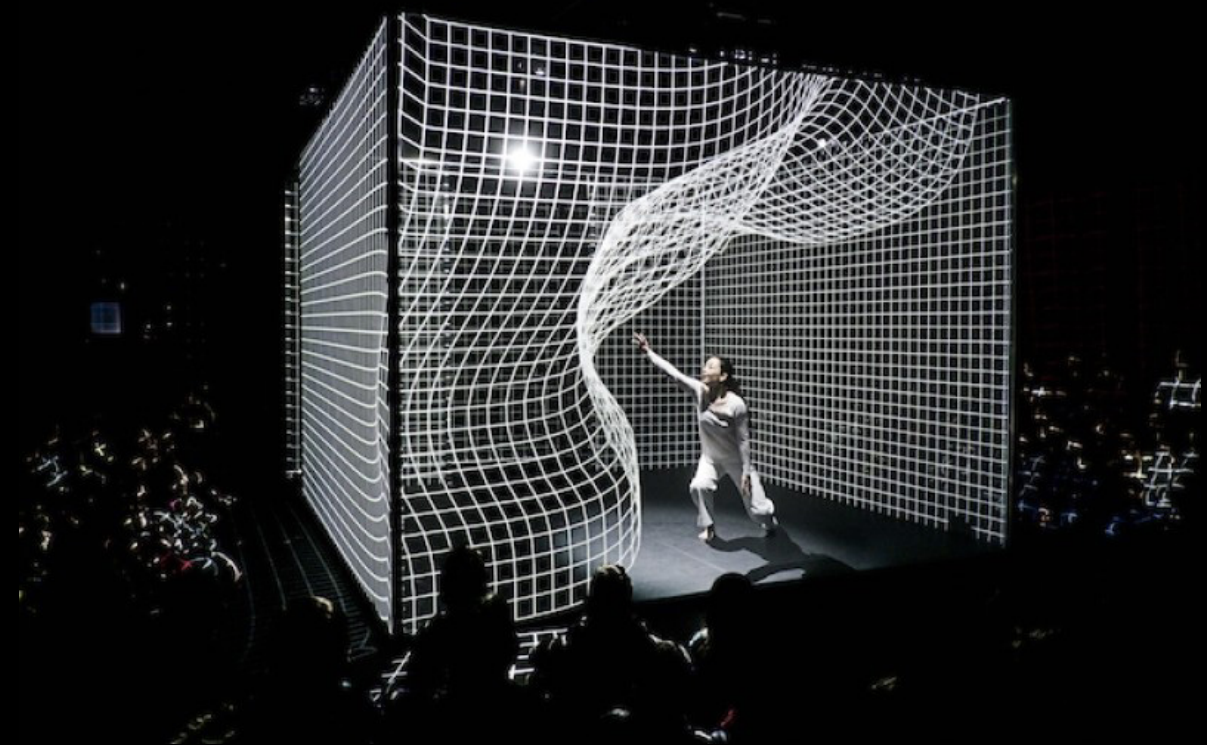




*Space Manipulation for Illusion
with Spatial Augmented Reality*

Explorelab 28 - Zhiyuan Li



*Architecture is the learned game, correct and magnificent, of forms
assembled in the light. -- Le Corbusier*

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Reference



Vivid Sydney - Projection mapping on Sydney Opera House

[Main Question]

How Spatial Augmented Reality could be integrated into space manipulation to create illusionary space?

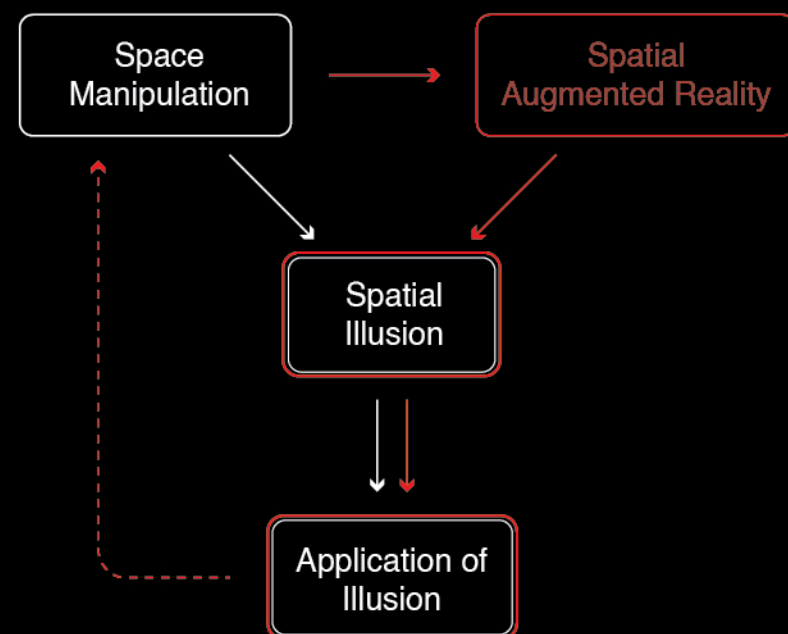
[Abstract]

Different design methods appeared along with the development of technologies and tools. Mixed Reality, as a new technology, gradually change ordinary people's daily life, including the use of physical space.

Spatial Augmented Reality (SAR) is a new technology which is always used in light shows on the facade of buildings. It varies the color, texture, and shadows of the facade to entertain people. But it also has the potential to be applied in architecture design because it is highly related to the space cognition. Based on the study in the technic of illusionism, this research is to explore the application of SAR in space manipulation to create illusionary space.

The research is to use different methods, such as literature, case study, fantasy, and model tests, to classify the principles and explore the possibilities and methods of using spatial illusion in space design.

Keywords: Spatial Augmented Reality, Mixed Reality, Projection Mapping, Illusionary space, Unreality, Illusionism, Space Cognition,



[Introduction]

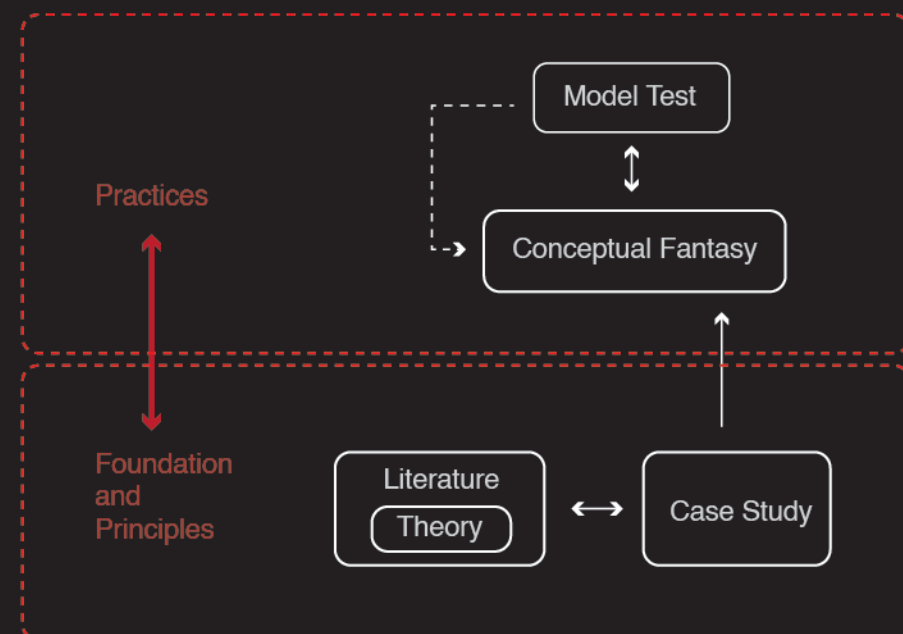
Space manipulation is one of the essential methods for architects to handle spatial issues. Manipulation means control with purpose, skills, and technics. Besides the primary purposes in architecture like *Firmitas* (Durability), *Utilitas* (Utility) and *Venustatis* (Beauty) ^[1], spiritual fulfillment is the other part of purposes what lots of architecture are pursuing. Creating a **spatial illusion** is a method to achieve some spiritual needs because our memory and experience is not just from passive sensory reception but also mixed with subjective selection and adjustment. Along with the history of art and architecture, brilliant artists and architects cooperate to create illusionary space with different methods, tools, and materials.

In the new era of mechanic, electronic, information and artificially intelligent, architects may have able to use some new methods, new tools, and new materials to achieve a better effect of these illusionary space. **Spatial augmented reality** is one of these new methods. All these new technologies would urge architects to create a new type of illusionary space and think about the new application. In the end, they could fulfill the current needs and maybe create some new needs. Later, it might go back to influence architecture and **spatial design**.

The future of architecture would be an interdisciplinary issue, especially with the technology of virtual reality and augmented reality. The word “**space manipulation**” may be better to describe those space combined with virtuality and real physical world, because it may transcend the narrow field of simple physical architectural design. Architecture could be regarded as part of the space of mixed reality. Also, all those virtual space could be viewed as part of illusionary space, as part of the architecture. The **application of illusion** could extend the possibilities of the pure physical environment. Though nobody can predict precisely what these illusionary space would have a better application, the potential of these spaces is obvious. It still needs a new generation of architects to explore and enlarge its architectural language.

Under this background, this research focuses on the technic of spatial illusion in space manipulation. From the intentions, principles to the cases in history, I hope to draw nutrients from analysis and at the same time consider the possibilities of using spatial augmented reality in architectural design.

¹ Three attributes of architecture, *De architectura*, Vitruvius



[Reseach Structure]

The whole research is divided into two parts: the foundation, including theory and case analysis, and experimental practice.

Firstly, before the experiments, it needs to collect the existing research on theory and principles to set up a foundation. By classification and summary of the cases, I use this as the guidelines to direct the experiments.

As a complement, the practice is to get actual feedback from experiments, including conceptual and practical tests. Use this feedback to rethink the foundation.

[Reseach Methods]

The whole research could be divided into four parts: literature, case study, fantasy, and model tests.

1. Literature: The first part of the research is to collect the related literature about topics such as illusionism, space cognition, mural painting, and augmented reality. Based on this literature, to conclude the key features and principles of human cognition and the development of space illusion, include the technological and artistical manipulation.

2. Case study: The second part is to collect and analyze the illusion in the history of art or architecture. By classification of cases into several types, it will be easier for us to understand and summarize the technics.

3. Fantasy: This part is similar to research by design. It is the trial and error of using the technics from the case study in concept design. The purpose is to think about the application and composition of these technics.

4. Model tests: This part is the supplement and verification of the fantasies. It is to use physical models and projection mapping to test the final effect. It is similar to the experiment process in other scientific research. Try to use direct simulation to get more feedback from practical experiments.

Chapter 1. Foundation and Principles

keywords: reality and virtuality, mixed reality
spatial augmented reality, projection mapping
space perception, illusion,

1.1 Concerto of Virtuality and Reality

--Introduction of Mixed Reality and Spatial Augmented Reality



Fig. 1 (a)

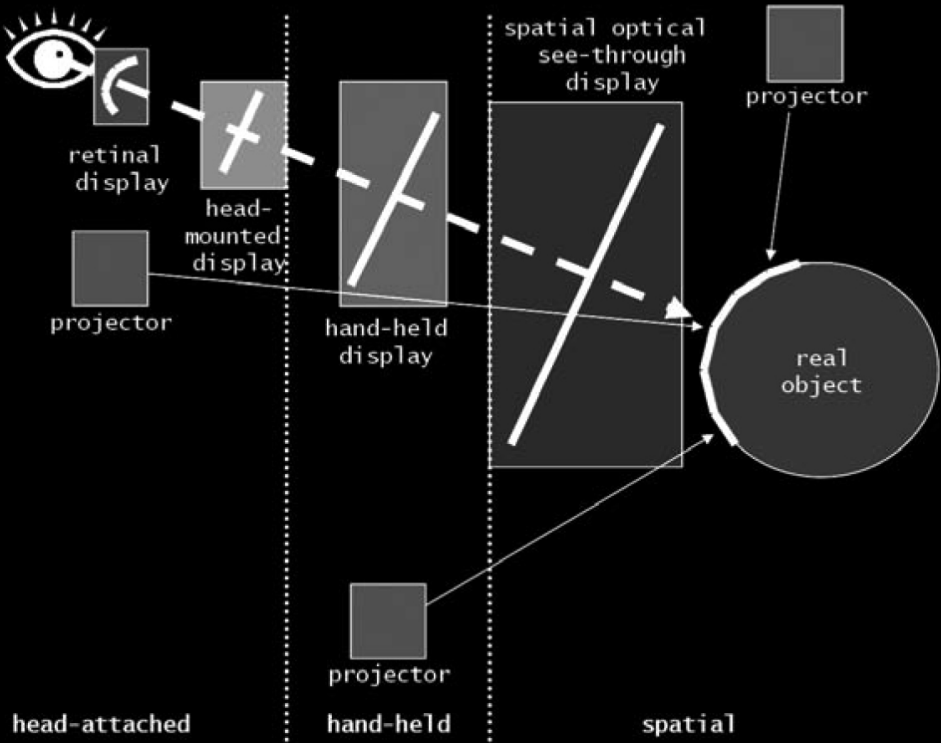


Fig. 1 (b)

“Virtual” and “Real” are two keywords to understand **Mixed Reality (MR)**. If we regard our familiar physical surrounding as the real world, and the artificial or fake or imaginary elements as the virtual world, the mixed reality is between them. On the reality-virtuality continuum proposed by P.Milgram and F.Kishino in 1994 (Fig.1), Augmented Reality (AR) is in the realm of Mixed Reality. Augmented Reality is a technology to insert additional virtual information into the user’s view of the real-world scene. It mixed the virtual elements with the real environment. However, different from Augmented Virtuality, the primary environment is the real world. The virtual parts are just the supplement.

There are many methods to insert virtual elements into users’ view of reality. Wearing AR glasses like Microsoft Hololens or using the smartphone as a media to integrate virtuality into reality like Pokemon Go may be the familiar AR technologies for the public. However, based on the nowadays technologies and the sensitivity of our senses, the distinction between virtuality and reality is distinct. We can easily and clearly distinguish these two worlds. The problem is, in the present, Virtuality and Reality merely appear at the same time, instead of being integrated. In contrast, compared with those head-held or hand-held augmented reality, spatial augmented reality (SAR) is another way to achieve mixed reality.

As shown in the diagram of image generation for augmented reality displays (Fig.1.b), different from the body-attached displays, spatial augmented reality detaches most of the technology from the users and integrates it into the environment. Users see the augmentation without wearing any optical equipment. In this word, the augmented reality become part of the real environment, even though it is not so “real”.

The most significant difference between spatial augmented reality with other types of AR is the location of equipment and the augmented object. With the head-held or hand-held augmented reality, users have to carry appropriate portable devices attached to their body, including the sensor or optical display screen. These body-touched equipments would, less or more, give the audiences a hint that it is unreal. However, the equipment of SAR is located in the surrounding environment and directly affect the environmental space without attaching a sense of the users. So that provides a possibility: if it ‘mixed’ world looks ‘real’ enough, it may distort the real world. In other words, it can create an illusion.

Another factor that needs to be considered is the accuracy of tracking, calibration, and display. If equipment influences the audiences’ eyes directly or the immediate virtual environment on the mobile device, it requires very high accuracy. Correspondingly, higher precision usually needs heavier equipment whose load would aggravate the ‘unreal’ feeling. It is a paradox. However, the spatial augmented reality can avoid these problems by the separation of users and equipment. Then the main augmented object is the environment itself.



Now, these technologies can mainly be classified into three: screen-based display, spatial optical see-through displays, and projection-based display.

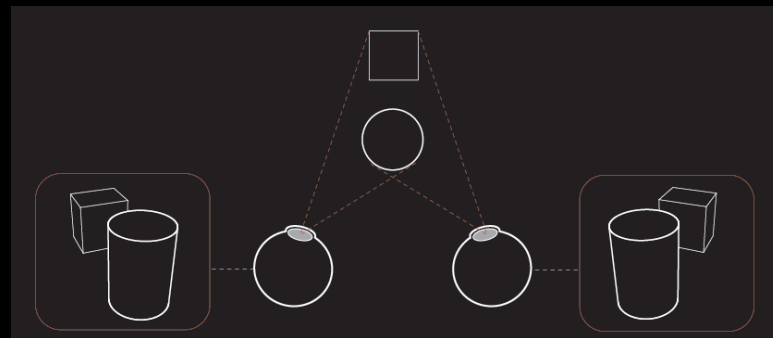
- Screen-based displays make use of video mixing technology to integrate the reality with virtual elements and show it in a regular monitor.
- Spatial optical see-through displays use spatial optical combiners such as transparent screens and optical holograms to show virtual objects within a physical space.
- Projection-based displays use a projector to project images directly on the surface of the physical environment. The viewers see the surface of the real environment overlapped with the virtual layer.

The first and second type of display needs a screen or specific optical hologram equipment. The third type only needs some normal physical environment like walls. Alternatively, all the walls or other parts of the buildings could be regarded as a special projection screen.

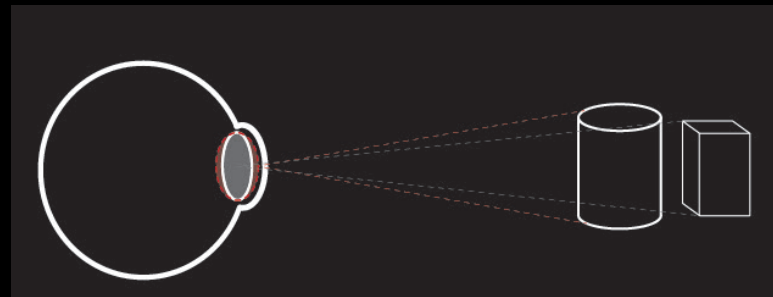
Of course, there is some limitation of SAR:

The limitation of spatial augmented reality is the augmented effect is attached on and based on the real physical environment. The attached effect is limited by the original attributes of the physical object itself, including the form, color of the surface, texture, smell. In other words, the augmented effect of the mixed reality is highly related to the original object. They need to be highly integrated.

Due to the stronger connection between reality and virtuality, it is difficult to create the illusion without considering the existing surrounding. The surrounding is more important than the other two types of SAR. In order to achieve a better augmented effect, designers need to organize both real and virtual elements according to lightness, size, order, texture, and composition, especially projection-based displays.



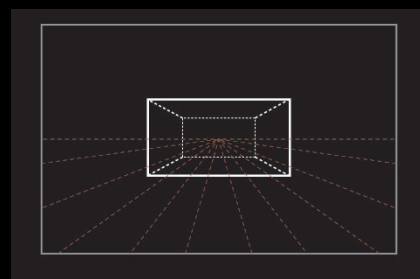
Binocular disparity



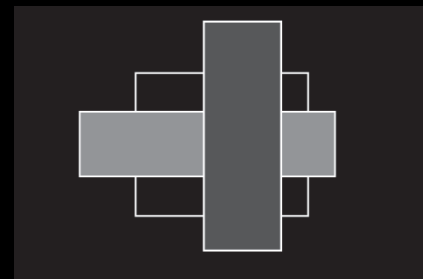
Change of lens thickness

Physiological Cues

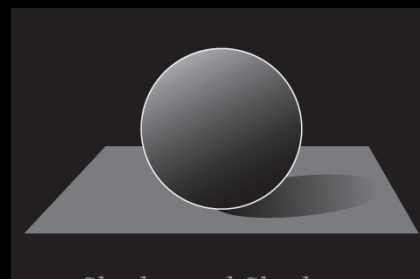
Optical science, Neurosciences, Ophthalmology
Computer graphics and geometric modeling
Automatic Location Identification and Programing



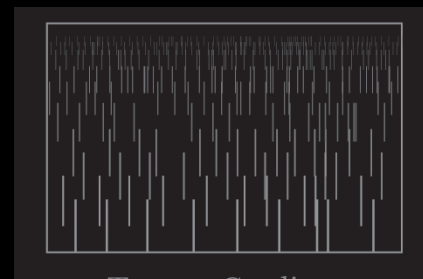
Linear Perspective



Overlapping



Shades and Shadows



Texture Gradient

Psychological Cues

Analyze visual information based on learned experiences
Infer rough 3D information from a 2D image

1.2 Principles of Space Cognition

In order to know how to create a believable illusion, it need to have a better understand of the spatial cognition of human, especially visual system. According to the research from neurosciences, cognition physiology and psychology, the human visual system (HVS) perceives the 3D information of an input image by various depth (or distance) cues, which can be categorized as psychological and physiological cues.

Physiological cues are information related to a physical reaction of the human body when a 3D image is given to the HVS. Physiological cues can provide more exact 3D information without ambiguity. The objective of 3D display is to reproduce 3D image by using various depth cues to stimulate the HVS.

Binocular disparity or stereopsis, which is most prominent among the physiological depth cues, is acquiring depth information from the parallax appearing in two images obtained from the left and right eyes. Because it gives most of the 3D information that can be obtained from physiological cues, early 3D displays were based on a binocular disparity. Stereoscopic or autostereoscopic displays are categories that use only binocular disparity from among the physiological depth cues

Psychological cues are associated with a process inside the brain to analyze visual information based on learned experiences. The HVS can infer rough 3D information from even a two-dimensional (2D) image, such as an ordinary photograph, with psychological cues if it does not include artificial contradictions or ambiguous relationships.

Psychological cues include linear perspective,
overlapping,
shading,
and texture gradients.

These representative psychological cues are learned through everyday life since we are born. The psychological cue is not just what we see but also include countless empirical knowledge and phenomenon.

However, such an image-based approach always involves ambiguities and errors because it cannot provide complete real depth information. With only psychological cues, one forms an understanding of 3D information rather than feeling it. Because of such ambiguities and errors, investigations on extracting depth information from a single 2D image based on psychological cues does not yet show satisfactory results. If a display system is to be categorized as 3D display, it should provide not only psychological but also physiological depth cues.



1.3 The descendants of spatial Illusionism

Some artists re-present a world by painting on architecture, based on their comprehension of the real world and imagination. From cave painting in ancient times to decoration in the modern interior design, all these simulated artworks are all the descendants of spatial illusionism.

The cave painting, such as the paintings in Clauvet-Pont-d'Arc, may be the earliest use of illusionism. Nobody know what exactly the function of these paintings. They may be used to illustrate the scene of hunting or to remember some important moments, or just for leisure. Even though those paintings were not related to the cave space, at least it brought the scene into the space and combine them together.

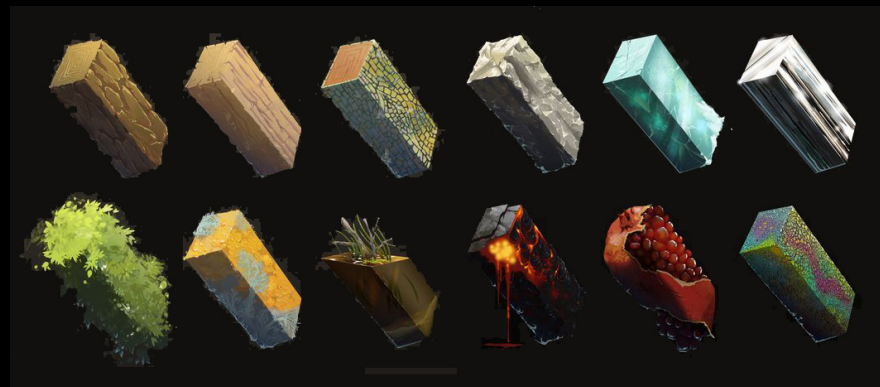
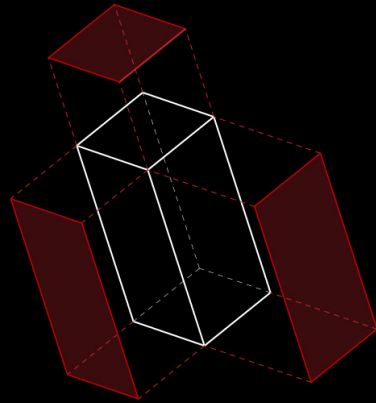
But till the period of the Pompeii and Roma empire, the painting of the interior wall was related to the space. Artists used the knowledge of perspective and their imagination to create the space within the indoor room. What had been painted were patterns, textures, perspective of the buildings or landscape, or interior furniture like cabinets. The paintings style in Pompei includes four period, they respectively focusing on different aspects of the space. Nonetheless, they are all the integration of virtual imagination and real physical environment.

With the help of media like paper or wood panel, painting has escaped from the wall and become an independent art - easel painting. In contrast, mural painting is bound to the surface of wall and is a part of the whole space. Mural painting still have the architectonic influence on the cognition of space. From Renaissance to Baroque period, mural paintings are one of the crucial spatial elements in architecture.

In the modern interior design, trompe-l'oeil is often used for special interior effect. Principles of optics and psychological cognition are applied in the painting to create optical illusion. In picture 3, even though the painting cannot move the room into the castle, it can provide a dramatic effect on the space.

All these three photos are not able to or deliberated to provide fully convincing illusion to users. But people are still willing to accept it. What they did is providing a scene for audience to use their imagination to compensate the unreal part. The final environment is the combination of the virtual world in their brain with real environment. It is not just an issue related to physiological visual illusion. The principle and usage of illusion is more complicated and complex.

Similar to mural painting, we can also regard spatial augmented reality is the relative or descendant of illusionism. By using optical technology to create illusions, all these art are mixing the virtual world with the real physical environment.



Digital Model and Digital Texture



High polygon Model Rendering
and Low polygon model

1.4 Separation of Surface and Object

At the beginning of prevalence of computer-aided design, some educators may blame this methods and do not encourage students to use the new technology. The reason is that when students build digital models in the computer, they easily neglect gravity, transmitting force and other properties of materials except the visual value. It is true. So tutors are always recommend students continue to use physical models to simulate the 'real' result of students' design. It seems that the drawback of digital model is not real enough. But it makes sense based on the whole building is real and physical. If the buildings in the future are the integration of virtuality and reality, is this drawback still a drawback?

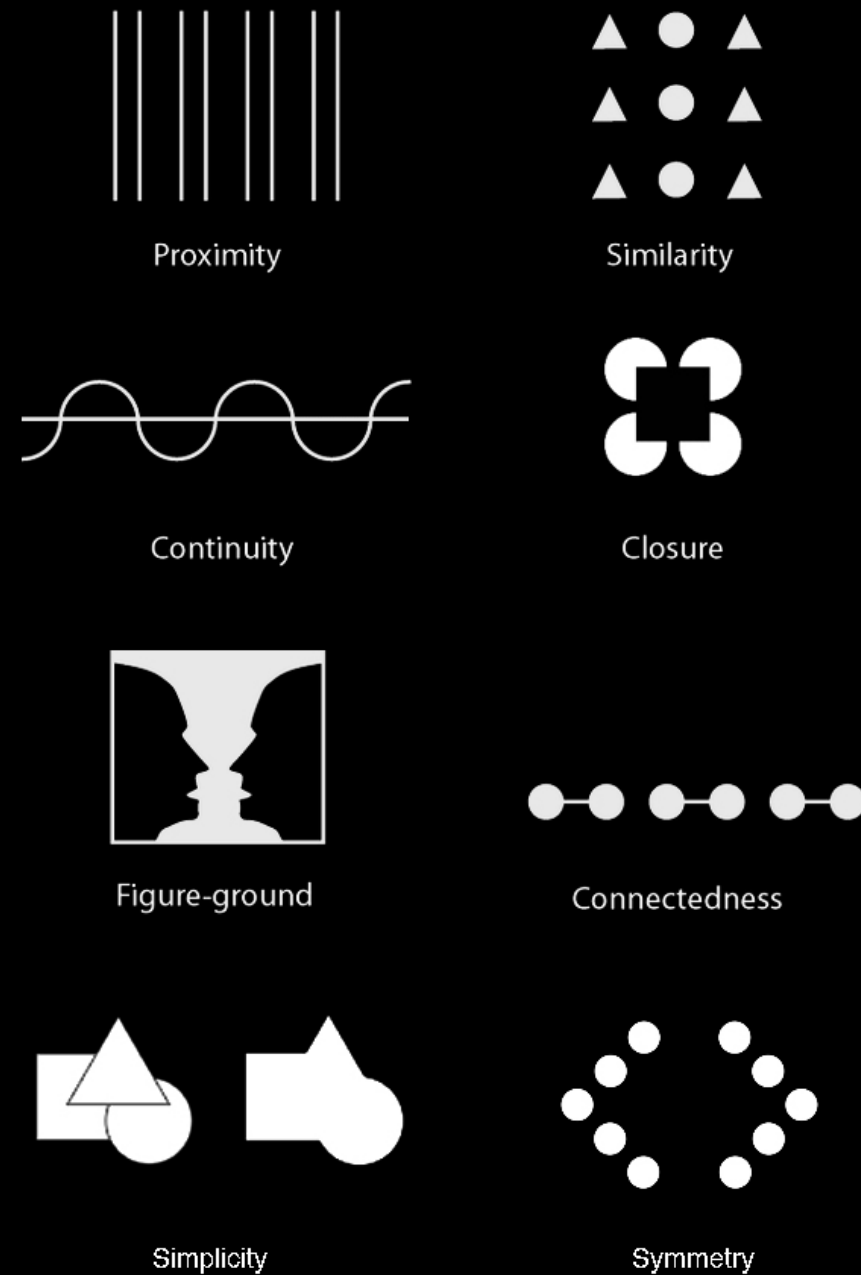
In the history of architecture, 'separation' means a lot to the evolution of architecture. The separation of the singular column from the massive wall represent the integration of material in rammed earth structure and building logic of wooden architecture. The separation of columns from the surface of the facade give birth to enormous possibilities of facade design, such as ribbon window and curtain wall. It also lead to a series of design methods, new construction details and industrial chains. Similarly, if the visual part of the building is separated from the tangible solid, it will be supposed to engage a new type of space, construction, and design method.

What is the advantage of the separation of surface and object?
One is decreasing the cost of changing the texture, including time costs and material cost. The other is decreasing the degree of elaboration.

In the early era of game design. A lot of game is base on the rectangle boxes with different texture or materials attached on. The function of the texture is provide the colors and more details information. The attached material change the perception of the object and represent the forms with an artistic style. In building a digital model for architecture, when the surface is separated from the form in the model, the appearance can be changed swiftly by replacing the texture map for the object. The appearance includes the color, pattern, shadow of the texture, which can visually represent different material. With the technology of projection mapping, it is possible to change the material of a wall in a lower budget and higher flexibility.

In the design of next-gen video game, designers need to guarantee the high quality of graphics and the smooth operation at the same time. One of the technic they use to achieve this goal is the integration of high polygon and low polygon model. High-polygon-count models are used when a model's level of detail needs to be impeccable, such as when the model is used in close-ups. High-polygon models are also used to generate displacement and normal maps which are used on lower-resolution models as the texture. This technique is used to add needed detail without the issues that come with high-resolution models. It reduces the operation of the hardware, ensuring a higher level of fluency, and keep an acceptable visual quality. Similarly, in projection mapping, the use of elaborated skin for a low-resolution physical model can provide a similar experience for audience. Besides, the new skin can be designed and adjusted according to different requirement.

The separation of surface and object is one of the foundation of spatial augmented reality. It provides the enormous potential for a new method for a new type of architecture.



Principles of Gestalt Psychology

1.5 the application of Gestalt Psychology

Gestalt theories of perception are based on human nature being inclined to understand objects as an entire structure rather than the sum of its parts.¹ It means when architects organize the elements inside a scene, it is not necessary to present the everything in the entire environment. After thoughtful arrangement, separate simpler elements involved will be connected by human cognitive system, combining together to represent an integrated scene.

This basic concept is crucial to design illusionary scenes with spatial augmented reality. Because architects make the best of the logic of our cognition system to overcome the difficulties of space construction, such as space limit and need of spatial variety. Architects can highlight separate elements, hiding other elements at the same time, to represent one scene instead of showing everything to audience in one space. It increase the flexibilities and possibilities to organize the elements in a space. For example, the function of screen wall in Chinese garden is to hide some space behind and only to show the picturesque scenery to dweller, to representing a beautiful environment surround the buildings. A projection mapping work of lighting show in Moscow, designed by a Japanese team called Heart-s, also highlight only part of the façade in the darkness to represent the scene, instead of show everything on the façade. Because human understand the world not as it really is but what they perceive.

Max Wertheimer defined a few principles that explain the ways humans perceive objects. These principles of Gestalt psychology is the foundation of the design method for the variation within the same physical environment. These principles can inspire architects how to organize the fragmentary elements and compose a relatively cognizable scene. Audience would not pay too much attention on the details of different small parts within a scene, but architects need to know.

The key principles of gestalt systems are emergence, reification, multistability and invariance.

Reification and the study of illusory contours, in which abstract contours are treated by the visual system as “real” contours, are very important for architects to use in design. It create a possibilities to use a few separated elements at the corner to hint the boundary and represent a whole object.

The principle of multistability allow designers to use one object to represent several objects. In contrast, the principle of invariance allow designers to use different methods to represent one object. It increase designers’ technique of expression.



1.6 Space Manipulation for Virtual Illusion

A man will be unable to create a illusionary painting with only profound knowledge of the laws of optics and projective geometry. Unless he is both an artist and scientist.

For creating an illusion, the relationship between the application of science and art is like bones and flesh. Scientific knowledge ensures the implement of laws and the artistic disposition make all the technologies work together in a particular way and avoid errors. A visual illusion works not only because of using the law of optics, but also require the knowledge of science in different fields, such as neurosciences, cognitional physiology, and cognitive ethology. It needs an comprehensive understanding of the tools and the feature of human being itself.

Every technology has its limits. Technology provides the possibilities but it do not guarantee the final outcome. It needs an artist to apply it to achieve the desired effect. For example, the camera need film director and film cutter to control the shooting angles, sequence of shots and rhythm of the scenario. It is the same for creating an visual illusion by the way of architecture. Architects need consider lots of factors which may influence the final effect. They are similar to space magician, hiding something to avoid detection and reveal only a part of the design for the audience. They need to manipulate space as artist, dealing with those limits and solve problems in an art way. An art way sometimes means avoiding facing the technical problem directly and solve it by another indirect method.

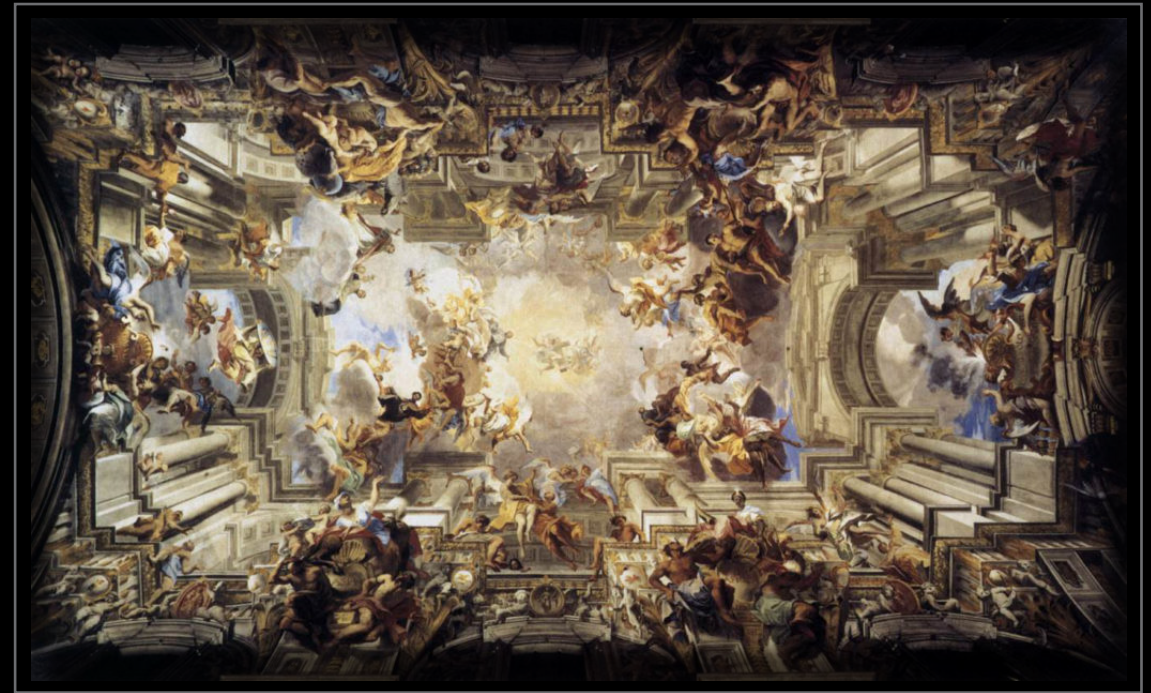
Specifically, to create a visual illusion within a space, architects need to control lots of things. Fundamentally, it can be divided into two main kinds of factors, the situation of observer and the scene.

For the situation of the observers, they need to control sequence of the journey, the path of the audience, the location and angle of observing. The designers should consider the feeling and behavior of users.

For the scene, it is about the manipulation of space, including lighting, material, obstruction and levels of unreality. It means to control the relationship of virtuality and reality, the visible and invisible. Architects should decide which item is real and which one can be replaced by virtual image. If the space is a mixed reality, the items should be designed for integration of the projected image and physical environment.

Chapter 2. Case study

- Extend space / Trompe-l'oeil
- Borrowed Scenery / Enframed Scenery
- Changing Face for Facade
- Boundary Hints
- Elaborate Heterotopia by Mirrors
- Duplication
- Perspective Reconstruction

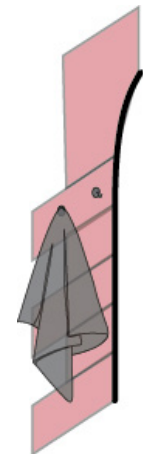
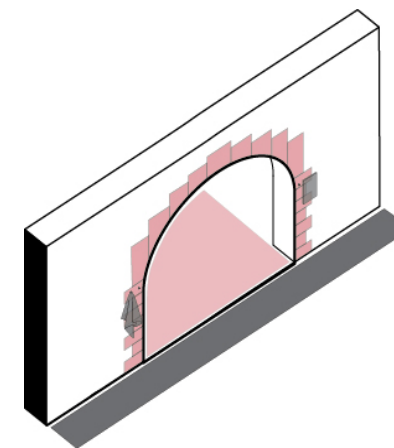
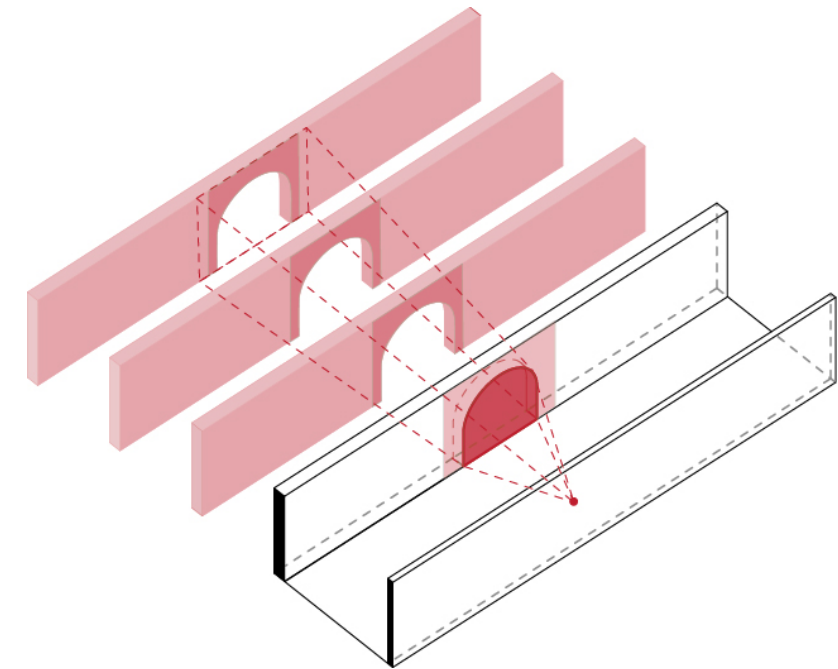


Extend space / Trompe-l'oeil

Trompe-l'œil means deceive the eye.

To use realistic imagery like perspective drawing or video to create optical illusion that the depicted objects exist in three dimension.

Artists use this technic to change the perception of the space.



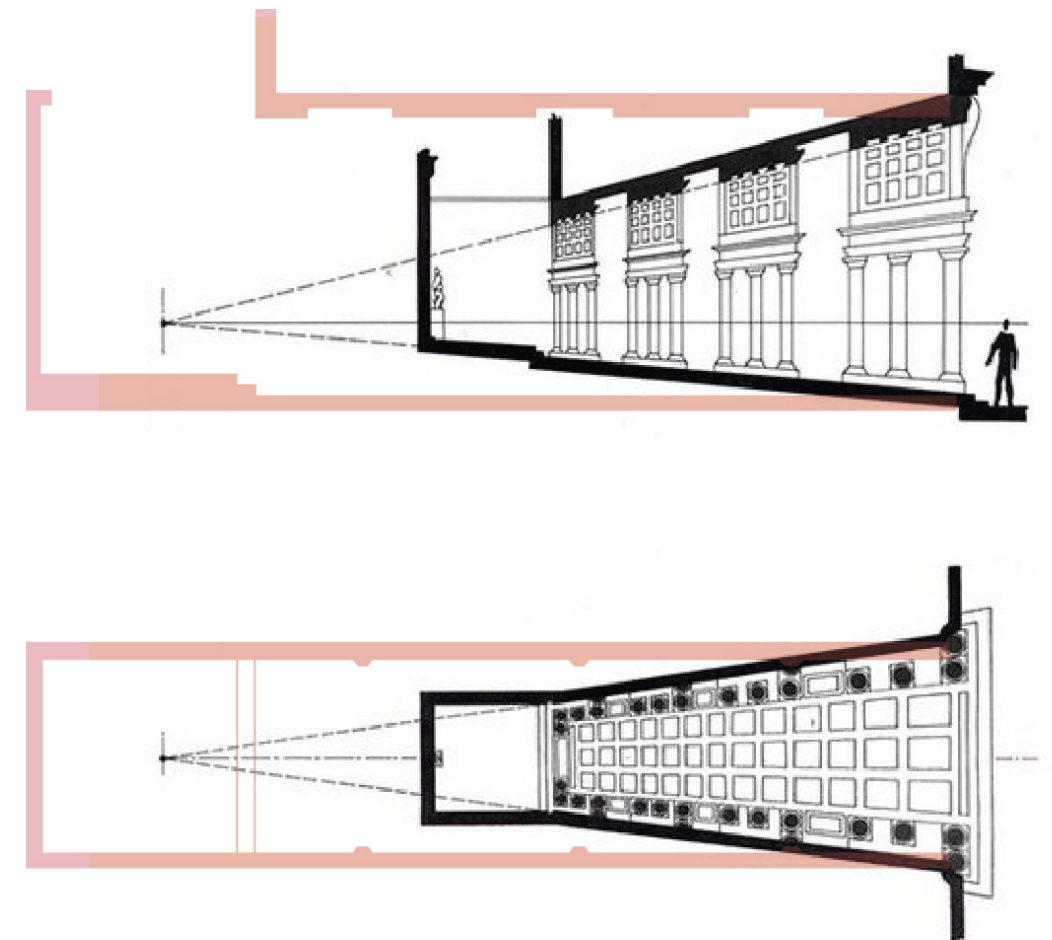
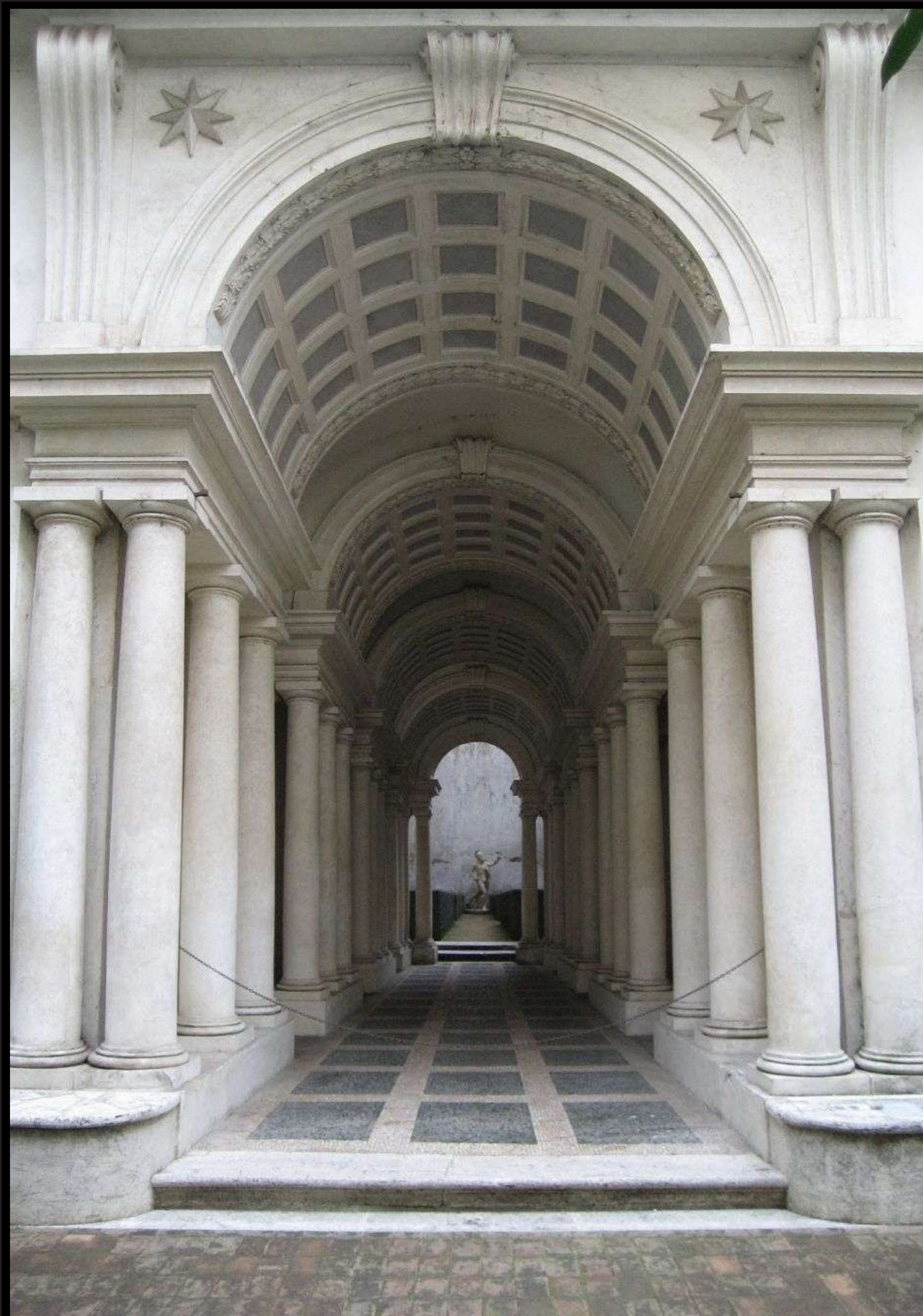
3D Printing / Trompe-l'oeil Art

Murals in Miller Brewery

Milwaukee, Wisconsin / Eric Grohe

Scene of corridor within the factory shows interior of Miller Brewery in the past. The layers of gates extend the depth of the space. Even though the painting only show the part of the passages, but the audience can imagine the other part as a whole.

The texture of the wall, wainscot and floor is the same in painting and reality. Hooks, clipboards and aprons were added to the surface of the murals to enhance the illusion.

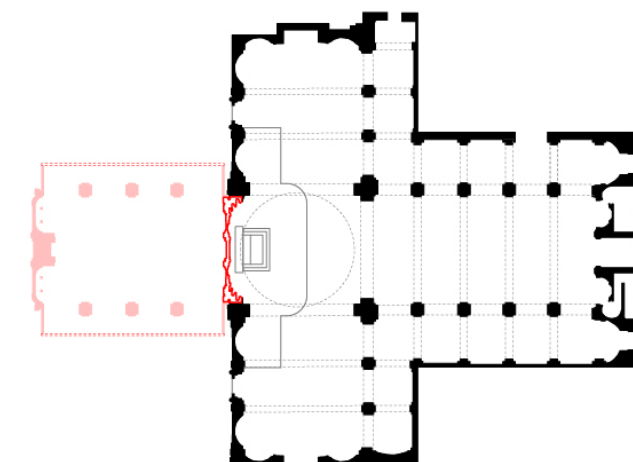
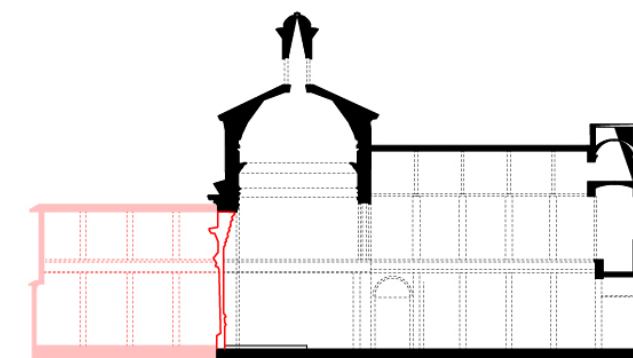
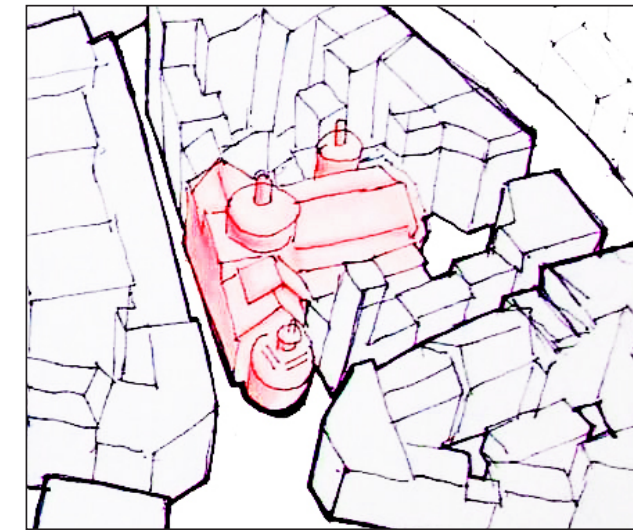


Perspective Manipulation

Galleria Spada

Rome, Italy / Francesco Borromini

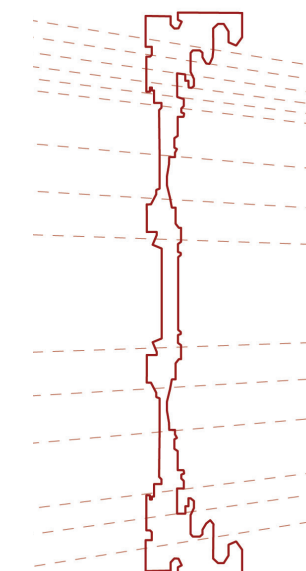
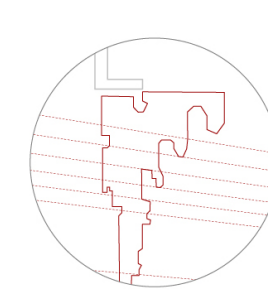
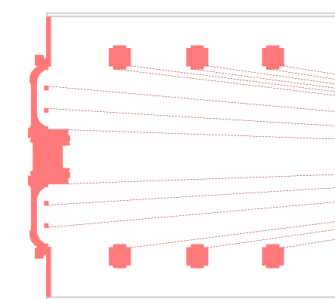
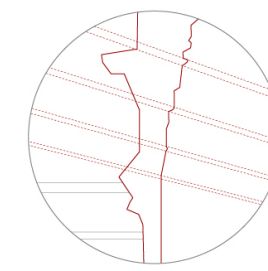
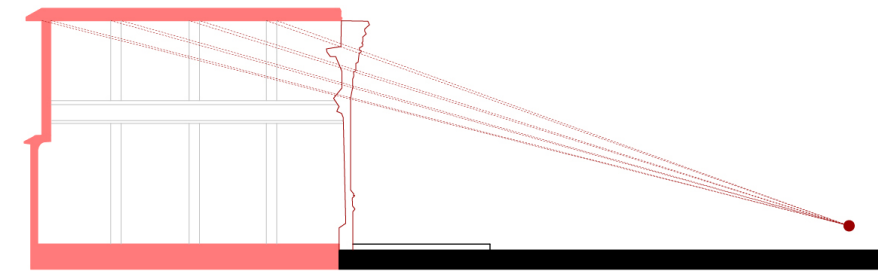
Borromini created the masterpiece of forced perspective optical illusion in the arcaded courtyard, in which diminishing rows of columns and a rising floor create the visual illusion of a gallery 37 meters long (it is 8 meters) with a lifesize sculpture at the end of the vista, in daylight beyond: the sculpture is 60 cm high. Borromini was aided in his perspective trick by a mathematician.



Santa Maria presso San Satiro

Milan, Italy / Donato Bramante

The choir, which had to be truncated a depth of only 90 cm (3.0 ft) due to the presence of the road Via Falcone behind the church, was replaced by Bramante with a painted perspective, realizing in this way one of the first examples of trompe l'oeil in history of art.



Instead of a flat wall with perspective painting, there is concave and convex on the wall to enhance the illusion. The concave and convex is based on the perspective in the drawing. It creates the natural shadow to make the painting more believable.

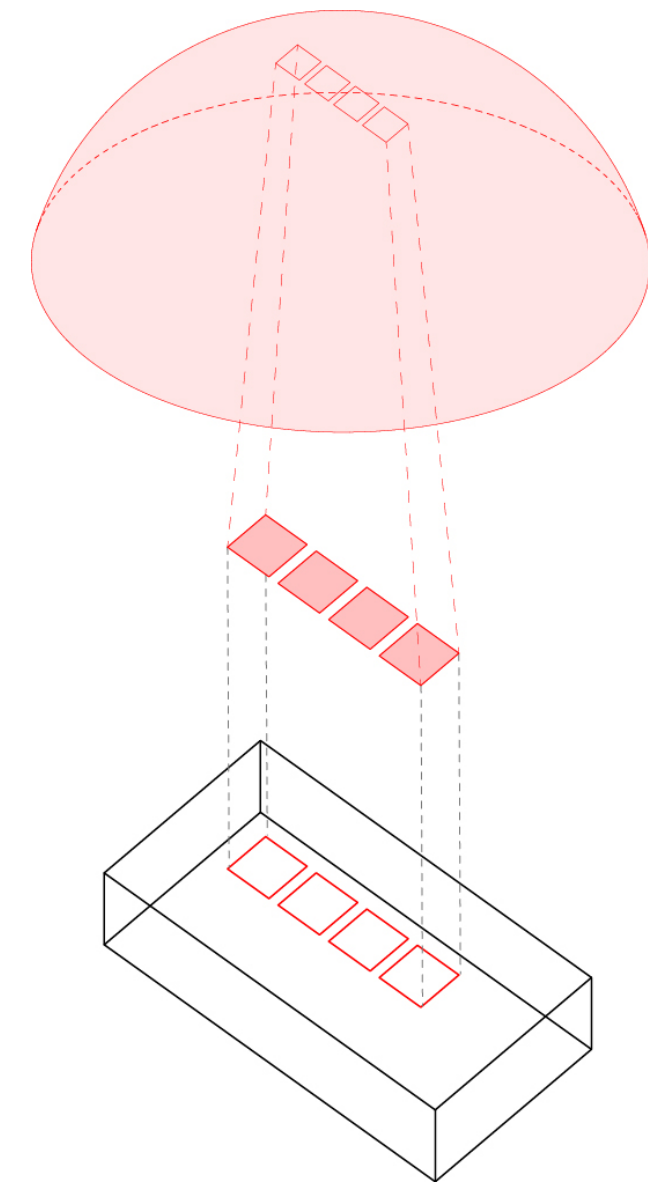
The cabinet in front of the drawing, the pulpit, the step of the altar is three-dimensional. All of this also reinforce the illusion.



Borrowed Scenery / Enframed Scenery

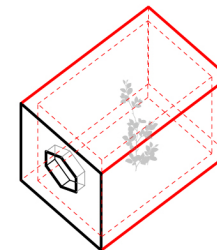
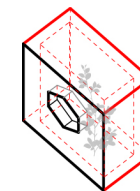
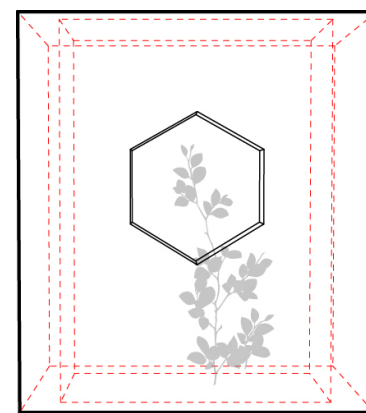
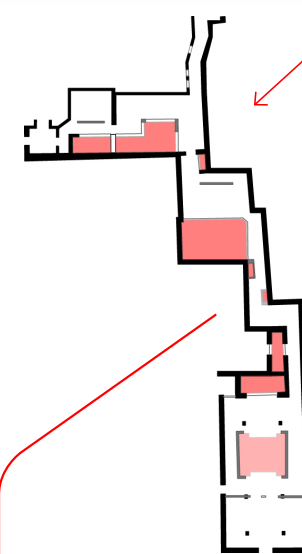
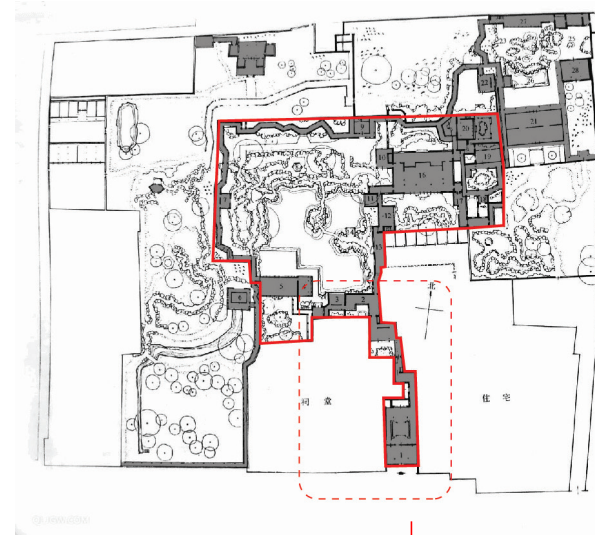
借景; Japanese: shakkei; Chinese: jièjǐng

The principle of “incorporating background landscape into the composition of a garden” found in traditional East Asian garden design



Illusionary skylight in the kitchen

In interior design, especially for dwelling or hospital, there are a lot of examples of these illusionary skylight. Within the window frame on the ceiling, the illusionary photos or drawing representing the outdoor nature makes the observers or users feel more comfortable inside the indoor space.

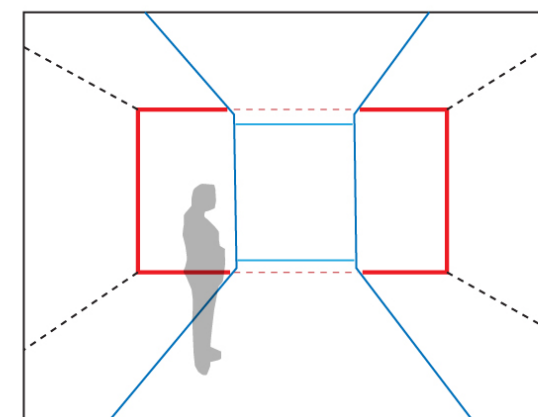
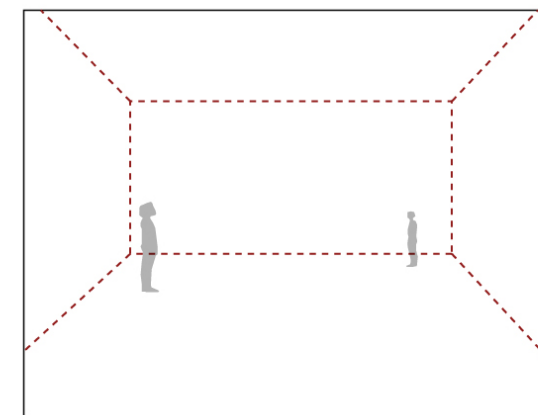
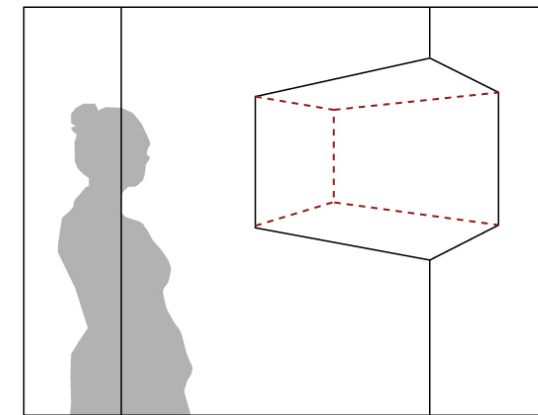
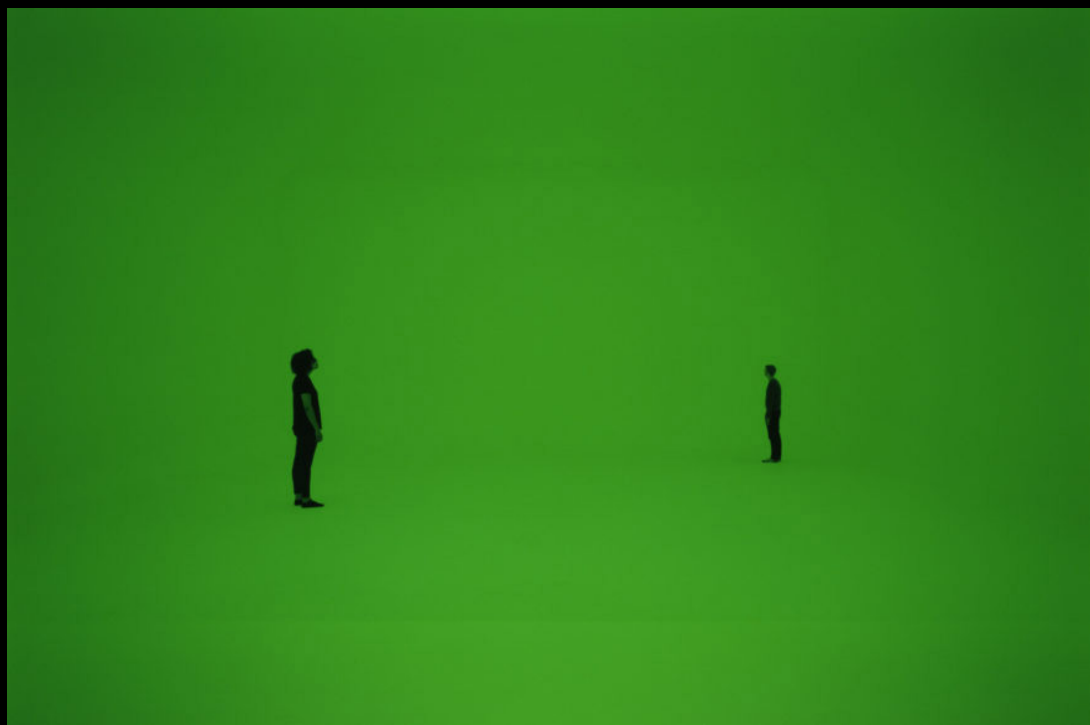
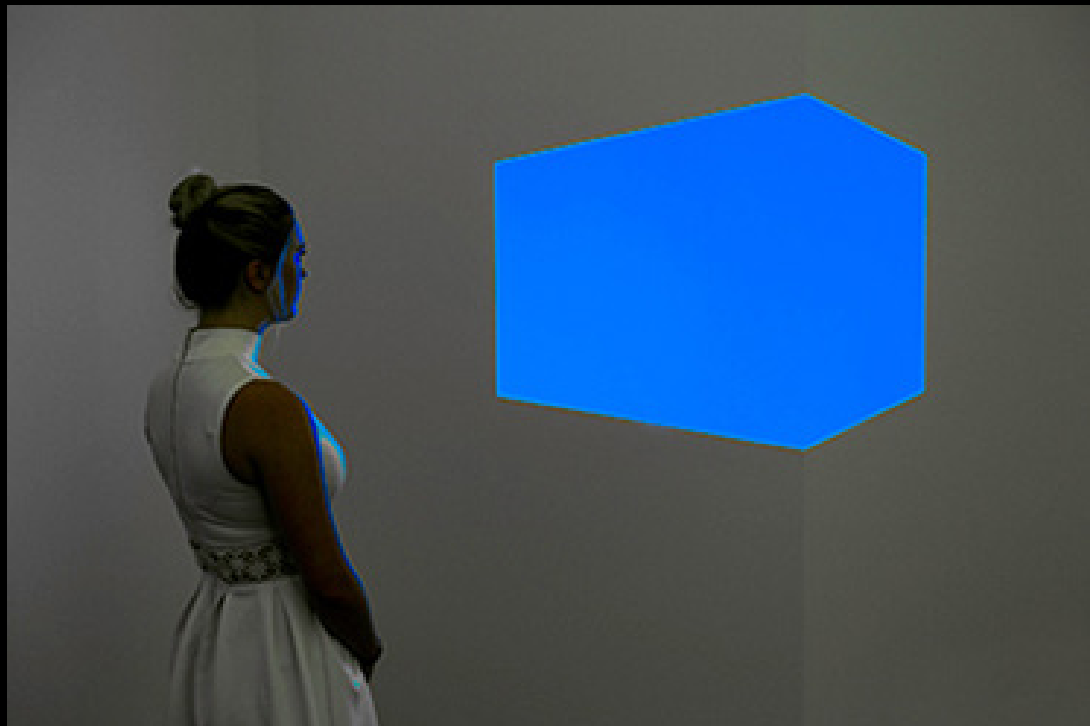


Enframed Scenery

Lingering Garden (Liu Yuan)

Suzhou, China

Enframed Scenery is a common technic in Suzhou classic garden. It usually used in the screen wall in the garden. It use the window frame to construct a picture and blocking the other items behind. Sometimes it makes the distance of the scenery vague because it also blocks the perspective lines. On the narrow path to garden after entering the gate, there are a few framed windows with a small courtyard behind. Even though the courtyard is very small but it enlarge the space in experience, by adding views on the space out of the corridor.



Corner Shallow Space / Ganzfeld / Tunnel Pieces

James Turrell

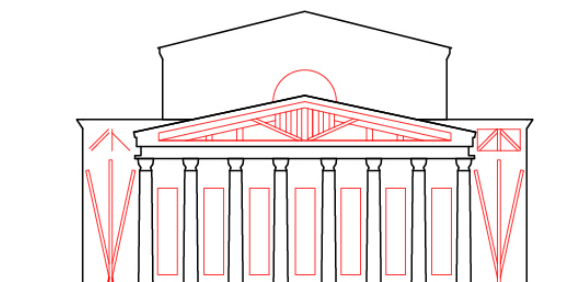
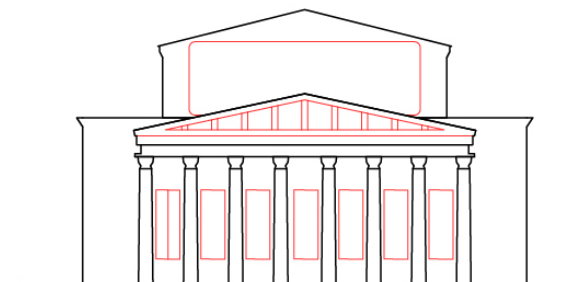
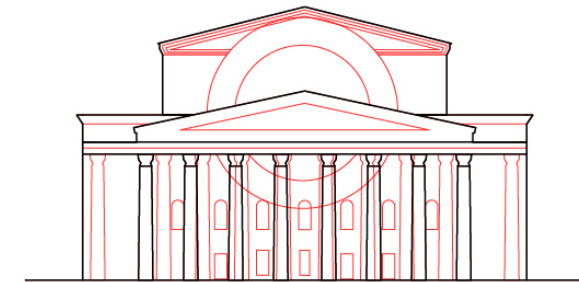
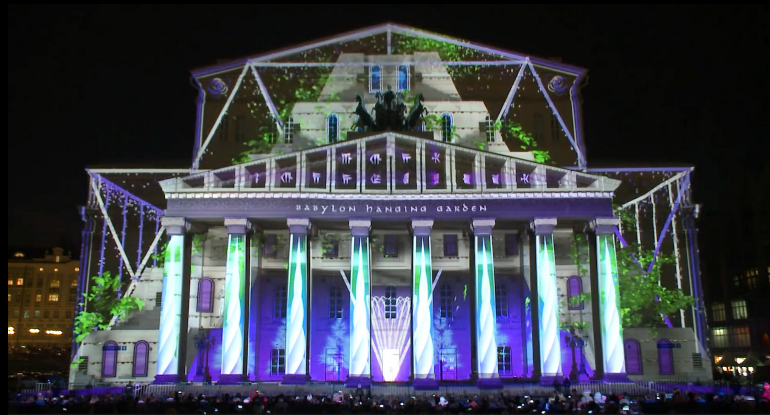
In the art installation of James Turrell, an important feature is that light is used as material. The space is solid and filled with light. In the series of corner shallow space and Ganzfeld, Turrell has installed the window-like opening between an infinite space and reality. Round corners and a special paint make the edges invisible. Through the opening, the hidden light cooperates with invisible edges to make space infinite.



Changing Face for Facade

The feature of masks in Chinese drama represents different character. Chaning face is a teachnic and dramatic art that actors can change their masks in a very high speed, switching from one character to another.

Projection mapping is a kind of modern performance which is similar to changing face. Cooperated with the dramatic music, the facade of buildings switch quickly among different appearance

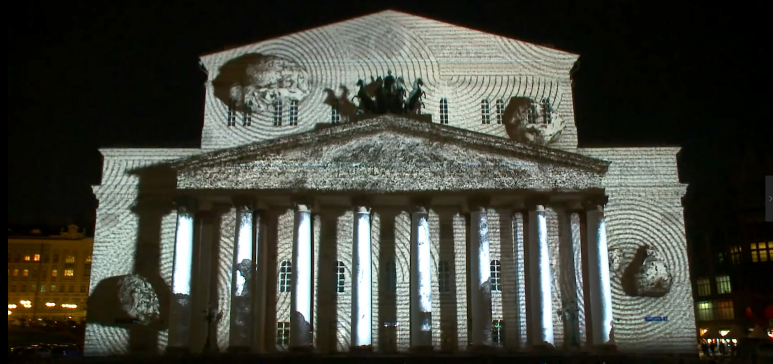
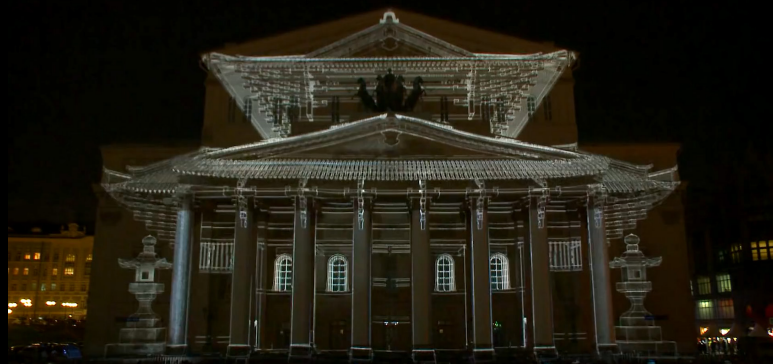


Projection mapping

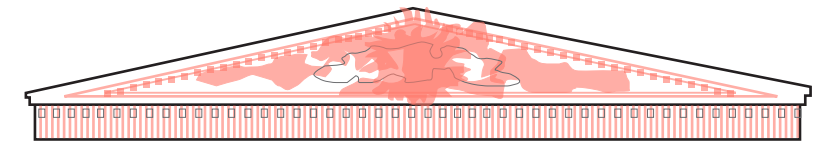
Art Vision Classic 2016

Moscow / Circle of Light Moscow International Festival / Gone Zhen

Nowadays projection mapping is always used in the lighting show as a new type of performance. With the dramatic music, lots of projectors light up the facade of the buildings and change their appearance. The design of lighting show is based on the main outline of building but change the pattern and color within the outlines. It can switch from one architectural style to another very quickly.



Origion Pattern



Designed Patterns in different Scenes

Art Vision Classic 2016

Moscow / Circle of Light Moscow International Festival / Heart-s

It is a projection mapping produced by Heart-s, a Japanese company. They integrated the feature of Japanese architecture into a classic facade of Basilica. It changes the texture and details of the facade by strong contrast pattern. Besides, the detail of the projection also consider hiding the original ornament. Because the texture or shape of origin building might have a shadow when light is projected on it.



Boundary Hints

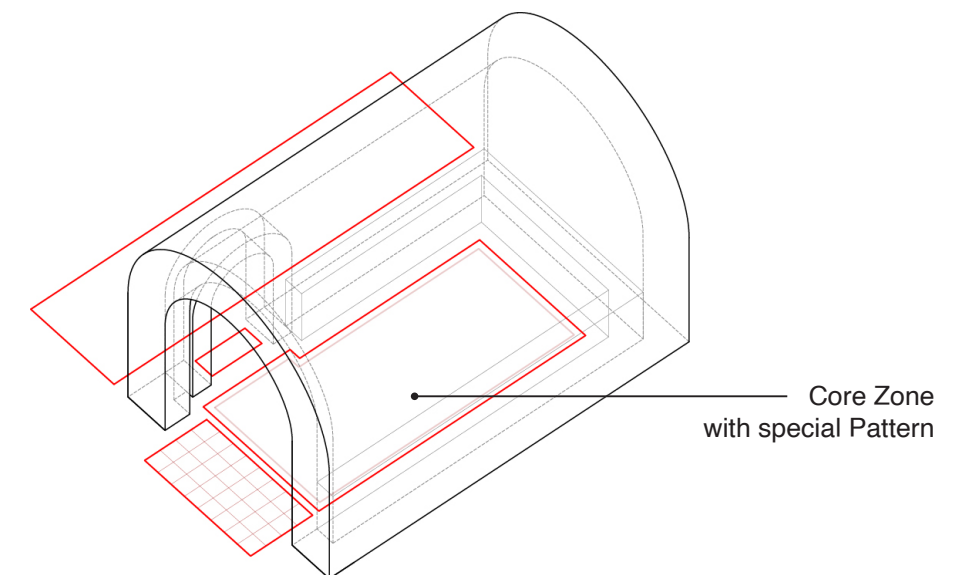
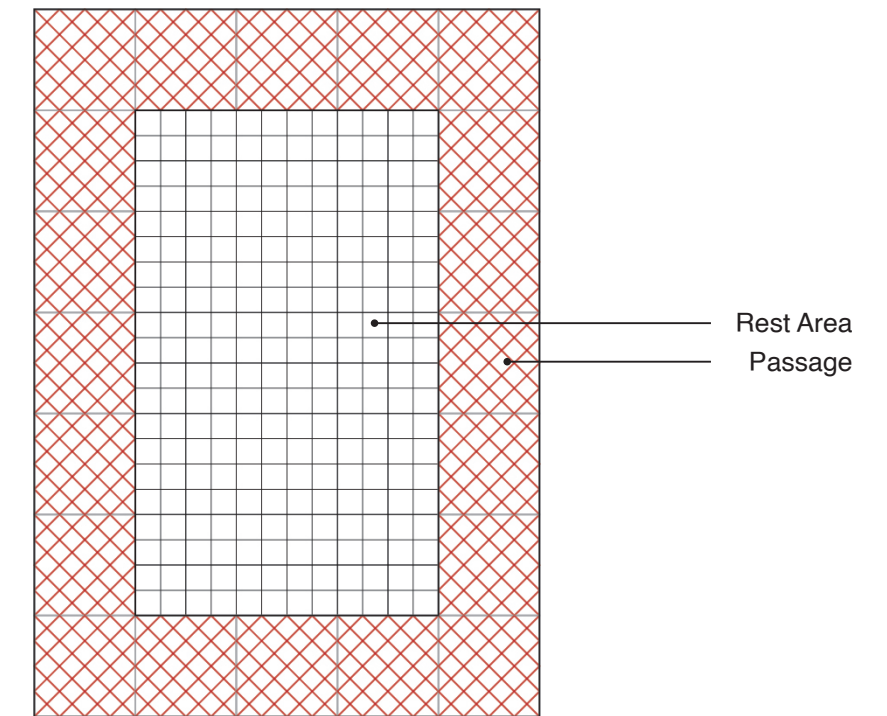
In the history of art, especially the history of painting, perspective lines and shadows are used to represent the depth of space. They are the hints for us to understand the boundary.



the Villa of the Mysteries in Pompeii, Italy
Digital reconstruction



Apodyterium of the women's baths,
Herculaneum, Italy



Zone defined by Pattern on floor

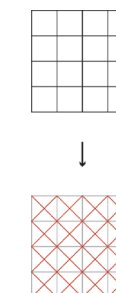
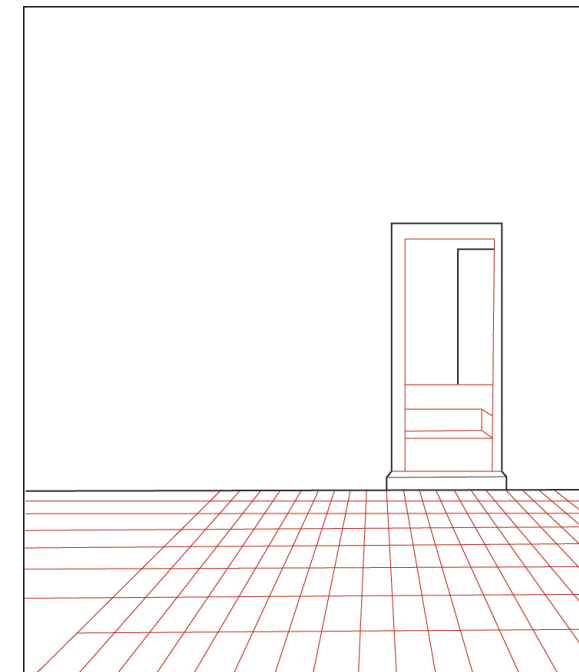
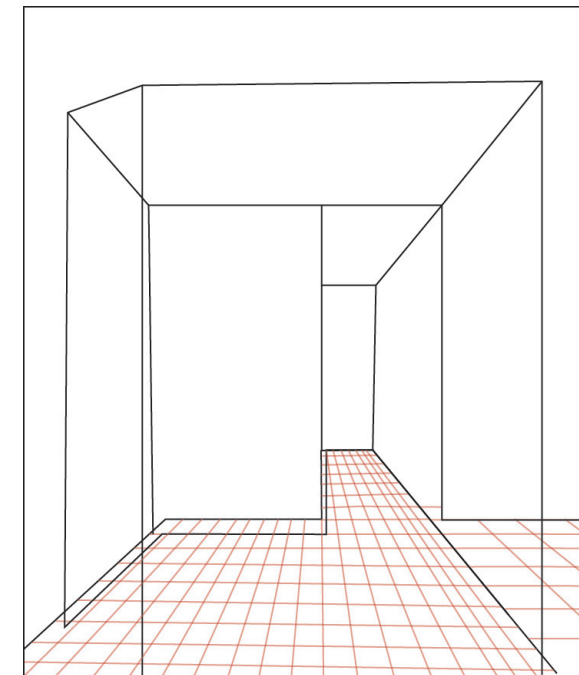
Space is not only defined by walls, columns or barriers. The pattern on floor sometimes are used for hint people about the border of different zones. It functions as a visible but intangible boundary. It usually enhance the importance of central area and seperate the passage area. With different pattern, the floors also strengthen the atmosphere and shows a sense of territory.



Annunciation and the Expulsion from the Paradise
Giovanni di Paolo

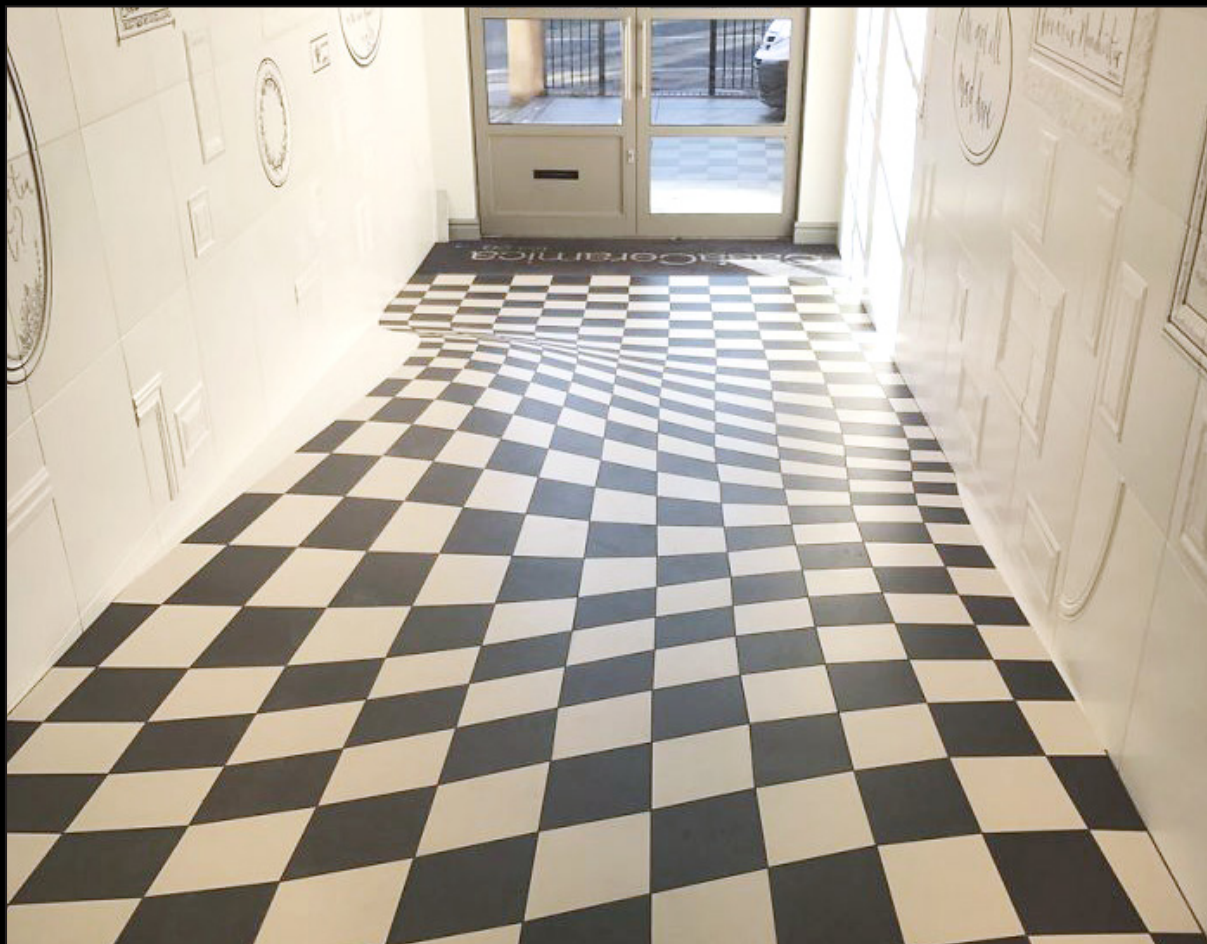


Drinkers Before The Fireplace, C. 1660'
Hendrik Van Der Burgh



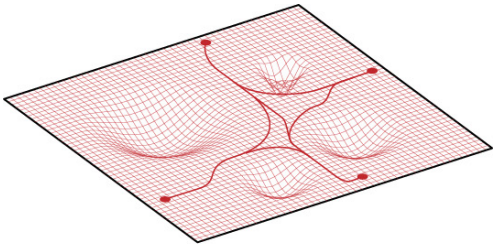
Perspective lines in Painting

In painting, linear perspective are often used as a hint for the depth of the space since Renaissance . It usually used in the pattern of The pattern of floors, especially, were often painted as perspective grids. There also some varient of perspective grids. One example is transforming the orthometric girds into the oblique crossing girds, like the floor in “Drinkers before the Fireplace” painted by Hendrik Van Der Burgh.

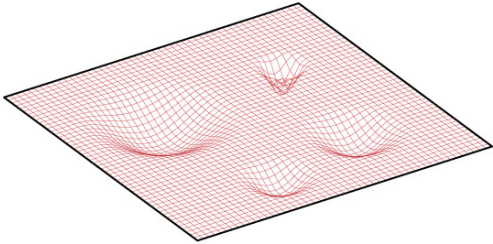


Floors in Hallway of a Showroom for Casa
Ceramica, Manchester, UK

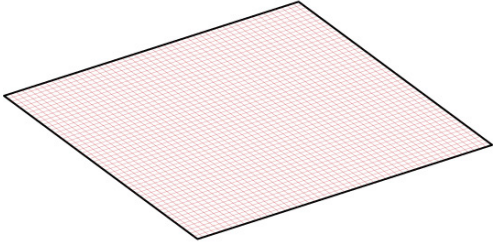
Result : Hint Boundary
-Path Hint



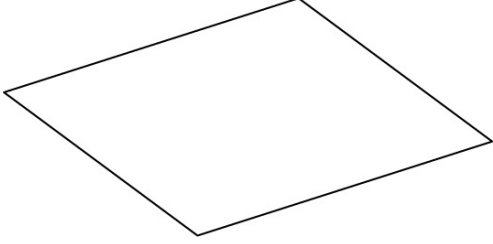
Step Two: Sunken



Step One: Meshing



Original Floor

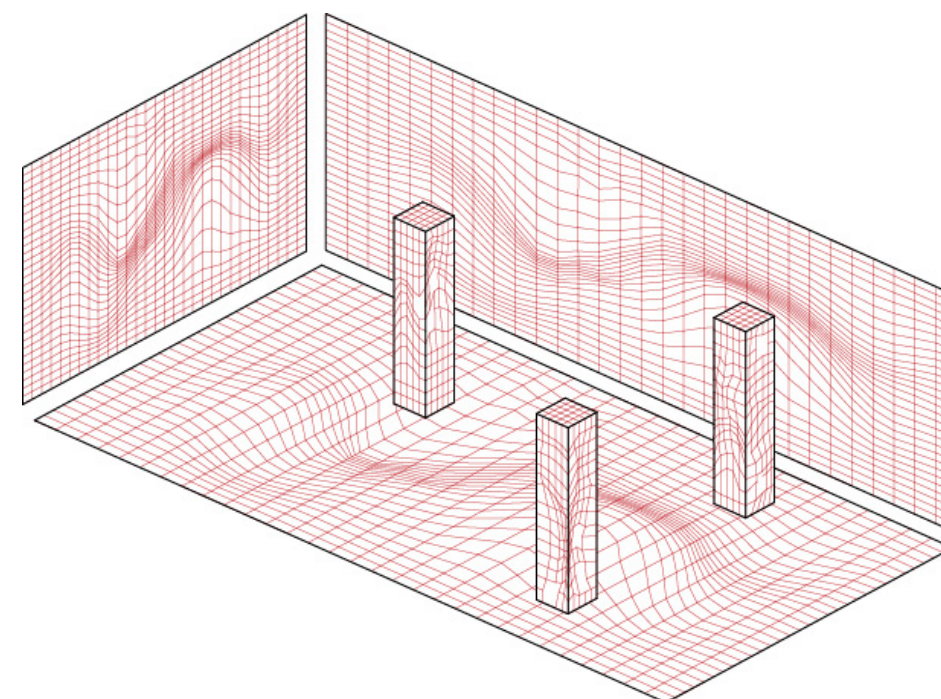


3D-Painting on the floor

Artist use the technic of pespective to create the illusion of sunken floor. They usually use the mesh or grids tiles to hint the change of the floor. It is easy for the eye to percept the change and rather easy to draw.

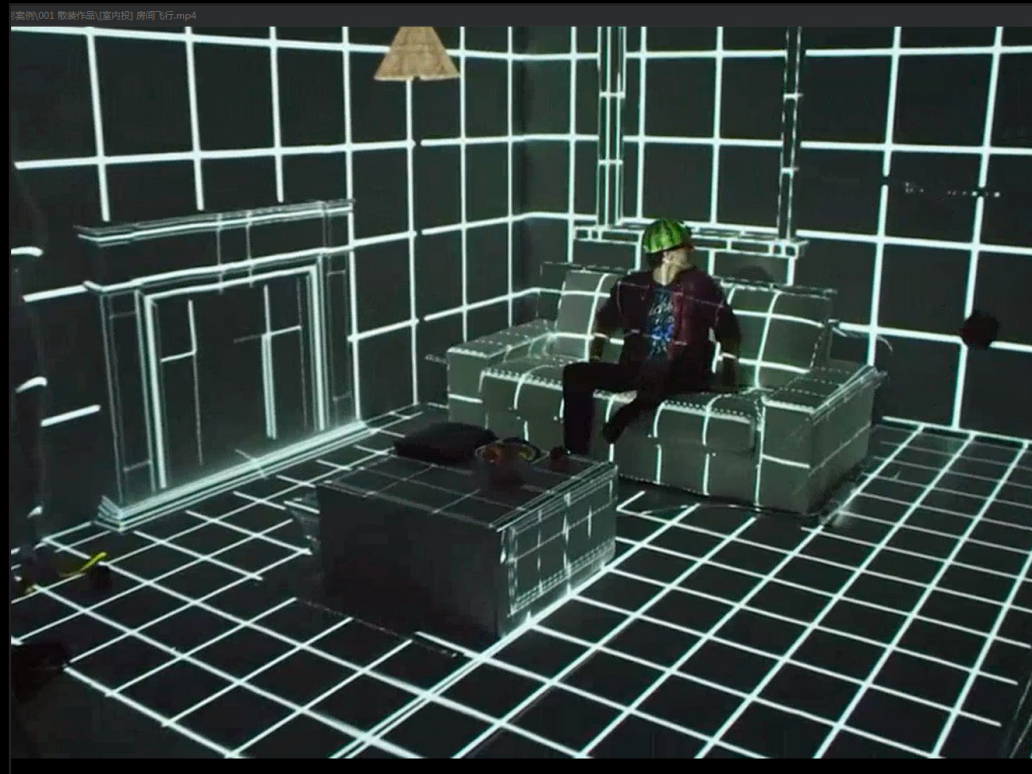


Dirimart Gallery, Istanbul, 2011
Peter Kogler

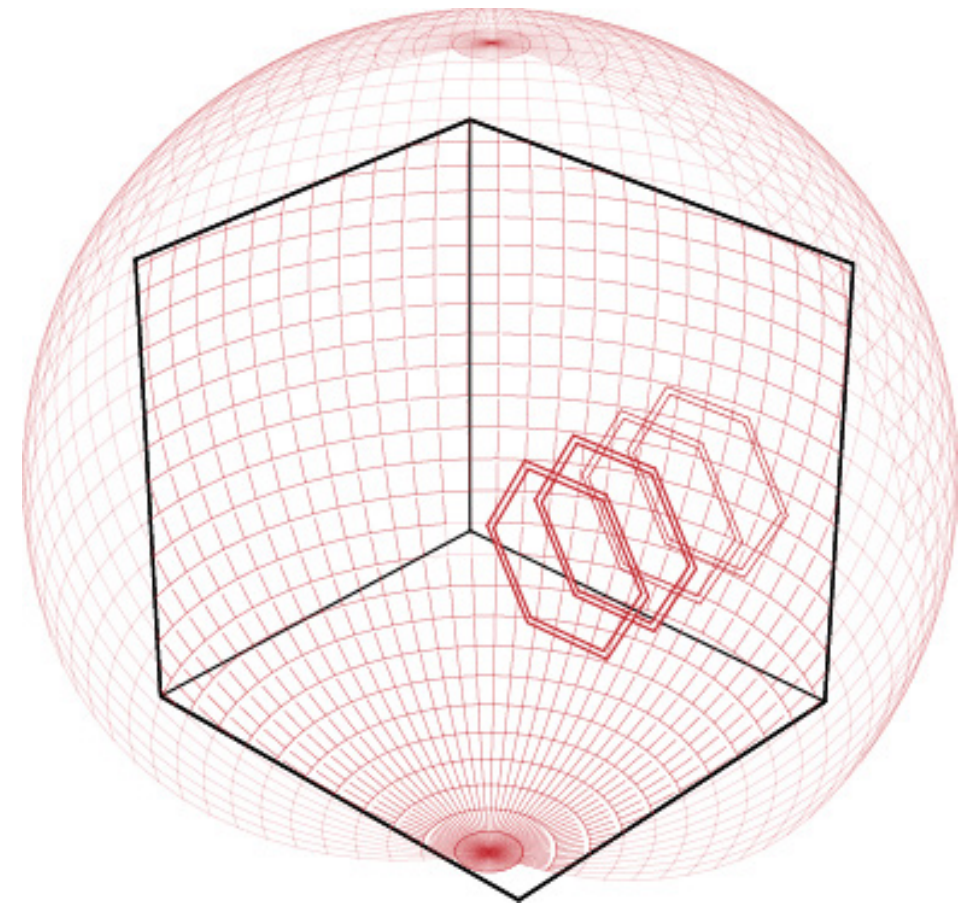


Delusive Painting on Surface in All-Direction

Space can be seen as the void between massing, but it can be seen as the volume enclosed by the surface. Artists like Peter Kogler use some digital-virtual images to create space between virtuality and reality. Subsequent computer-animated wallpapers and projections on all the surface of all the ceiling, floors and columns delude audience's perception of space.



Dirimart Gallery, Istanbul, 2011
Peter Kogler



Perspective Grids in Projection Mapping

Perspective grids is often used in projectionmapping to tranform from one type of space to another. The grids only highlight small part of the surface but represent the shape of the space very well. In projection mapping, it is better not to highlight every part of the space.

Besides, By some software in computer, the different grids can tranform smoothly and swiftly. The grids of the shape is mainly based on the location of the observer. There will be distortion if the observing point is not close to the best location.



Elaborate Heterotopia by Mirrors

Heterotopia is a concept elaborated by philosopher Michel Foucault to describe certain cultural, institutional and discursive spaces that are somehow 'other'. Heterotopias are worlds within worlds, mirroring what is outside in different ways. It is juxtaposed with reality. It seems real but virtual at the same time.

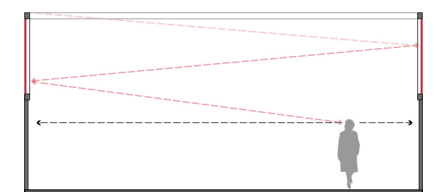
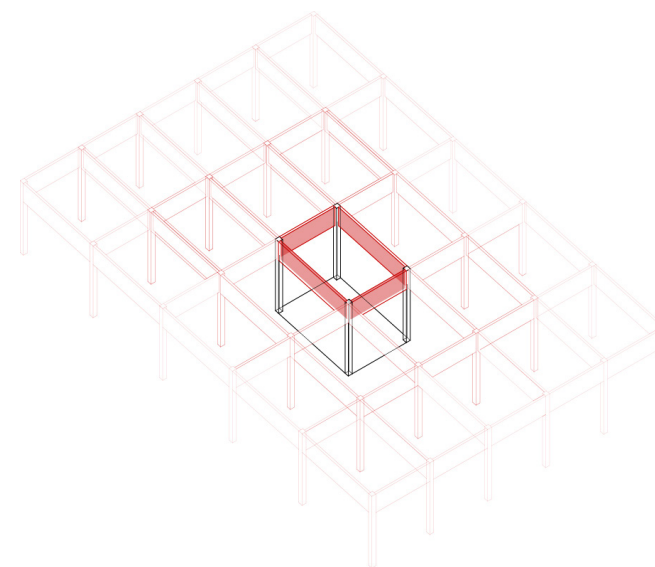
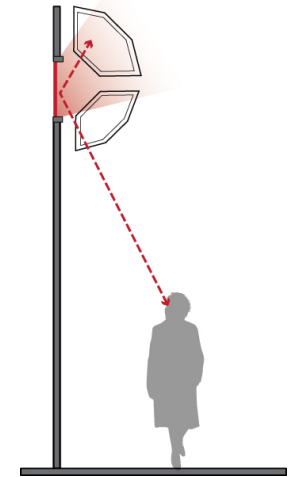
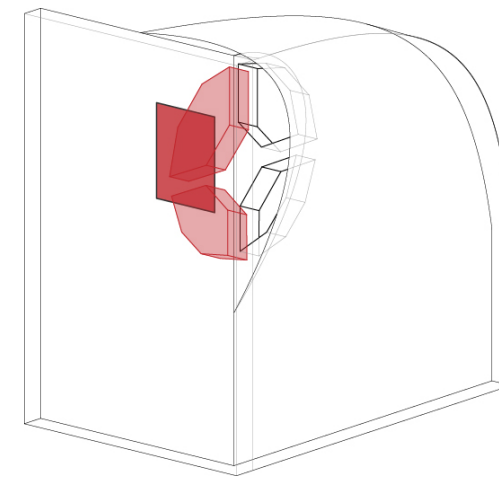
The purpose of some paintings, decorations in the building, and mirrors in common area is to create an illusion. The illusion works because of not only the simple simulation or reflection by the mirror but also the composition of different elements. Those elements are positioned and designed elaborately to achieve the desired effect.



“mis-position”
Mirror in Casa del Guarda, Parc Güell, Barcelona



Infinite space - Double Mirror
Mirror in American Bar, Vienna, Adolf Loos



Mis-position Mirror in Interior

Mirrors are often used as decoration in the interior, not only the bathroom or dressing room, but also the living room. Except reflecting the light, one of the reason is that they are used to extend the space by reflecting the space in front of them.

But the location of the mirror is carefully designed. One technic is not easy to see the observers themselves. Because the illusion vanishes when observer saw themselves in the mirror. If they are placed higher than the visual line, it is more difficult to see themselves or other people in the mirror. Another technic is to restrict the size of the mirror and reflect only part of space, for example only part of windows in the photo of casa del Guarda. Through a small window, observer will imagine the other part in the reflection and have the illusion.

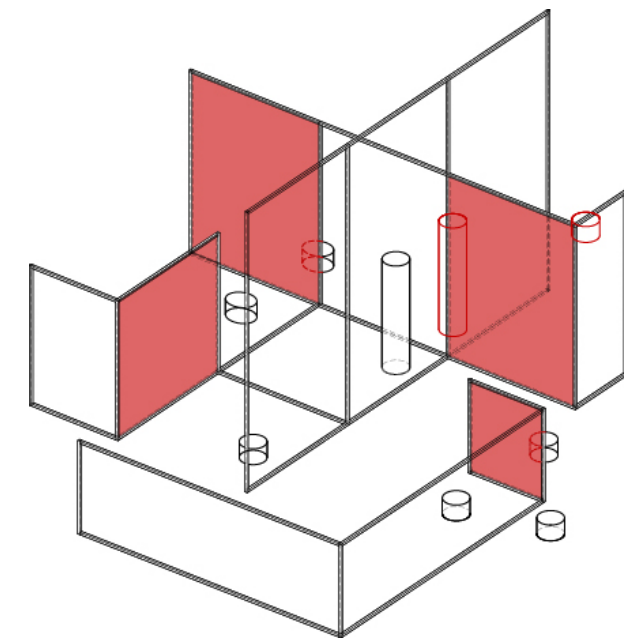
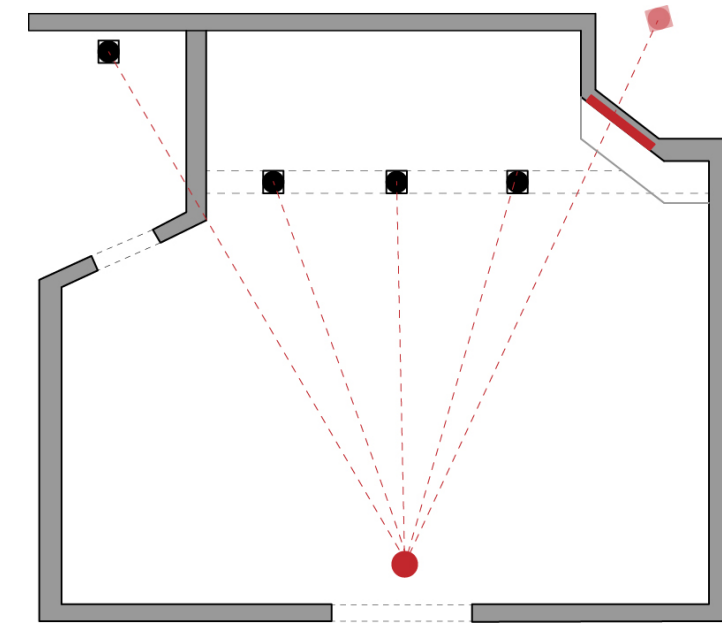
The mirrors in American bar only reflect the ceiling and the upper part of the walls. And the double-facing mirrors creates the illusion of infinite space.



Mirror in Palau Güell, Barcelona
Second floor - Bedroom
Antony Gaudi



Mirror in Palau Güell, Barcelona
Second floor - Bedroom
Antony Gaudi

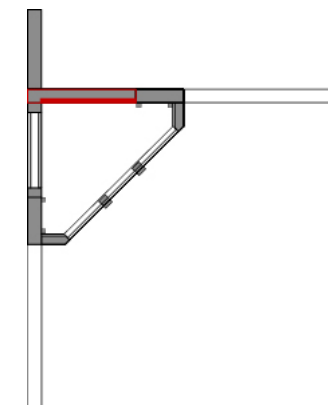
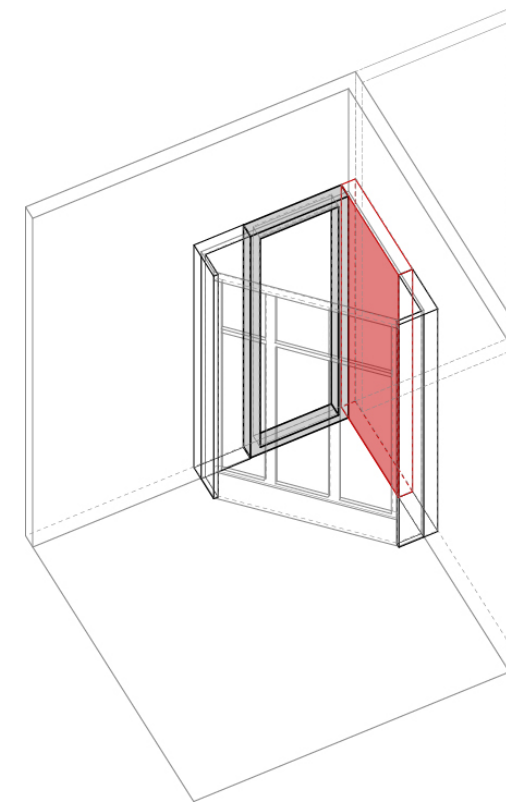


Boundary between Reality and Virtuality

Use the mirror to 'duplicate' items and represent the other space behind the frames. Some items are carefully placed on the spot where are reflection of items locate. It creates the illusion of the space is overlap and confuse the audience about the boundary between virtuality and reality.



Mirror in Palau Güell, Barcelona, Antony Gaudi
Second floor - Bedroom



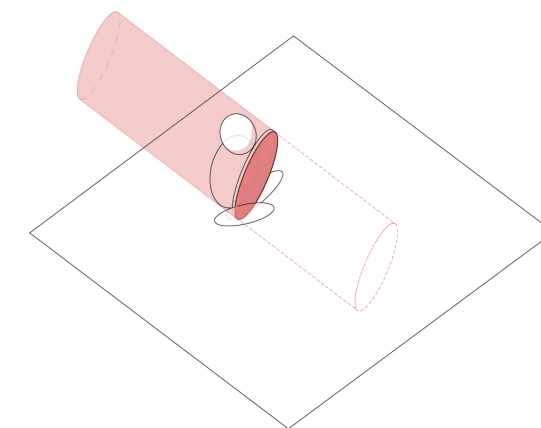
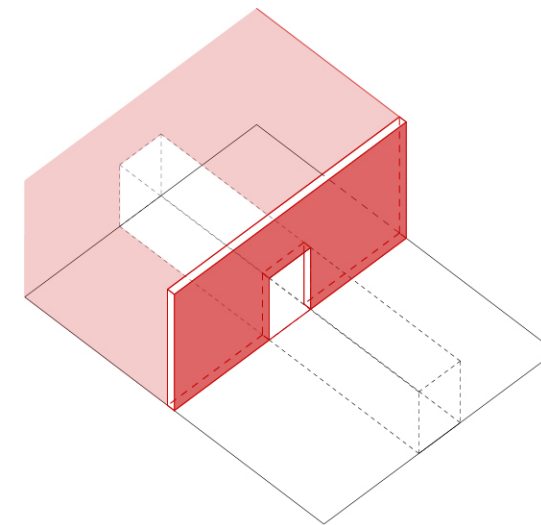
It looks like a corner window. But it was just a illusion by a mirror. All the frame of the window is symmetry, including the board inside the outer frame. The outer frame prevents observer to see it clearly and provides a black foreground. The mirror reflect the window, lighting and the outside view. All the elements are designed for this illusion.



Alice in Amsterdam, Amsterdam
UXUS

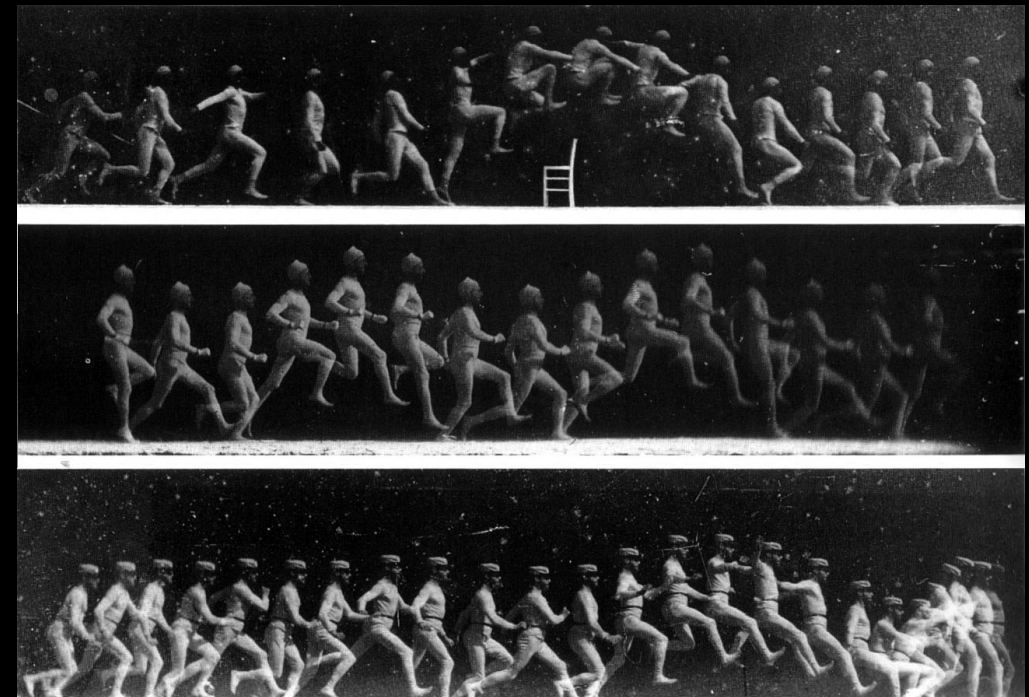


Photograph, Laura Williams



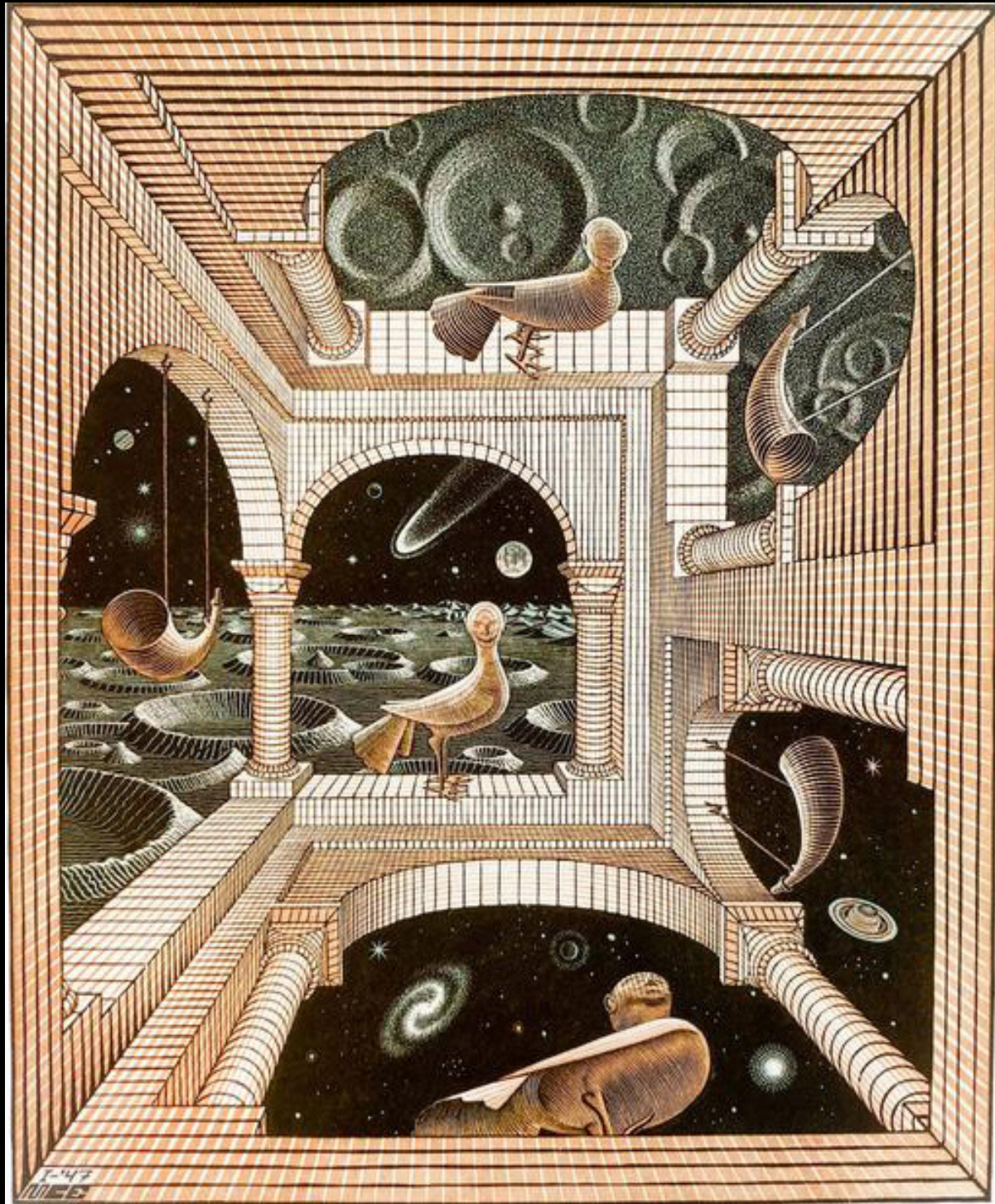
One of the technic in the office in Amsterdam is the door preventing observer see themselves in the mirror. It avoids the appearance of themselves in the scene, making the illusion more believable.

In picture 2, the illusion is the view in the mirror is the same as the view in behind. Audience is seemingly see through the mirror in the girl's hand. It is not sure the view is the reflection of the grass in front of the girl or using software like photoshop to overlap the image behind onto the mirror. The technic is that in the image in the mirror, the boundary of grass is at the same height as the real scene behind the girl.

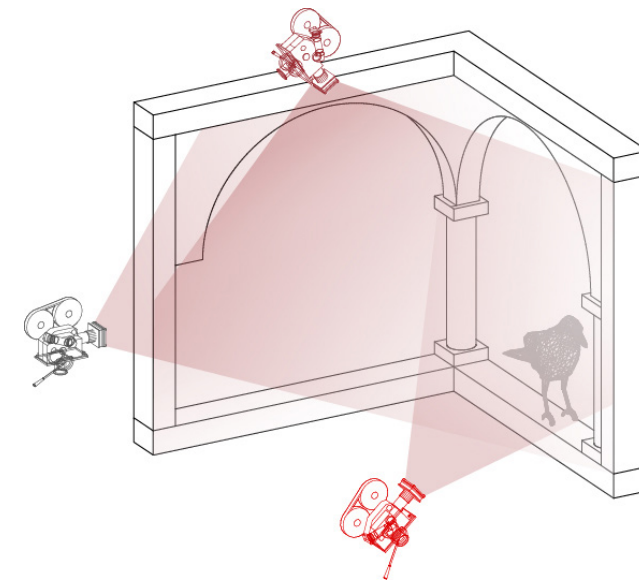
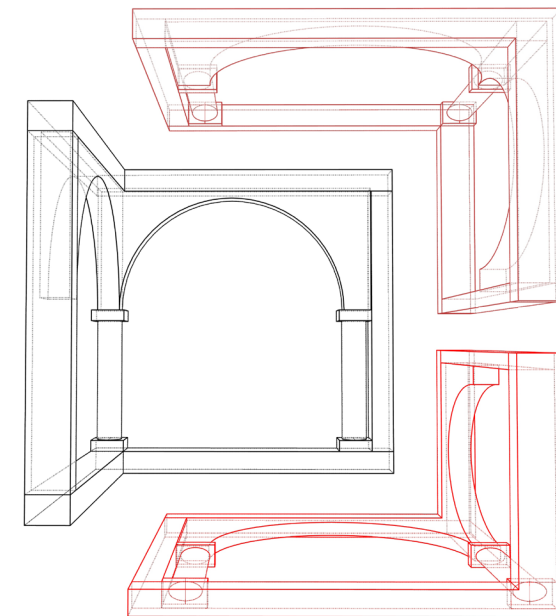


Duplication

an antique photographic technique from the Victorian era (beginning about 1867–68), which captures movement in several frames of print



Photograph, Laura Williams



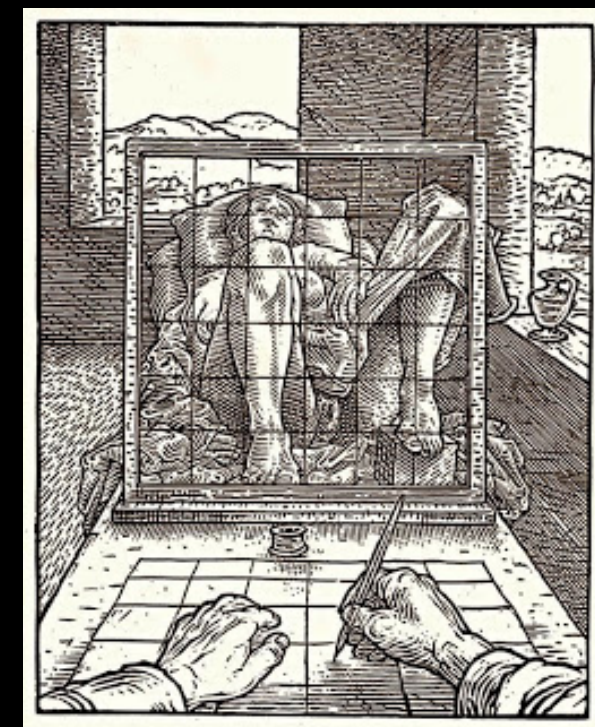
Repetition by different angle

The drawing is composed by three angle from different position and reflection. In reality, it is impossible to view a space in more than one perspective. But in drawing, it is possible to combine more than two angles into one scene. In the drawings of Maurits C. Escher, this is a typical technic to create the illusion.

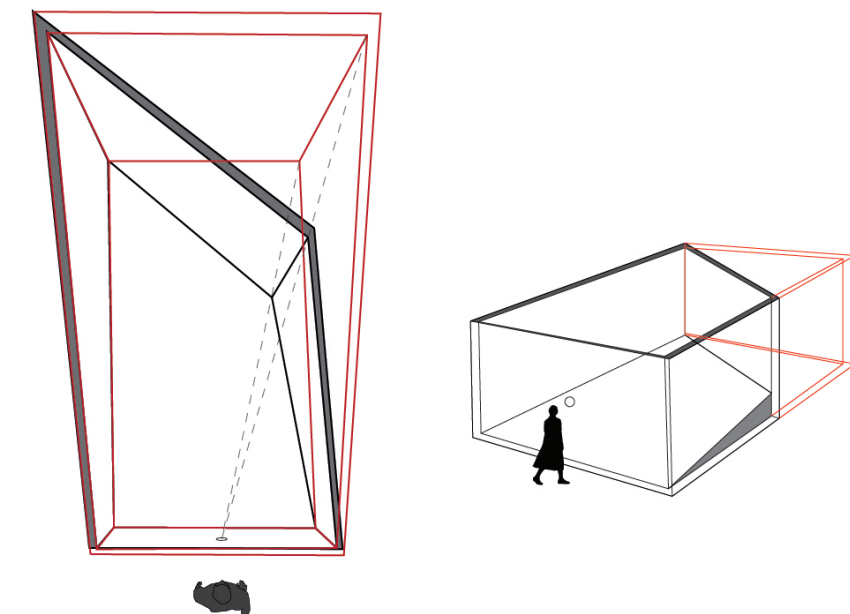
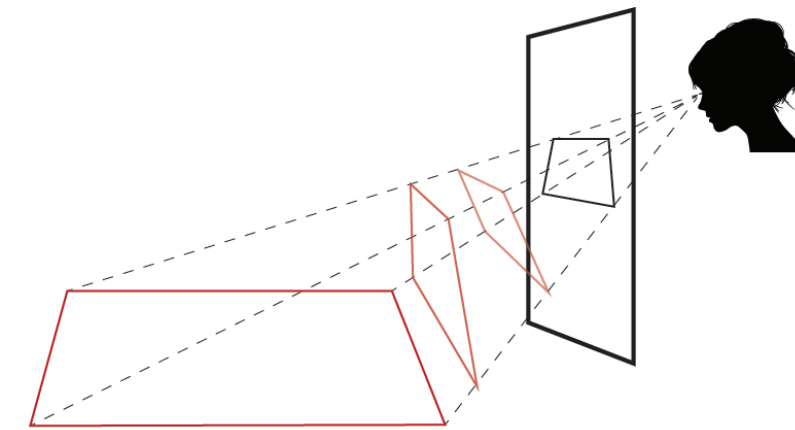
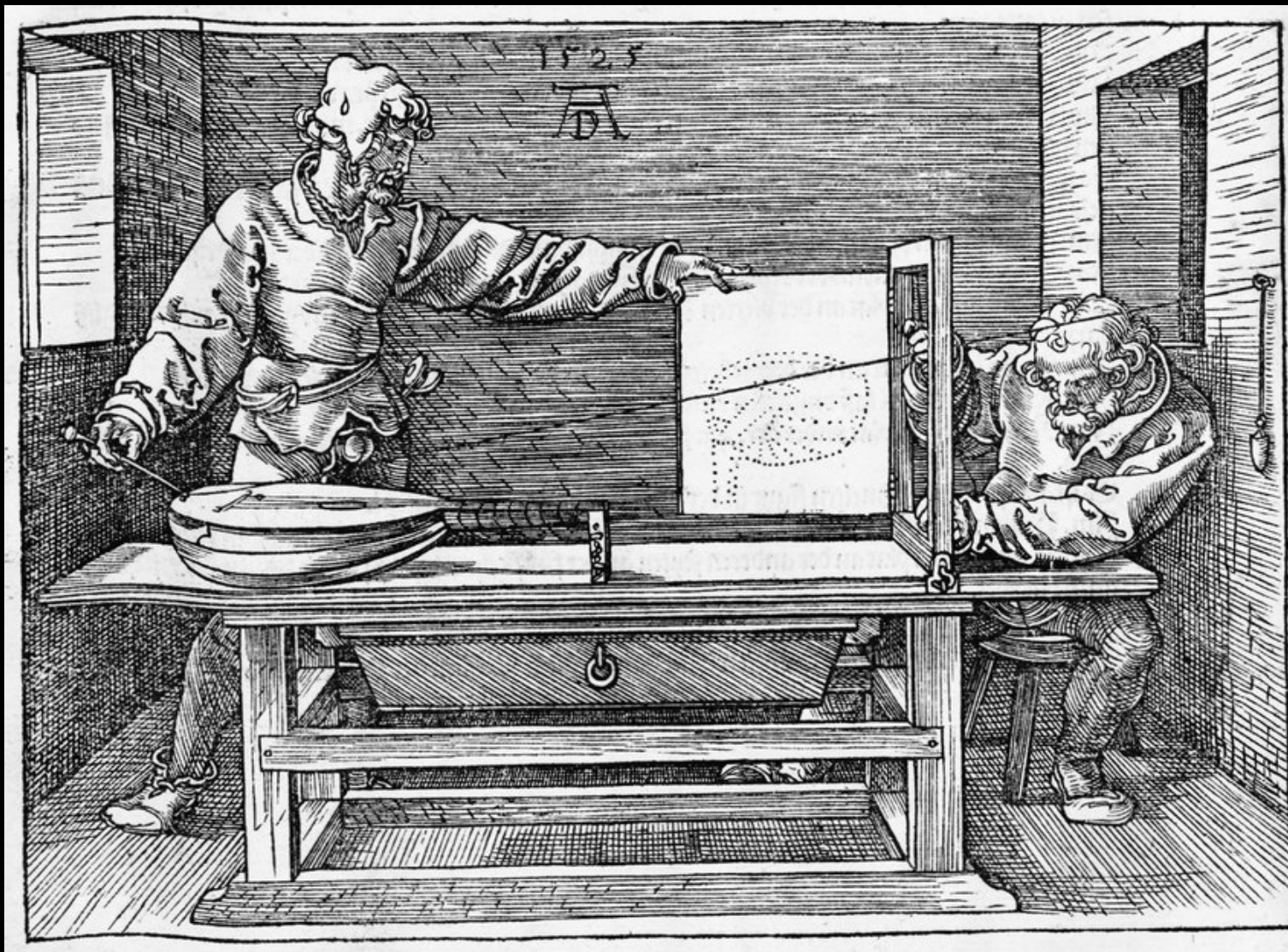


Ghost Effect

In the performance of Beyoncé's concert, she dances with herself by using projection mapping. It is easy to duplicate herself and use it in different ways. But to avoid the duplication is overlap with the real person, it leaves Beyonce a white gap between herself and virtual image.



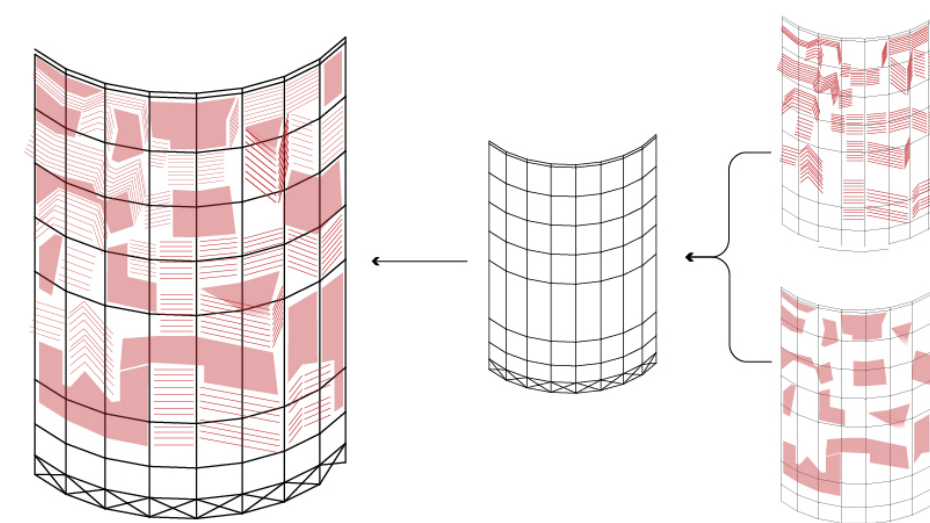
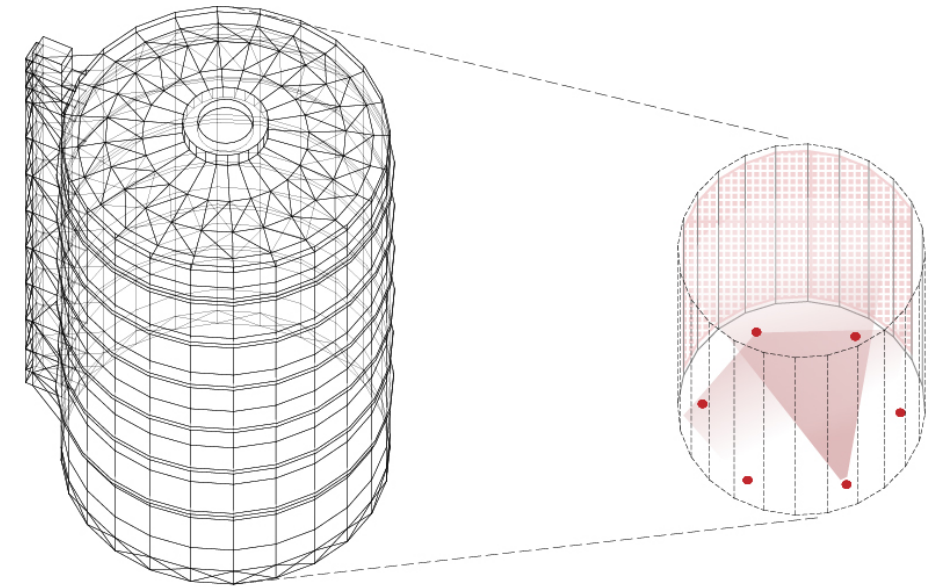
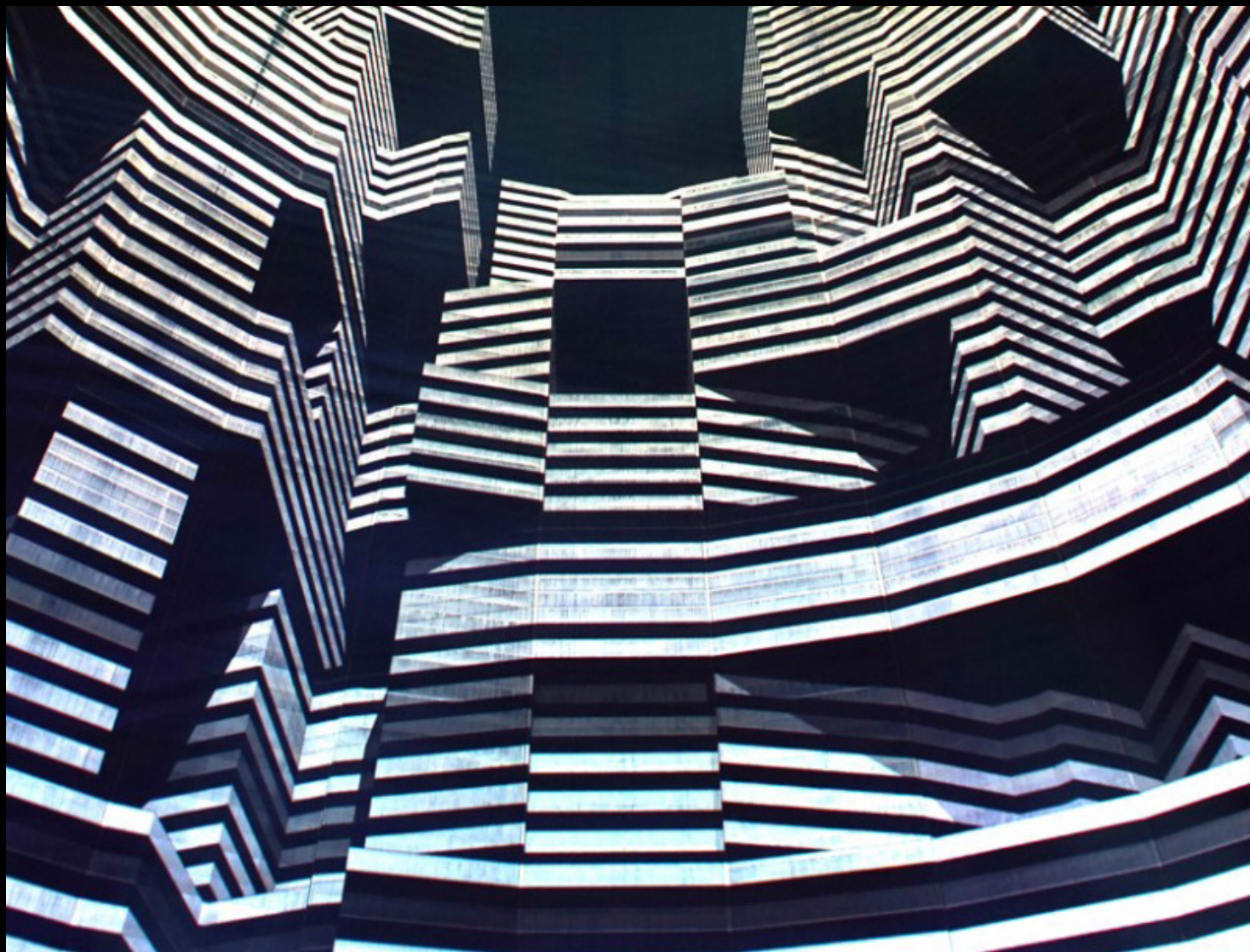
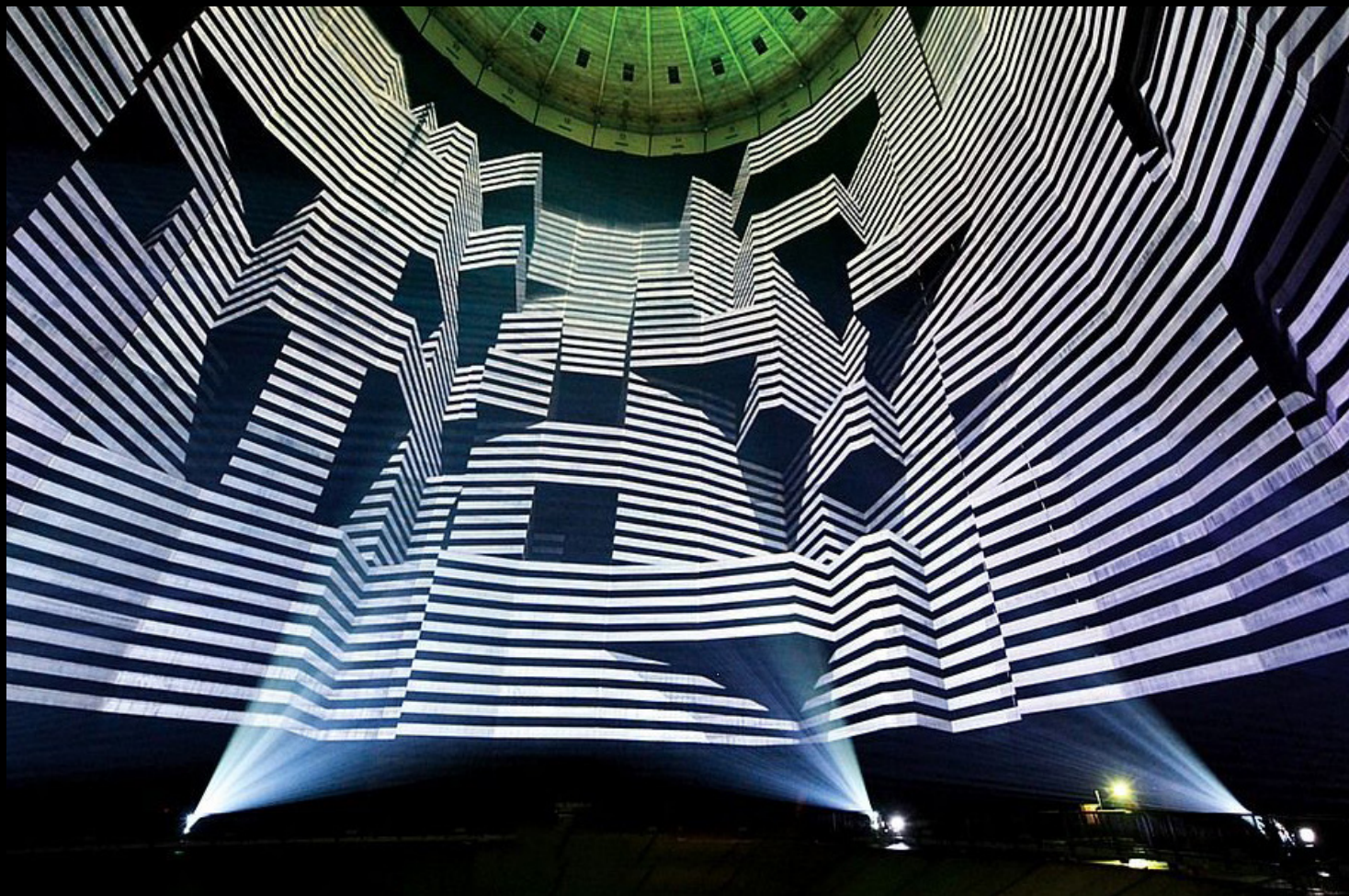
Perspective Reconstruction



Size constancy illusion

Human visual system is constantly making inferences based on constraints derived from the regularities of the visual environment. What we see is based on the perspective. It means the item can change the position and size to achieve the same effect. Like the Ames room illusion, through a small hole, the observer might think the room is a ordinary rectangle room but the actual shape is a six-sided convex polyhedron. The restriction is very important because it ensure the 'correctness' of the illusion. The peephole prevent the other information to tell the truth of the room.





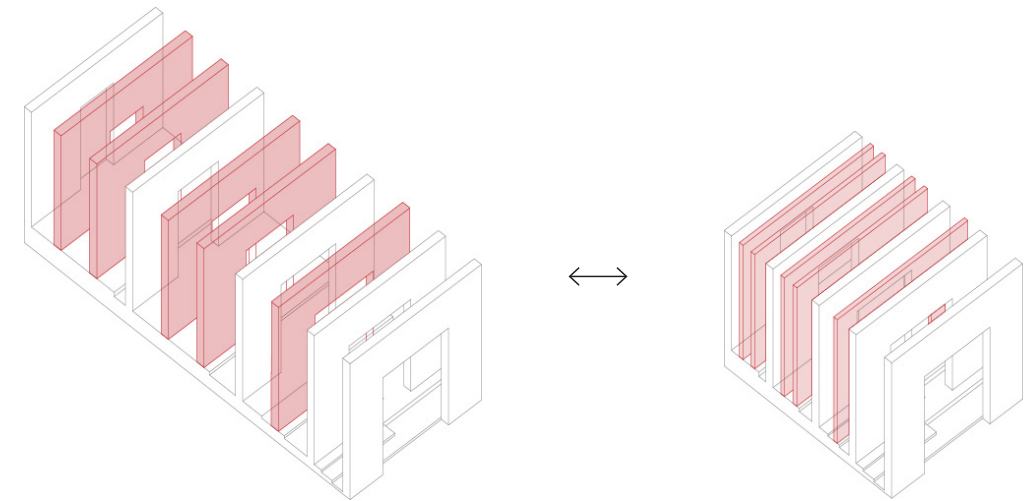
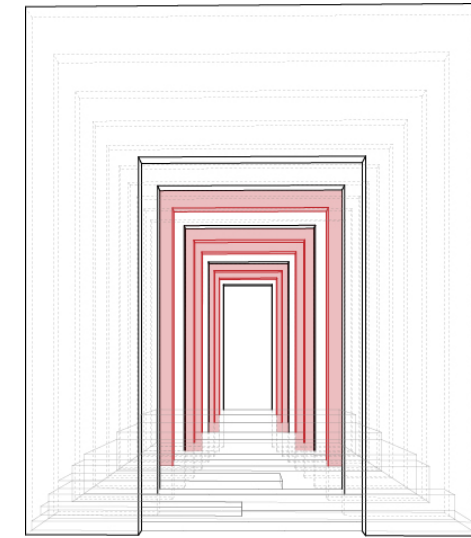
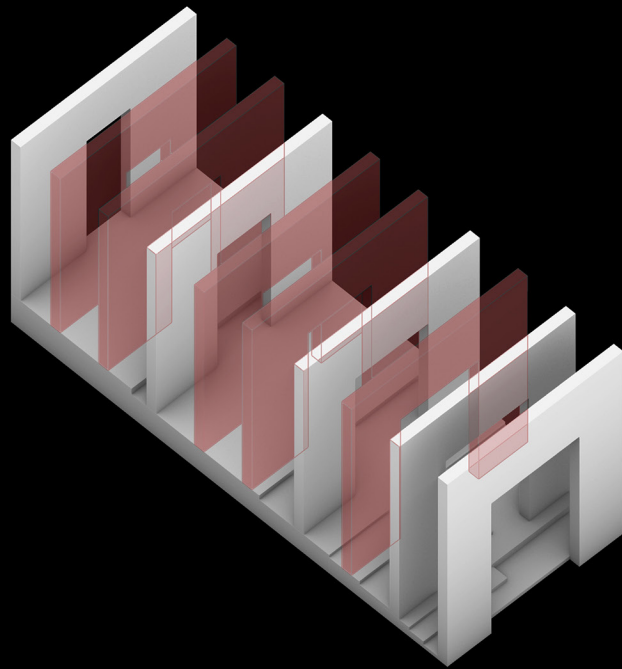
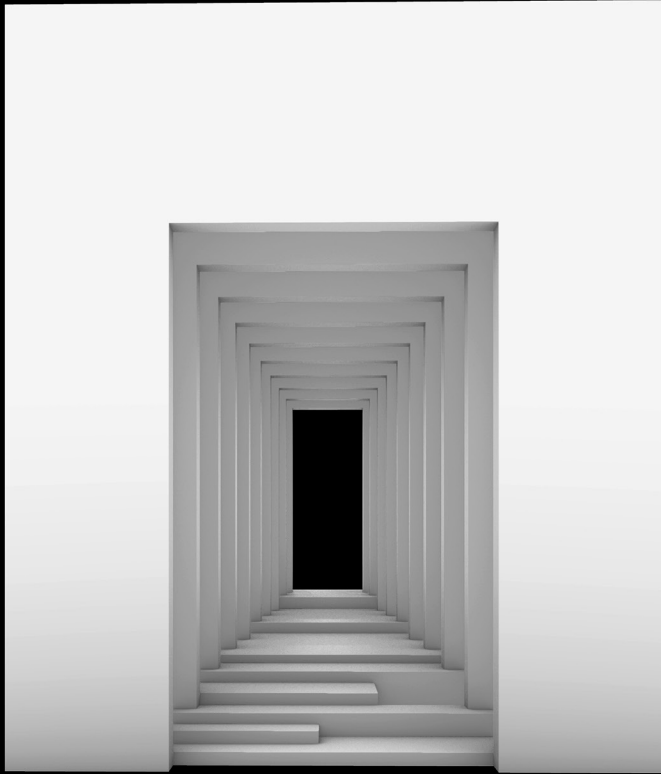
Lines and Shadow

The projection mapping on Gasometer Oberhausen shows the possibilities of changing the interior space. Along with the changing image on the internal surface, it provides a overwhelming environment around audience.

Within the huge gas container, the contour Lines and shadows are used to hint the shape of a mountain-like wall. According to lots of projection mapping, lines and shadows are the two basic tools to manipulate the space. The advantage of lines is that it does not need to light up a large part of the surface, decreasing the possibilities of finding the mistake. The shadows would enhance the influence if the images match the original surface.

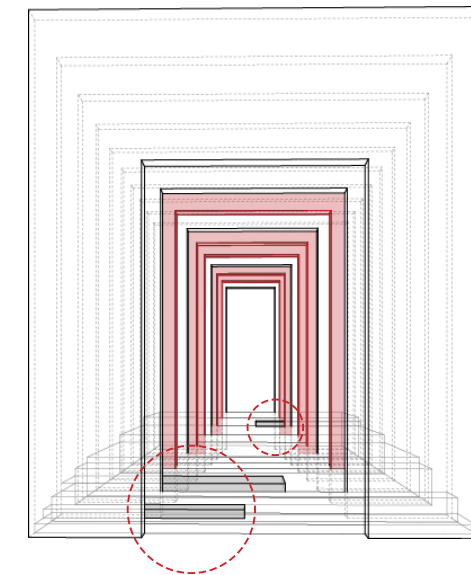
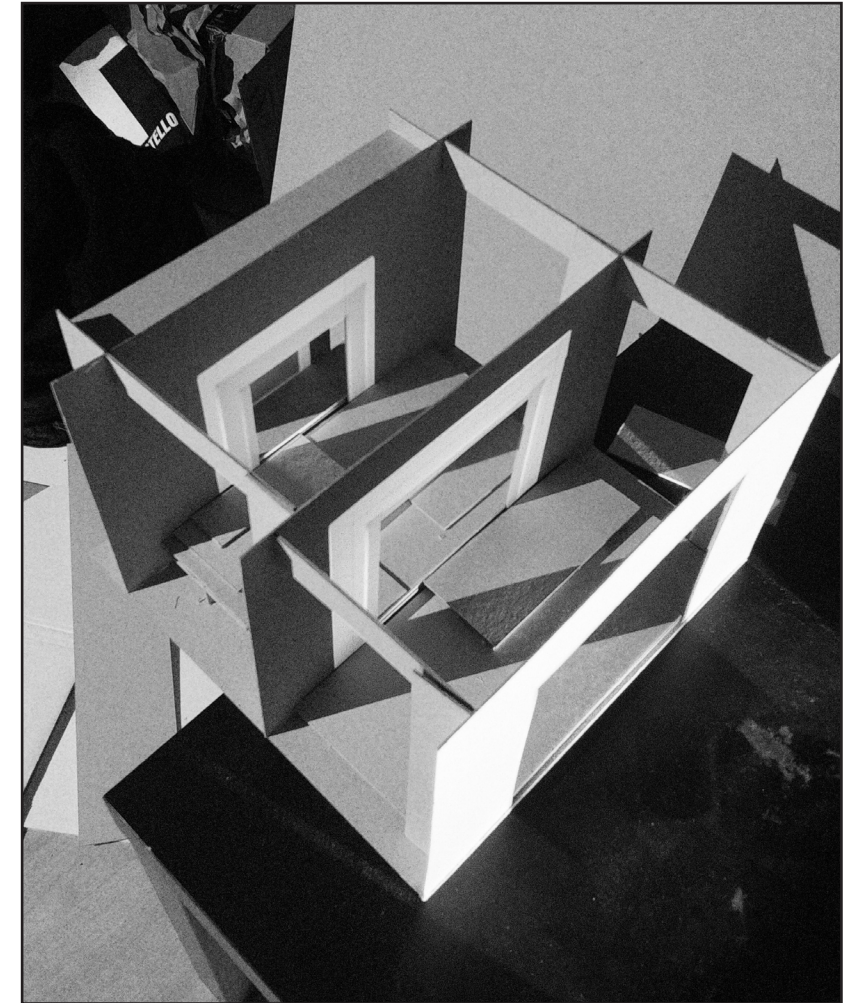
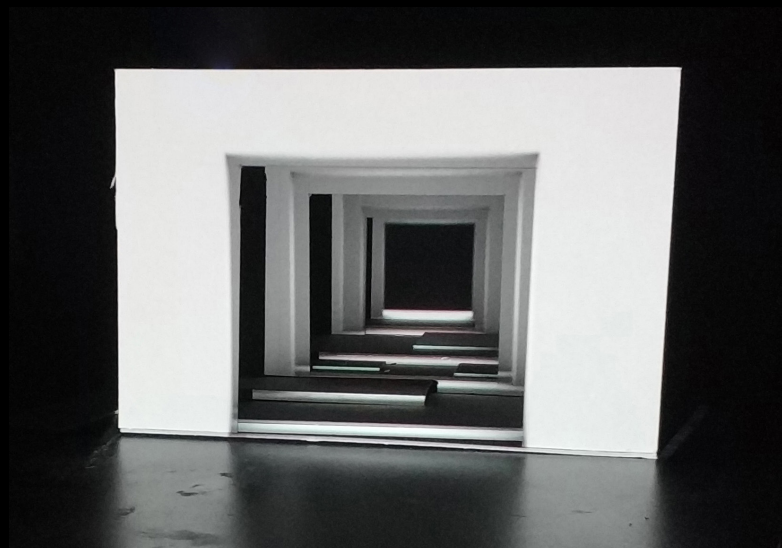
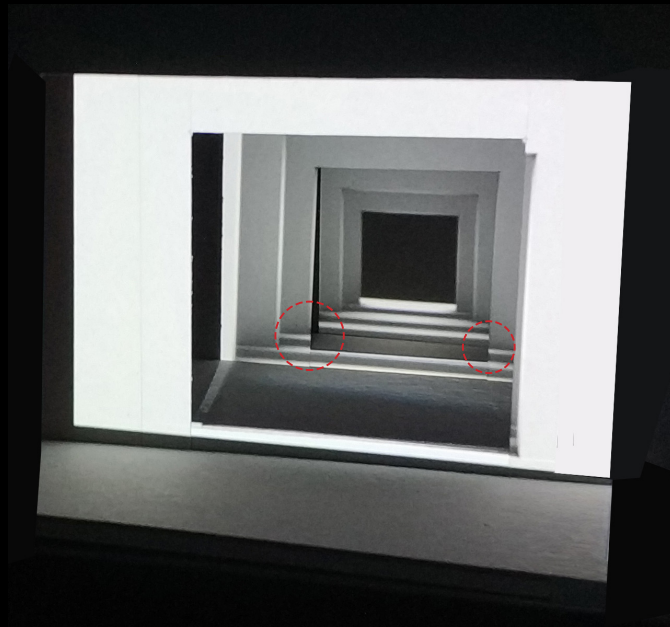
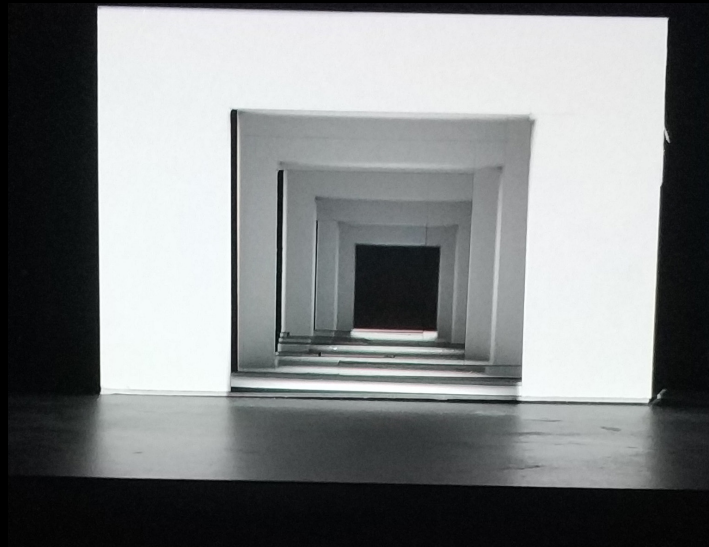
Chapter 3. Fantasy

- Accordion Corridor
- Delusion of Mess
- “Infinite” Staircase
- Borrow Scenery Screen Wall
- Column Forest
- Walls of Mountain
- Changed Shape based on Perspective
- “Mirror” Maze
- Double Faces

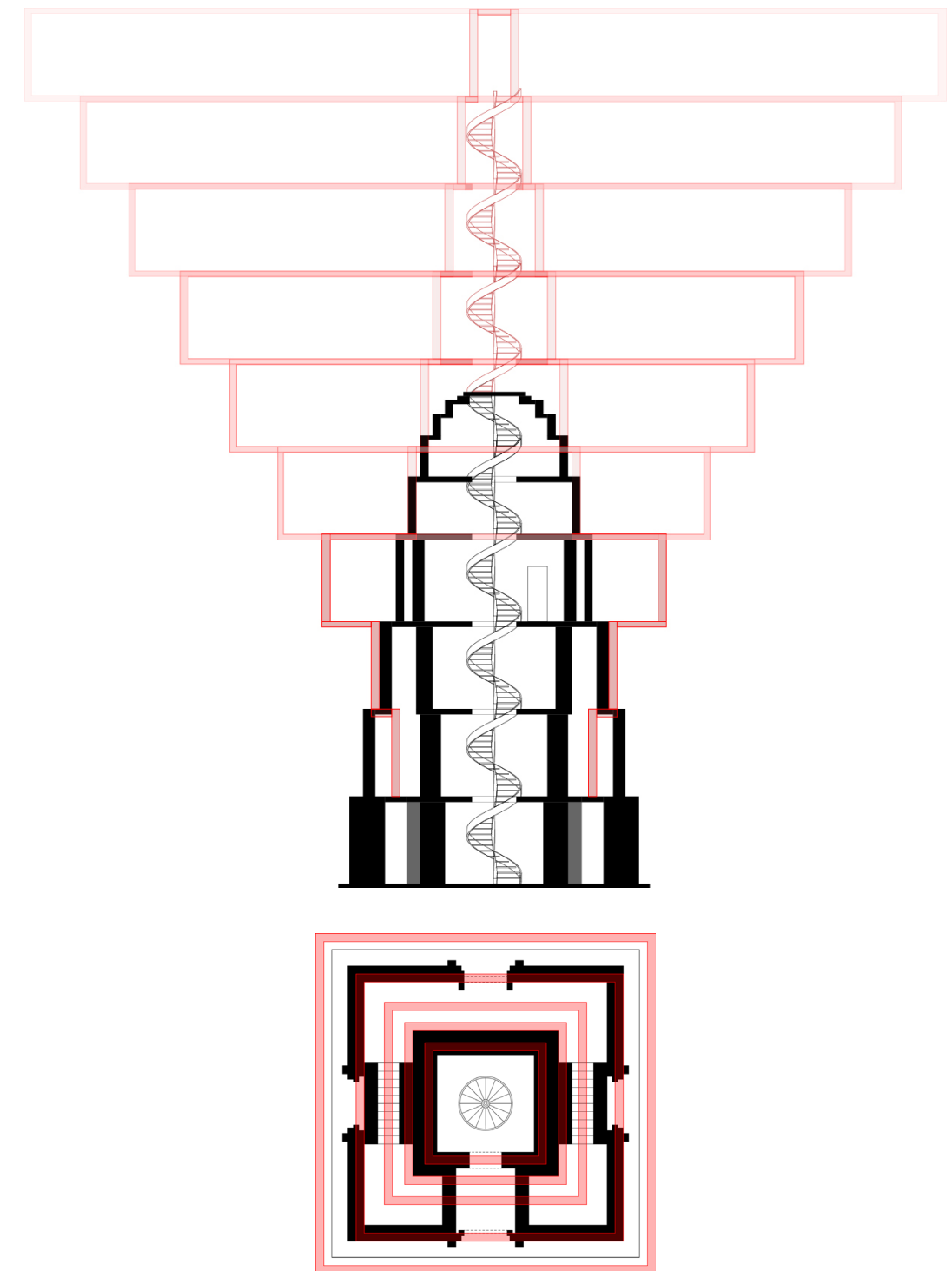
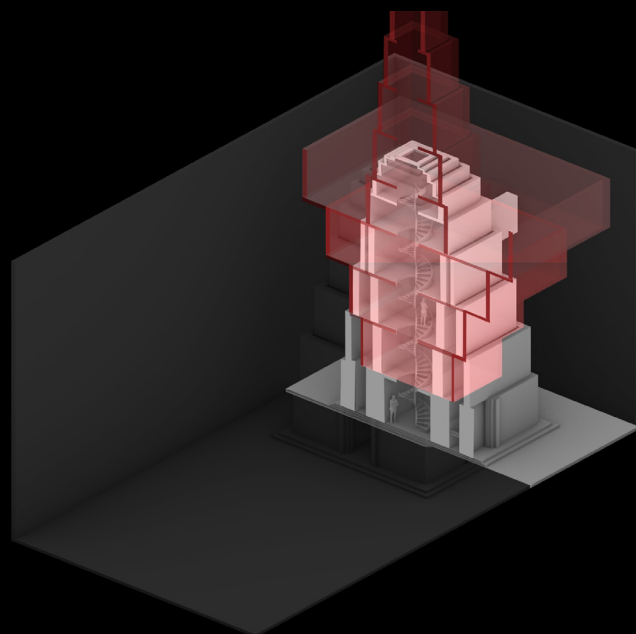
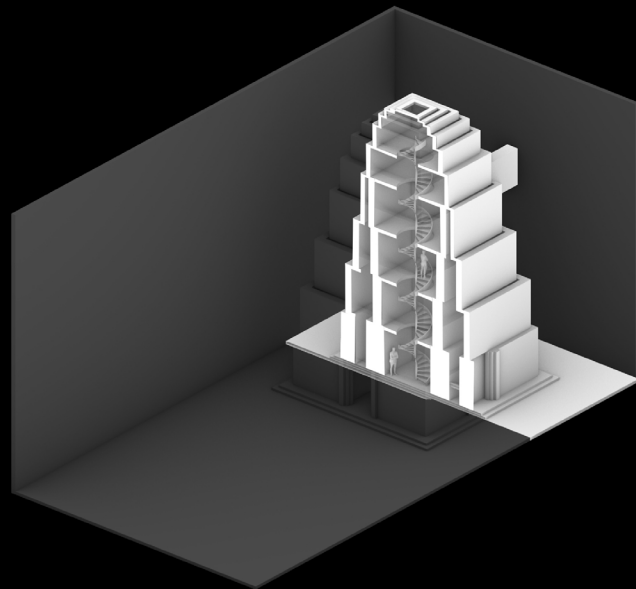
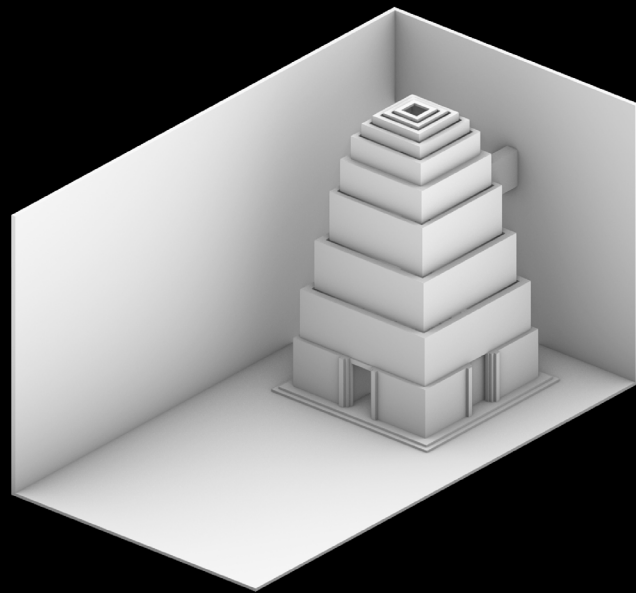


Accordion Corridor

Use the virtual image to change the perception of layers of archway.
The gates seems to be increased and the depth of the corridor has been extended.
It is also possible to create different space between the real gates or compressed the corridor if the space is limited.



By the experiment, the effect of increasing the depth of corridor is great. The shadows on the surface of the gate makes the illusion of adding one more gate. But if camera go closer into the gate, the mismatch of the projection and stairs seems weird. The stairs is tidy so it is clear to see this bug. In order to cover up this bug, more random steps are added on the original ones to make the stairs a little messy. It can be regarded as a delusion caused by messy elements.

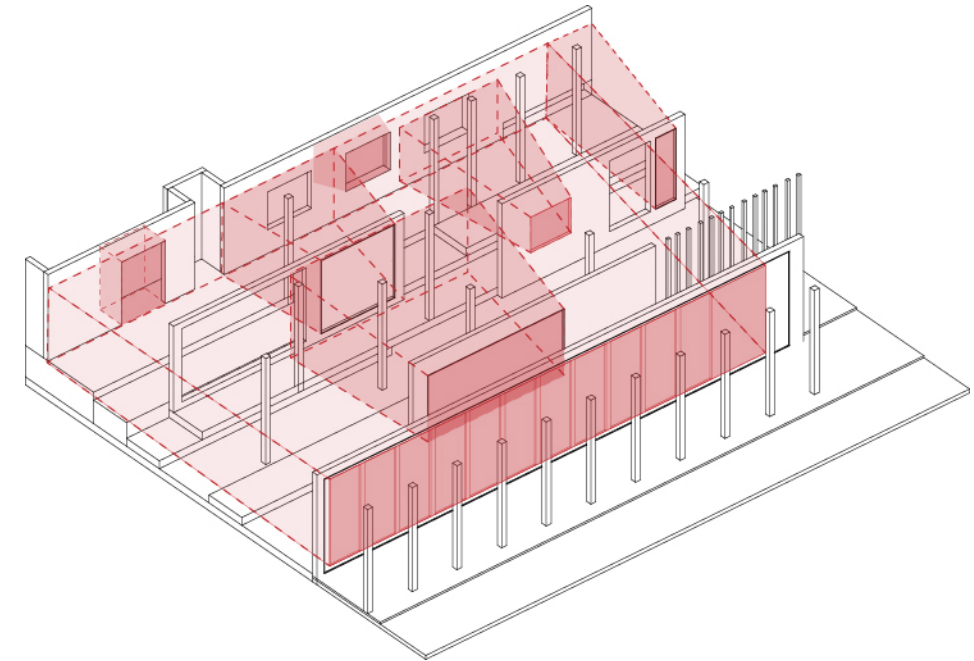
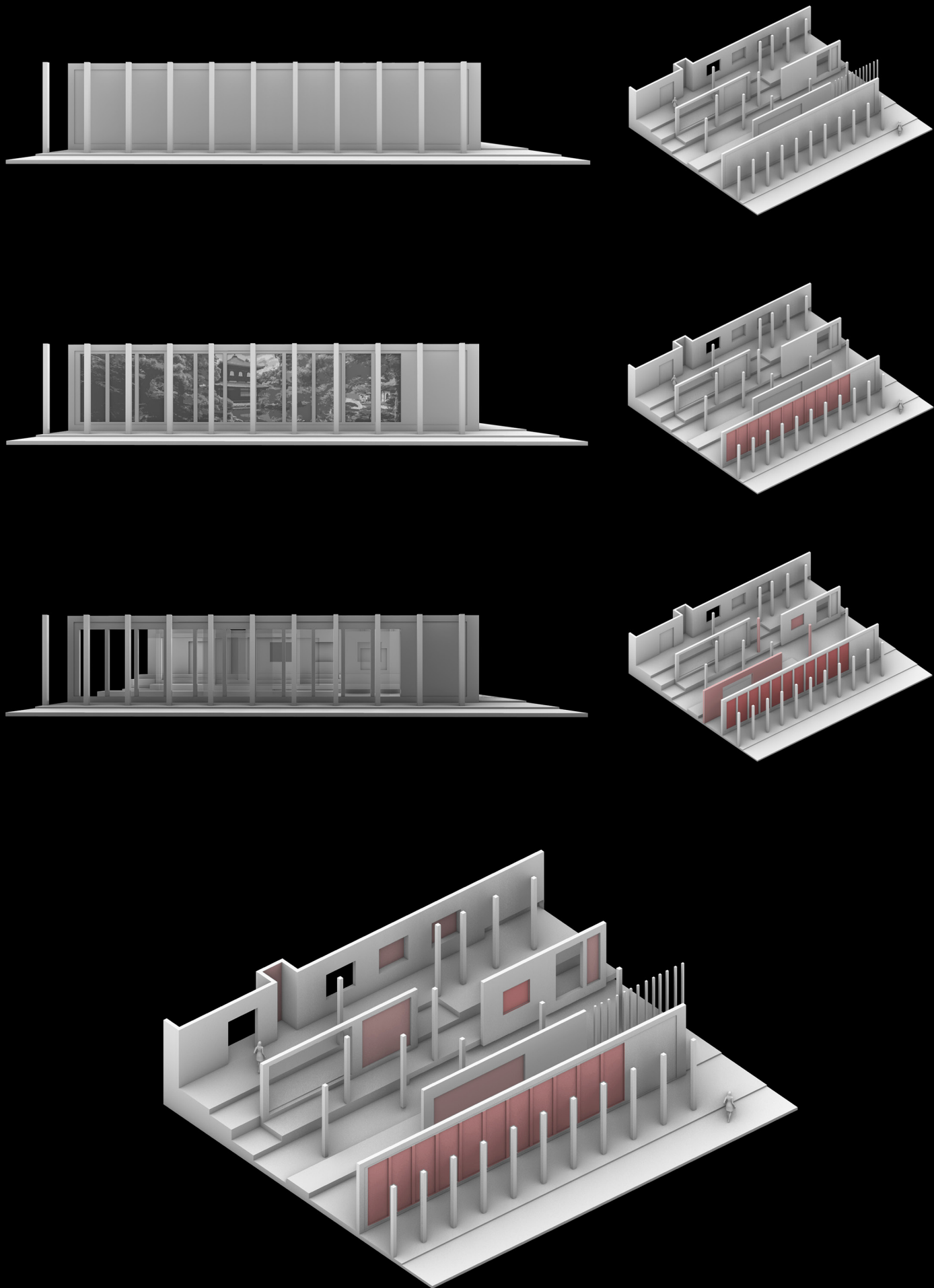


“Infinite” Staircase

The design is to create a contrast between expectation and real experience. With the application of augmented reality, the contrast can be reinforced.

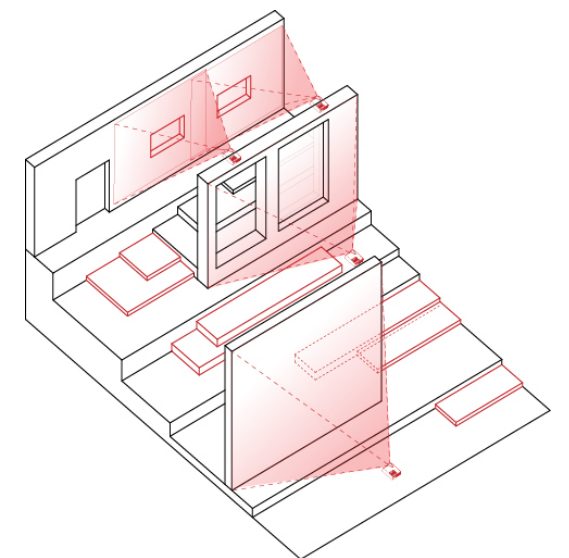
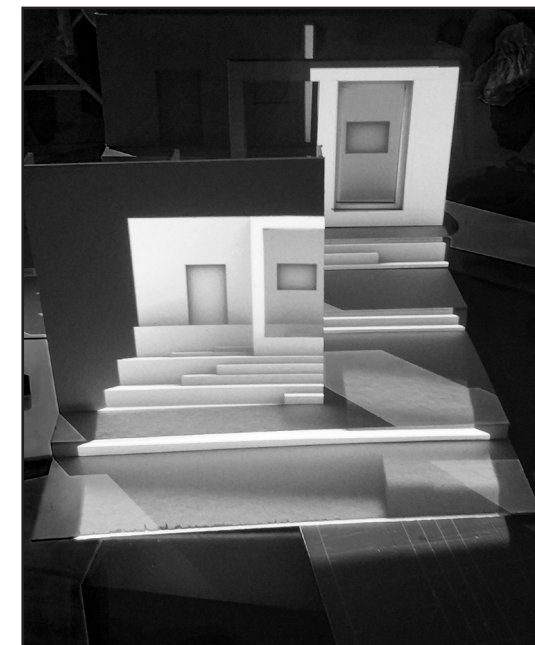
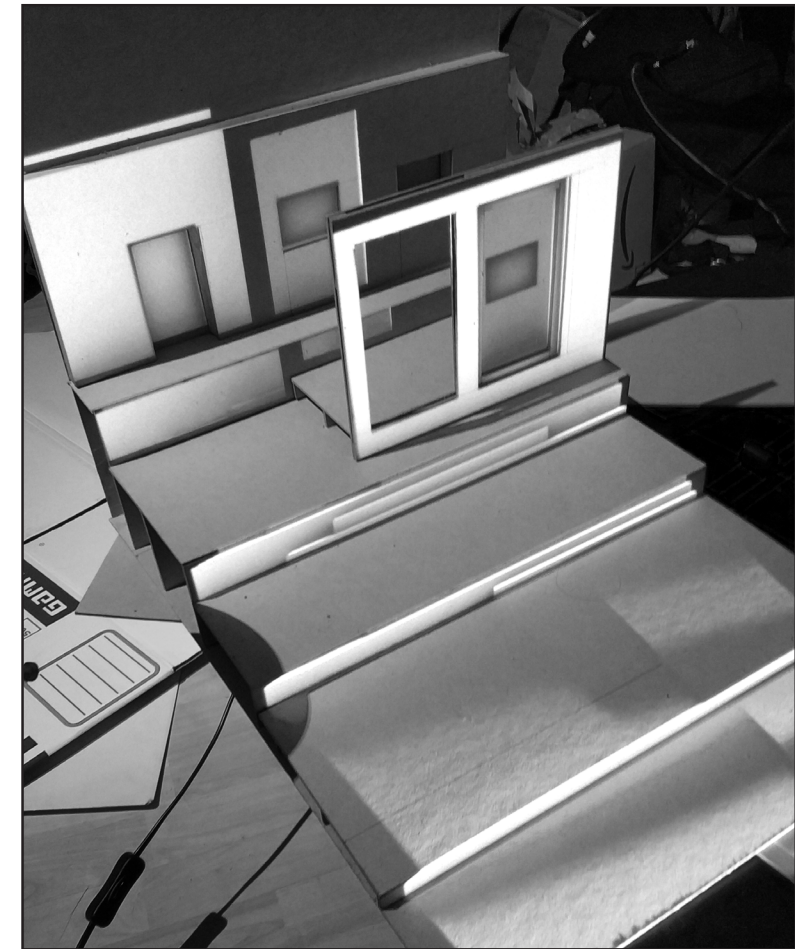
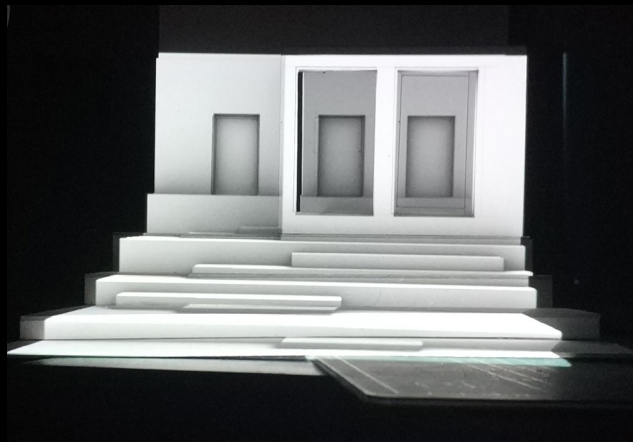
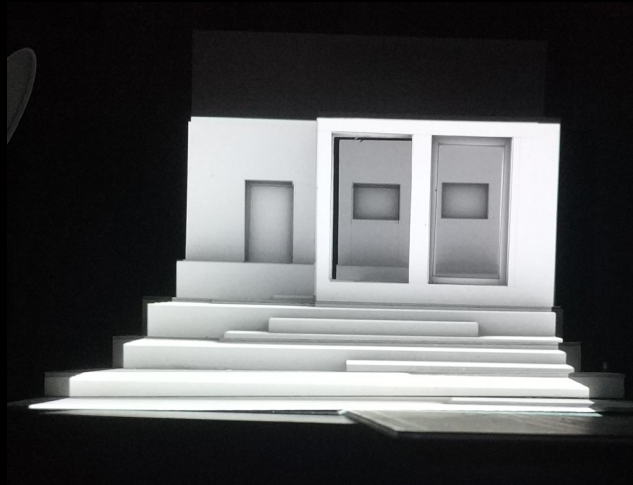
Before people come into the tower, they might imagine the space inside the tower becomes smaller when along the increase of height. But actually inside the tower, the space of the staircase becomes bigger when you go upper.

The image on the wall inside the staircase provides a perception that it becomes even bigger.

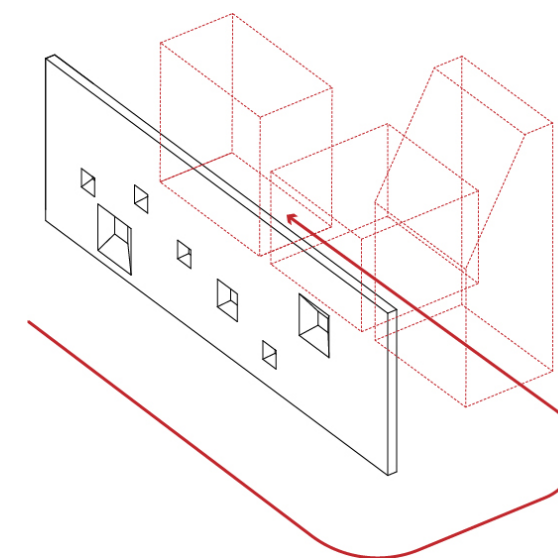
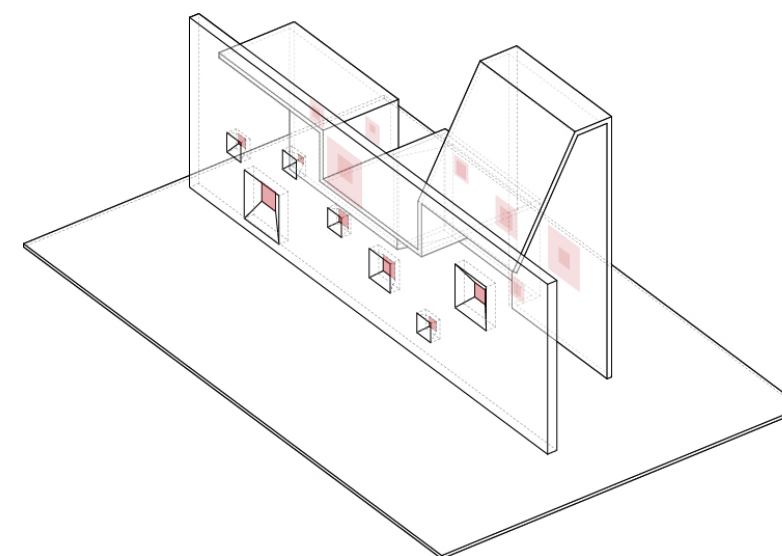
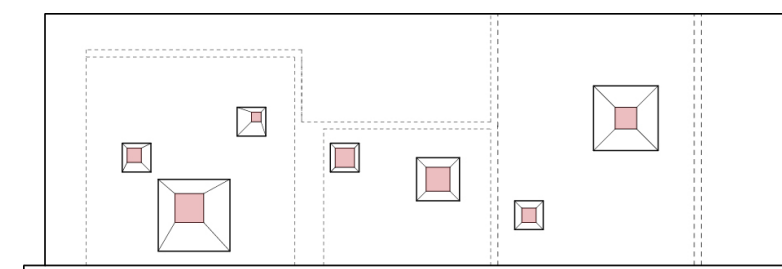
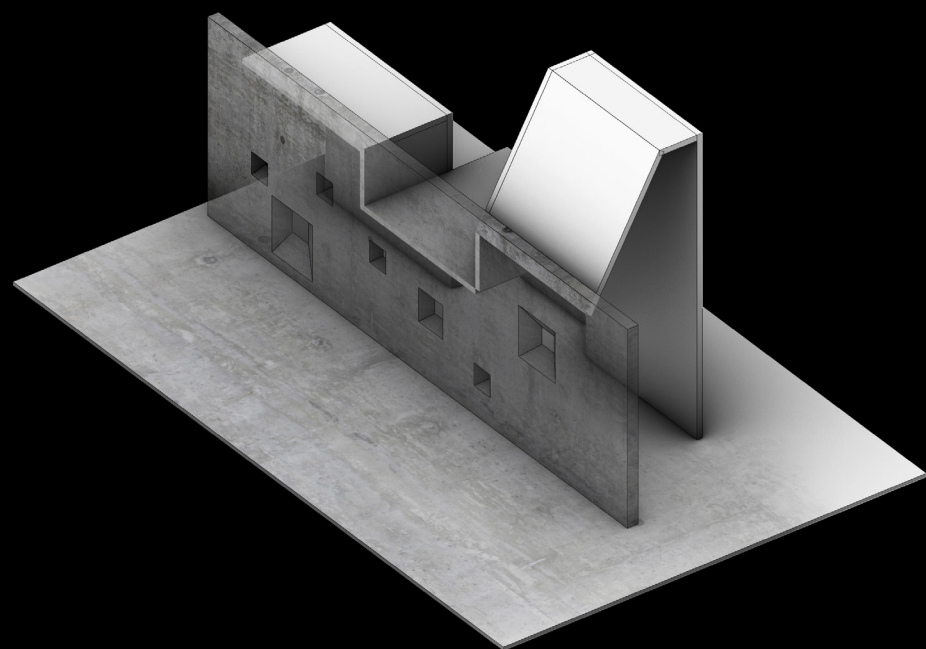


Borrow Scenery Screen Wall

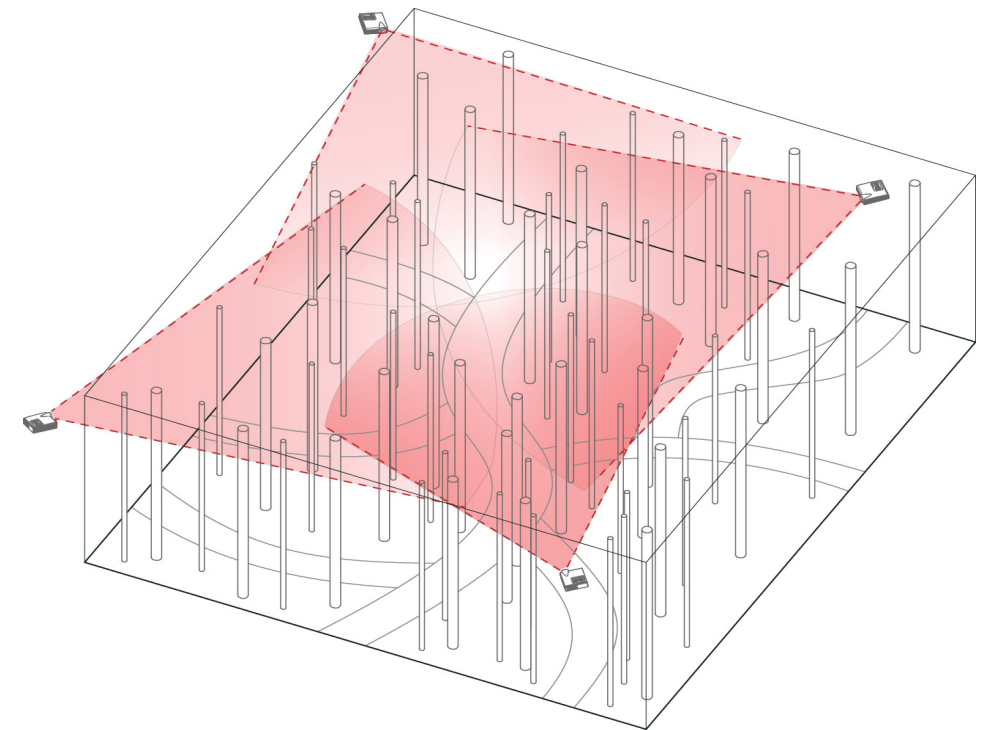
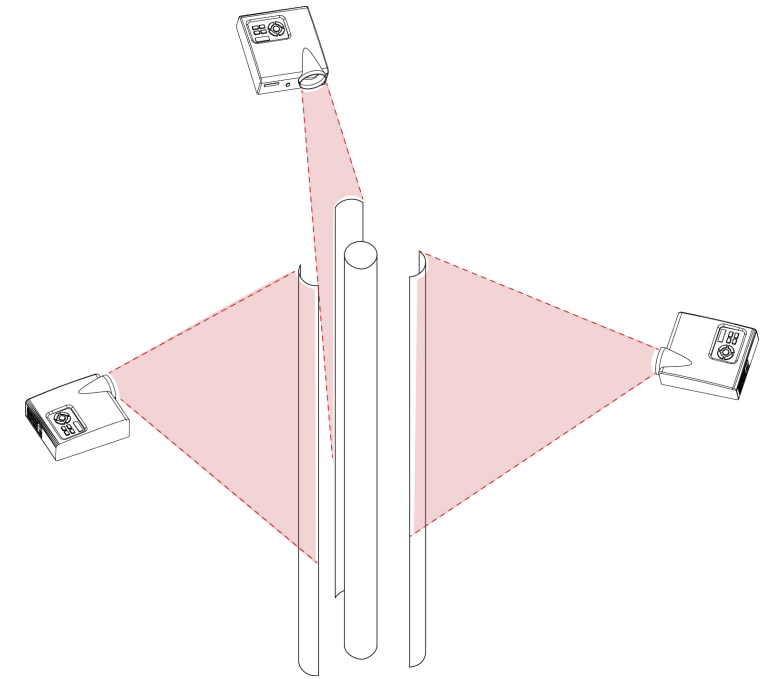
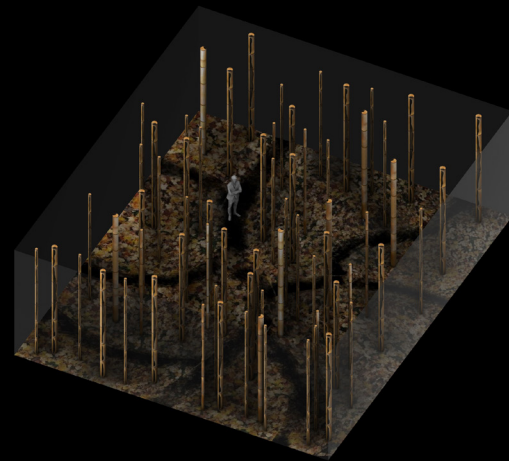
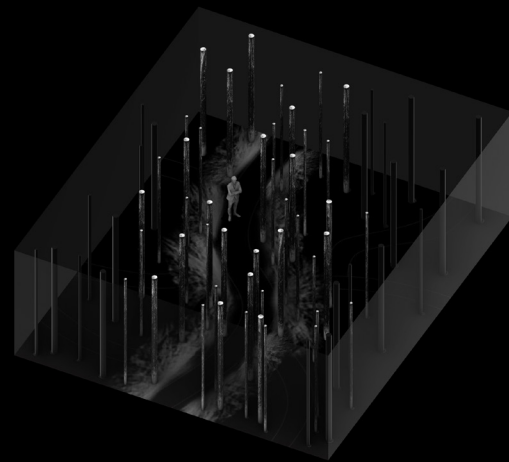
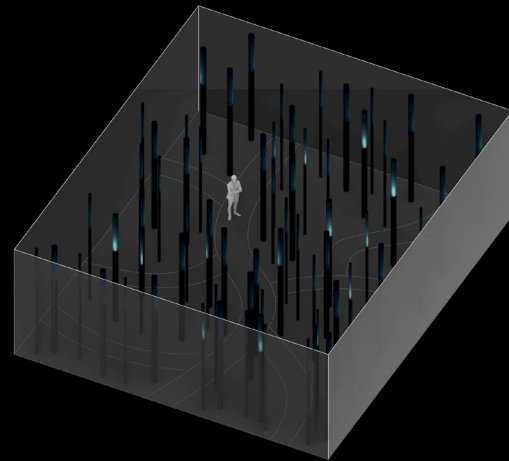
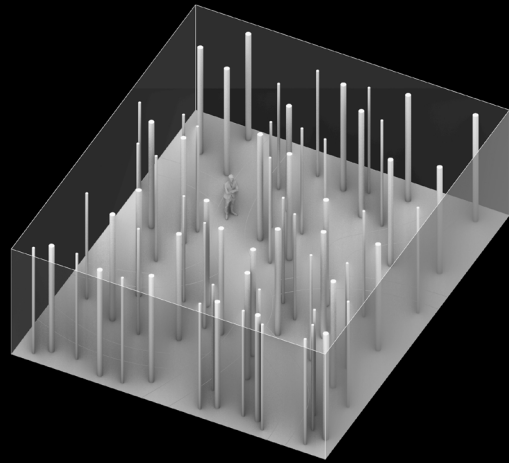
Use the virtual image to change the perception of what audience can see though the windows. Sometimes it can be the fake scenery and sometimes it can be the wrong perspective of the walls behind. So audience can see different views though the windows.



The visible scene, such as the view inside the windows and the stairs in the photo, is easily to switch from one form to another. And by adding the shadow in the image in the projection, it is difficult to tell the depth of space. But if the distance between to wall is larger, it would create a big gap between two walls. It is better to use two projector if the distance is large.

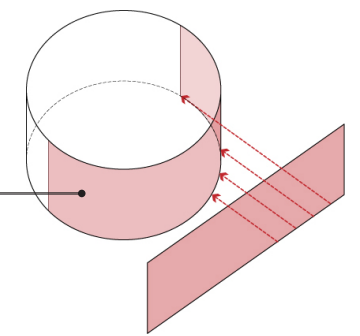
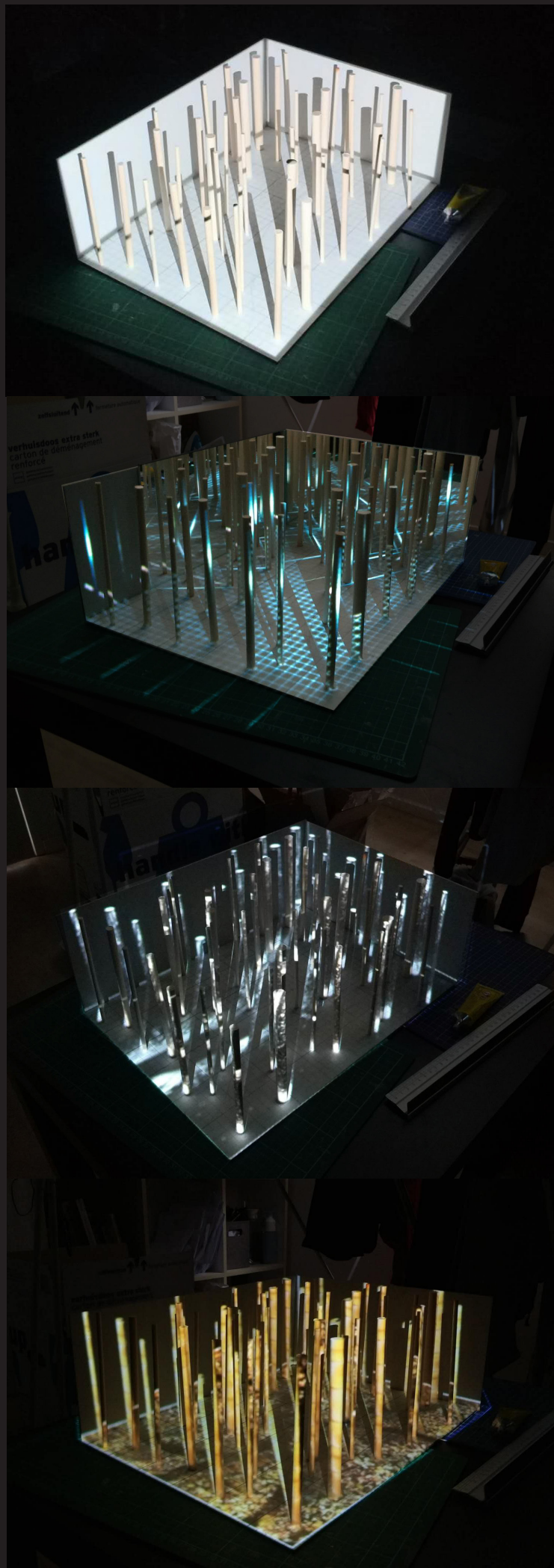


Through a series of small windows, audiences may regard the space behind the wall as a whole. But after they go to the back of the wall, they may find out the space is totally different in height and depth. With the different projection on the wall, the space have potential to become different part of the building.

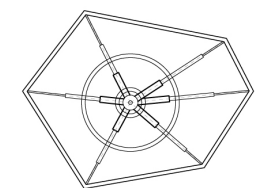
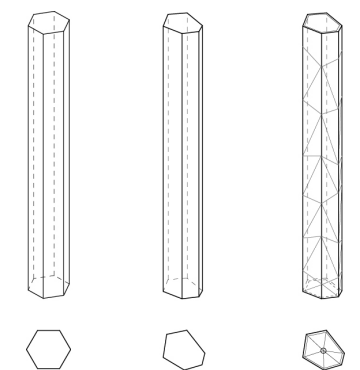
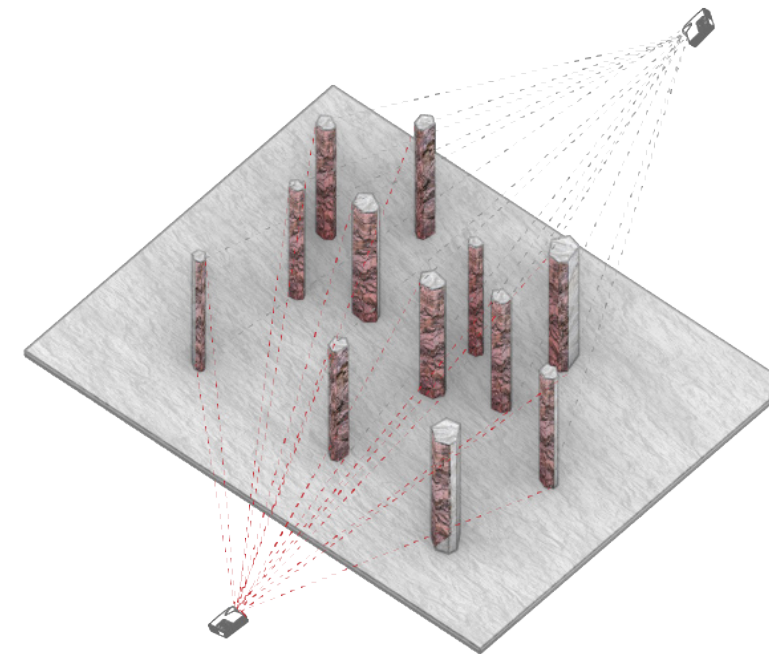


Column Forest

It make use of the round shape of the circular columns to provide different face in the space. So the columns forest provide different screen for the projector. It might create different impression for audience along the path. It can also change the pattern projected on these columns and change the atmosphere and scene. But it also need boundary hint for audience to avoid crash intot he columns.

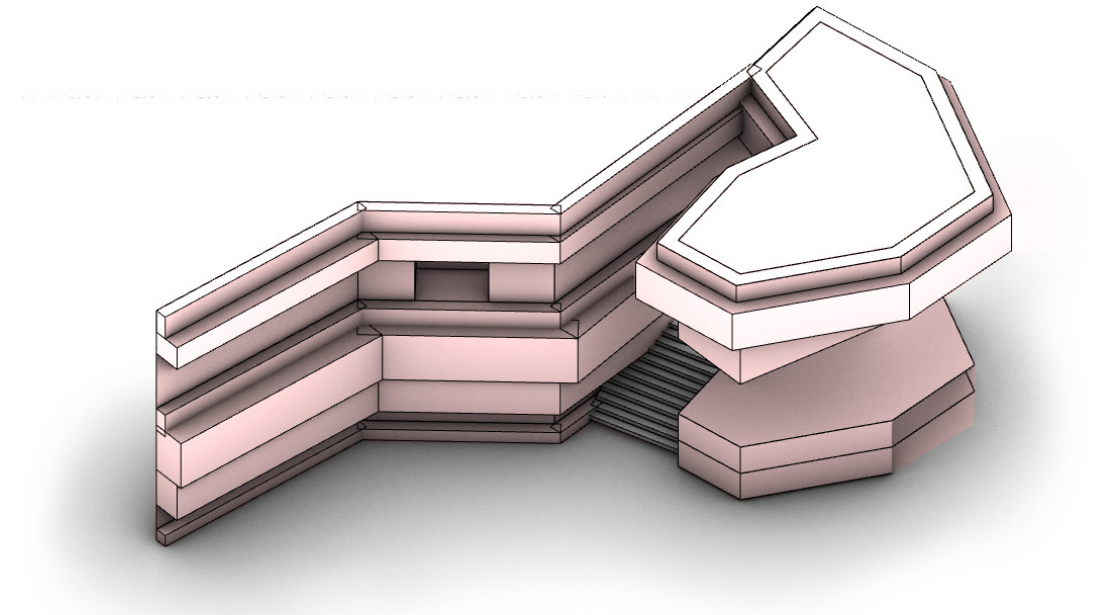
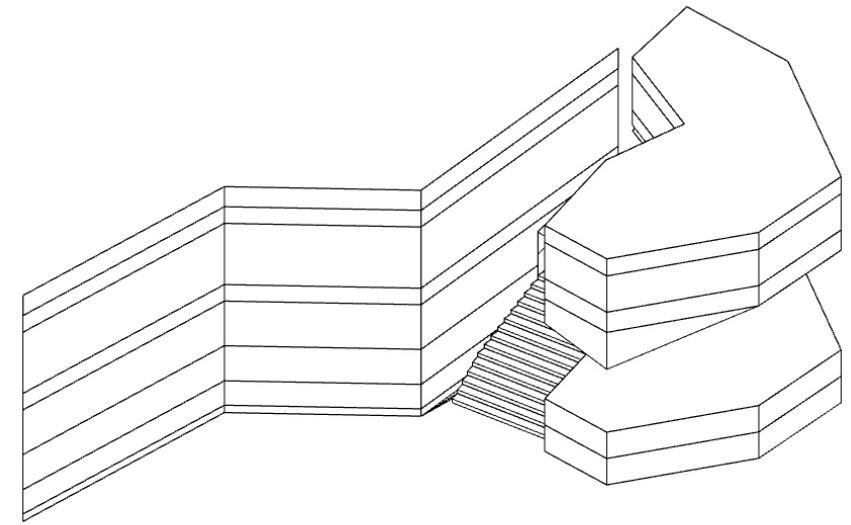
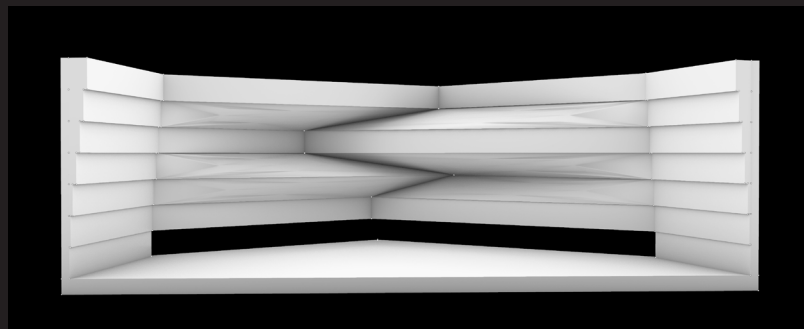
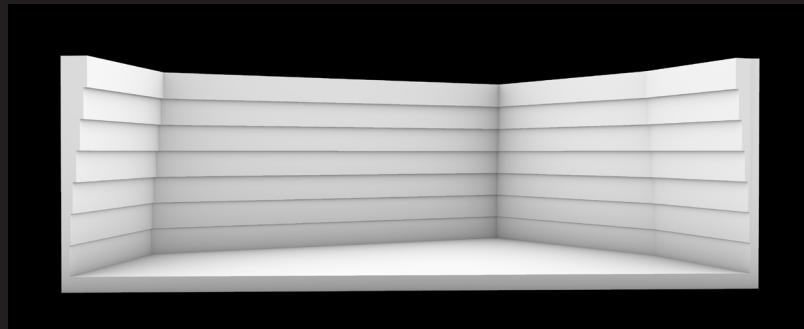
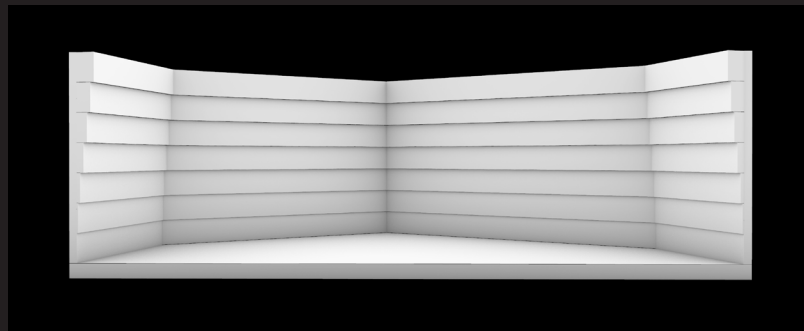
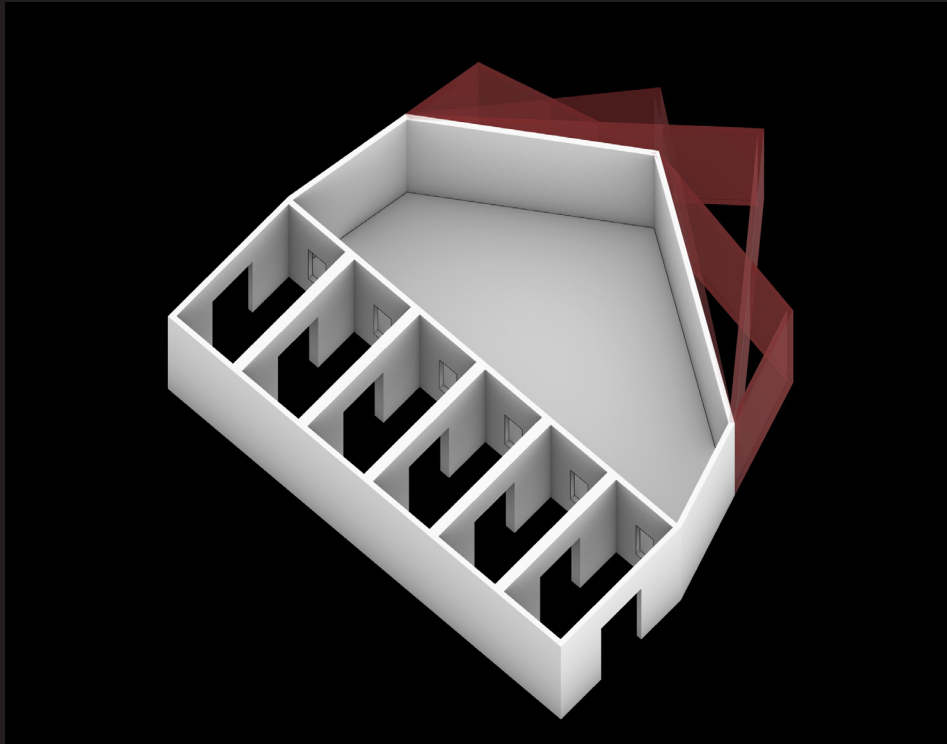


Distortion of the image



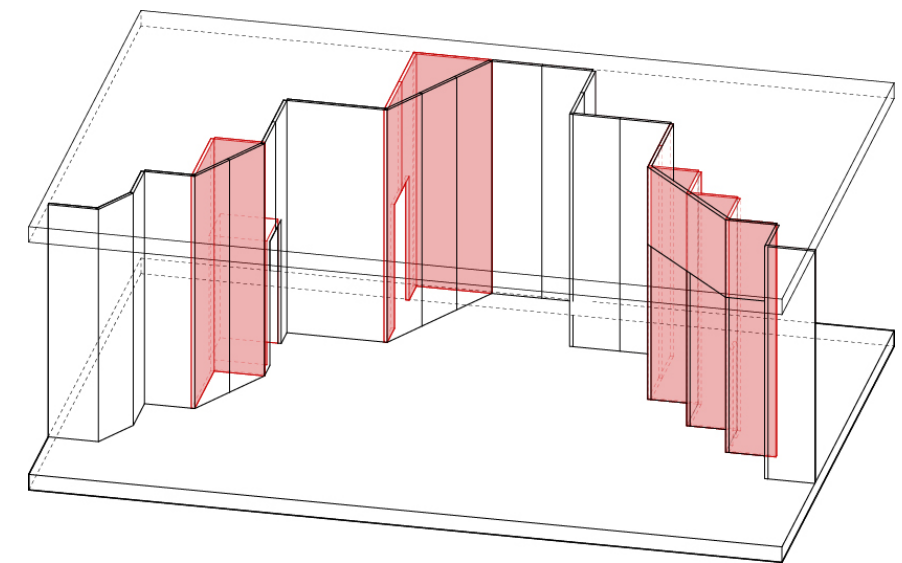
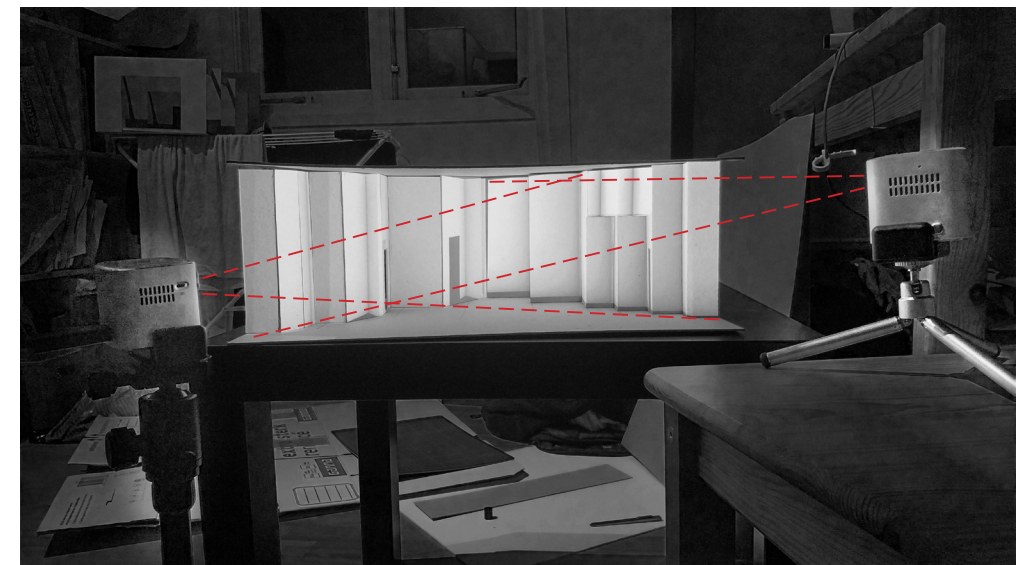
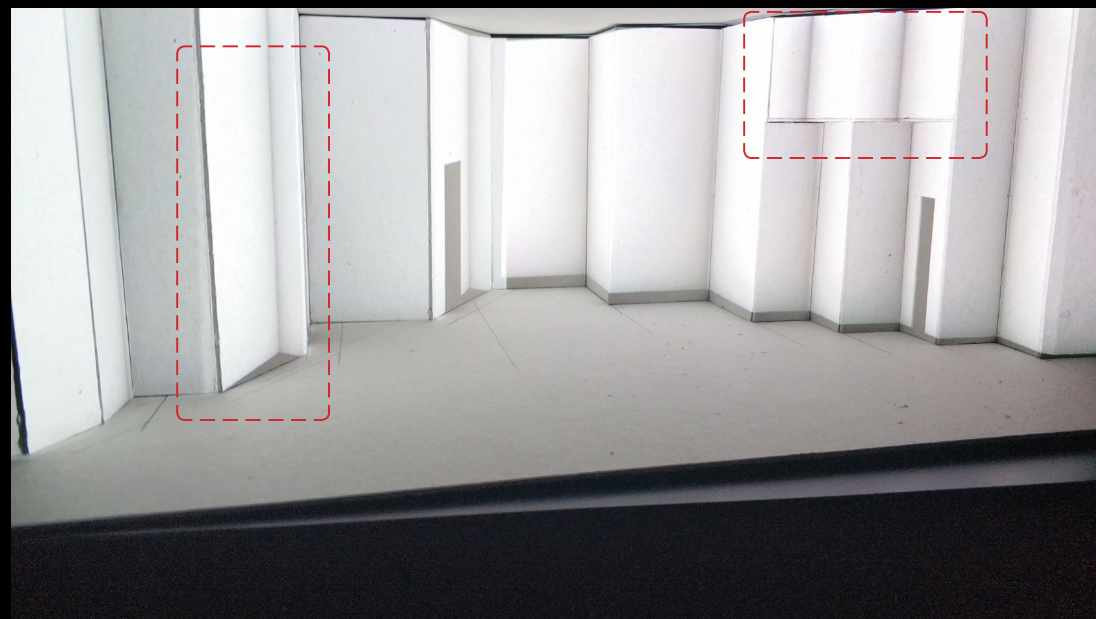
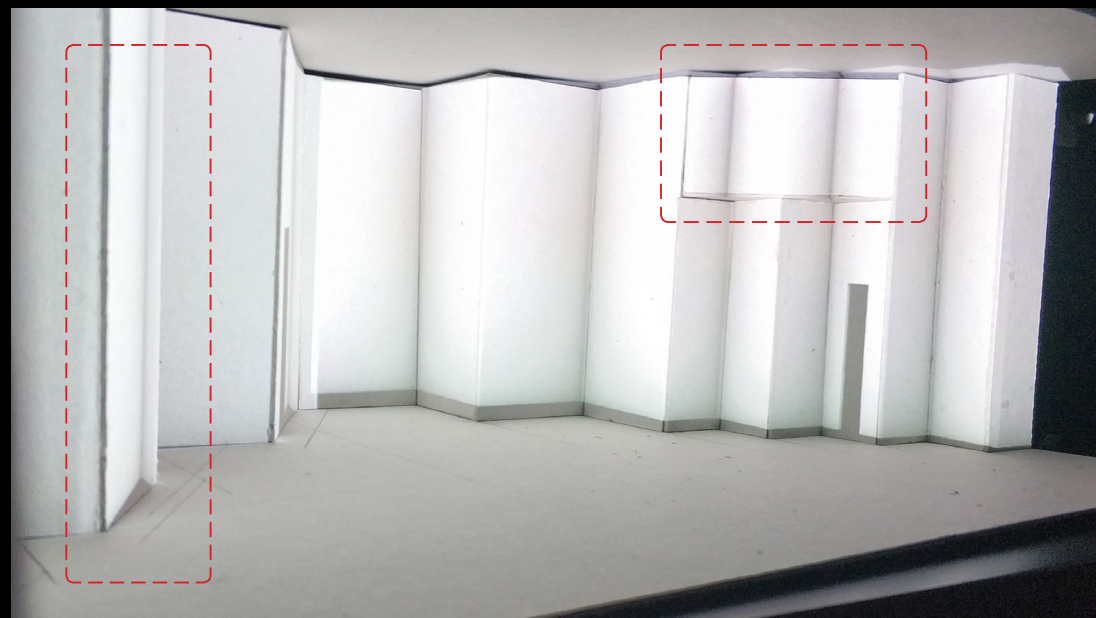
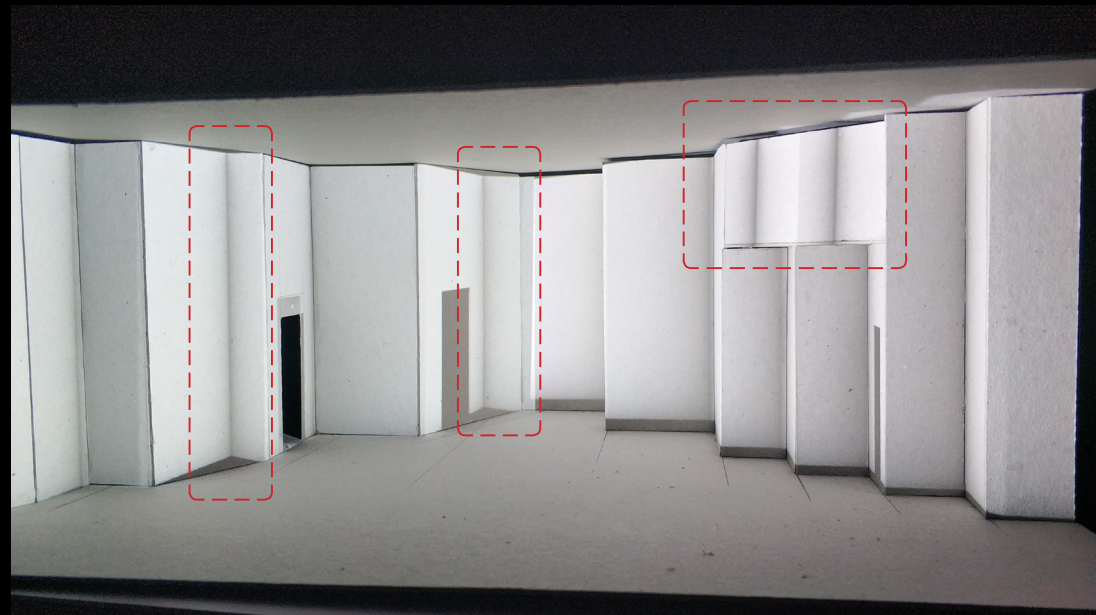
Columns with flexible surface

Due to the difference in the shape of surface and projection, the image may be distorted in the end. It could be solved by pre-distortion in software. But if the surface is a geometric instead of hyperboloid, it would be easier to solve the problem by simply move the control point. Also if the columns consist of a series of triangular facets, it could be integrated with mechanical equipment to realize the flexible transformation.

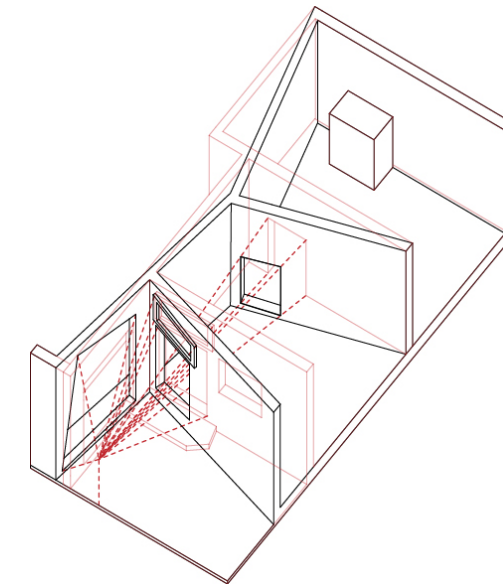
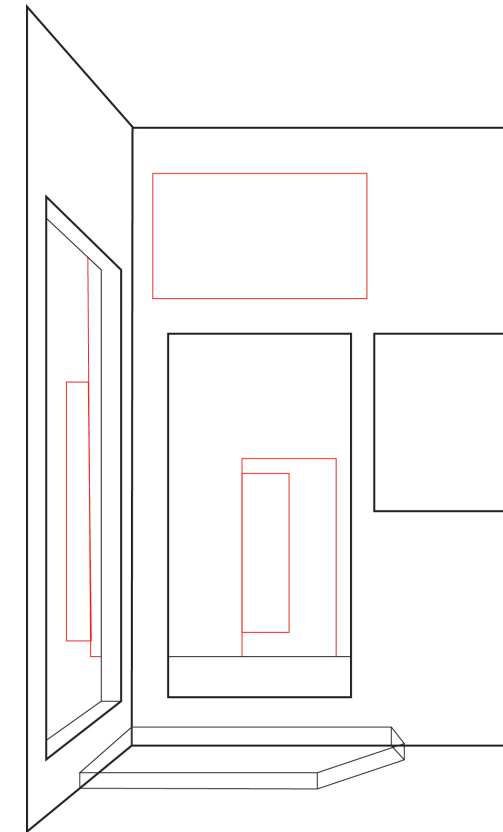


Walls of Mountain

The huge wall of can be used for projection as a cliff inside the mountain. Contour lines and shadows can be used to create convex and concave on the walls. Some holes in the walls is actual holes which audience can look out from the holes.

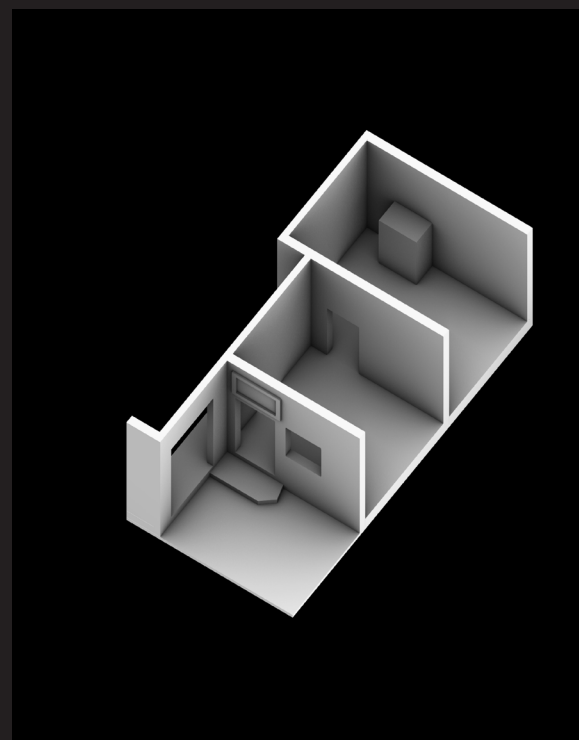
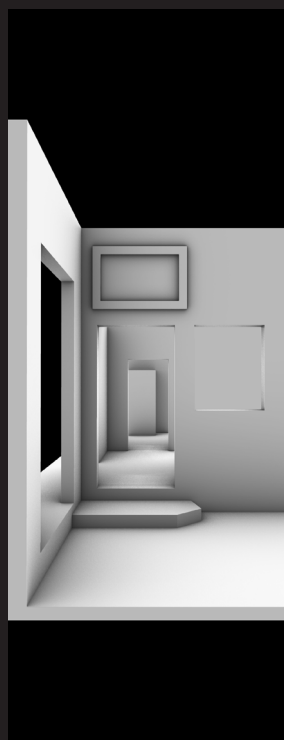


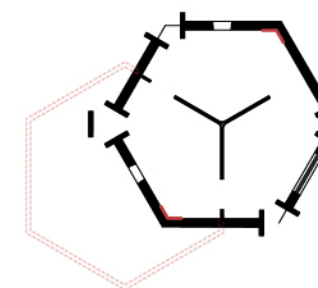
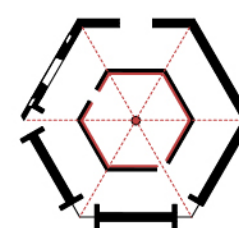
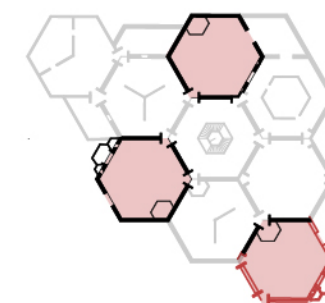
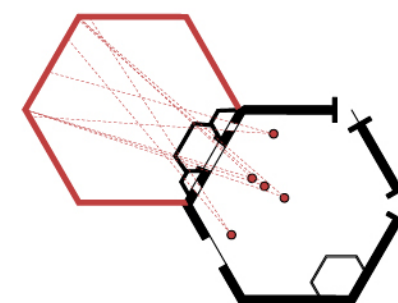
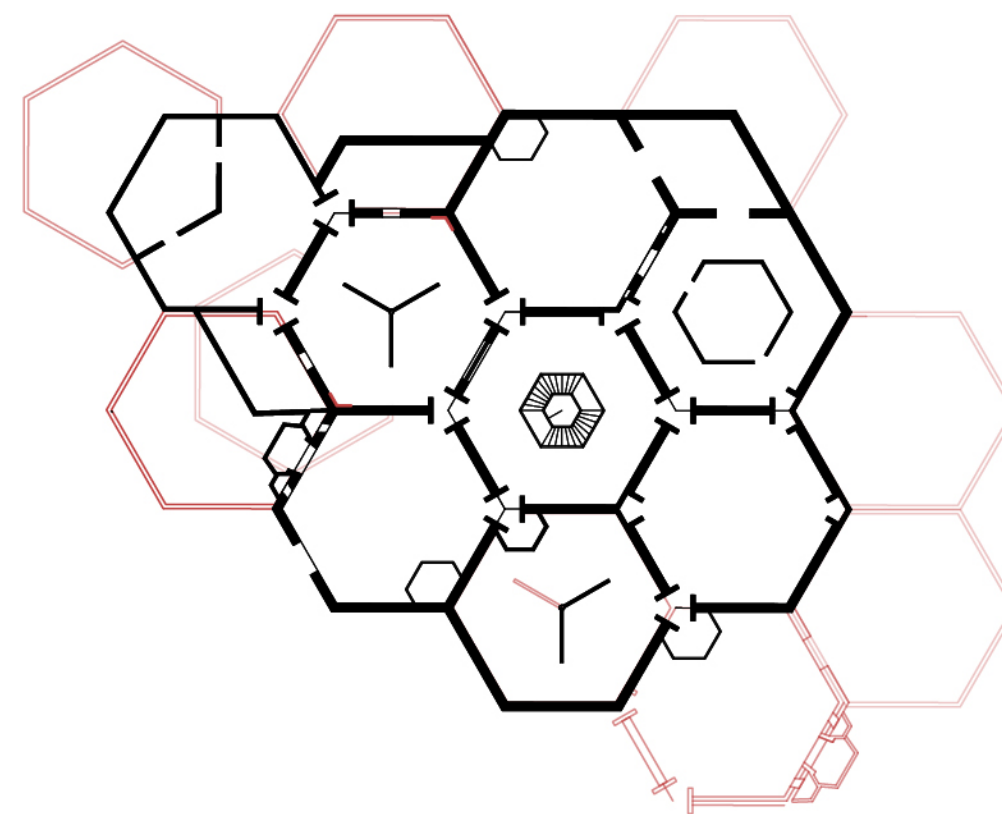
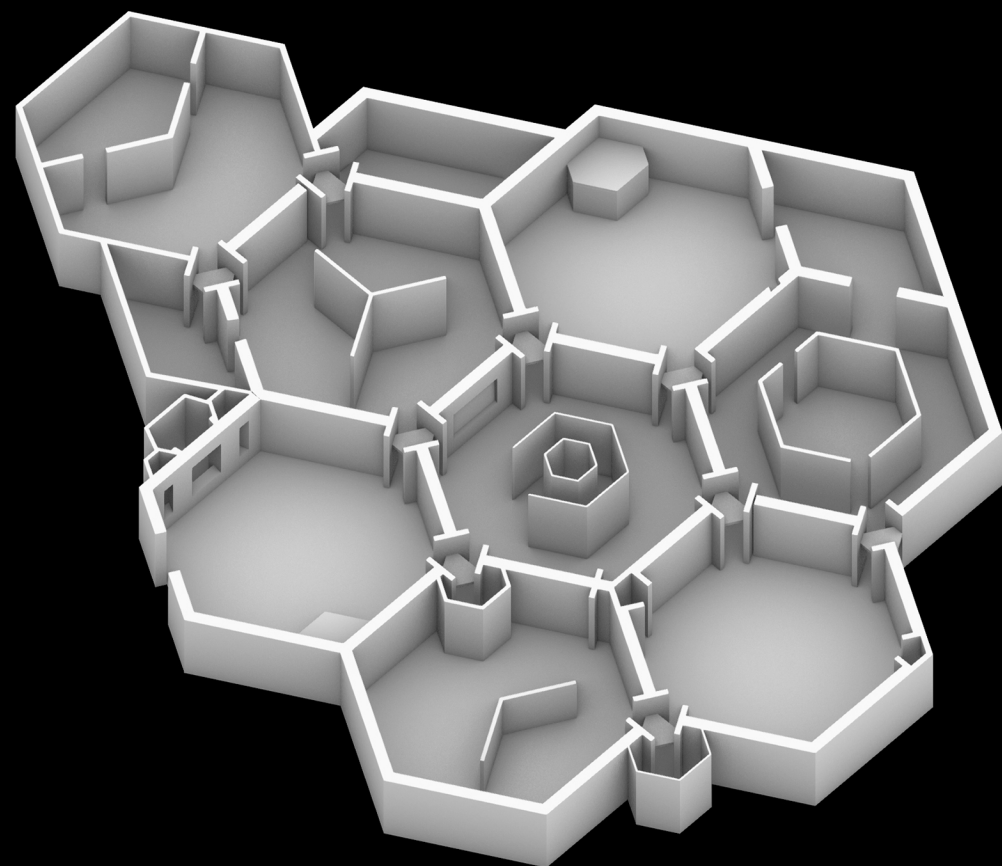
The visible scene, such as the view inside the windows and the stairs in the photo, is easily to switch from one form to another. And by adding the shadow in the image in the projection, it is difficult to tell the depth of space. But if the distance between to wall is larger, it would create a big gap between two walls. It is better to use two projector if the distance is large.



Changed Shape based on Perspective

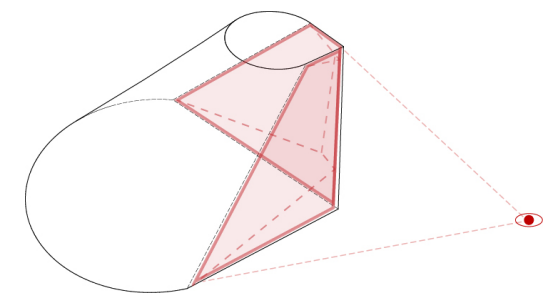
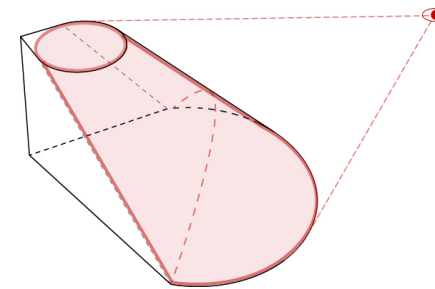
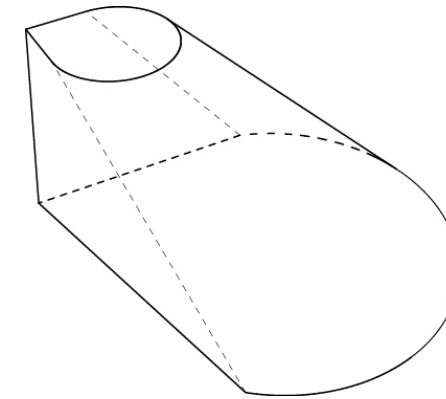
The space is edited based on the perspective lines. From an observing hole, the scene is exactly the same as the scene in the drawing, an ordinary rectangle room. But the actual space and the elements in the room are special shapes. If audience come into the room from the other direction, they will not find out any connection with the original scene.





"Mirror" Maze

Use hexagon as the main characters of the rooms to mislead the direction-sense of the audience.
 Use similar room the repeat the similar experience of the room at first to let audience thought they are in the same room again. Then change the direction of the doors to manipulate the tour.
 A lot of elements are made similar to create "mirrored" scenes.



Double Faces

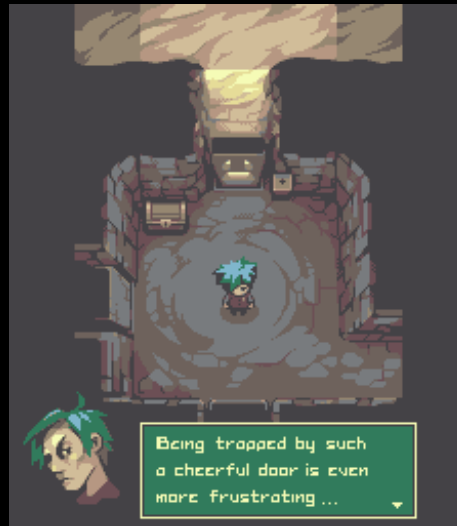
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Chapter 4. Conclusion

- Control Boundaries
- Space Addition and Compression
- Multi-faceted and switch space
- Similarity and Typology
- Two workflows
- Possibilities for developing



Control Boundaries

Creating a scene with projection mapping or other tools of spatial augmented reality is similar to creating a scene in video games.

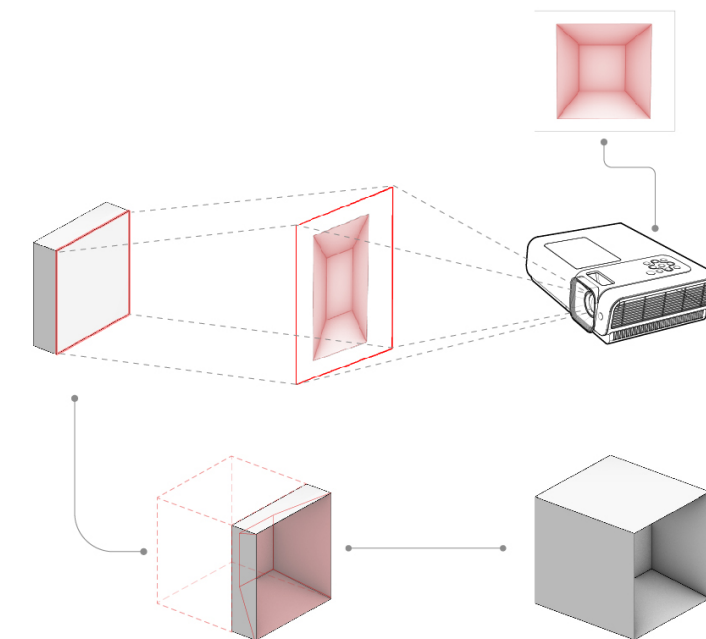
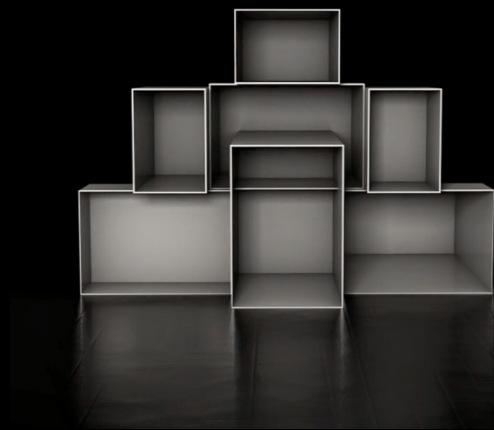
In video game design, there is a crucial work before deciding the method to create a scene – Defining boundaries. What video game is different from the reality is that player is usually restricted inside some areas. There is some boundaries to limit the range of action. Players are not encouraged to behave 'meaningless' but focus on the 'right' objective. From the perspective of producing a game scene, there is two reason. One is the operating speed. The detail of models and textures in scene are depend on the distance from the character who the player is controlling. For example, the details of model of the main character is in high precision and the landscape far away from character maybe is simply a picture inside of a 3D model or a low polygon model with a rendering texture. But it would not degrade the game experience because the player would not play much attention on it. The second reason is the budget of time and producers is limited. There is no necessary for designers to design the details if everything inside the scenes to the same level.

The logic is the same in designing an illusionary scene with spatial augmented reality within a building. If we see the whole experience as a show, it need to control the position of audience. Because it always have the best area to observe the visual illusion. Nearly all the visual illusion have a error range. If the audience go out of that range, they will find out that they are deceived. Like magicians, the architects need to know what to hide and how to control the audience's attention. It means they need to set up the environment to guide audience's behaviors, to reduce the possibilities of beyond the error range, to increase the error range by adjusting the physical environment and virtual image.

The first thing to begin the design is also defining boundaries. Because it is the base for the designer to make decisions.

1. Designer need to design the tangible boundaries and visible boundaries. The virtual part of illusion is usually used in the area beyond tangible boundaries and within the boundaries. Architects need to control the area where audience is walking pass, standing or sitting. They should control the audience's attention during the journey inside the space. The environment may hint audience to change their sight.

2. Designers need to design the boundaries of virtuality and reality. They should decide which part in the scene is virtual and which part is real. Sometimes architects should keep some distance from audience to the projection area. Because the precision of the projection may not enough to convince audience. The distance would make the effect better. Sometimes in order to provide an immersive environment and the precision is not so important. The projection could also overlap the audience.



Space Addition and Compression

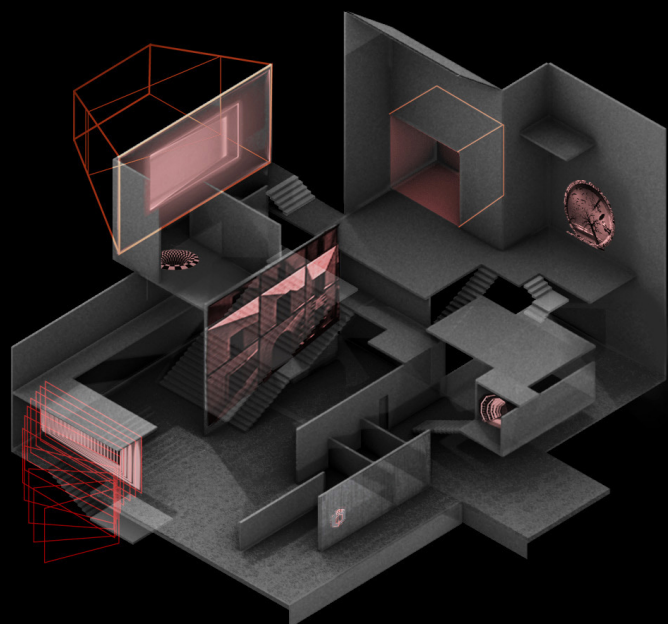
What can spatial augmented reality augment in a space? One of the answer is the volume of space.

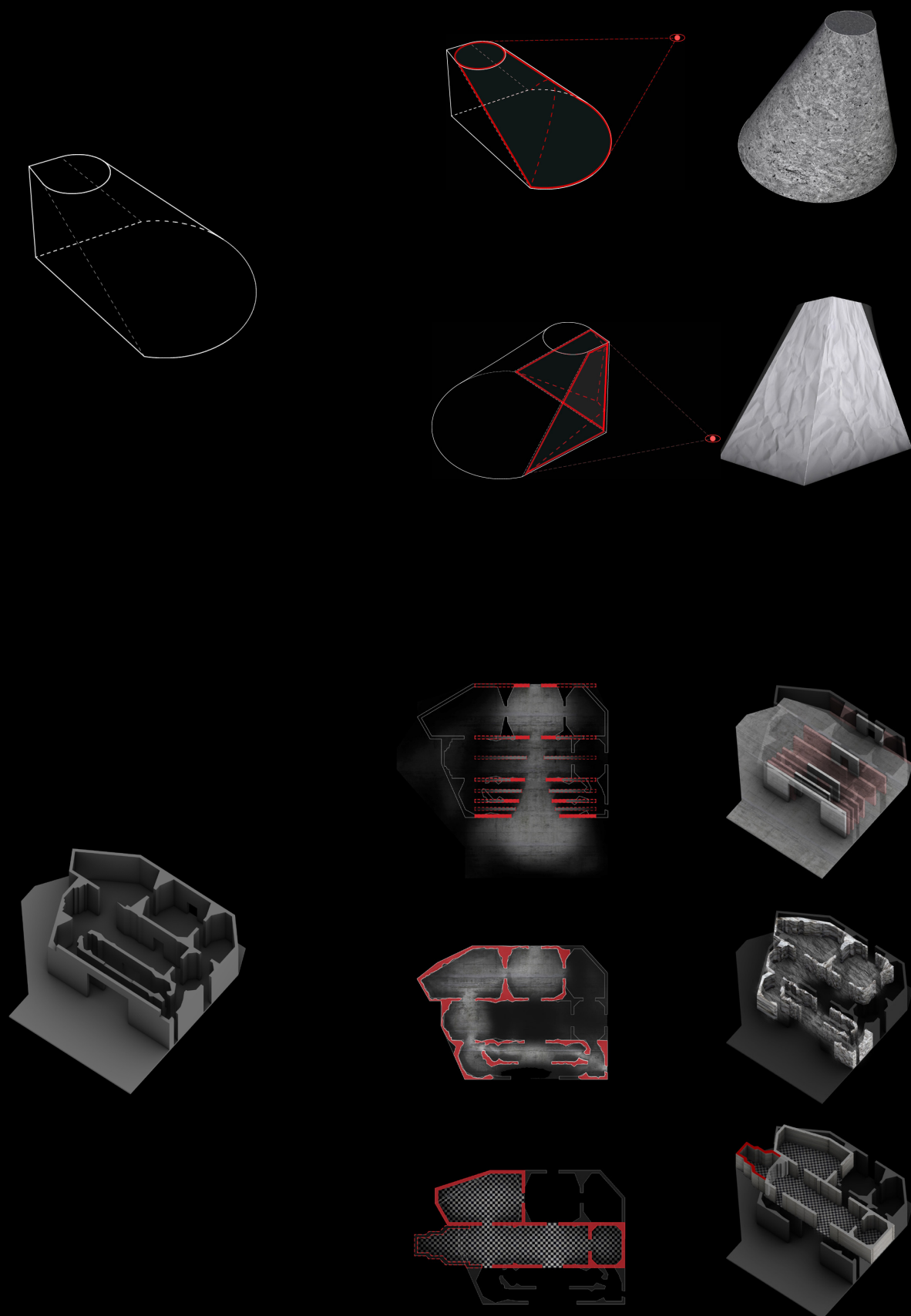
When we experience a building or a nature environment, some area is just within the visible scope but beyond the accessible region, like the upper part of the church and mountains far away near the horizon line. But it does not means those area is important. They are part of the space and sometimes is the crucial part within a scene. But sometimes the scene need those visible elements but it is impossible to build them. At these moments, spatial augmented reality might help architects to meet these needs.

To use light to change the perspective, texture and shadow of an environment, architects can give the psychological hints to audience and influence their perception of the space. Within the particular frames, architects can 'extend' the space by extend the virtual perspective lines, adding the virtual shadow and change the virtual texture of the surface. Those virtual elements increase the depth of space.

Conversely, if an architect have the tool to add the extra space within a physical space, they will be able to compress the space. For example, after they deciding the visual size of space, they can consider which part can be virtual or physical. So they are able to compress the initial physical space at the very beginning of the design and leave more spare space.

Meanwhile, Architects can use Gestalt psychology to compress and extend space. With a serials of hints, It is possible to use a few smaller space to represent the different parts of the bigger space. Audience can combine those information, imagine the missing parts and finally have a perception of whole virtual space.





Multi-faceted and switch space

One of the main application of projection mapping is changing the pattern or texture on the surface swiftly. The relationship of projection and the object being projected is similar to software and hardware. Various software can be operated to create multiple influence by the same hardware. Similarly, projection mapping can provide architects a tool to switch several scenes within the same physical environment. Just one second, with the changing of projecting image, architects can use this magical technology to 'change' the style of the building. The 'change' here means changing audience's perception of the space by the light in a dark environment instead of changing the solid object.

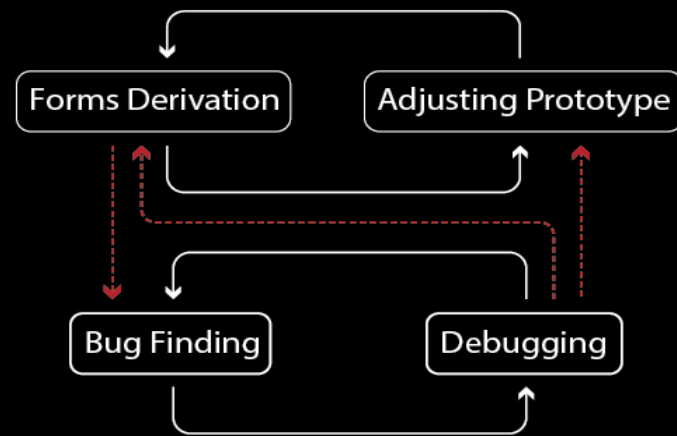
The interesting part is what we project on the wall will make a difference. Like different period of Pompeii style in wall painting, it can vary from simple pattern or texture to the three-dimensional illusionary picture with painted shadow and perspective lines. It means architects could select use an image of two-dimensional texture or a image of three-dimensional drawing on a surface, like selecting the veneer and relieve on the façade. It is a kind of staccato made by light, using shadow to represent the shape and depth of the object. It can delude audience's cognition of space.

For further application, it provide a possibility of combining two or three objects into one. There is two methods to do it. One is overlapping similar parts of the objects and using it to connect each other. Looking for the similarities among different objects and use it as the common area to connect those object to create a bigger object. When needed, highlighting different part of the bigger object to show various face of it, leaving other parts in darkness. Another method is using the outline in different angles to represent different object. A three dimensional object can show different appearance from different angles. So theoretically it is possible to use it as stereoscopic screen. But after a few test, in practical it is quite difficult to combine two objects into one. In the research, using the perspective lines to adjust the shape is one of the method, but the scope of adjusting is not big enough.

Instead of a fixed object, a flexible object or partial flexible object may be a better solution in most case. Similar to the interior of the building, except the fixed wall, it also need the screen, curtain and furniture which are able to be moved to construct different need of space.

Similarity and Typology

in order to fit different scenes, it need the basic form and the variant. The technic of design the basic form is to focus on the similarity among different forms. It is similar to a prototype. It should be designed base on common feature. Typology is a method to deal with the form of different elements. It is easier to recognize and classify the forms. But it does not mean the whole basic form has to be showed. Architects can select part of the basic form and overlap with virtual augmented image to create a flexible object.



Two workflows

One circulation is derivation and adjusting prototype.

Base on the basic form, architects can add texture or project shadow on it to create different appearance. It is one of the main tasks during the period of design. Later architects may encounter some problem which could not be solved by adjusting the projection. Then they need to go back to adjust the basic form to develop the prototype. Base on the adjusted form, they continue to develop the new augmented appearance again.

The other circulation is testing and debug.

It is a process like programing in design. The whole circulation is between error detection and problem solving. It means architects need to keep testing to find out the bug in the illusion and then adjust the design to fix the problem. What need to be adjusted may be either the virtual image or the solid object. Similar to normal architecture design, the whole process is a journey of trial and error.

Possibilities for developing

Tracing and real-time adjusting. Because the visual illusionary effect is related to the position of the audience. If we can adjust the projection base on the location of the audience. It will provide more flexibility of the space. It will provide more freedom to design the space instead of tightly restrict the path of audience. Base on technologies of tracing people, it can ensure the precision of illusionary view from audience's perspective.

Consider the interior space with mechanical design. Lots of architects avoid to design the flexible building because they lack the knowledge of mechanical design and programing. If architects can learn some knowledge from these subject. It will provide architects some powerful tool to rethink the whole design method and principles in architecture design. Because the flexible building provides more possibilities within limited physical environment.

The future is experiential architecture design is not just the designing pure physical environment anymore. It is likely to be regarded as user experience design or space design as a package. It means a lot of elements during the whole experience, including sound, smell, touching, should be considered in at the same time.

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