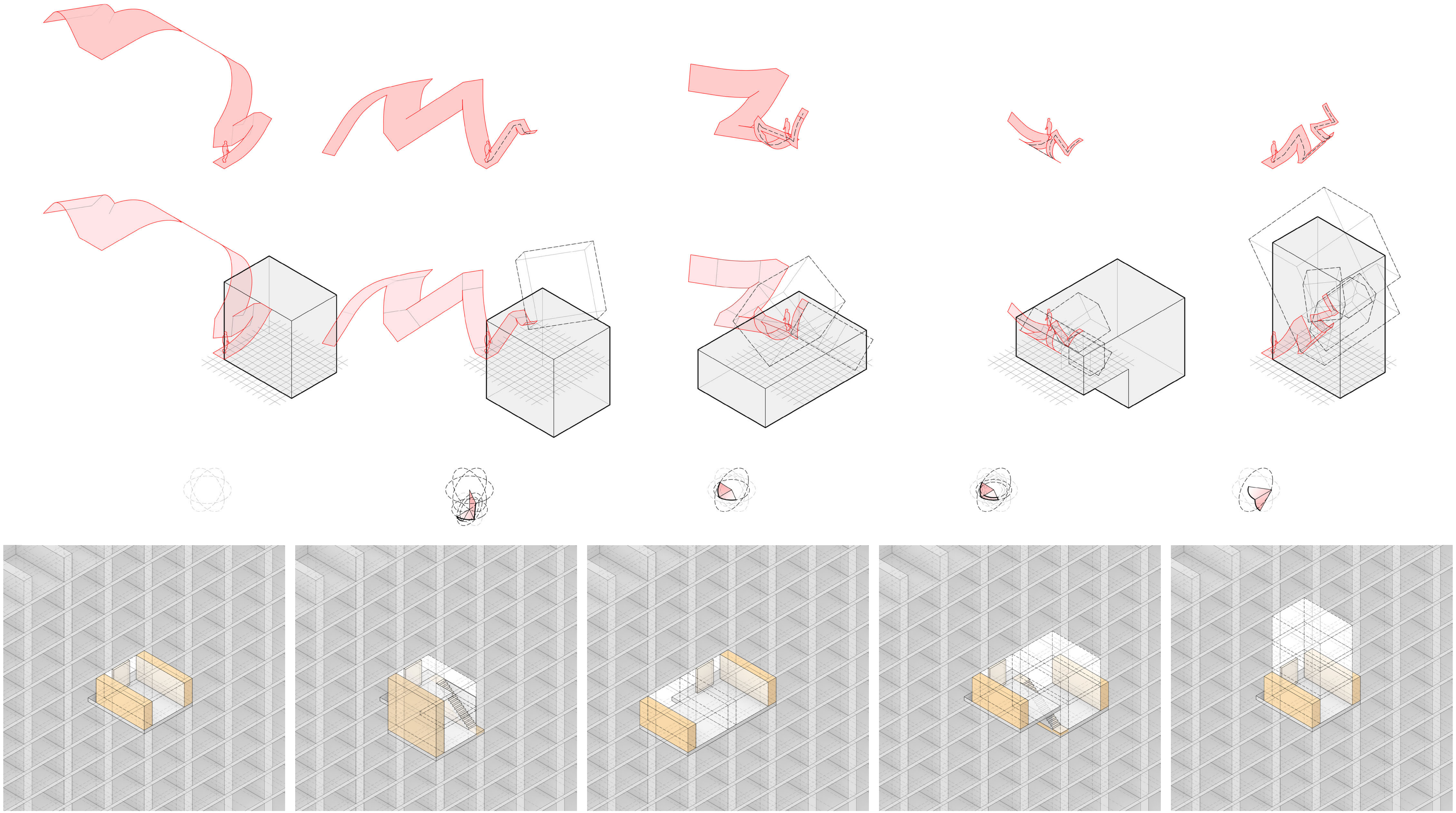


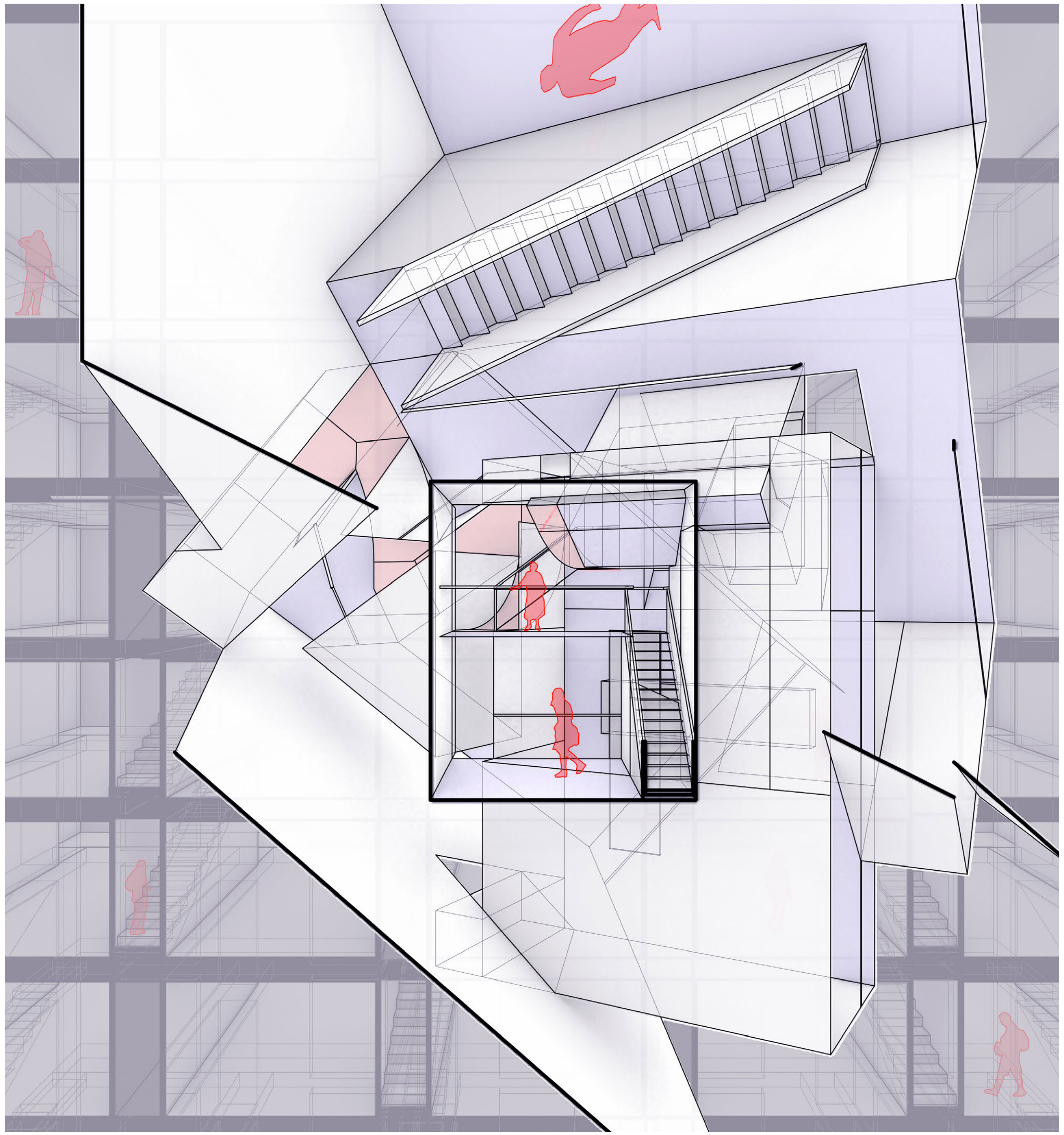


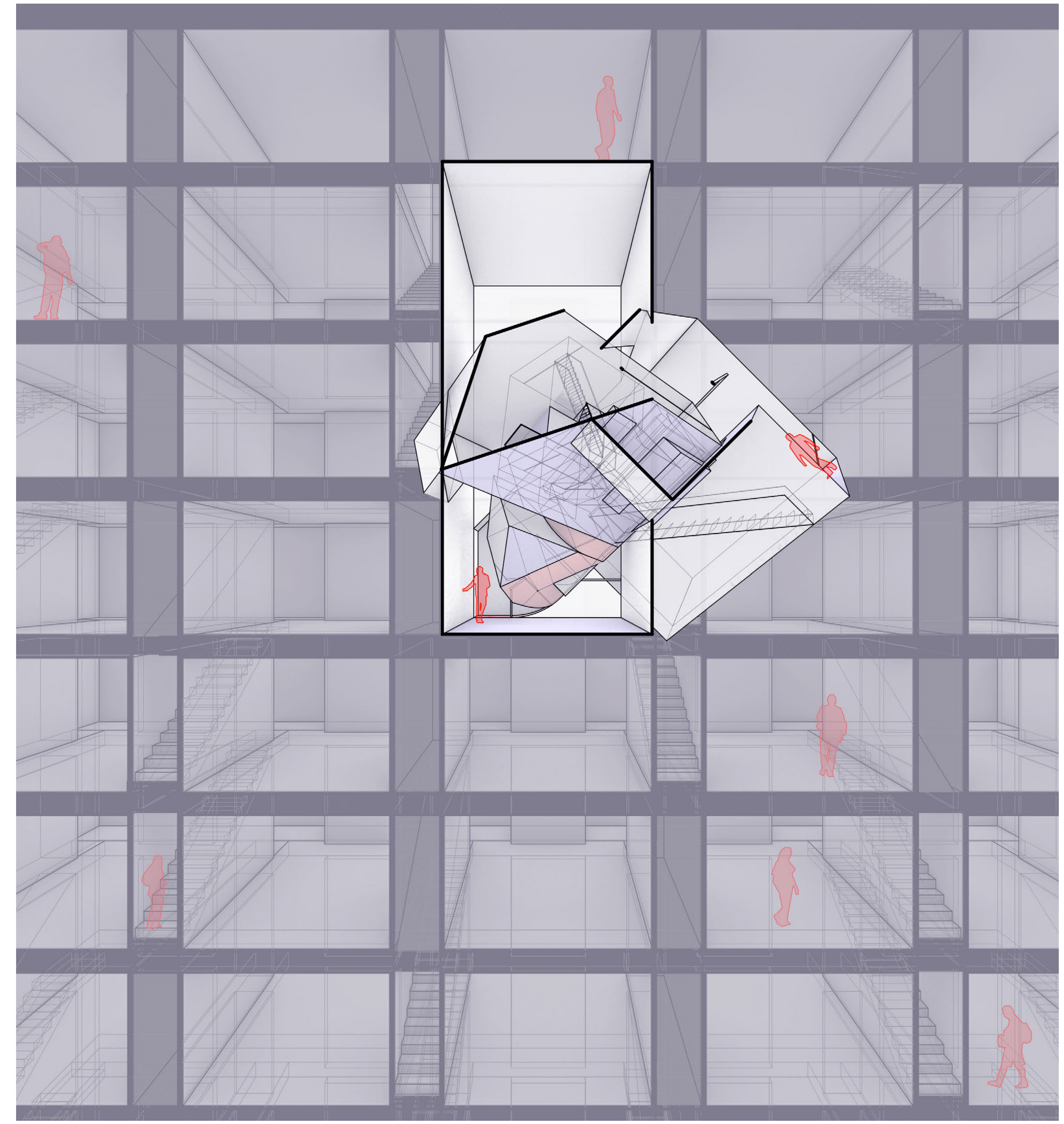


Through hiding and revealing physical floor planes and walls with Extended Reality technology, boundaries among units can be blurred and the single unit starts to expand beyond itself to form double-height volumes or larger rooms, generating the following five conditions. A circulation path defined by the virtual locomotive techniques is used to thread the spaces into a continuous experience. The scaling parameter is pushed into an extreme, resulting in an extended virtual bounding of surreal spaces around the first vignette, and a virtual sculpture composed of virtual walls at smaller scales floating in the last vignette. The virtual design shifts and rotates around the physical design as the user walks along the circulation path, and realigns with the physical unit when the user enters the next space. The stationary physical unit, when augmented with different virtual spaces, can be reconfigured for both public and private programs.

VIRTUAL HOUSING
Reforming Boundaries



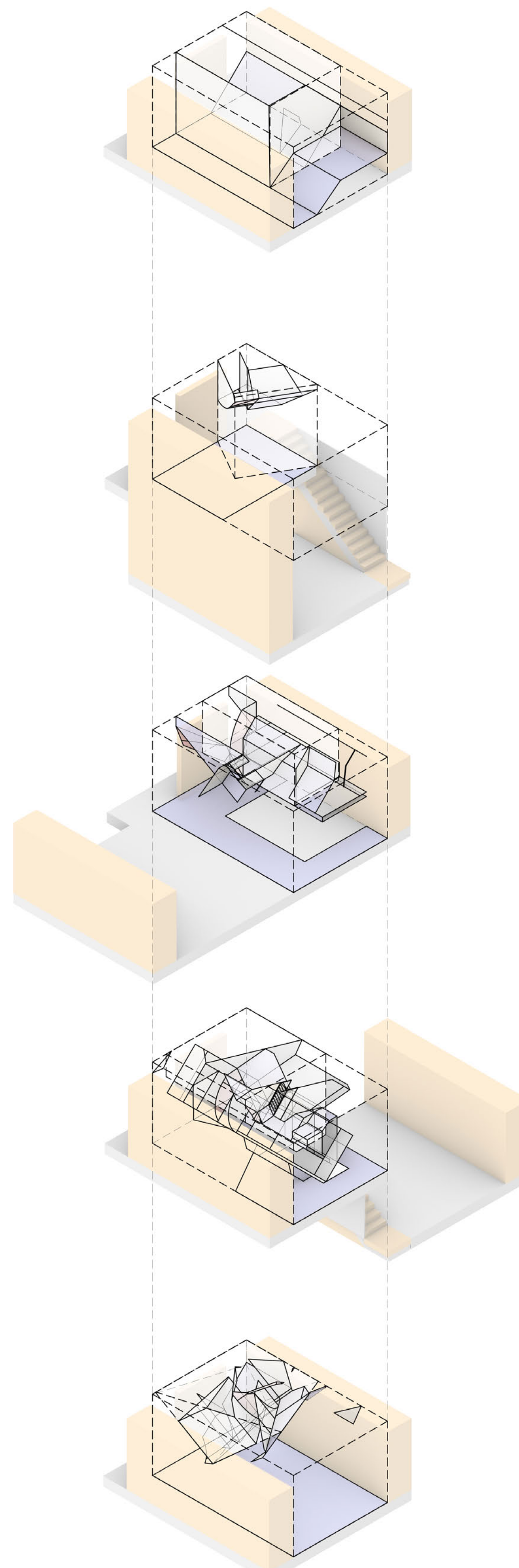


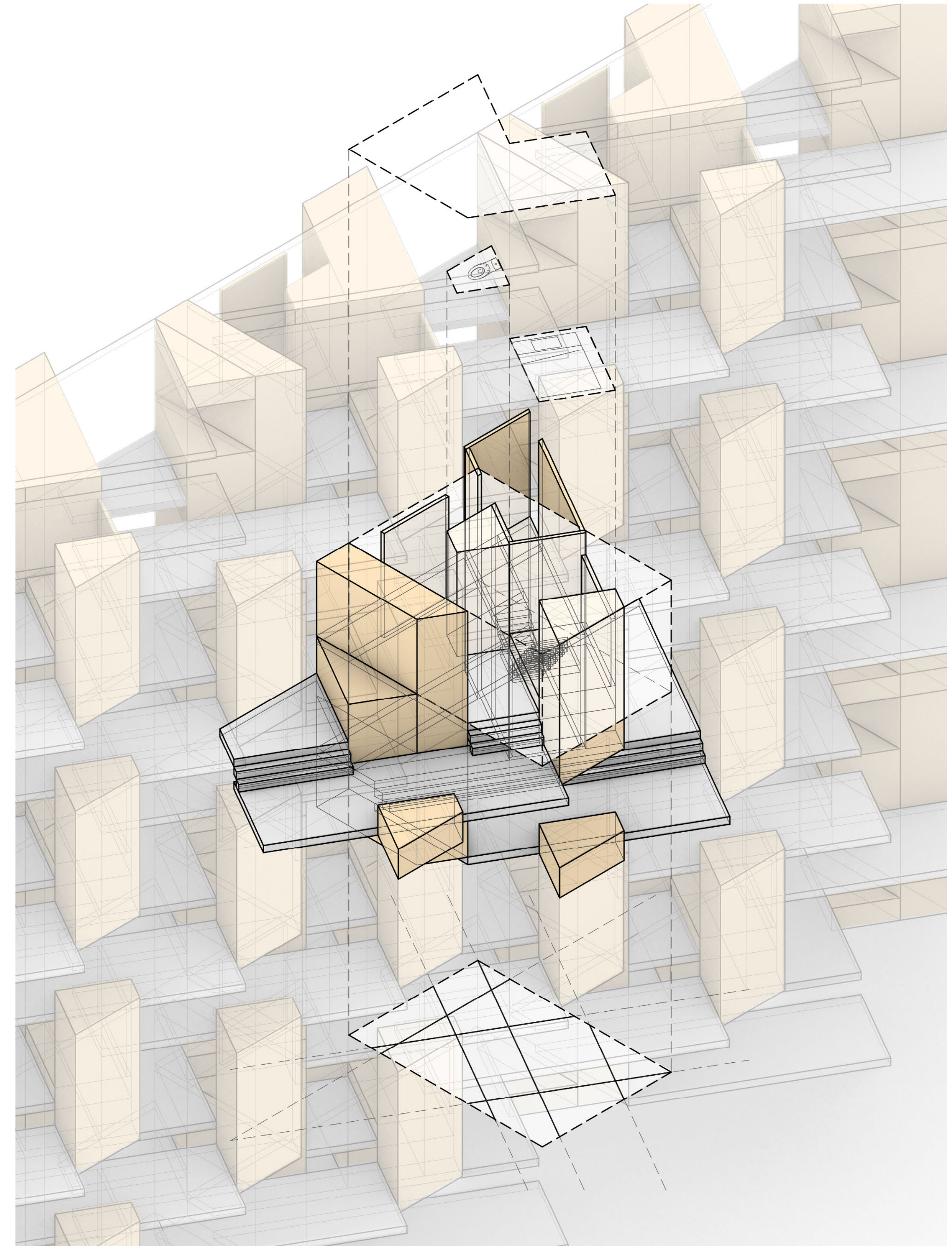


VIRTUAL HOUSING
Reconfiguring Furnishing

The virtual design expanding beyond the bounding of a unit leads to the goal of breaking up the regular shoebox physically. Using the virtual experience created in the previous step as guides, the next iteration of design deconstructs the walls and shatters the regular shoebox units.

Through intersecting the virtual complex with the shoebox space, datum planes and volumes are extracted and transformed into guidelines. Together with physical constraints of the size of a bathroom and a bed, an open matrix of furnishing is generated as a result. The deconstruction happens in all three dimensions, as the floor segments vary in heights.

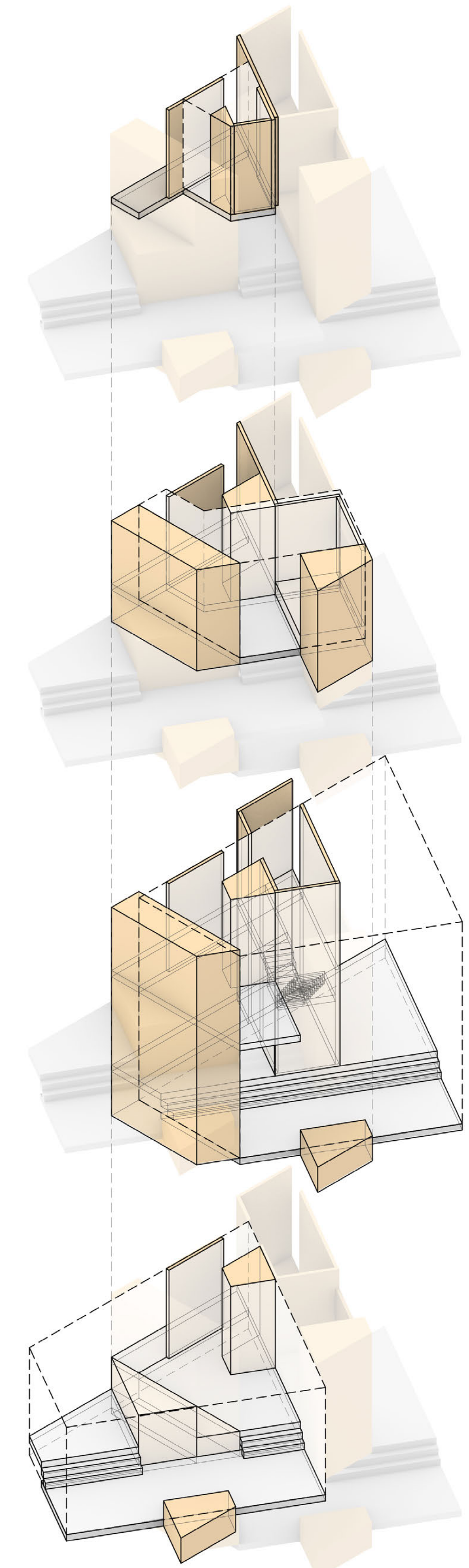




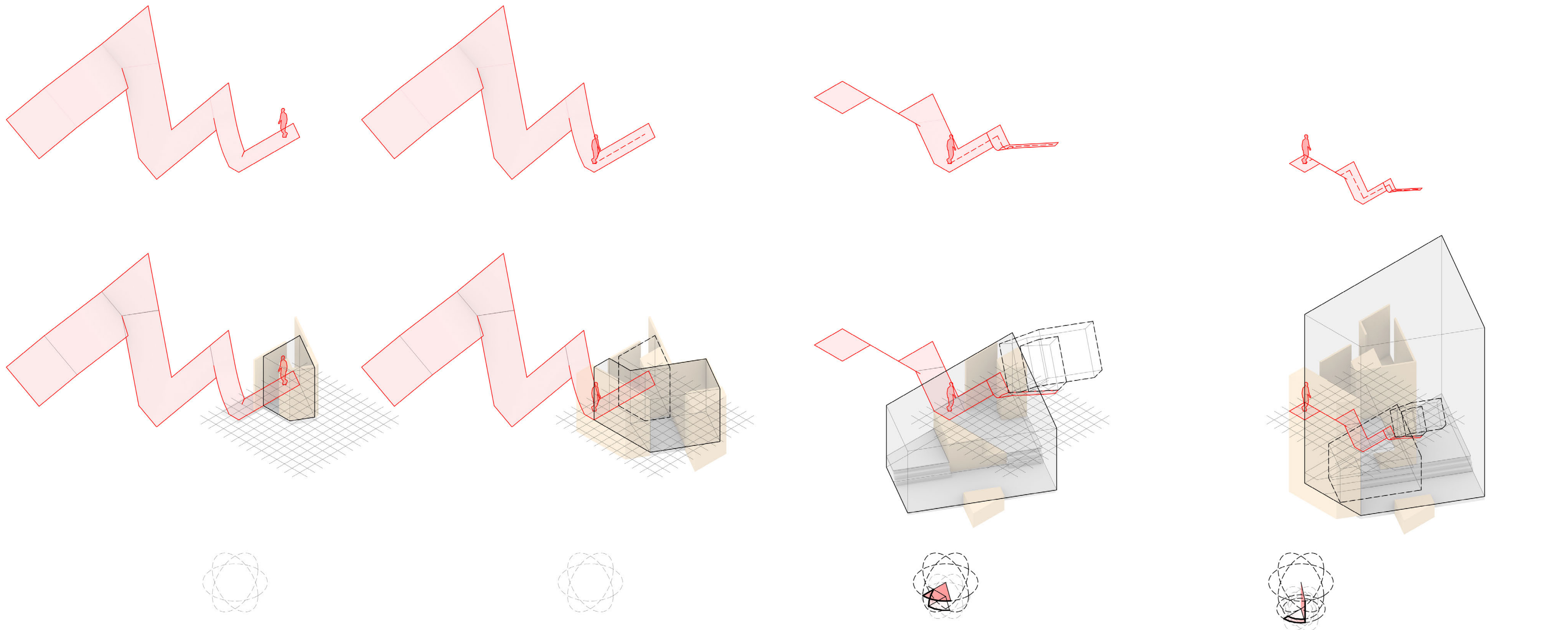
VIRTUAL HOUSING
Reconfiguring Furnishing

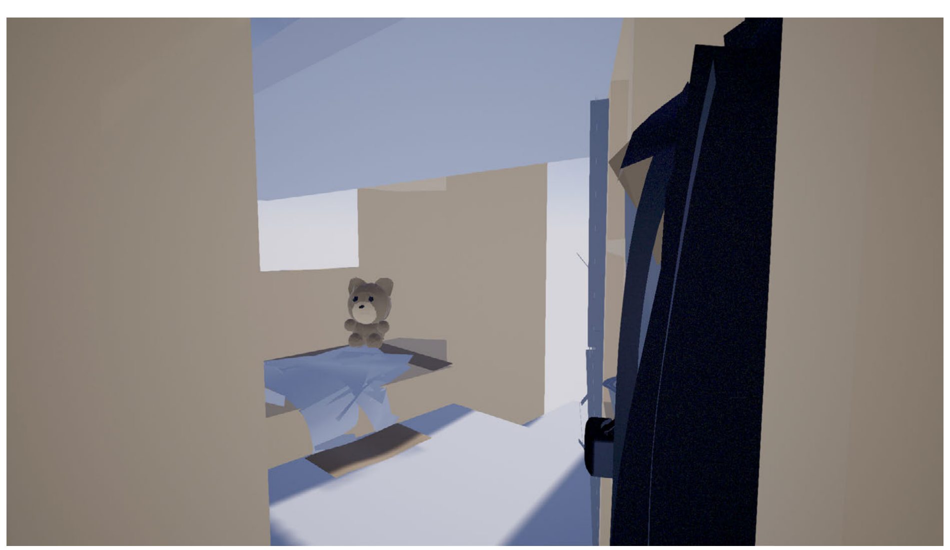
From the core of a bathroom and a bedroom, to a double height public space, the openings in vertical furnishing and floors can only be filled with virtual augmentation. The two realms become more interdependent, because the scattered physical elements only make sense when augmented by their virtual counterparts.

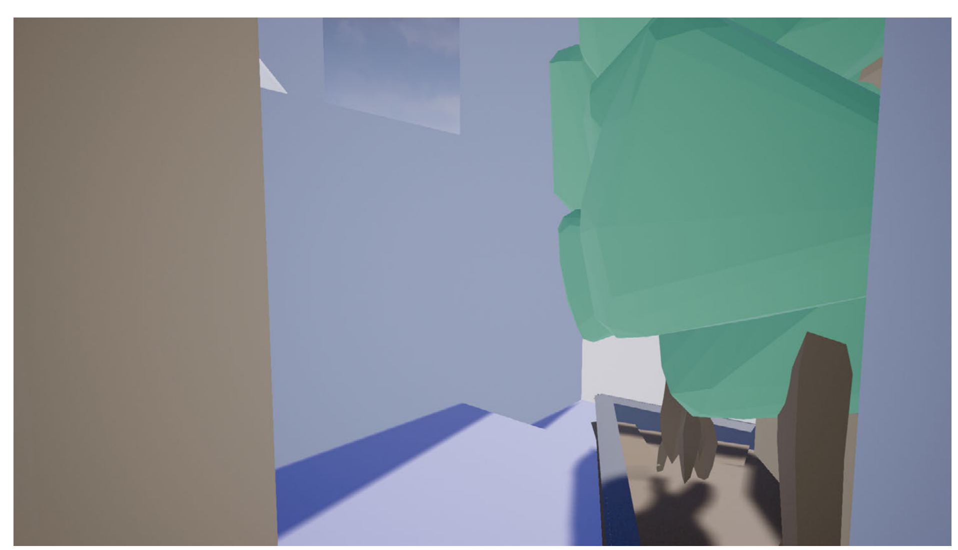
Similar to the previous iteration, a virtual path defined by the virtual locomotive techniques is used to thread the different topologies into a continuous experience. This experience is visualized with Unreal Engine 4 and is experienced and analyzed subjectively with Virtual Reality.

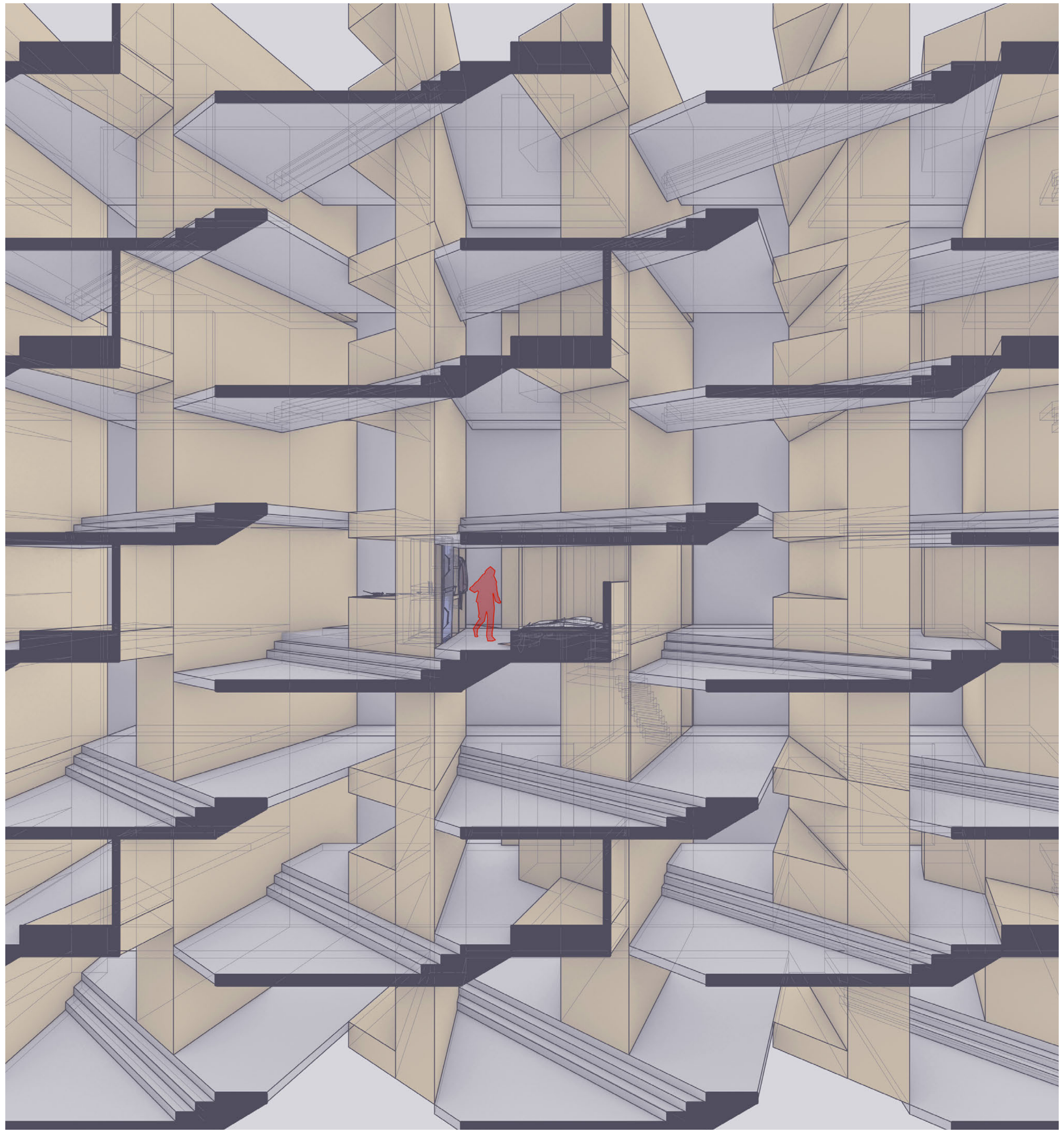


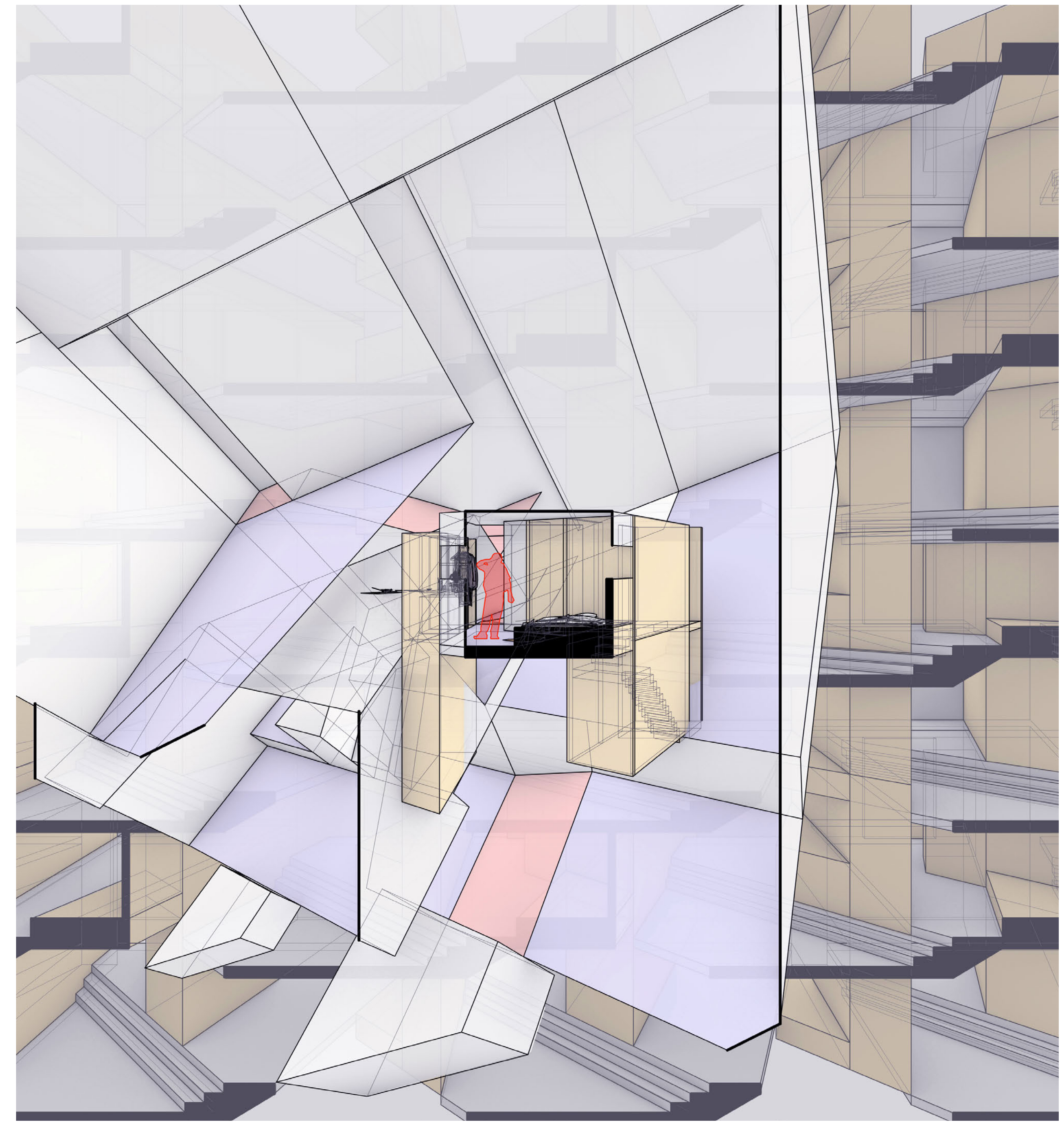
VIRTUAL HOUSING
Reconfiguring Furnishing

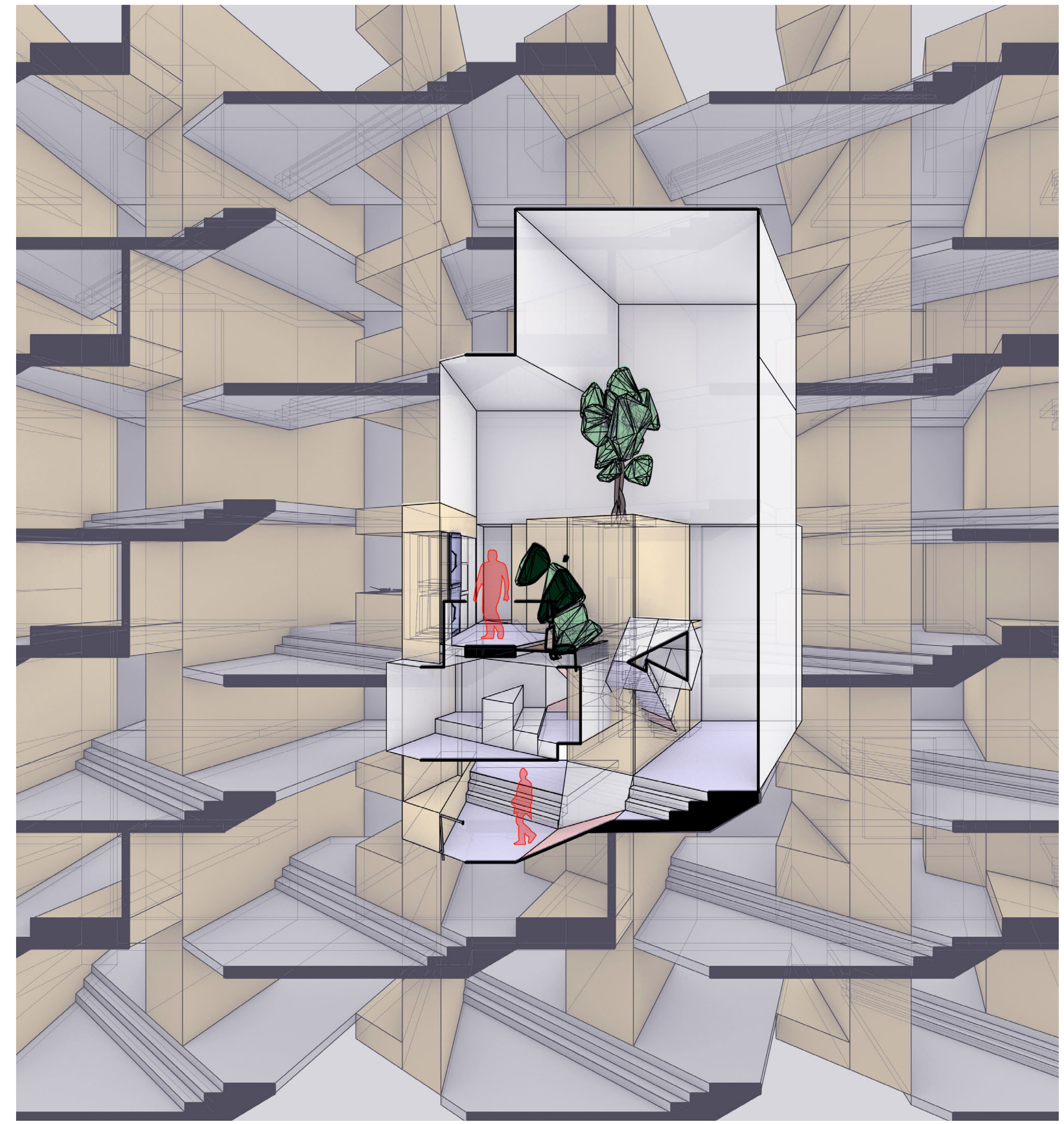


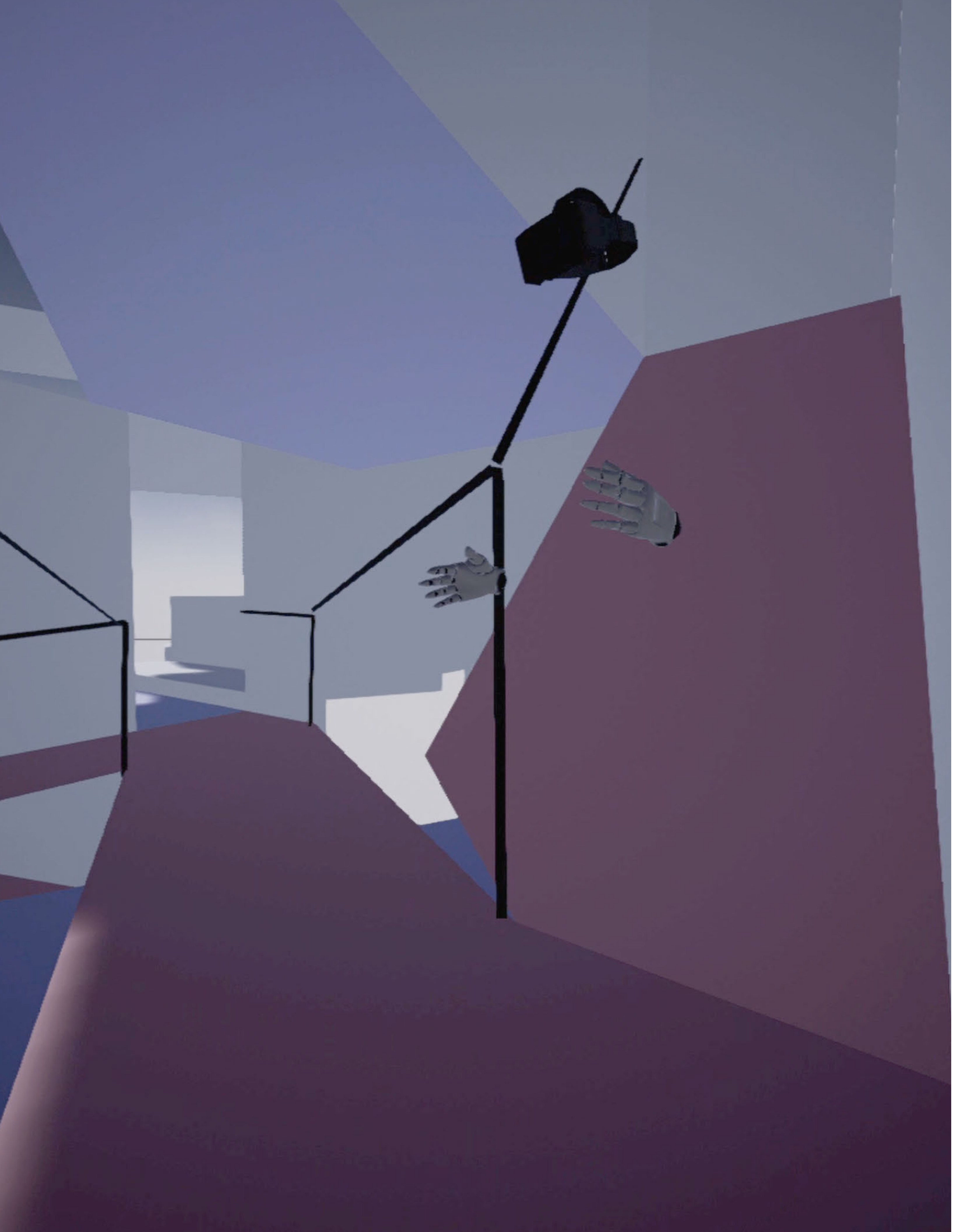












VI. TOOLS DEVELOPED

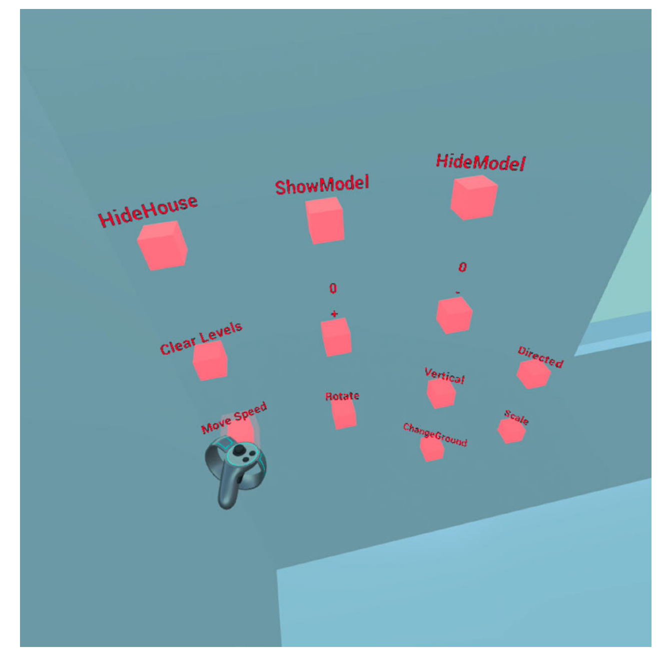
Virtual experiences all center around the user. Therefore, subjectively experiencing wearing Virtual Reality headsets is the best way to analyze the virtual designs. Three virtual reality tools are developed throughout the process to formulate this subjective perspective. The packaged applications are available at the project website:

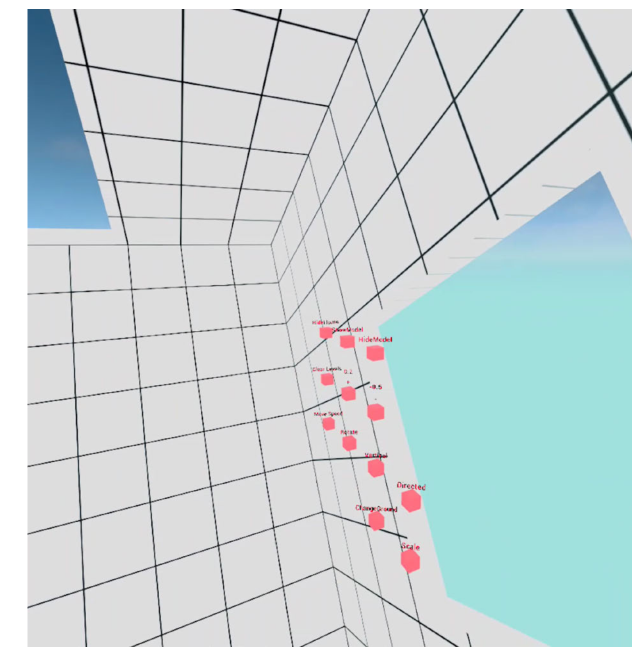
https://adamyuzhenzhang.github.io/thesis.html

TOOLS DEVELOPED
Redirected Walking Simulator

The Redirected Walking Simulator was used to immersively experience the six virtual locomotion techniques, including translation, rotation, curvature, vertical translation, scaling, and ground shifting. Buttons could be clicked with motion controllers in virtual reality to switch between the techniques and adjust the gains of effects. The user can also switch between a stationary model representing the physical space and the virtual scene that offsets relative to the physical root to clearly compare and understand the effects of the techniques.

The application was developed using Unreal Engine version 4.24 and was packaged for use with the Oculus Quest standalone headset.

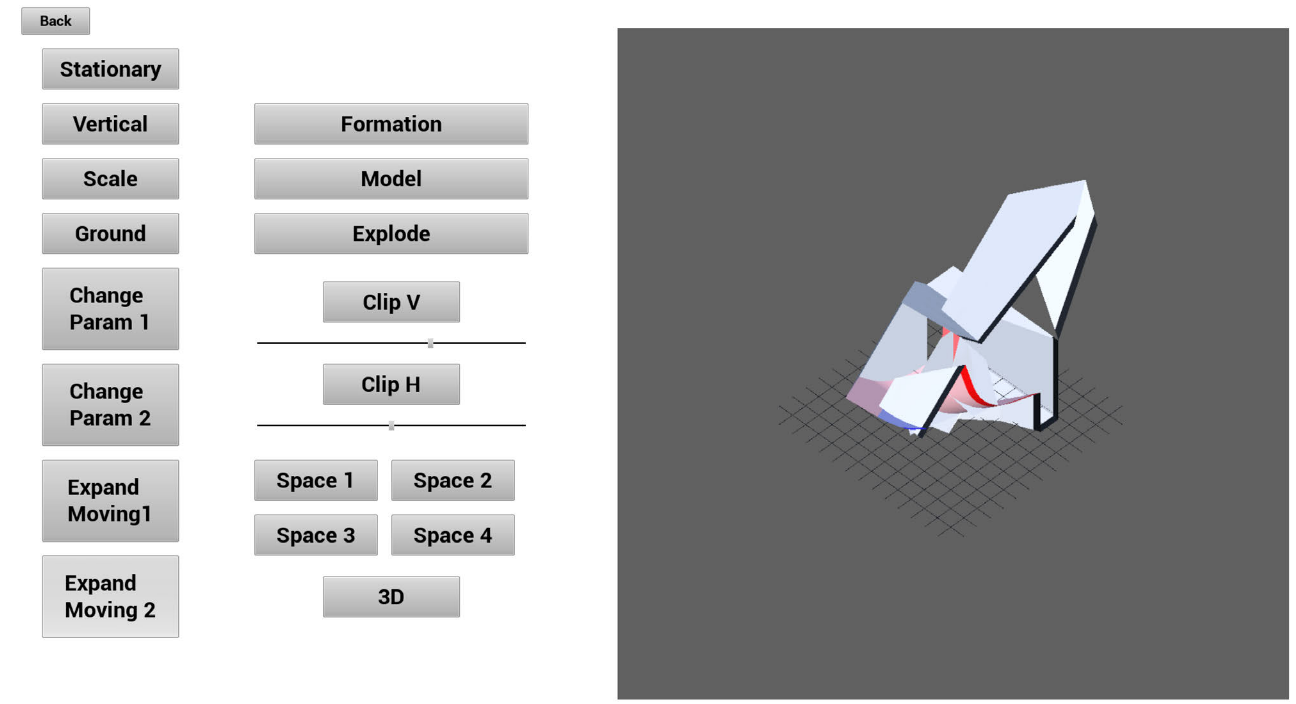


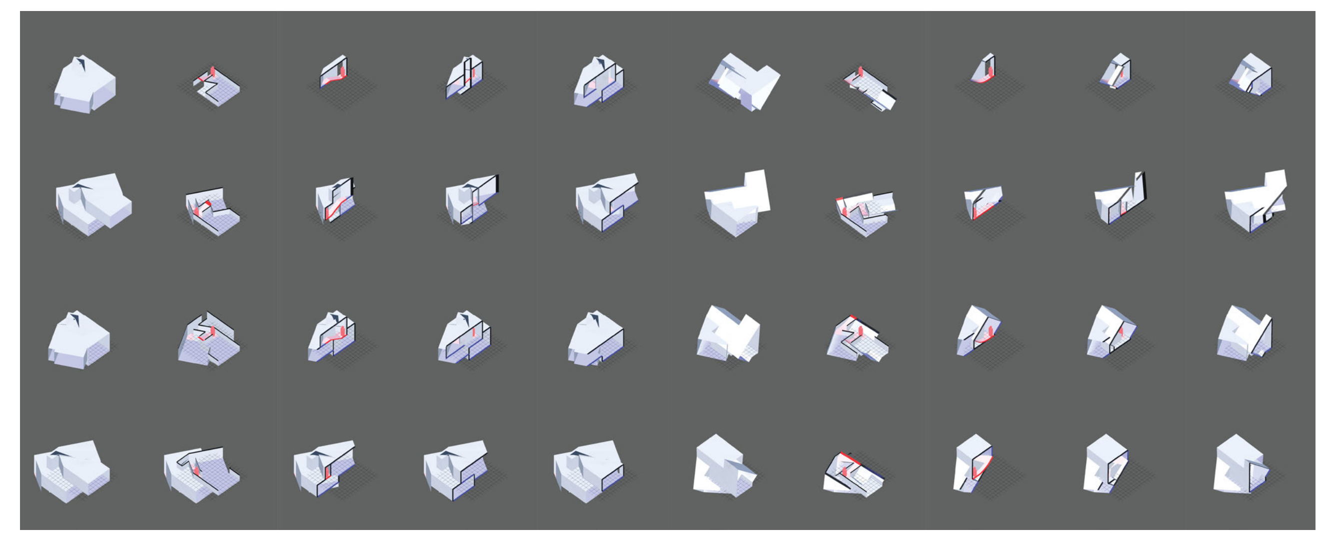


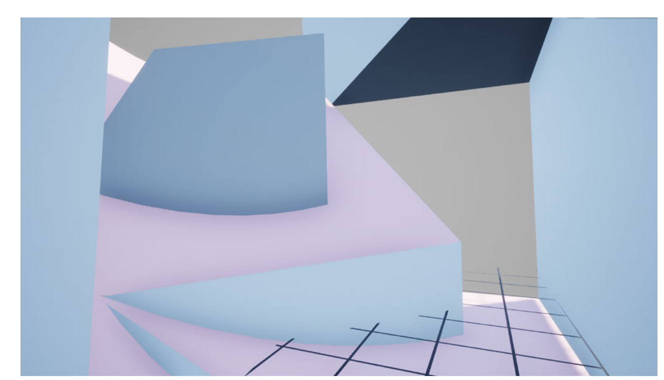
TOOLS DEVELOPED
Spatial Prototype Visualizer

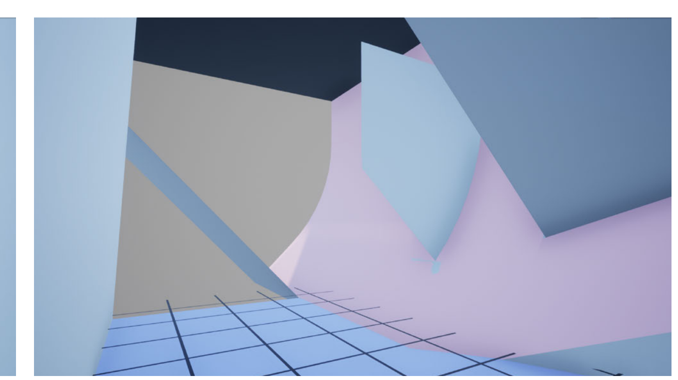
The Spatial Prototype Visualizer was developed for representing the spatial prototypes generated from virtual locomotion paths. A set of buttons are created to switch between the prototypes, play the formation animation, view exploded axons at all angles, and cut sections and plans through any location. Since the intersections among virtual spaces become too intricate to understand from static drawings, this visualizer creates dynamic sections and dynamic plans, clearly representing the mobile aspect of the prototypes. Additionally, the “3D” button switches between the isometric diagram and perspective VR views from within the prototypes. So the immersive virtual reality experience could be compared directly to the diagrams to help understand the design.

The application was developed using Unreal Engine version 4.24 and was packaged for the Windows system. The VR views were experienced with the Oculus Quest connected to the PC using Oculus Link.

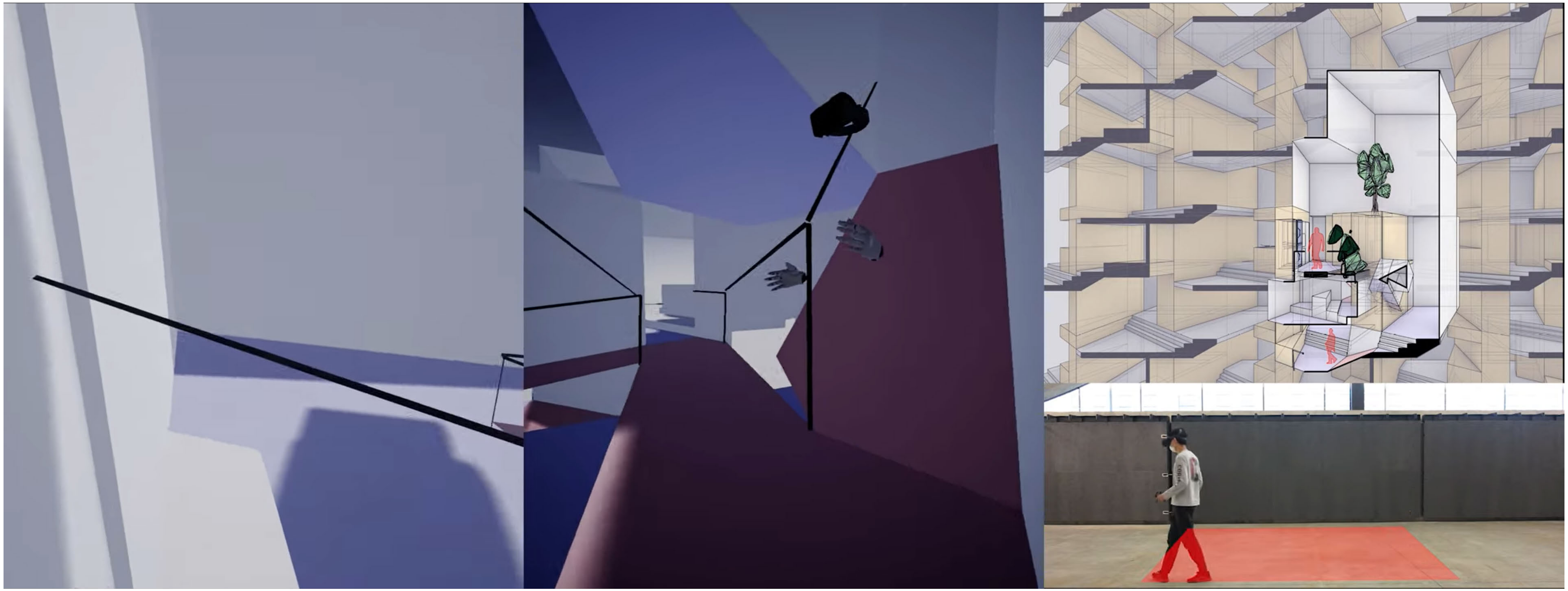






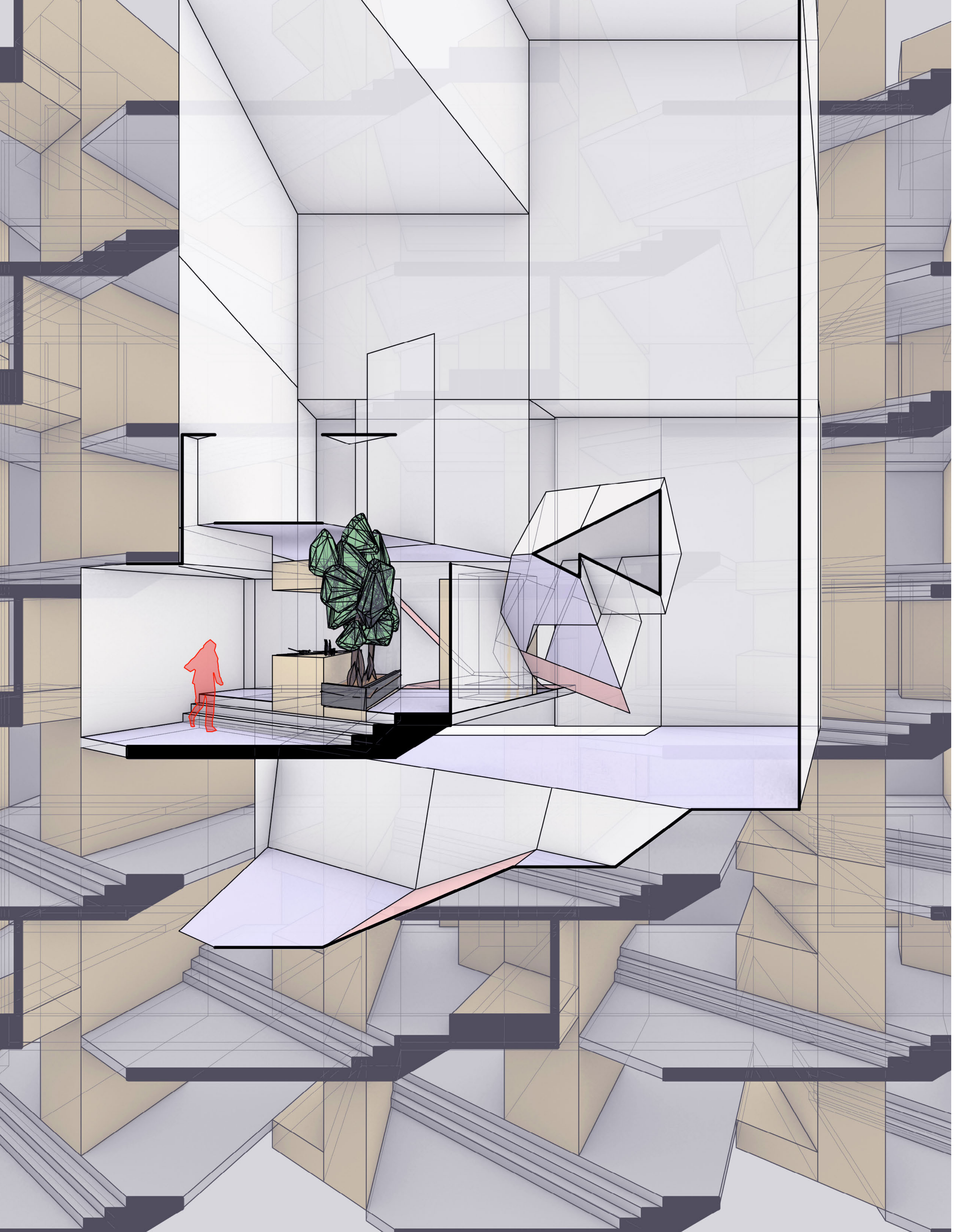


TOOLS DEVELOPED
Virtual Housing Experience



The Virtual Housing Experience was used to visualize the final housing proposal. The physical architecture, the virtual complex that could be realigned with the physical in different ways, and the virtual locomotion techniques along the path threading different rooms are all implemented in the final experience. The senses of scales, the moments of surreal architecture, and the hiding and revealing of physical furniture can only be best analyzed from the perspective from inside the spaces. A spectator camera was also implemented to help document the user's movement through the sequential spaces.

This application was developed using Unreal Engine version 4.25 and was packaged for PC VR on Windows systems. Wireless VR streaming on the Oculus Quest with the Virtual Desktop software was used to remove the constraint of cables.

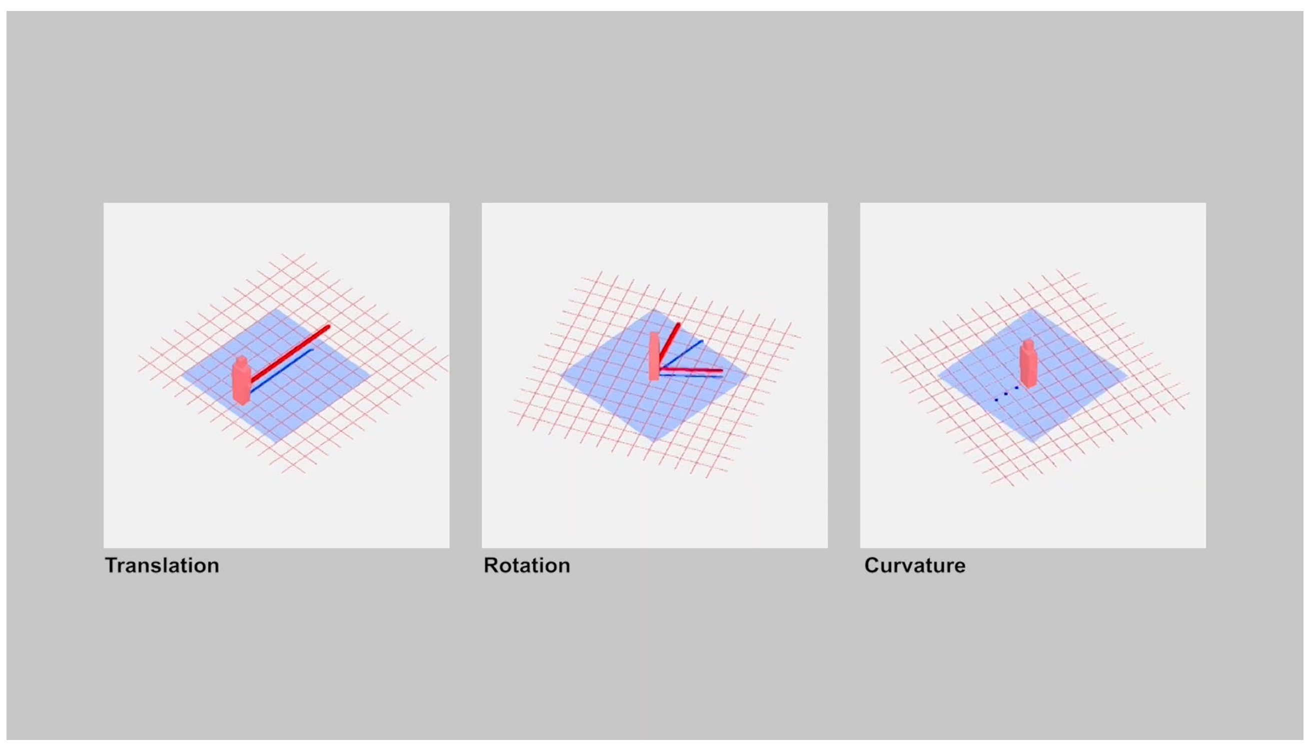


VII. APPENDIX

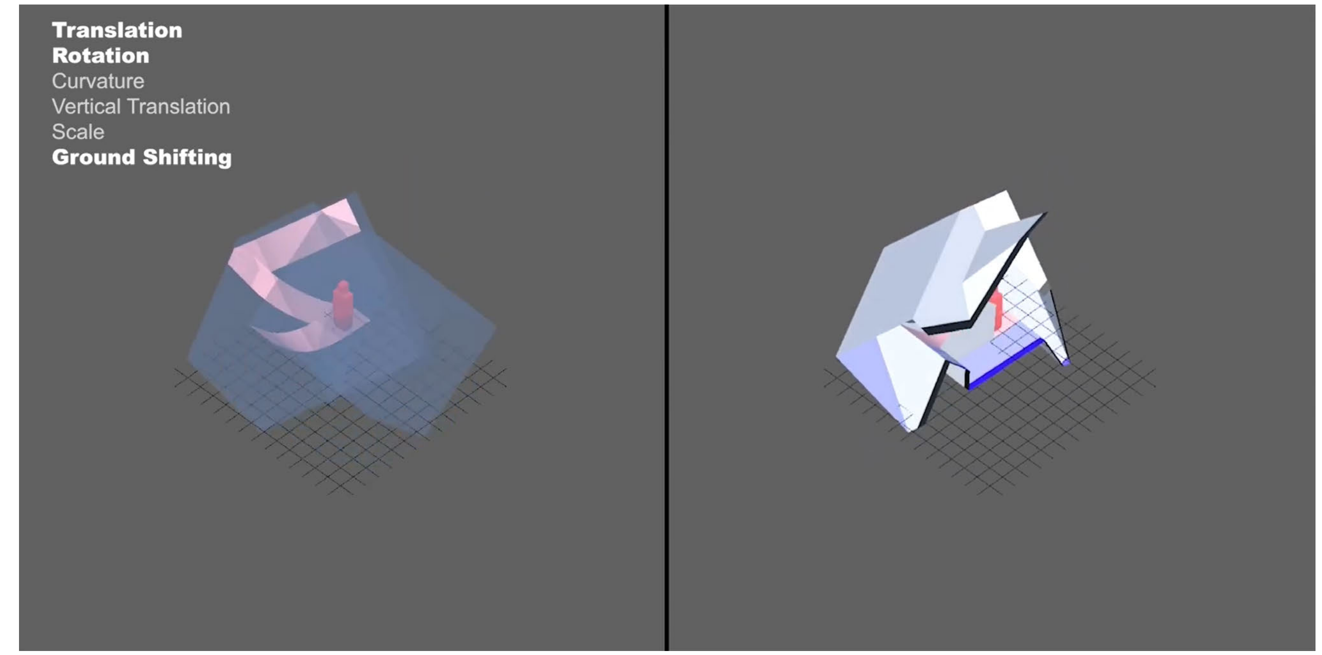
APPENDIX
Video Presentations

The virtual locomotion animation, spatial composition animation, and virtual reality recordings were an essential component of the final presentation. Since they cannot be fully documented with in this thesis book, the videos are available at the project website:

https://adamyuzhenzhang.github.io/thesis.html



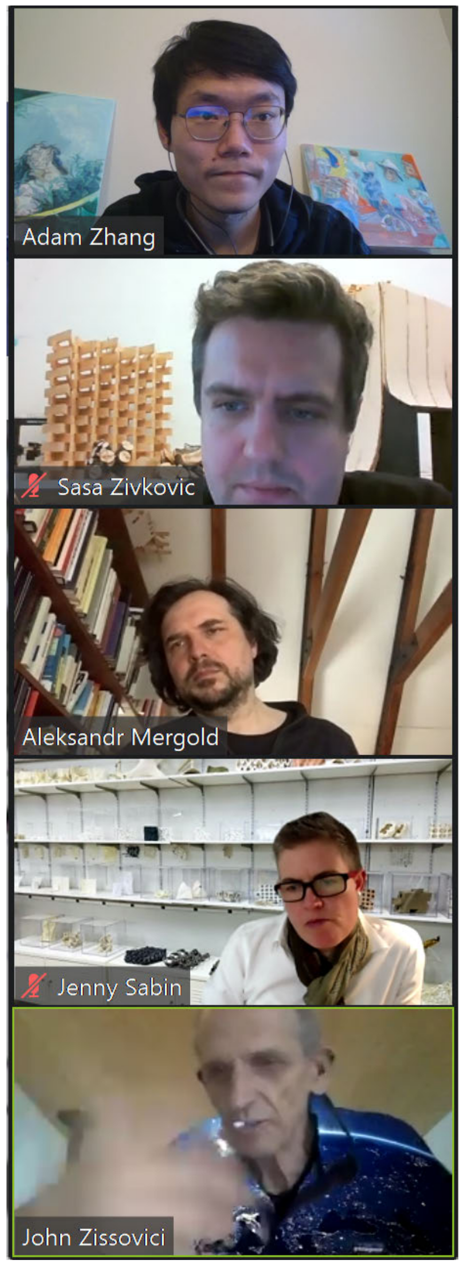
Virtual Locomotion Video



Spatial Composition Video

Final Experience Video

APPENDIX
Thesis Reviews



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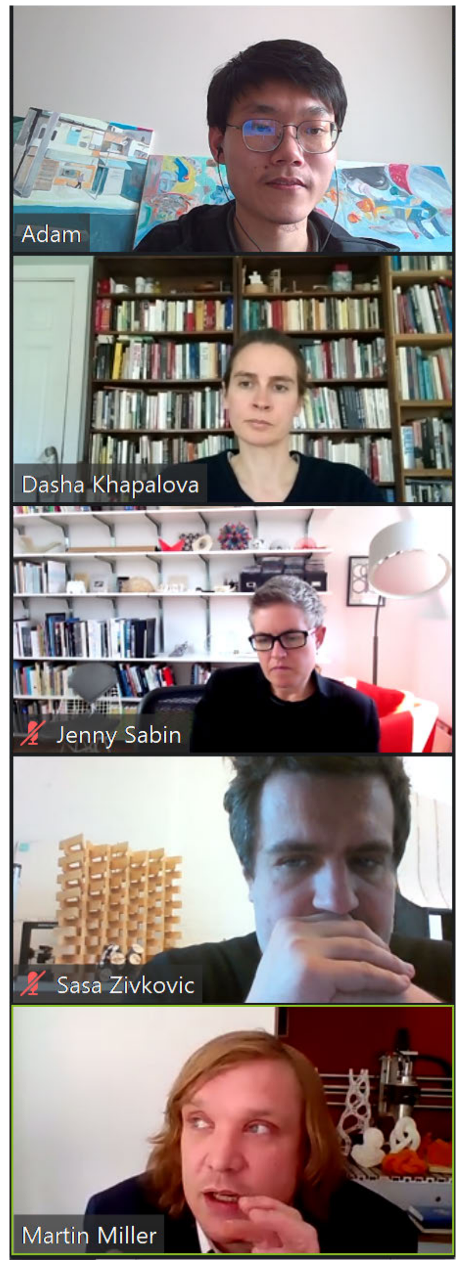
March 1, 2021



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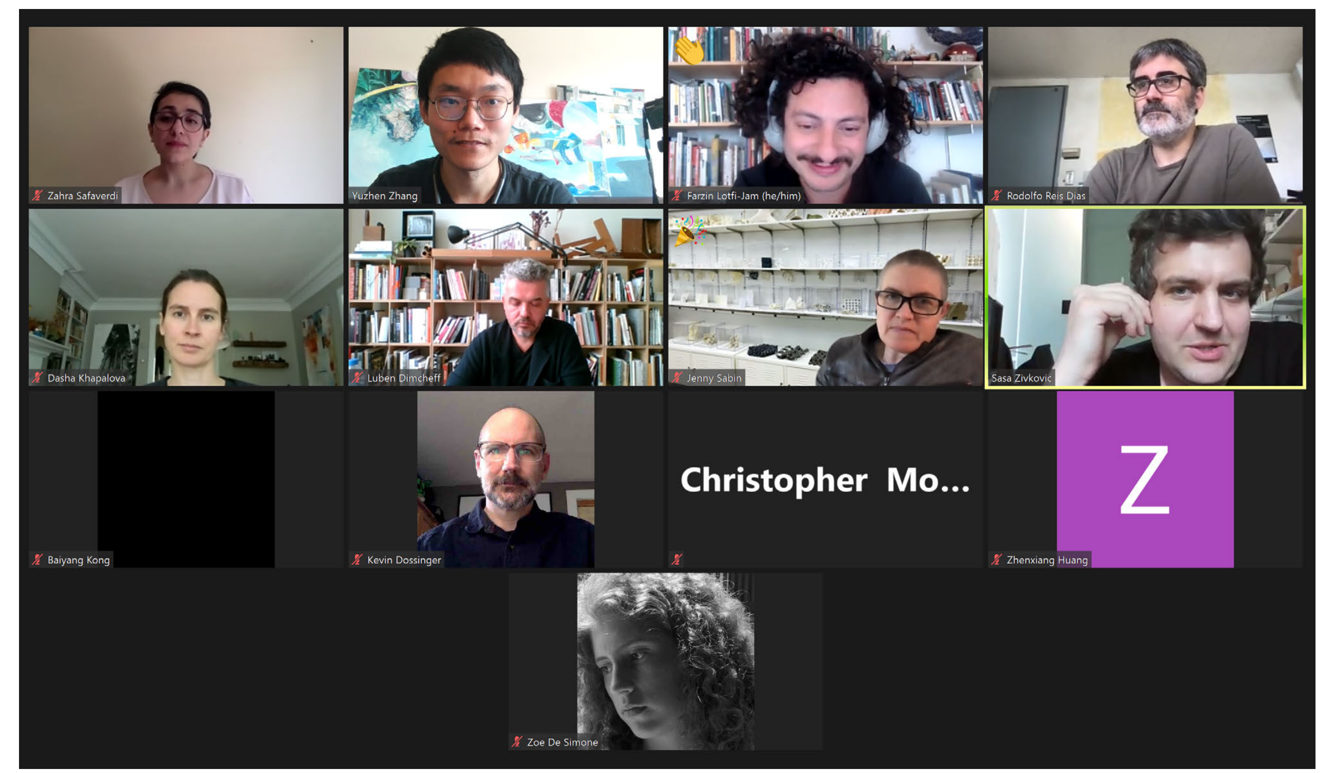

Final Review
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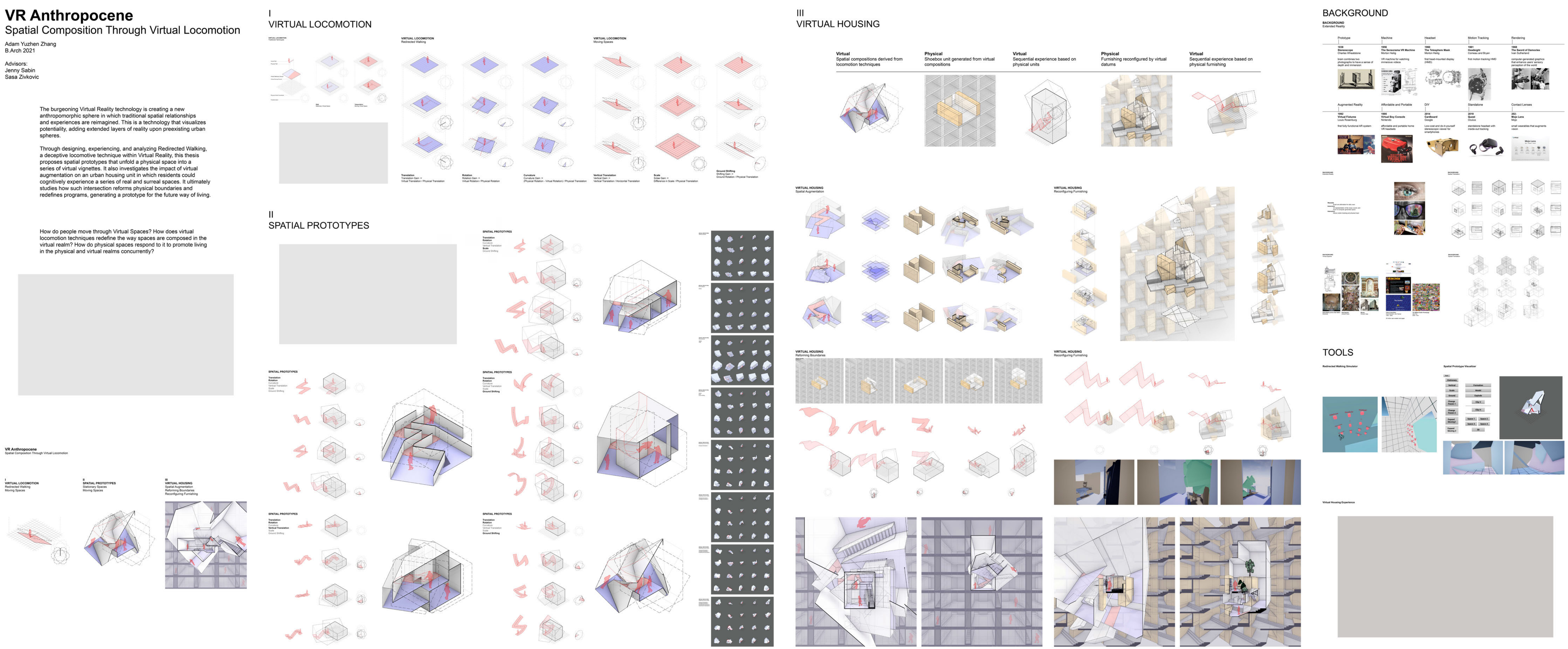
APPENDIX
Thesis Reviews



Final Presentation Materials

APPENDIX
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