The Virtual Drawing

Architectural Representation in Virtual Reality

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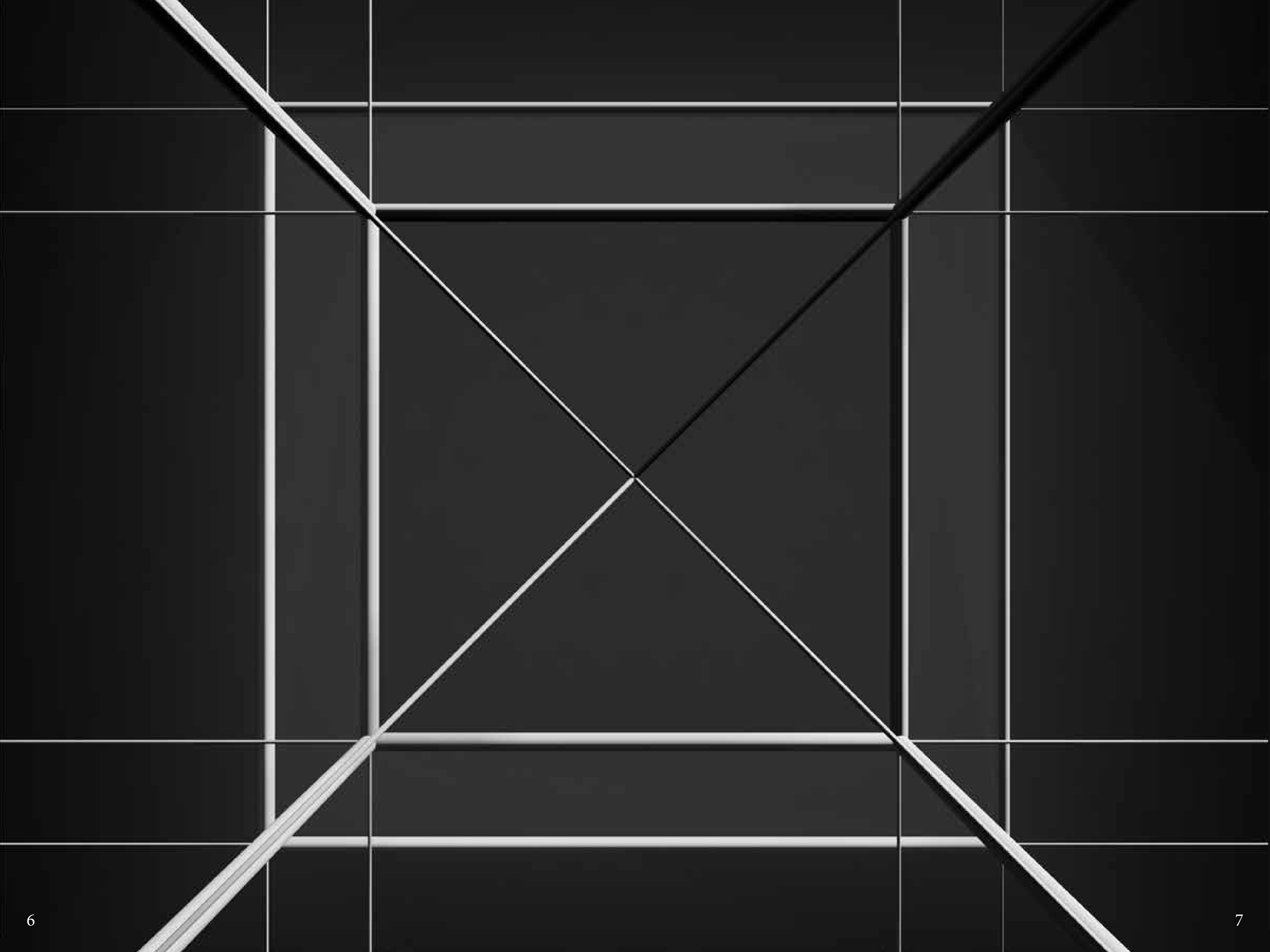
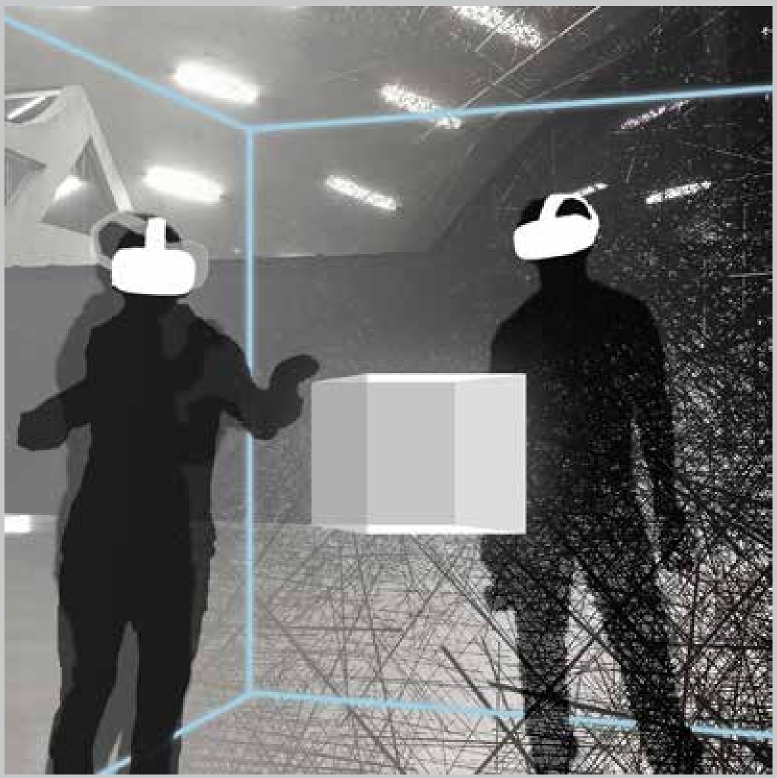


How do new constructs of architectural representation made available through Virtual Reality influence our perception of physical space and our relationship to the built environment? How will this altered perception affect the architecture that we design?



00 - ABSTRACT

Virtual reality offers a unique platform for visual representation. As means of communication, drawings frame the ways in which architects think about space. By repositioning the viewer inside a three-dimensional world, VR creates fundamentally new relationships between the body and the drawing, and offers the potential for spatial experiences that could not be produced in physical space.

This thesis uses the framework of language to structure its investigation and seeks to understand the inherent possibilities and biases of VR. It develops a spatial experience that explores how this medium will redefine the way we understand the space we inhabit as well as the presence of our own bodies within that space.

01 - THESIS STATEMENT

The history of architecture is intimately related to the development of architectural representation. The job of the modern architect is not to build a building but rather to communicate the necessary features and information that will allow the building in the mind of the architect to become reality. The architect necessarily can only produce representations of a building. Every mode of representation has potentials and limitations. As new technologies and methods of drawing have been developed and spread through the field of architecture, they have allowed for the creation of new thoughts while at the same time their inherent limitations have suppressed other thoughts.

While still in its early stages, Virtual Reality provides the opportunity for new modes of representation that have never before been possible. What potentials are afforded by the ability to 'draw' in three dimensions? What can be gained by a medium which is dynamic and interactive? Equally important to these questions, however, are the limitations inherent in the medium. What opportunities does VR restrict, as compared to 2d representation on paper? How will the facilities of the medium of representation potentially affect the thoughts that are produced, and the architecture that results?

As a tool of representation, virtual reality has already begun to be used by architecture firms. Currently it is primarily used as a sales tool which allows clients to step into designs before they are built. This use of virtual reality has the problem that it both overestimates the abilities of VR to simulate physical space, while at the same time underestimates its potentials as a medium of visual communication.

By positioning the observer into the same space as the 'drawing', VR creates a new relationship between the body and the representation. It is no longer something to just look at, but instead something to experience. The physical limitations of VR systems allow a person to walk around only a small physical area, even in a wide open virtula scene like a field outside. This introduces a tension between endless and limited spaces. At the same time, motion within the bounds is completely unrestricted by normal constraints of matter. You can walk through walls or stick your head into the furniture. The contrast between the large scale restrictions and small scale freedom is fundamentally different than how we normally experience movement through space.

Similarly, there exists within VR a paradoxical association with the body. Current software does not allow the user's body to be rendered visually within the scene, and yet the sense of proprioception ensures that you still know where your body is, even when you cannot see it. Representational elements which in 2d exist in dialog only with each other now have an inherent relationship relative to the body as well.

These attributes have a significant impact our perception of the virtual spaces we experience. In order to use this tool effectively, it is necessary to be aware of these impacts so as to not allow them to unconciously bias our thinking about space. At the same time, these conflicts between space and body have the potential to create experiences that are not possible in other mediums. Given the early stages of software development for designing within virtual reality, we need to more fully explore these potentials so that we as architects can be part of the process to design software instead of being restricted by the software that others develop.

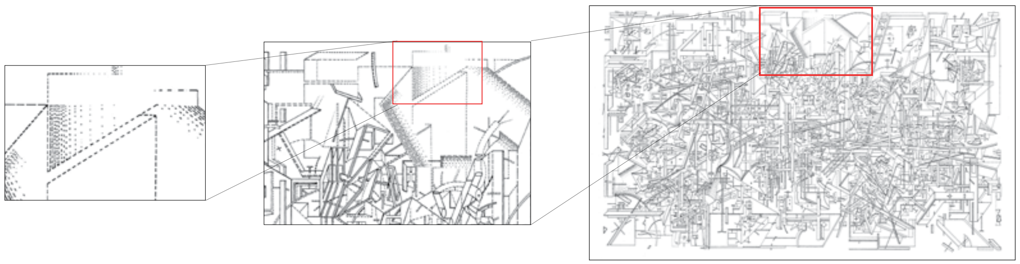
Virtual reality is fundamentally a spatial experience. The mechanics and details of that experience will affect how we understand the concepts that are communicated with it. It will affect how we interact with people, it will affect how we undrestand our own bodies within the spaces we inhabit, and it will affect the very way in which we think about space. We are currently in the middle of the development of a fundamentally new mode of visual representation. The changes brought about by virtual reality with regards to the way we think about space and the way we design have the potential to be as fundamental to the field of architecture as the development of perspectival drawing, axonometry, or the development of computer aided design. As designers of space, architects need to be a part of this.

02 - LANGUAGE ANALYSIS

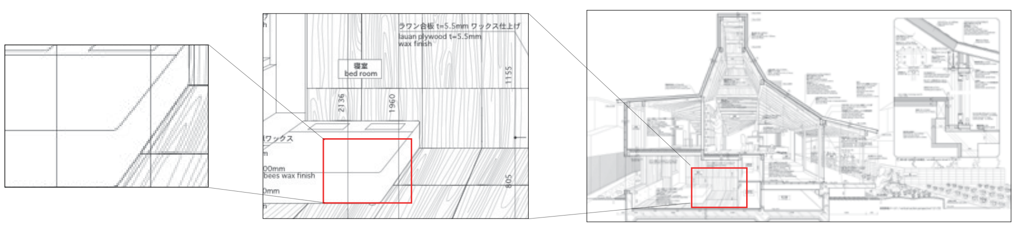
'Drawing' is both a noun and a verb. The word 'drawing' can refer to the act of putting pen to paper and creating a work, or it can refer to the work itself as something to be viewed by others. The former can be compared to the process of thinking, as designers will often think through their sketches, while the latter is a form of communication, with the primary purpose of the drawing to produce an understanding of some idea or concept in others. With this dual purpose of communicating and thinking, drawing can be compared to a language, with similar heirarchy and levels of meaning. By breaking VR down into similar levels, we can better understand how it behaves differently from other modes of communication and representation, and we can then build up levels of drawings with increasing complexity. In this section, I attempt to analyze line drawings through the lens of the heirarchy of langugae. The framework developed will then be able to be applied to virtual reality.

Languages can be broken down into four levels of increasing complexity that allow us to communicate concepts and ideas to each other. The most basic building blocks of a language are its vocabulary. These are the nouns, verbs, and adjectives that have meaning inherent in themselves. On the second level of complexity, these words are combined together through the rules of Syntax and grammar. Certain combinations are allowed, while other combinations are non-sensical. The meaning of individual words can change depending on how they are combined with other words. The third level is the level of Semantics. Syntax alone can provide rules for how to put words together, but even sentences that are syntactically correct may not produce the intended understanding of the concept we are trying to communicate. The final level consists of Pragmatics. This is the level at which culture, society, and convention come into play and allow for the

Syntax **Semantics** **Pragmatics**



Micromegas, Daniel Libeskind



Graphic Anatomy, Atelier Bow Wow

Piranesi

understanding of speech to go beyond simply the literal definition of the words used.

To understand how these layers of communication apply to virtual reality, they are first applied to traditionally drawing, by looking at three different works of architectural drawing. This analysis is not intended to be a complete and thorough investigation into the language of these drawings, but rather to establish a framework through which to understand virtual reality. In order to limit the scope of this investigation, I have chosen to focus on specifcally on line drawings, although similar levels of heirarchy could be established for painting, collage, graphic design, or any other form of visual communication.

The works chosen include Daniel Libeskind's Micromegas, Graphic Anatomy by Atelier Bow Wow, and a typical work of Pirinesi. These were chosen for the variety of ideas they are attempting to communicate through the use of only lines. We start by looking at the indivdual lines used (Vocabulary), then progress through the ways in which multiple lines are combined together (Syntax), to a literal understanding of the drawing (Semantics), and finally to the greater message or concepts these works are communicating through their use or mis-use of conventions, as well as through the historical and contemporary understanding of the drawing at the time.

English - Vocabulary
Vocabulary consists of the basic buildings blocks of communication. They are individual elements which carry with them a certain definition. In English, these are things such as nouns, adjectives, verbs, etc.

Eg: dog (noun)
house (noun)
tired (adj)
red (adj)
blue (adj)
the (article)
feel (stative verb)

Syntax
The syntax of a language is the rules that govern how the building blocks of a language are allowed to go together. Certain combinations of words are allowed in a language, while others appear to be non-sensical. For example, in the English language adjectives are modifiers and come before a noun rather than after a noun. This can also be called the grammar of a language.
Eg: tired dog
(adj + noun)

❌ house red
(noun + adj)

Semantics
The grammar of a language is a set of rules that defines how the building blocks are allowed to come together, but just because a phrase or sentence is grammatically correct does not ensure that that phrase conveys sensible information. Two sentences that are grammatically identical in terms of parts of speech and word order can still differ in their ability to convey understanding. For example, just because it is grammatically correct to create a sentence in which a noun is equated with an adjective through a stative verb does not mean that all adjectives can apply to all stative verbs and nouns. In the example below, the two sentences are grammatically equivelent, yet the second is non-sensical at the semantic level.

Eg: The dog feels tired.
(article + noun + stative verb + adj)

❌ The house feels red.
(article + noun + stative verb + adj)

Pragmatics
The final level in the heirarchy of language is pragmatics. This is the level that allows language to convey understanding beyond the literal semantic meaning of a phrase or sentence. At the semantic level, a noun cannot feel like a color. At the pragmatic level, however, certain colors have come to denote emotions or feelings. These meanings are created through social convention and context. They exist at a cultural level and can vary among different groups or societies even if they speak the same language.

Eg: The dog feels blue.
(article + noun + stative verb + adj)

❌ The dog feels red.
(article + noun + stative verb + adj)

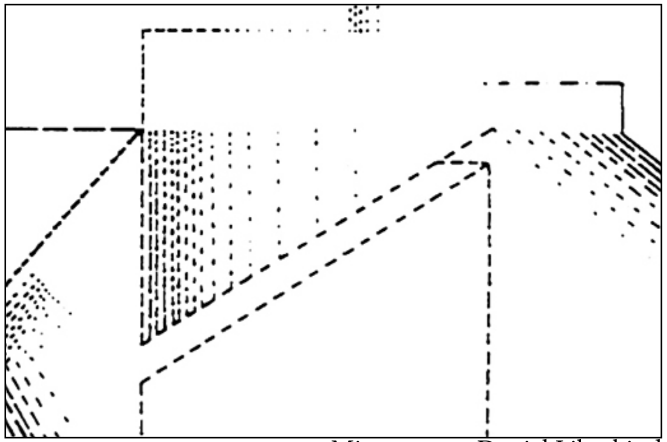
- Drawing Element
  - Inherent
    - **Color**
    - **Weight**
    - **Quality**
  - Geometric
    - **Length**
    - **Angle**
    - **Straight**
    - **Arc**
    - **Curve**

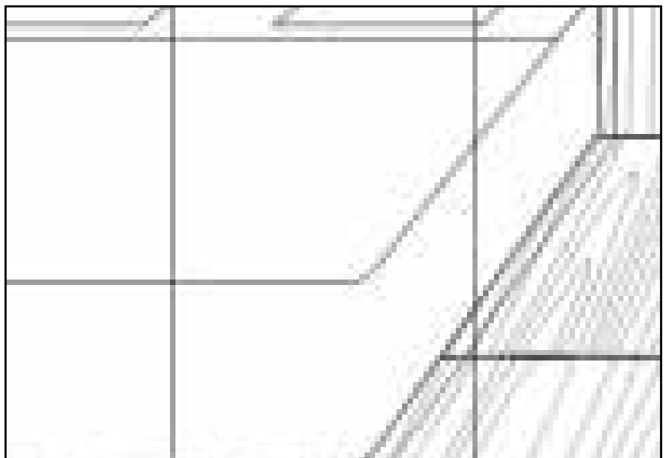
- Drawing Environment
  - Inherent
    - **Paper**
    - **Position**
  - Relative
    - **Layout**
    - **Scale**

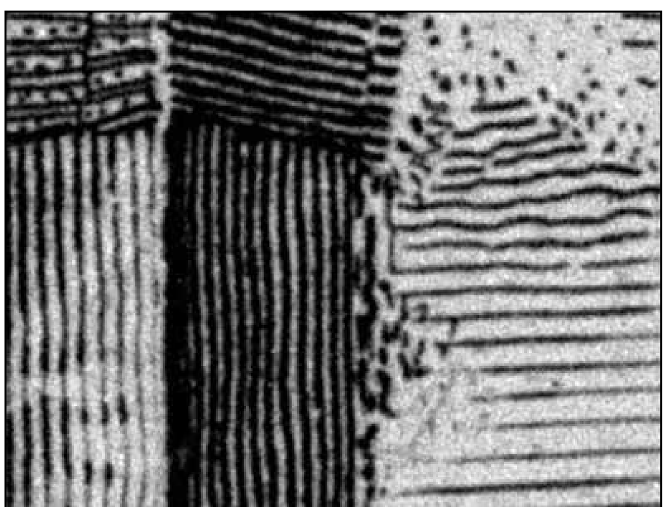
Line Drawings - Vocabulary

The building blocks of a line drawing include two categories of characteristics - those that belong to the individual element itself, and those that belong to the environment of the drawing.

The drawing element in this case is a line. The vocabular of a line has been further broken down into two categories - a geometric category that involves measurable conditions, and an inherent category.


Micromegas, Daniel Libeskind


Graphic Anatomy, Atelier Bow Wow


Piranesi

Line Drawings - Syntax

In the second level of the heirarchy of language, the individual building blocks are combined together. These combinations often adhere to certain rules, and the understanding of the drawings can change based on the rules that used.

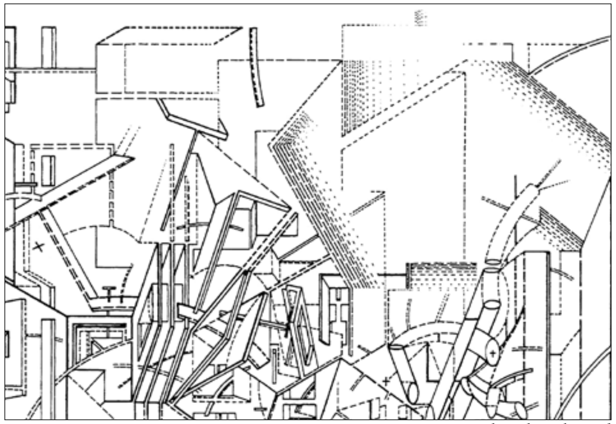
In these three examples, we see lines that meet other lines at different angles. We see lines that cross other lines. We also see lines that are used repetitively in patterns. At this level of understanding, the rules of syntax are mostly consistent across different drawings.

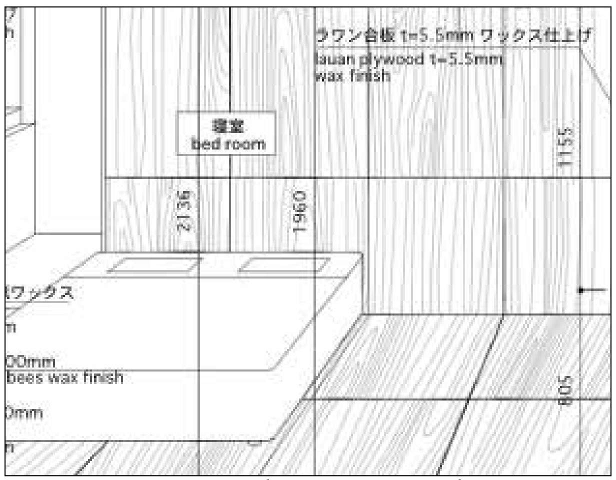
Three lines at different angles that meet at a corner can indicate the intersection of three planes, with spatial implications of surfaces that are horizontal or vertical.

Lines that cross over each other are following different rules. In the second drawing, for example, we can see that the two vertical lines are behaving quite differently than than the horizontal or angled lines they cross, while the vertical lines in the upper right hand portion are seen as part of the same system as the rest of the lines.

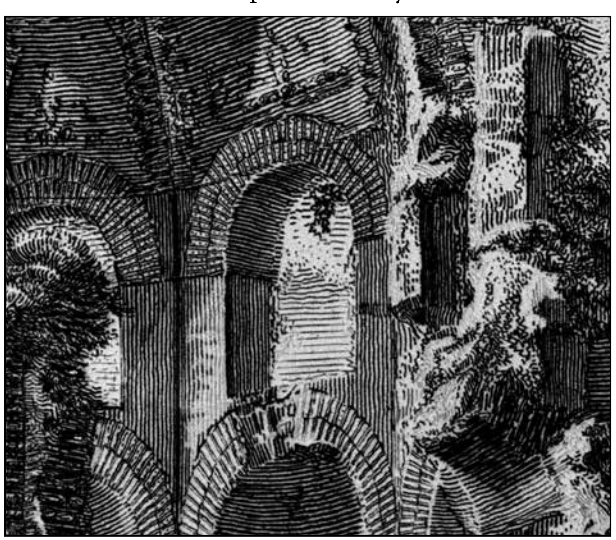
Patterns of lines imply texture or shading, telling us about the quality of the materials or the depth of the space. The relationship between heavy lines and light lines indicate borders of objects, while curved lines contrast with straight lines to differentiate larger elements of the drawing.

At the level of syntax, we still do not yet have an overall understanding of what the drawing is representing.


Micromegas, Daniel Libeskind



Graphic Anatomy, Atelier Bow Wow


Piranesi

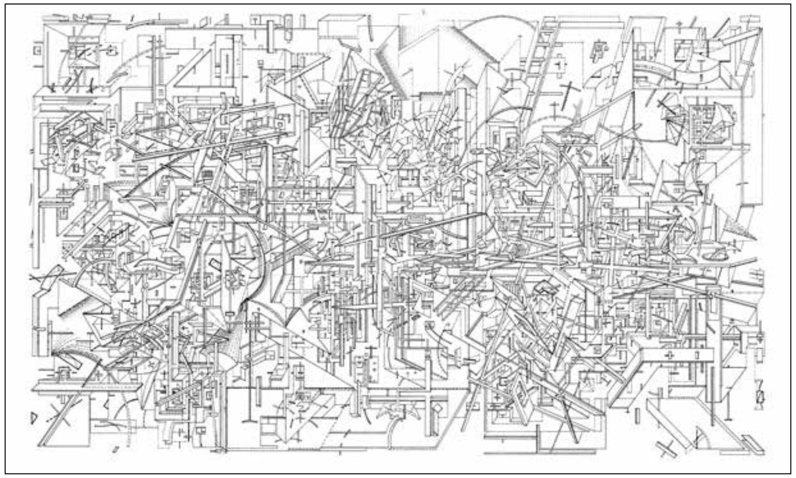
Line Drawings - Semantics

At the level of Semantics, we can start to understand a drawing at a practical level.

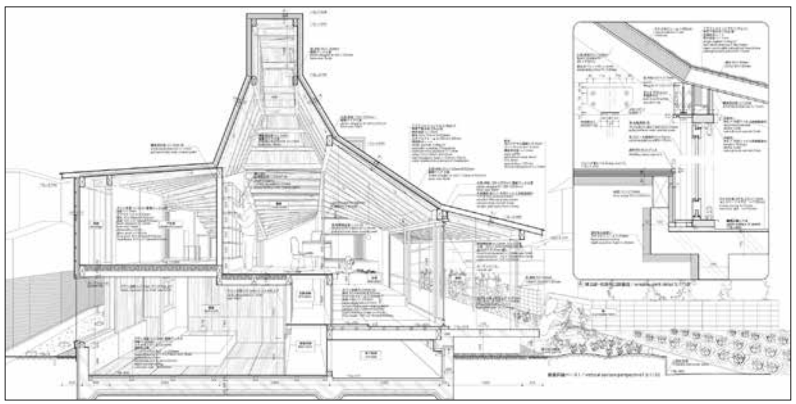
In the second drawing, by Atelier Bow Wow, we can see that this drawing is showing a bedroom, that the drawing is a perspectival projection, and that it contains information about the dimensions of the bulding to be constructed.

Piranesi's drawing becomes recognizable as a masonry building in ruin. This drawing is also perspectival, giving the impression of trying to put the viewer into the scene. It is an atmospheric drawing rather than a technical drawing that is meant to convey emotion and feeling of the space rather than dimensional and material detail.

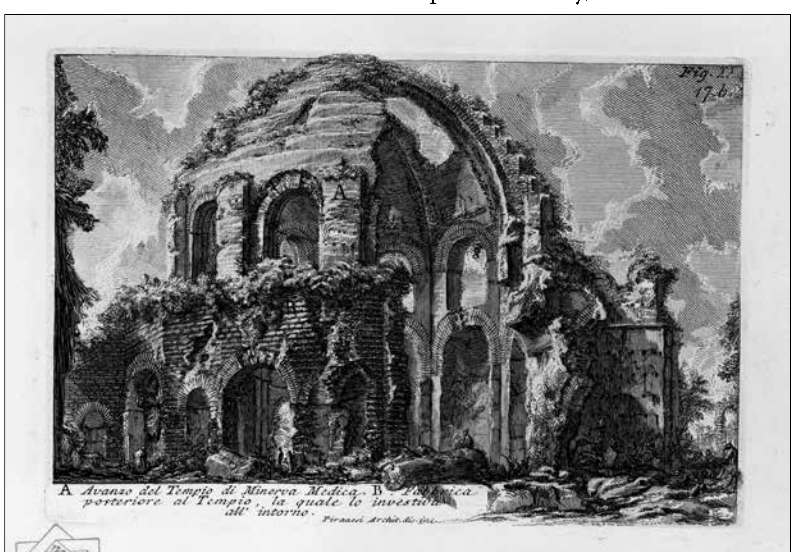
Libeskind drawing, by contrast, breaks down at the level of Semantics. Indivdiual moments that are identifiable at planes or building elements don't fit with each other when seen as a larger scale. The drawing appears to be axonometric in that objects that are interpreted as planes have parallel edges, yet different planes have diffenent angles providing a a discontinuous suggestion of perspective.



Micromegas, Daniel Libeskind



Graphic Anatomy, Atelier Bow Wow



Piranesi

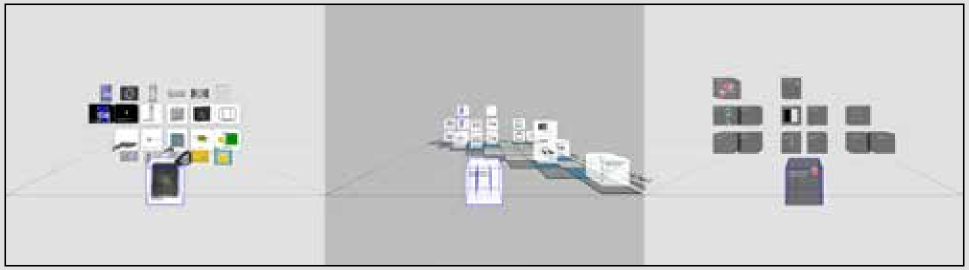
Line Drawings - Pragmatics

At the level of Pragmatics, a drawing is viewed as more than just a literal representation. Layers of social understanding, convention, and context are applied. The understanding at this level is not contained solely within the drawing, but rather from the relationship between the drawing and the larger ecology in which the drawing is recieved and viewed.

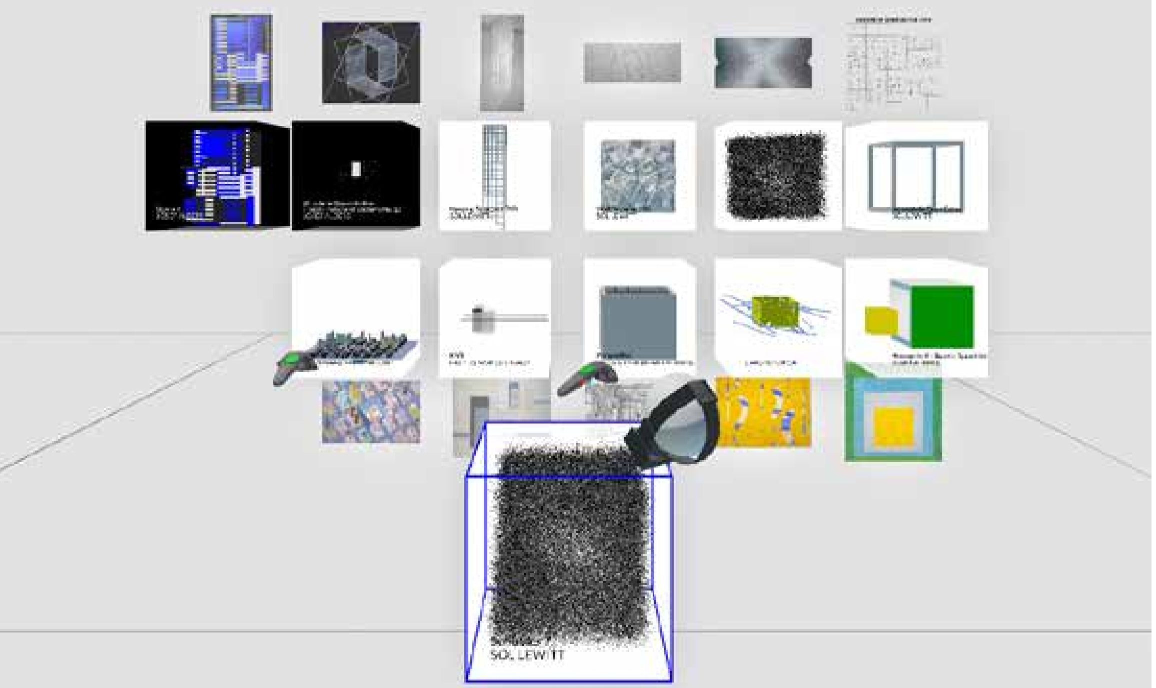
Libeskind's Micromegas drawing carries with it references to Deconstructionist ideas, and presents the impression of architectural potentials within the fractured and expansive drawings. We can read into it a commentary on the restrictive nature of convential drawings such as plans and sections, and see a desire to communicate a concept beyond a physical building.

Atelier Bow Wow's method of Graphic Anatomy is definitely communicated a building. These drawings are in fact construction drawings which should allow for the exact reproduction of the bulding itself. At the same time, however, they are also communicate use and inhabitation of the drawing. They serve as a larger reminder to the field that architecture is ultimately designed to be used, that a building is in fact more than the dimensions and materials. The building is changed by the people that use it.

Piranesi's drawings were not just recreations of existing scenes. His drawings were part historic, part reality, and part fantasy. He took liberties with his drawings to present the scenes in hyperrealistic ways that communicated feelings and impressions more than physical details. These were not recordings of existing ruins, but advertisements for a society that once was, and for the romance of what they left behind.



The Salon



The Salon
Vocabulary Drawings

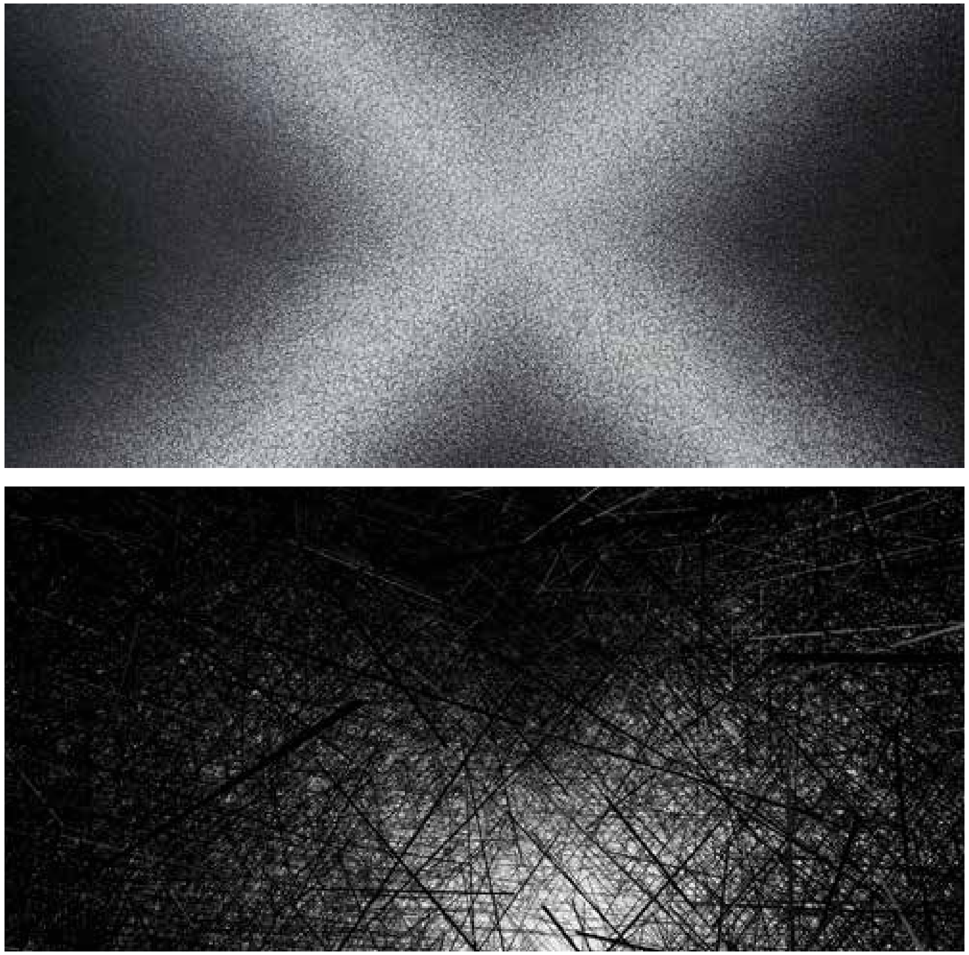
03 - VOCABULARY

Using the framework of language established in the previous section, this phase of thesis seeks to develop the vocabulary of virtual reality.

To help structure the exploration into these building blocks, a selection of works of art were re-interpreted as virtual reality drawings. The works were selected for the way in which two dimensional work could produce spatial experiences and readings. By using these drawings, the goal was to avoid pre-concieved notions about the nature of the virtual reality medium. This phase provided the opportunity to learn some of the technical tools, while also exploring the relationship between two dimensional and three dimensional drawings.

In the following pages, a reproducting of the original work is shown next to a screenshot of the virtual reality translation of that work. It should be emphasised at this point (and will continue to be emphasised through this thesis) that the representations of the virtual drawings are necessarily lacking. The drawings were made as three-dimensional spaces, and intended to be experienced as such. For informatoin on how to view the drawings in VR, please see the section on technical information in the appendix.

Scribbles 7
SOL LEWITT

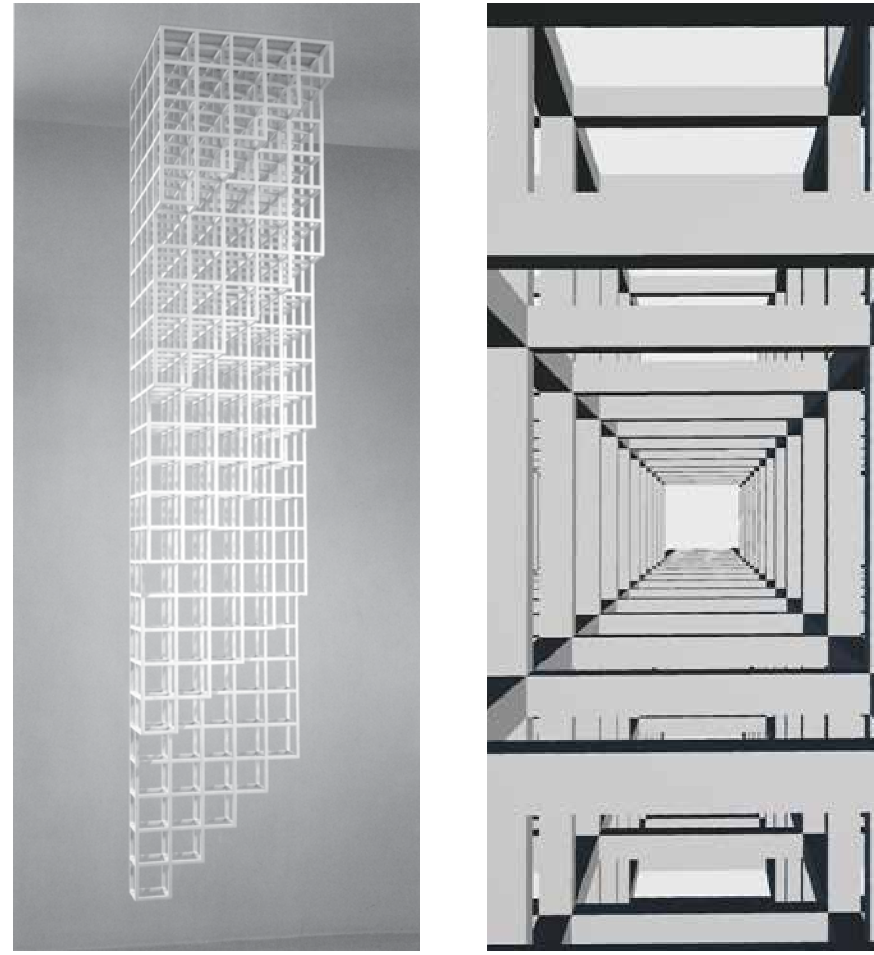


Top: Original; Bottom: Screenshot

Sol Lewitt's Scribbles series was made by proscribing regions of more dense or less dense scribbles. The drawings were then completed by assistants and technicions.

The virtual interpretation used an algorithm to populate a space with a set of random lines, with density set according to the distance from a diagonal line crossing the space. There is a visceral reation to occupying the same space as the lines pass through the body of the observer. The lines in this virtual drawing are implemented as narrow planar elements, and the random orientation of the planes allows for a distribution and scattering of light that references the inherent chaoticness of the individual hands the created the original drawing.

Hanging Structure
SOL LEWITT

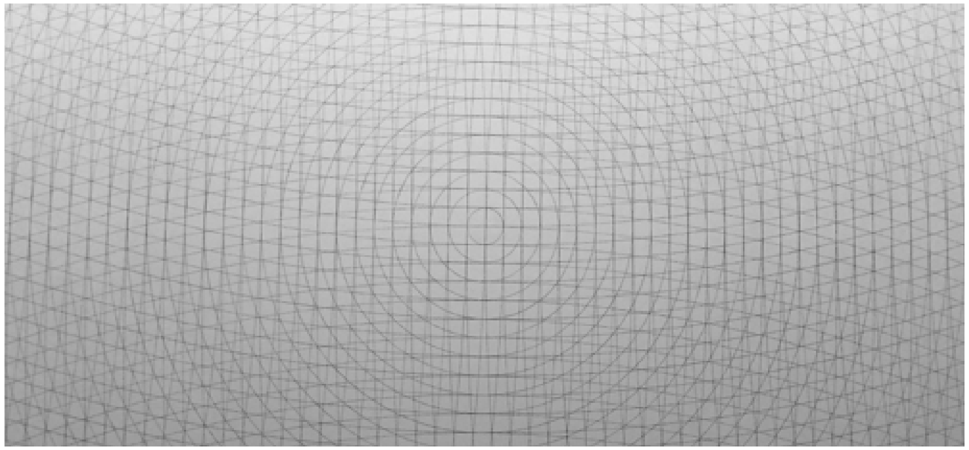


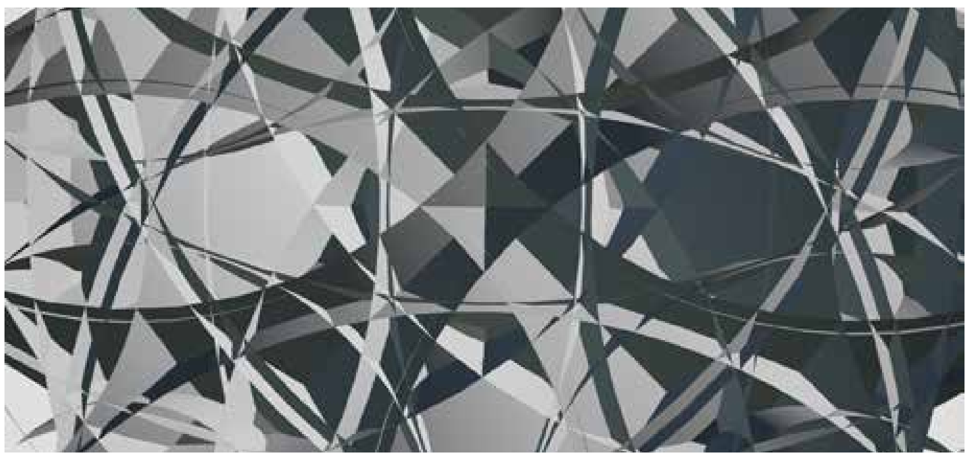
Left: Original; Right: Screenshot

The translation from a physical structure to a virtual 3d structure did not require any of the same interpretations or projections that the other works in this section required. Instead, the discoveries from this piece come purely from the viewing of the work and not the creation.

The two most immediate reactions to viewing Sol Lewitt's Hanging Structure in VR are the ability to scale, and the ability to occupy the space within the structure. The original piece is approximately 9 feet tall, and the tiered organization gives the impression of an upside-down skyscraper. When viewing in 3D, it is intuitive to scale the structure up until the individual boxes feel similar to the scale of a room. There is also a strong tendency for viewers to occupy the interior of the structure, rather than passively viewing from the outside.

Wall Drawing 138: Circles and arcs from the midpoints of 4 sides
SOL LEWITT





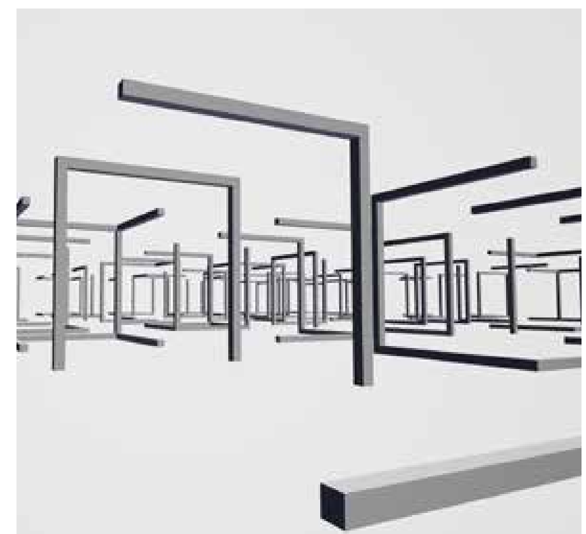
Top: Original; Bottom: Screenshot

The original drawing was made with the instructions to draw circles and arcs from the mid points of the four sides of a wall, and from the middle of the wall. The intersecting arcs and circles create a patterned space that is richer and more complex than can be anticipated by the simple rule set, while also being site-specific to the dimensions the wall on which the drawing is made.

The interpretation in this drawing came from adapting a description of a two-dimensional rule set into a three-dimensional space. Circles and arcs necessarily become segments of a sphere, while the mid-points of the a wall become the mid-points of the edges of a three dimensional volume.

The most apparent different in the perception of the space is the visual opacity that the spheres produce relative to the lines produced by the original drawing.

Variations of Incomplete Open Cubes
SOL LEWITT



Top: Original; Bottom: Screenshot

Rather than simply modeling each of the incomplete cubes cataloged by Sol Lewitt, this virtual drawing presented an array of cubes, each randomly iterating through different permutations of visible and missing edges of the cube. Similar to the original, each cube is incomplete, yet provides the information needed to understand the cube as a whole. Additionally, the impression of a complete catalog of the different possible arragments is produced. The difference is that the virtual experience provides this information temporally, while the original provides the information graphically as a chart.

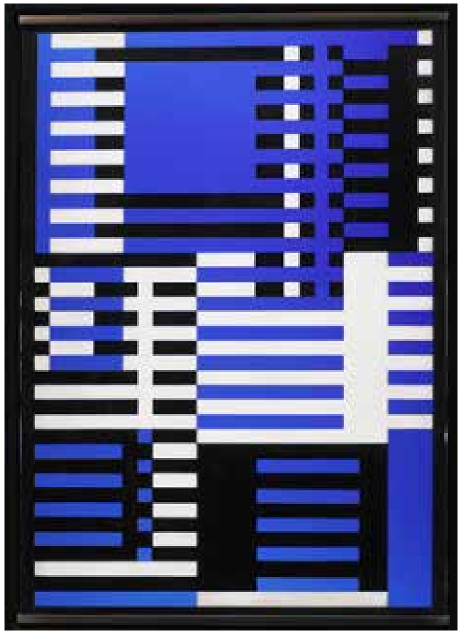
Homage to the Square: Apparition
JOSEF ALBERS

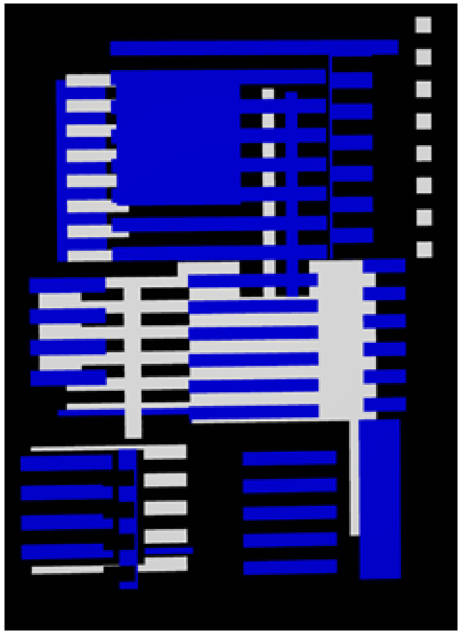
Left: Original; Right: Screenshot

Josef Albers produced a large series of drawings exploring the relationship of color to the perception of a drawing. In this case, it was necessary to choose a specf-ic interpretation of the drawing. Are the different colors in the flat drawing showing planes, sides of squares, or the inside of a square.

I choose to incorporate as manny diffferent intepretations as possible into one drawing. The outer green rectangle becomes the inside of a cube. The dark blue becomes a flat plate with a square hole, acting as a frame between the green cube and the outise. The light blue is the further in depth when represented as the back-ground color of the scene. The final yellow square is interpreted as a box outside of the gree box, it's small size a function of distance rather than a function of size.

Upward
JOSEF ALBERS



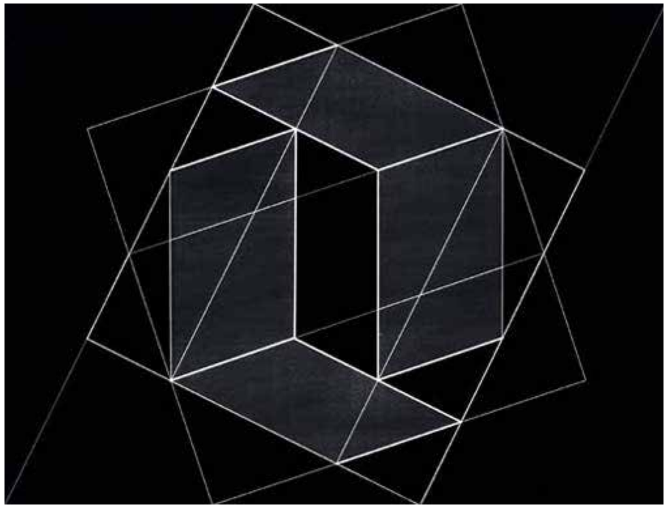


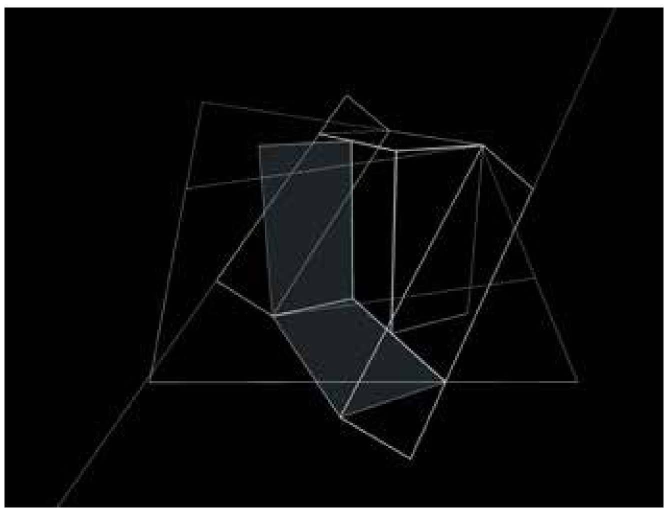
Left: Original; Right: Screenshot

Upward gives the impression of depth by creating an ambiguous layout of col-ors that imply figure and ground in confliction ways. A series of white lines can be read as a single white plane behind a set of blue bands or vice versa. There is a combination of vertical and horizontal continuity and discontinuity that defies attempts to arrive at a single interpretation.

In the virtual interpretation, choices were made as to which colors were in front of others . There are an infinite number of ways to interpret which planes are behind others. Even in the spatial experience of virtual reality, the distinction between near planes and far planes is not immediately apparent, and the viewer intuitively makes certain assumptions. Walking forward through the planes is guaranteed not to match exactly those assumptions, and a sense of exploration and surprise is created.

Structural Constellation: Transformation of a Scheme No. 12
JOSEF ALBERS



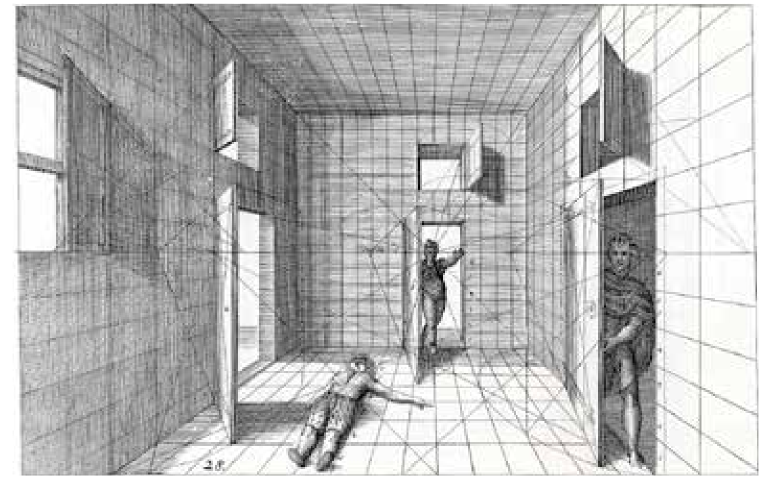


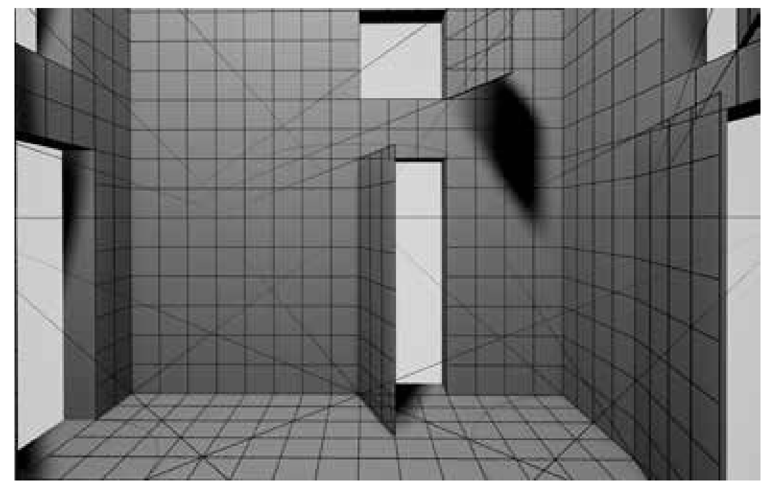
Top: Original; Bottom: Screenshot

In this drawing, Josef Albers takes advantage of axonometry to produce an ambigous structure. The depth and orientation of the lines can flip in the mind of the viewer, and questions arise as to whether the objects depicted are planar or spatial.

In the virtual interpretation, choices were made as to what lines were truly connected at points, and which were not. Due to the three dimensional nature of virtual reality, ambiguity of the same kind as axonometry is not possible. A level of ambiguity is attempted by incorporating one-sided planes that are only visible to the viewer from one side, creating the impression that the solid vs void aspect of the construction is not well defined.

Perspective
HANS VREDERMAN DE VRIES



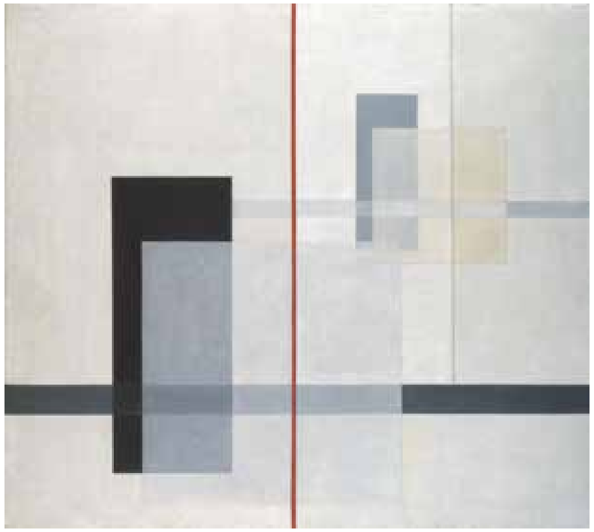


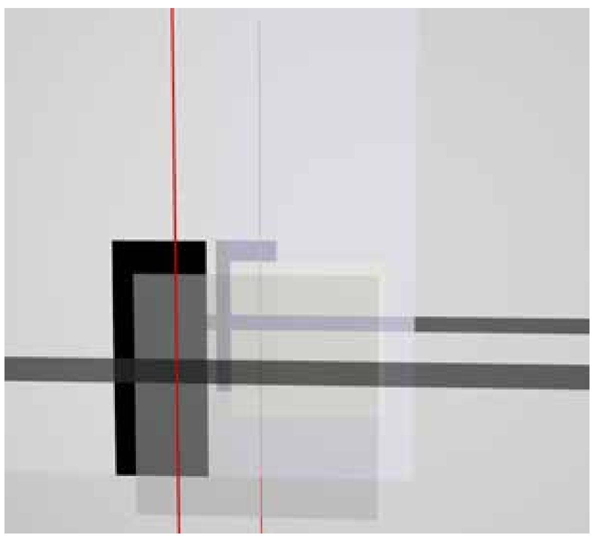
Top: Original; Bottom: Screenshot

The imposition of the grid on this perspective drawing, and the the extennsion of certain lines to their vanishing points contrasts with the human figures that are place in the drawing.

In the virtual interpretation, the most immediate difference is the lack of human figures in the drawing. While in the orginal, the human figures help provide a sense of dimension and scale, the virtual drawing has scale and dimenstion inherently experienced by the viewer. The space is depicted as square in the orginal, but the actual experience of a square space feels narrow and tall, emphasizing the difference between our perception of a physical space, and our interpretation of a perspectival drawing of that space.

K VII
LAZLO MOHOLY-NAGY





Top: Original; Bottom: Screenshot

This painting was selected for the implication of transparency and depth created by the size and colors of the rectangles drawn.

The virtual interpretation of this drawing felt more straight-forward than some of the other works. The repetition of the same forms at a smaller size imply distance, while the indivdual colors of the rectangles imple which planes are in front of others. Out of the 11 examples presented, this is the case where the virtual exerience most closesly match the 2d viewing experience.

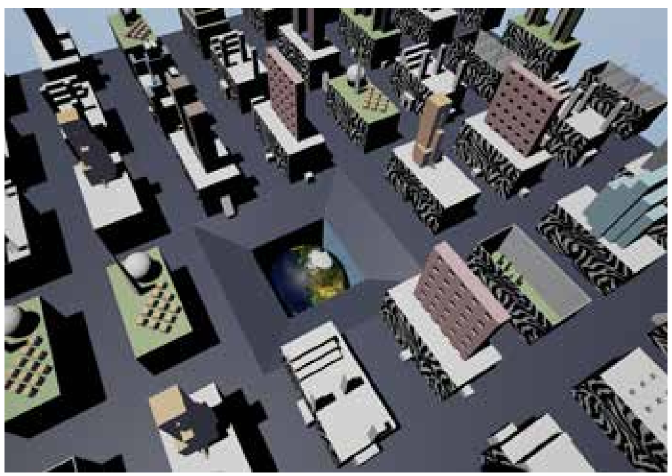
Pietrasanta
CAIO FONSECA

Top: Original; Bottom: Screenshot

Caio Fonseca create a series of paintings that use masking and layering to imply space. The blue lines are interpreted as continuous objects in the background behind a yellow screen with slits and holes.

This work was translated fairly directly, using the image itself as an opacity mask to produce the windows in the surface.

City of the Captive Globe
REM KOOLHAAS, MADELON VRIESENDORP



Top: Original; Bottom: Screenshot

City of the Captive globe uses an oblique axonometric projection in combination with fantastical and referential bulidings to provide a sense of infinite space and infinite possibility. The viewer is invited to imagine themselves experiencing this world at a birds eye view, but also inhabiting the world as a person walking through the canyons between skyscrapers.

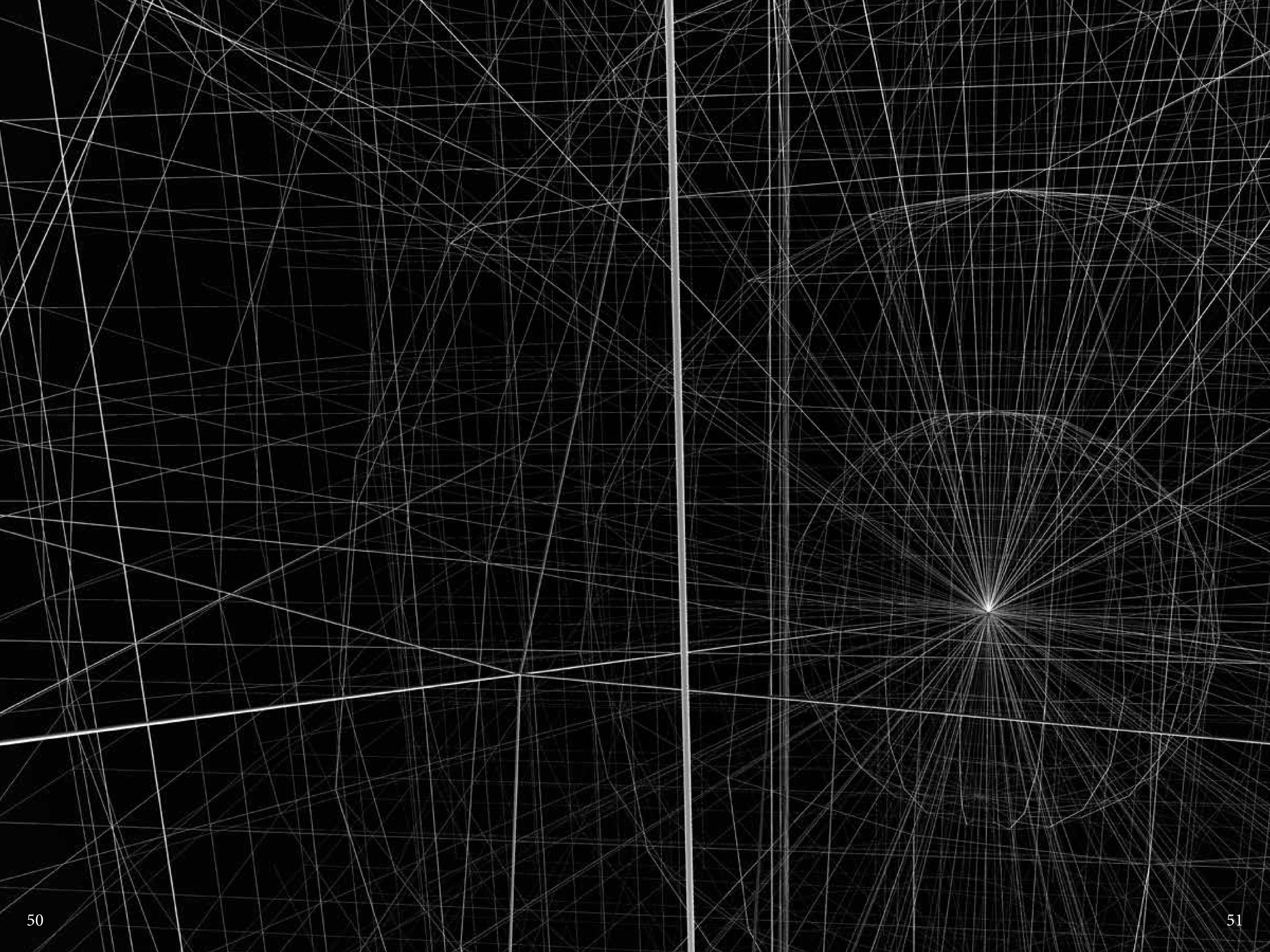
The virtual version allows the viewer to scale the world and experience it from both inside and outside. The limitations of the software, however, actually make it more difficult to provide the sense of infinitiy. There is no edge to the drawing, and so the buildings would have to modelled out to a point where the computer can no longer render them or the viewer can no longer distinguish them.

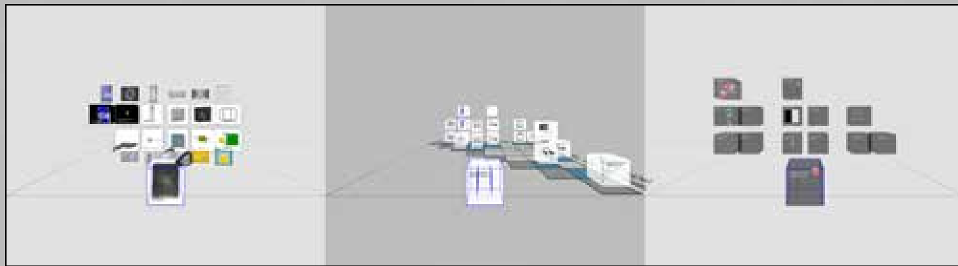
- Element
  - Inherent
    - **Size**
    - **Position**
    - **Color**
    - **Opacity**
    - **Texture**
  - Geometric
    - **Line**
    - **Spline**
    - **Plane**
- Environment
  - Inherent
    - **Background**
    - **Lighting**
  - Relative
    - **Scale**
    - **Distance**
    - **Motion**
    - **Multiple Viewers**

From the above explorations into the translation from 2d and 3d works of art, a list of basic building blocks of the language of virtual space was developed. This list is not exhaustive, nor is it intended to be understood as a final enumeration of building blocks. It is rather intended to act as a starting point for the next section - Syntax. It is expected that this list will be revisted and revised as further explorations into the language of Virtual Drawings are completed.

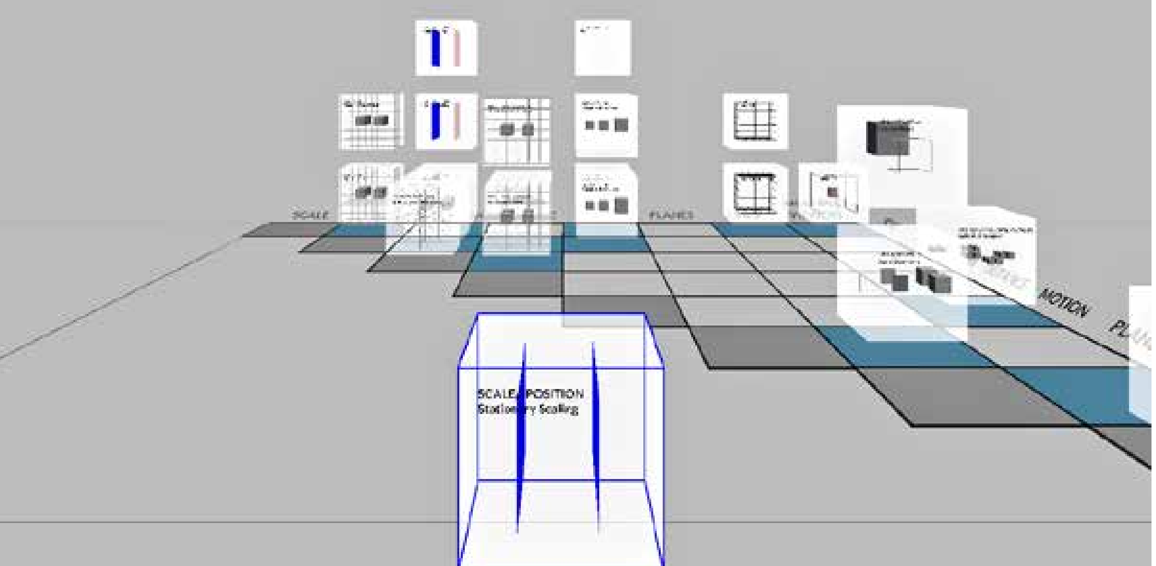
The list of vocabulary is largely similar, though not identical, to that of line drawings. The notable exception is the 'Relative' category under 'Environment'. The presence of the viewer within the drawing immediately changes the frame of reference to which relative elements such as scale are understood. In 2D line drawings, a frame of reference is either explicitly provided in the form of a graphic scale or reference marks, implied by elements of the drawing itself, or sometimes left intentionally ambiguous in order to allow for the viewer to provide their own interpretation.

Virtual Drawings, by contrast, have an inherent frame of reference necessarily built in - that of the body of the viewer. As we are humans inhabiting the space of the drowing, references such as scale, direction, gravity, movement, etc, are forced upon the drawing. Any attempt to change the frame of reference requires intentional disruption of the inherent self-centered frame of the viewer. It is this area which provides the most distinct characteristics of the virtual drawing.





The Salon



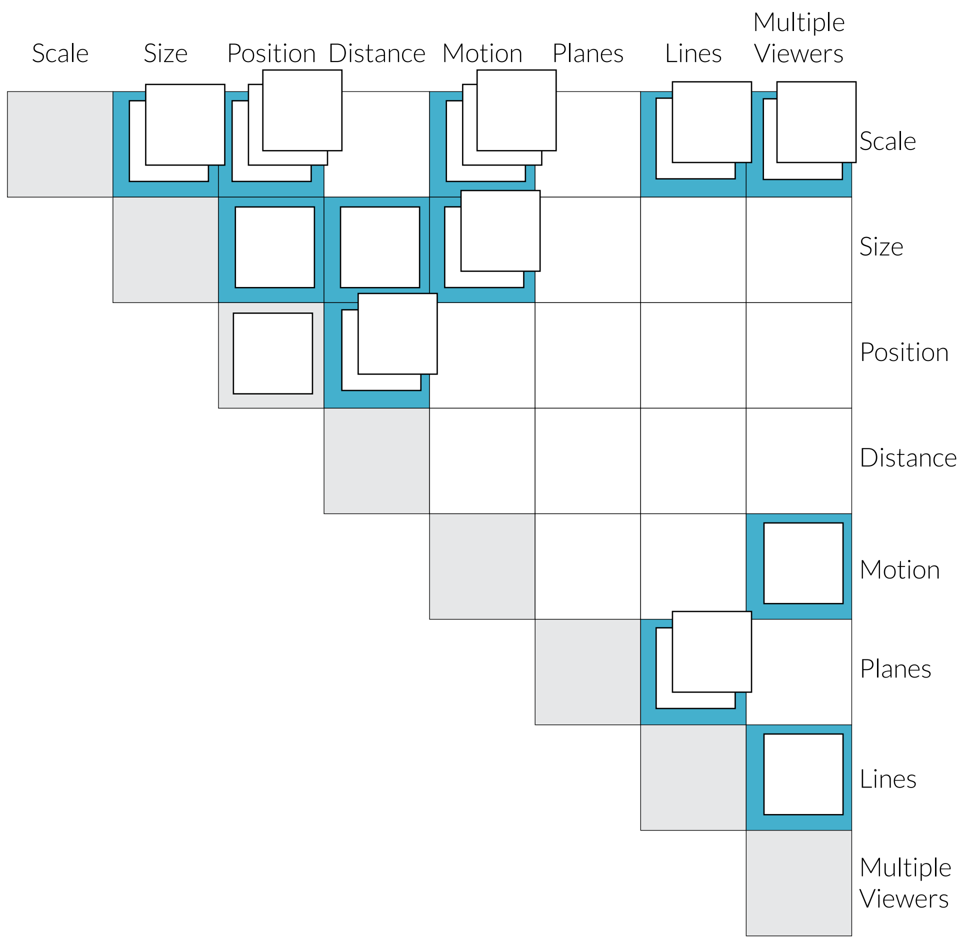
The Salon
Syntax Drawings

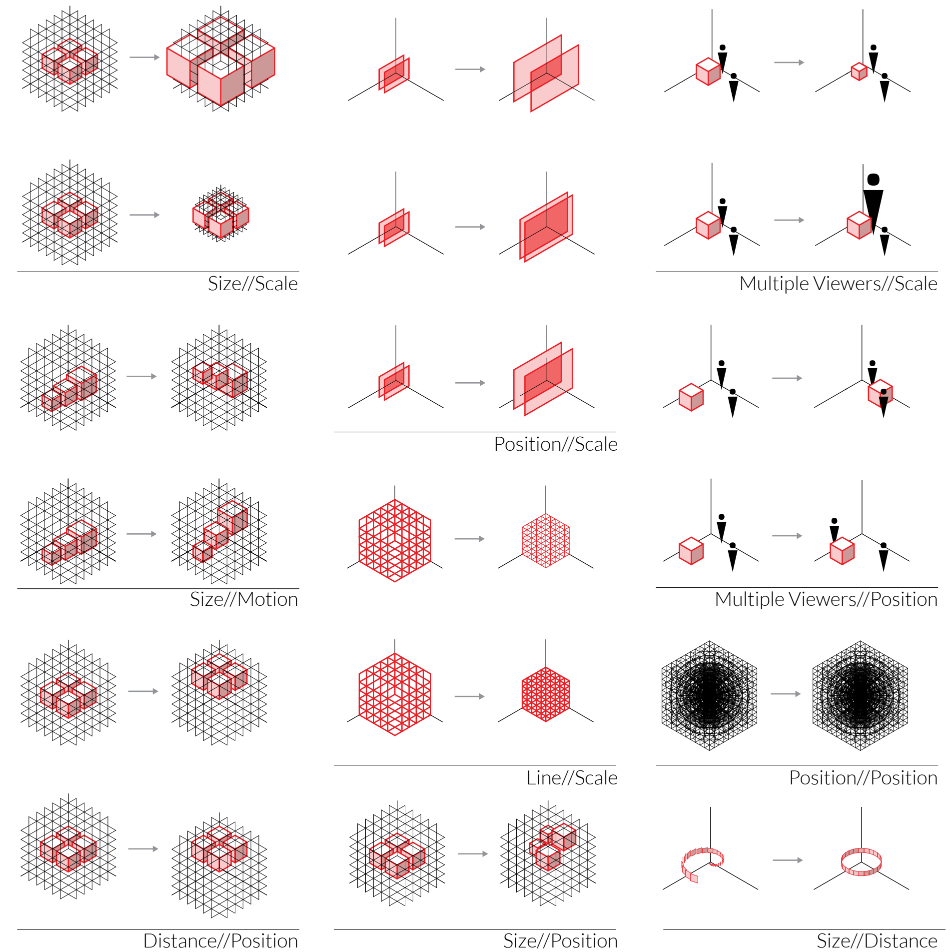
04 - SYNTAX

After establishing a basic vocabulary of the building blocks of a language, the next level of heirarchy to establish meaning is to understand the rules for combining those building blocks together. This can be considered as analogous to the grammar or syntax of a spoken language.

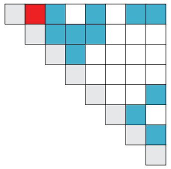
Within this framework, a selection of elements identified as part of the vocabulary of a virtual drawing are paired together, and the rules defining the comination of these elements are explored. In the drawings that result, an attempt was made to isolate the two selected vocabulary elements as much as possible, although it must be acknowledged that complete isolation is often not possible. It must also be noted that due mainly to limitations of time, not all pairs of vocabulary were explored together.

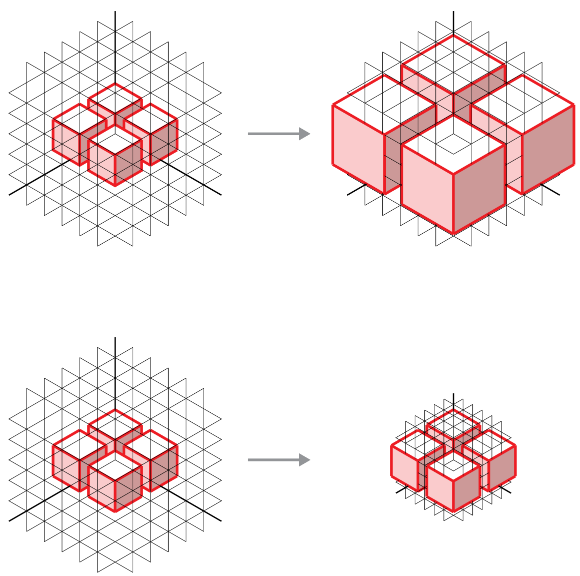
The diagram to the right shows the organization of the eight vocabulary elements that were selected, as well as the pairings that were further explored. In most cases, multiple different rule sets were employed for each pair, indicated by the number of drawing per pair. A brief description of each drawing is provided, along with initial reactions regarding how the different rule sets employed can produce different spatial understandings of the virtual drawing elements.


Scale
Size
Position
Distance
Motion
Planes
Lines
Multiple Viewers
Scale
Size
Position
Distance
Motion
Planes
Lines
Multiple Viewers


Size//Scale
Multiple Viewers//Scale
Position//Scale
Size//Motion
Multiple Viewers//Position
Line//Scale
Position//Position
Distance//Position
Size//Position
Size//Distance

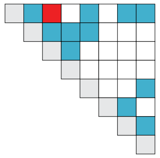
1. Size || Scale



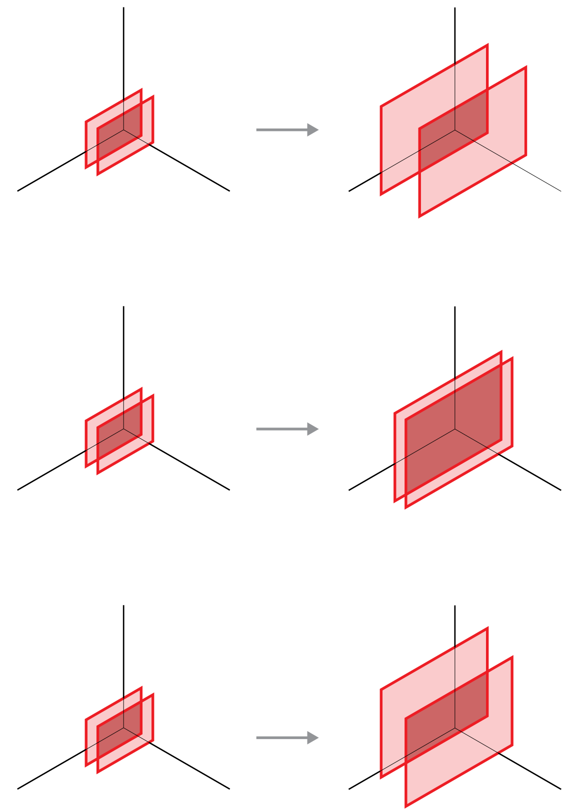


These drawings were designed to investigate the relationship between size (defined as the actual represented dimension of an element) and scale (defined as the percieved size relative to a specified reference frame). A grid is provided to act as a reference frame. The relevant question in these drawings is whether the user feels as though they are changing the size of individual objects or the scale of the overall drawing. If the scale of objects is understood relative to the provided frame of reference, then scaling down the grid could also be interpreted as making the cubes larger while simultaneously changing the scale of the drawing.

2. Position || Scale

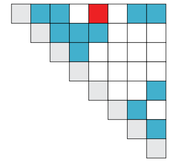


Geometry: Two paralell planes
Variation A: Absolute position of planes scales along with the size of the plane
Variation B: The absolute position of planes remains constant
Variation C: One plane keeps absolute position, the other uses scaled position



Two planes are initially place parallel and approximately 1m apart. In one variation, the position of the planes changes along with the scale, providing the impression of the entire drawing scaling together. In the second variation, the position of the planes remain constant as the drawing scales. This provides the impression of the two planes moving closer together as they get larger.

3. Motion || Scale



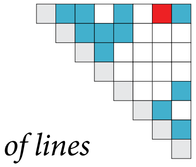
Geometry: Four cubes positioned in a 3D rectangular grid.
Variation A: Motion scaled larger than actual distance controllers move
Variation B: Motion scaled smaller than actual distance controllers move
Variation C: Motion scaled according to scale of objects

Objects in the drawing are moved by the user pressing a button and then moving their controller. In the first variation, the amount of movement is three times more than the actual distance the controller moves. The second drawing has the amount of movement set to be one third of the actual distance. The impressions of theses drawings can be interpreted as 'fast' and 'slow', or 'heavy' and 'light'. Despite the lack of any actual physical detection of weight, the geometry which moves slower feels as if it is somehow 'heavier' or more massive than when the geometry moves faster than the actual motion.

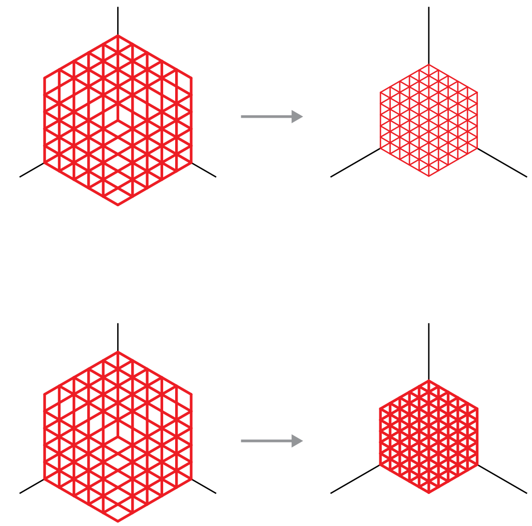
The syntax described by these drawinsg involves the rules of combining mass with speed. Objects of the same physical size which move more slowly are percieved to be more massive, while objects that move faster are percieved to be less massive.

In the third variation, the scale of motion corresponds to the scale of the drawing. That is, when the drawing is scaled down to smaller object, they also move slower. This is counter intuitive, as smaller object would normally be expected to be lighter and therefore move more quickly.

4. Lines || Scale



Geometry: A cube whose six faces are divided into square grid of lines
Variation 1: The lineweight scales relative to the scale of the cube
Variation 2: The lineweight is constant regardless of scale of cube

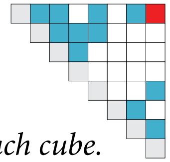


A 'line' is defined mathematically as a one-dimensional object, that is one that has only length and no depth. In reality, lines must have width in order to be visible. On paper, this width is known as the lineweight. Within VR, a line can be represented by a very thin plane, box, or cylinder. In the specifc case of this thesis, a line is drawn as two planes intersecting at right angles in a x-shaped orientation.

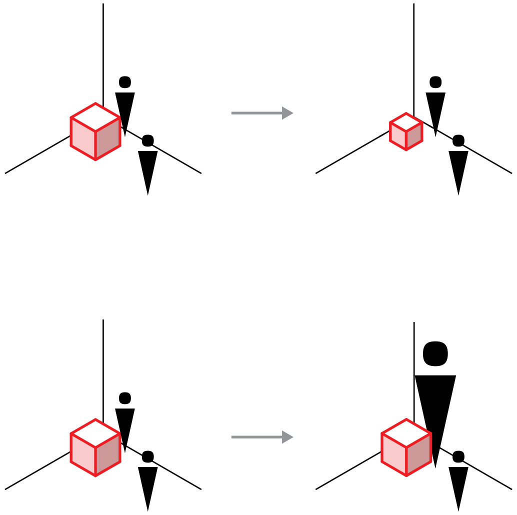
In the first of the two variations, the width of the lines is scaled along with the cube itself. The lines get smaller and larger along with the cube, giving the appearance of a cube made with actual planar elements. In the second variation, the lines maintain a constant size withour regard to the scale of the drawing. This gives the impression of the lines getting larger as the cube gets smaller, and vice versa as the cube gets larger.

In this case, the size of the lines is understood primarily as relative to the cube. The cube acts as the governing body, of which the lines are sub elements. They are expected to follow the same rules as their 'parent' element.

5. Multiple Viewers || Scale



Geometry: 3x3x3 array of frames, with small floating cubes in each cube.
Variation A: Geometry scales, while different viewers maintain absolute scale
Variation B: Each viewer scales their own view independently from the others

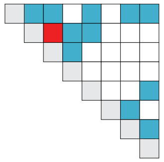


These drawings explore the impact of other people on the sense of scale. In a 2d drawing, the scale of a scene is often indicated by drawing a scale figure. In virtual reality, there is an ambiguity between whether the viewer is making themselves larger or making the world smaller.

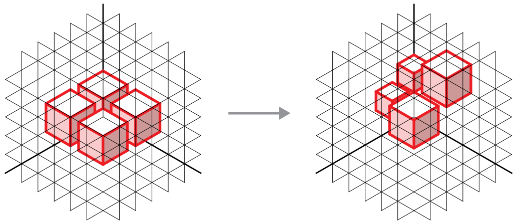
In the first variation, when a user scales the world, the other viewers in the same world remain the same place and size. This provides a visual reference frame that is constant and reinforces the point of view that is the world that is getting smaller rather than the viewer getting larger.

In the second variation, the individual user who uses the scale function experiences a change in scale, while the other uses do not. To the other users, it appears that the scaler is growing or shrinking, while to the scaler, they appear to themselves as remaining the same size while everyone else changes. An additional effect of this second variation is to create a disconnect between the visual and physical location of other people. The users still know through sound, and general knowledge, that there colleague is in the same place and the same size they used to be, but they visually appear to be different.

6. Position || Size



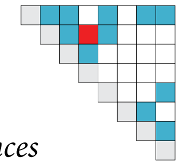
Geometry: Four cubes positioned in a 3D rectangular grid
Variation A: Four cubes react differently to scaling and moving



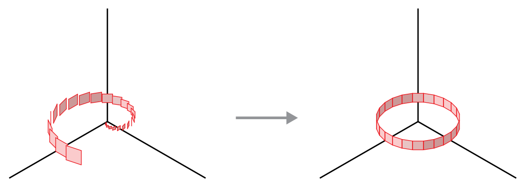
This drawing consists of 4 cubes. One of the cubes remains stationar. One cube is able to move, but not change size. A third cube can change size, but does not change position. The final cube is allowed to change both size and position.

There exists a disconnect between the resulting position and resulting size of the different cubes, producing tension between the expectations of ‘reality’ of the viewer and the visual results of ones actions.

7. Distance || Size



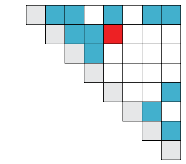
Geometry: A series of planes of different sizes at different distances
Variatian A: The distance and size of the planes are calibrated so the apparent size is equal



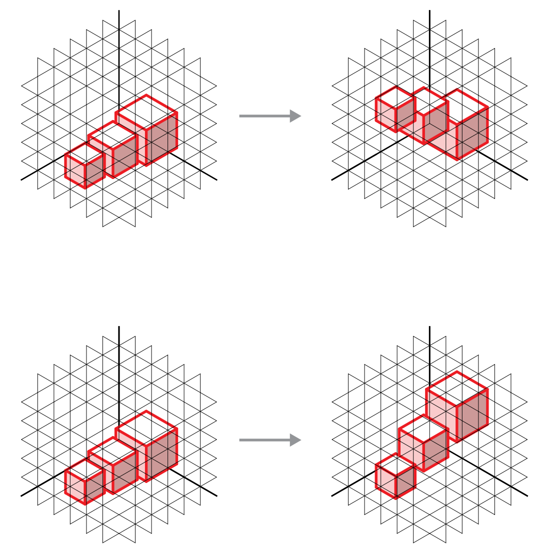
The apparant size of an object depends on the distance of that object from a viewer. By setting the size of a series of planes inversely to their distance, this drawing creates a radial series of planes that grow as they move outward such that each plane has an equal apparent size, despite different distances and sizes.

In the real world, there are myriad factors involved in the psychological perception of depth. Some, but not all of these factors are present within a virtual environment. At close distances, binocular vision is enough to distinguish between objects that are close and objects that are far away. This perception has a limit, however, and at some point the changing focus of the human eye takes over as a primary indicator of depth. This indicator is absent within VR, however, and so only the first few planes in this drawing can be distinguished as 'smaller', while the majority of the planes appear to be

8. Motion || Size



Geometry: Three cubes of different sizes in a rectangular grid
Variation 1: The amount a cube moves is directly proportional to its size
Variation 2: The amount a cube moves is inversely proportional to its size

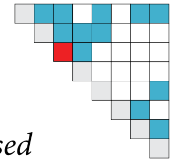


In the real world there is a instinctive rreclation between size and mass of an object. Larger objects are expected to be more massive, and therefore more difficult to move.

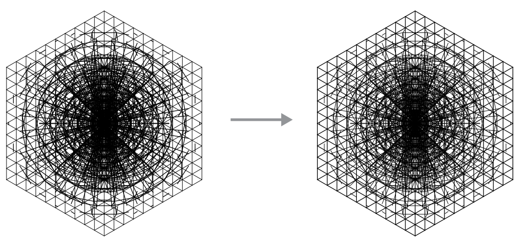
In the first variation, the intuitive expectation of larger objects being harder to move is used. The large cube moves less quickly than the smaller one, giving the impression of a larger and heavier object.

In the second variation, the correlation is reversed, and the smaller object moves more slowly than the larger one. This creates an intuitive sense of 'mass' in the smaller object that outweights the initial assumptions based on size alone.

9. Position || Position



Geometry: A spherical grid and rectangular grid are superimposed

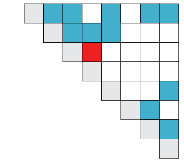


This drawing is intended to emphasize the difference between different ways of measuring the world around us.

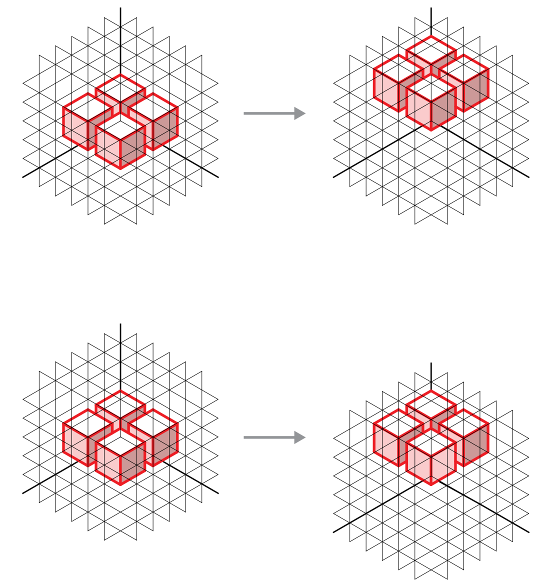
We are accustomed to a cartesian system of measurement, where objects in a drawing are described by their horizontal and vertical position (or x and y coordinates). In 3d modelling software, this is extended by adding a depth (or z) dimension.

In virtual reality, however, there exists an inherent frame of reference produced by the physical position and body of the viewer. The position of objects within the drawing, then, assume a second system of measurement based on the radial distance from the viewer and whether they are above or below, left or right of the viewer. This is an inherently spherical coordinate system.

10. Distance || Position



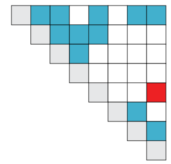
Geometry: Four cubes positioned in a 3D rectangular grid.
Variation A: Cubes can be moved, while the grid remains static
Variation B: Cubes remain static, while the grid can be moved



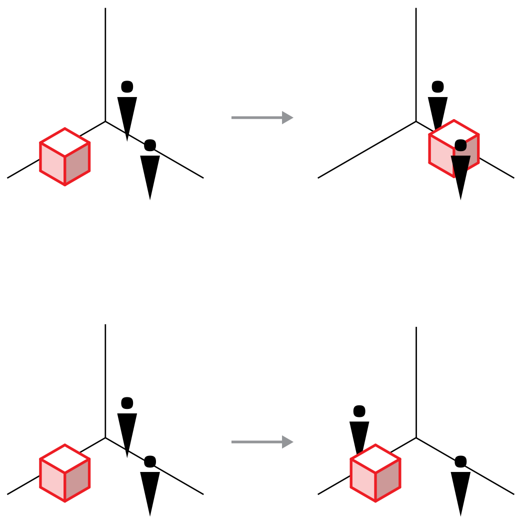
These drawings were designed to investigate the relationship between distance (defined as the actual represented dimension of an element) and position (defined as the percieved placement relative to a specified reference frame).

A grid is provided to act as a reference frame. The relevant question in these drawings is whether the user feels as though they are changing the location of individual objects or the reference frame of the overall drawing. If the location of objects is understood relative to the provided frame of reference, then moving down the grid could be interpreted either as moing the cubes or moving the viewer.

11. Multiple Viewers || Motion



Geometry: Several clusters of cubes spread out through space
Variation A: Geometry moves, while viewers maintain absolute position
Variation B: Each viewer movies their own view independently from others

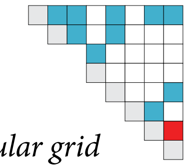


These drawings explore the impact of other people on the sense of location. In virtual reality, there is an ambiguity between whether the viewer is moving themselves through a world, or moving the world around them.

In the first variation, when a user teleports the world, the other viewers in the same world remain the same place and size. This provides a visual reference frame that is constant and reinforces the point of view that is the world that is moning rather than the viewer.

In the second variation, the individual user who uses the teleport function experiences a change in position, while the other uses do not. To the other users, it appears that the teleporter is moving, while to the teleporter, they appear to themselves as remaining still while everyone else changes. An additional effect of this second variation is to create a disconnect between the visual and physical location of other people. The users still know through sound, and general knowledge, that there colleague is in the same place and the same size they used to be, but they visually appear to be different.

13. Multiple Viewers || Lines



Geometry: Users can create networked points within a rectangular grid

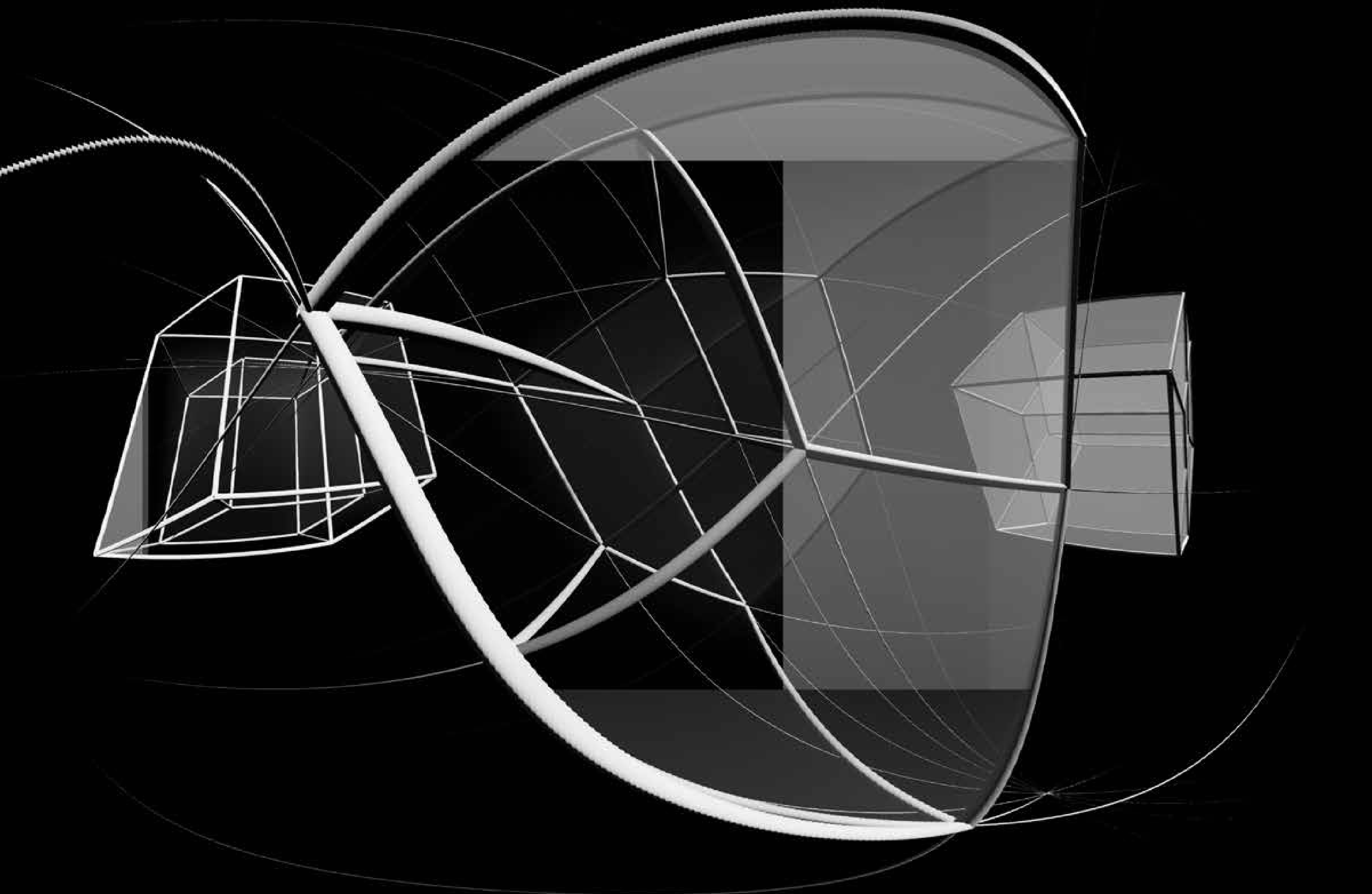
This drawing allows multiple users to create a network of lines in real time. A point can be placed in the world by pressing a button. Each new point that is created is connected to each previous point with a line, creating an completely interconnected network.

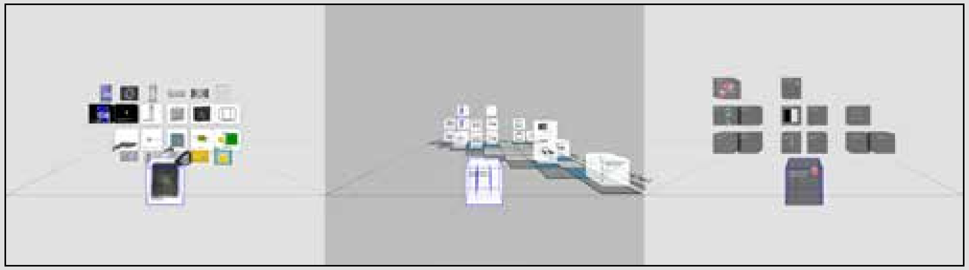
The Syntax of Virtual Drawings

Investigations into the rule set combining different vocabular elements of virtual drawings provides some immediate initial reactions towards how these combinations may be imployed to produce experiences that are not possible within 2d drawings.

One of the most compelling rule sets comes from the category of multiple viewers. Virtual reality provides for the opportunity for multiple people to inhabit the same virtual space at the same time. These viewers may or may not be simultaneously inhabiting the same physical space. In the case where they are in the same physical space, a disconnect can be created between the physical and the virtual. The position and scale of individuals within virtual reality is not directly tied to their scale in the physical world, and yet the inherent reference frame of the body must necessarily remain constant. A situation can be produced where the physical presence of another person is clearly understood (through audio cues, or direct physical contact), while the visual and virtual location of that person is in conflict with the physical. What implications for the understanding of shared space does this disconnect produce? How does the dichomoty of private space versus public space change when a space is simultaneously both private and public?

Another area of interest in terms of syntax is the relationship between the movement and position of a viewer. Due to the physical limitations of virtual reality technology, it is possible/likely that a virtual space will be larger than the physical space allowed. Different rules for travelling through virtual space can be derived which are tied either more closely or less closely to the physical motion of the viewer. The simplest rule is to restrict motion in the virtual space to equivalent physical motion. In such a case, large portions of the drawing are potentially inaccessible to the viewer producing a form of heirarchy between drawing elements with range of the viewer and drawing elements outside of that range. A second method of motion explored in this section is using the hand controllers to move by the action of clicking and dragging. This objective motion can be subjectively interpreted separately as either moving the viewer through the drawing or moving the drawing around the viewer. The primacy of one subjective mode versus another can depend greatly on other visual cues, and begins to suggest ways in which multiple rules of syntax might combine together to produce a semantic understanding of a space within a virtual drawing. A third method of movement involves the ability to instantly 'teleport' from one location to another. In the most common form, this ability to teleport is allowed for any position along the 'floor' of the drawing, maintaining a sense of a horizontal dimension that remains visually distinct from a vertical dimension, despite the lack of any requirement of gravity within a virtual environment.





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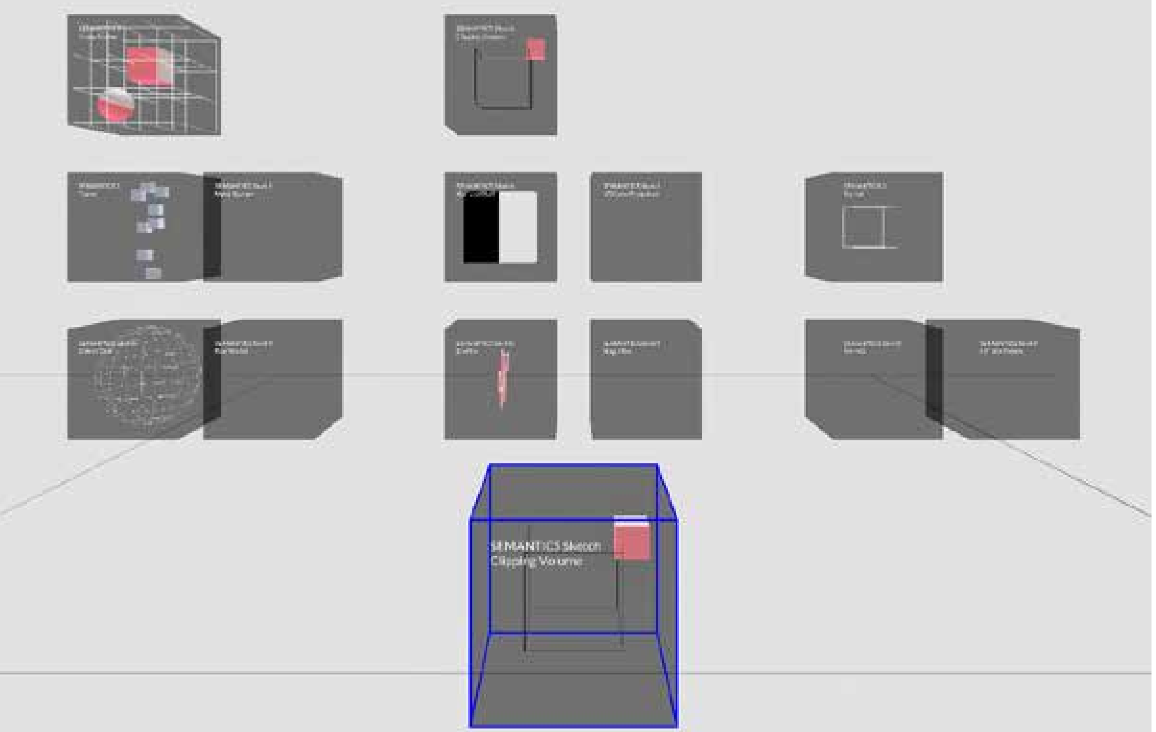

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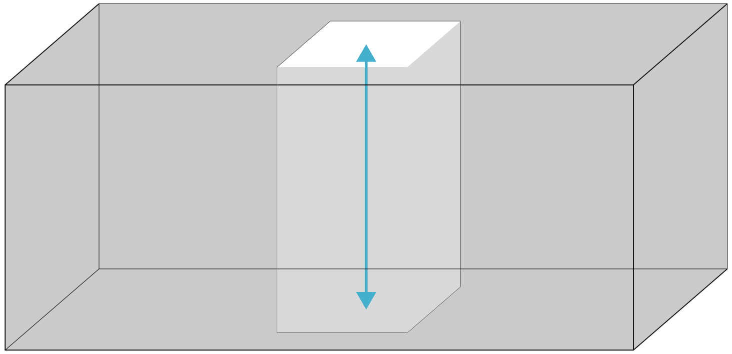
Semantics Drawings

05 - SEMANTICS

Once the rules for combinations of individual elements of the vocabulary of virtual drawings have been investigated, it is then possible to begin to develop a higher level of meaning within the drawing. Choices in rules of motion, scale, visibility, multiple viewers, etc will have different impacts on the way in which the space of a virtual drawing is understood. The question for this phase is how those differences aggregate to produce an overall level of meaning with an indivdual drawing.

Following the progress made in understanding the syntax of virtual drawings, a new method of representation unique to Virtual Reality is developed. What are the effects of the observer inhabiting the same space as the representation? Does the line lose its primacy to the surface? Is movement liberating or restrictive? In what ways does the representation react to the user? Is it dynamic or static?

The goal of this phase is to demonstrate the abilities of Virtual Reality to communicate architectural ideas in ways that are fundamentally different from 2D modes of representation. In addition to the representation itself, this level of communication asks us to also consider the presentation of the VR experience. Is the entire presentation experienced in virtual reality, or is there a corresponding 2d component? To what extent are viewers guided through a virtual interface versus left to freely explore on their own?



DIS-LOCATION

How virtual reality reacts with sense of place.

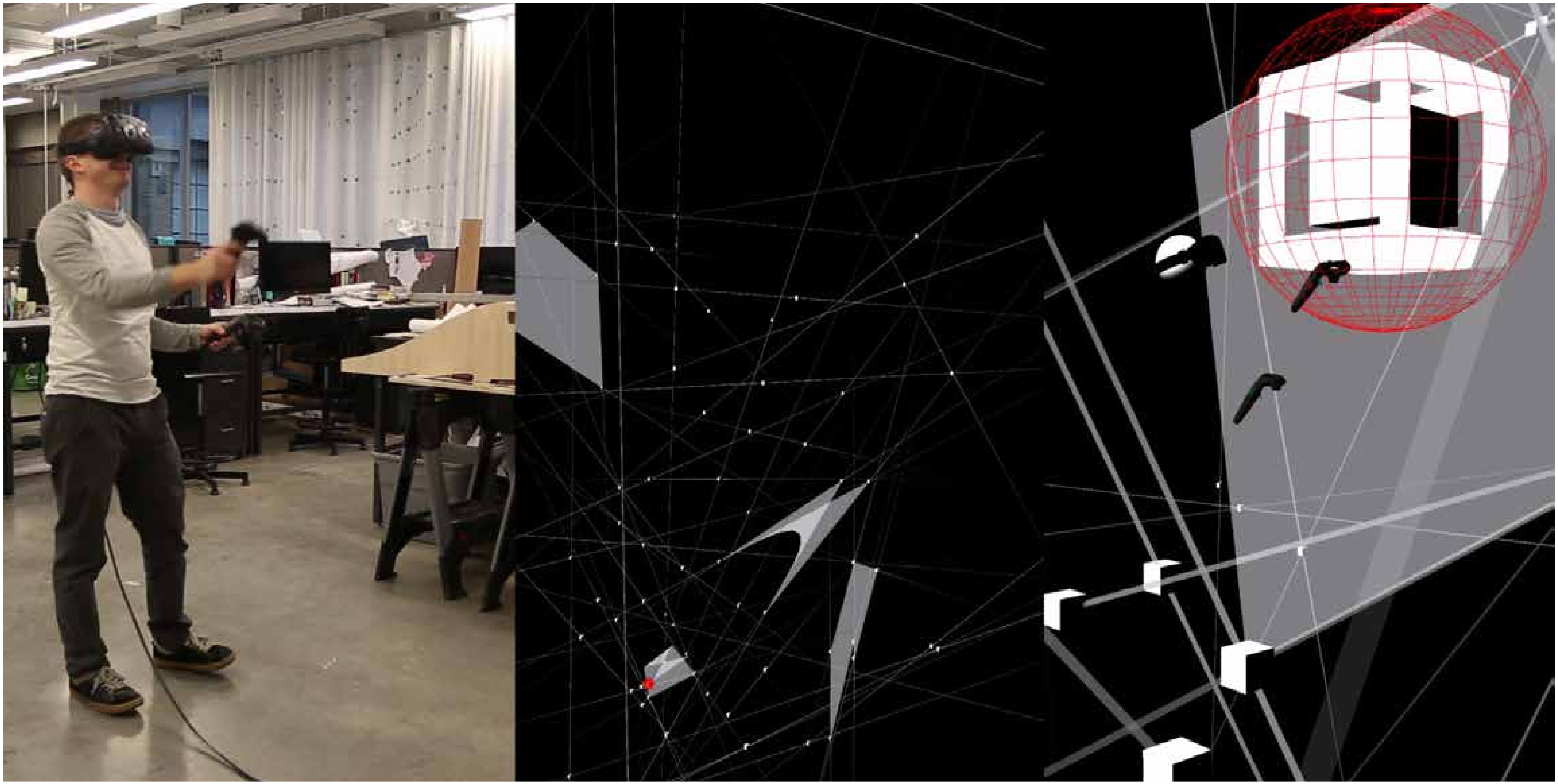
The interactions between the virtual and the physical. The sounds and feelings of the physical versus the sights of the virtual.

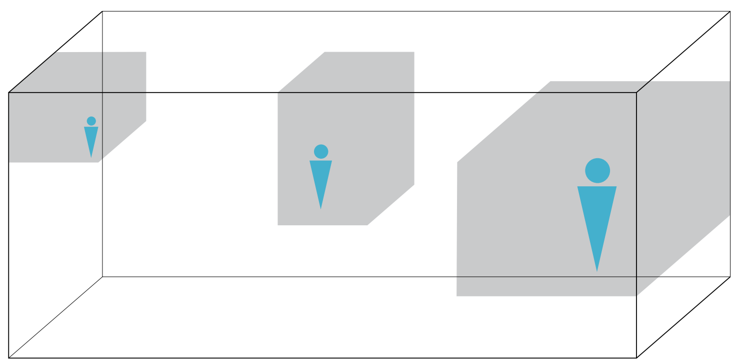
The proprioceptive knowledge of motion versus the mathematical ambiguity of the virtual.

The ability to occupy two different places at the same time.

Below: The same scene from three points of view - physical reality (left), virtual camera stationary with the virtual world (center), and virtual camera stationary with the viewer (right)

Above: PORTAL - A infinitely thin black plane in a white environment becomes a portal to an opposite arrangement, creating a literal spatial experience of figure becoming ground





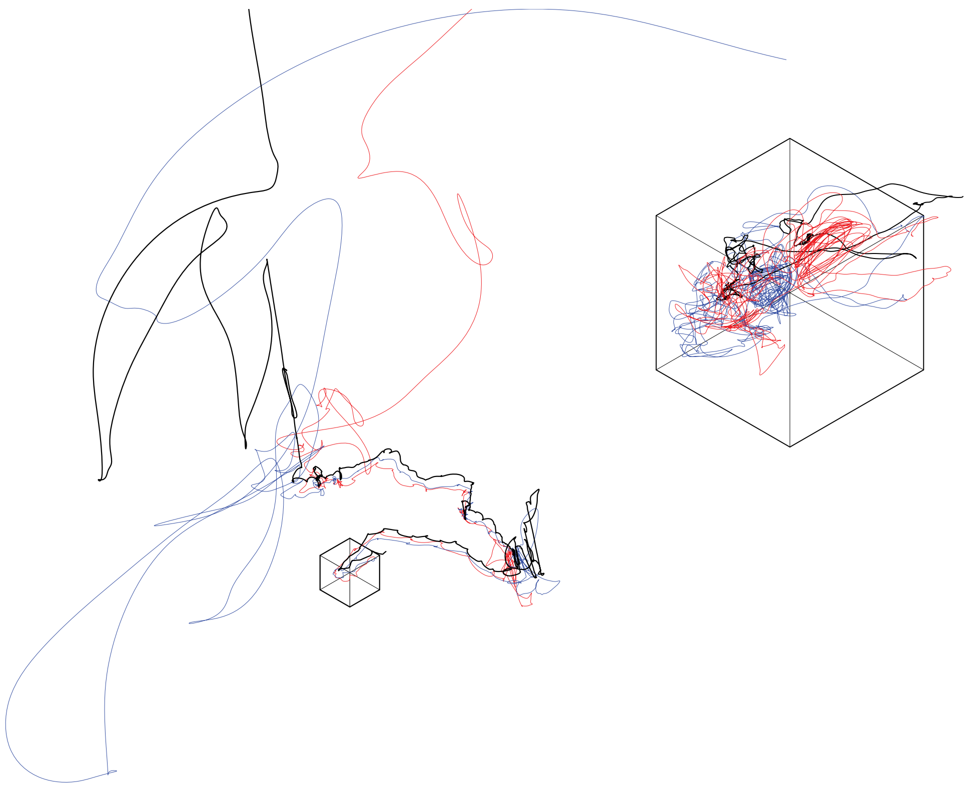
SELF-SCALAR

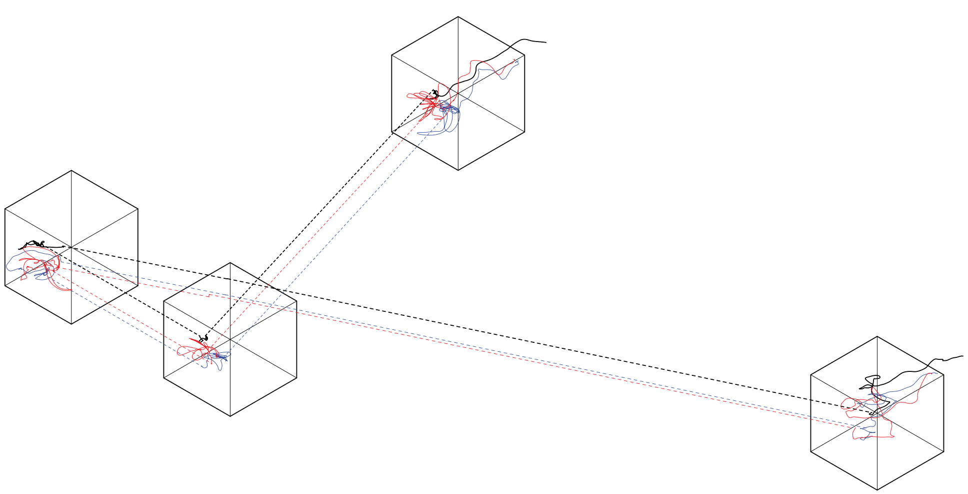
How the self-reference frame imposes itself onto the perception of the virtual.

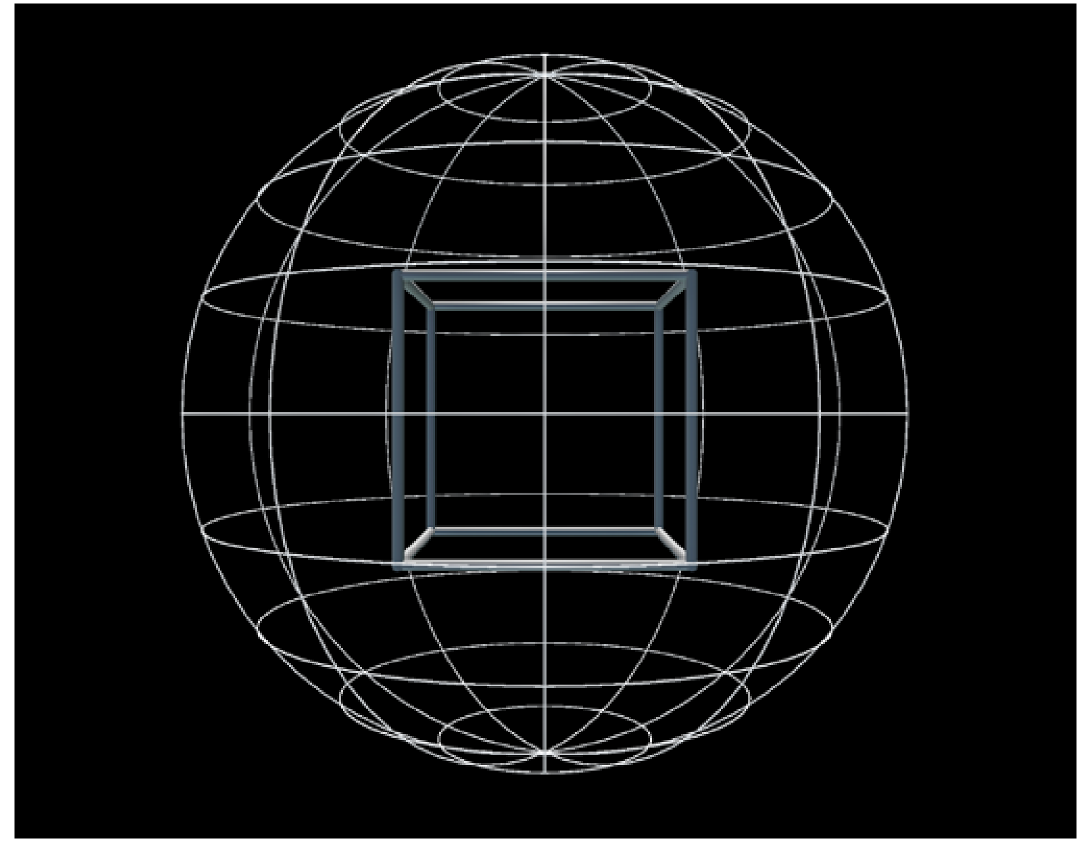
Up/Down, Above/Below, Near/Far, Large/Small are relative characteristics that depend on a frame of reference. Within VR, the only static references are the self and gravity.

Scale dependent perception arises from the inherent frame of reference produced by body.

Three traces of movement within a virtual environment, illustrating the difference in perception between moving through space versus moving space around the viewer.

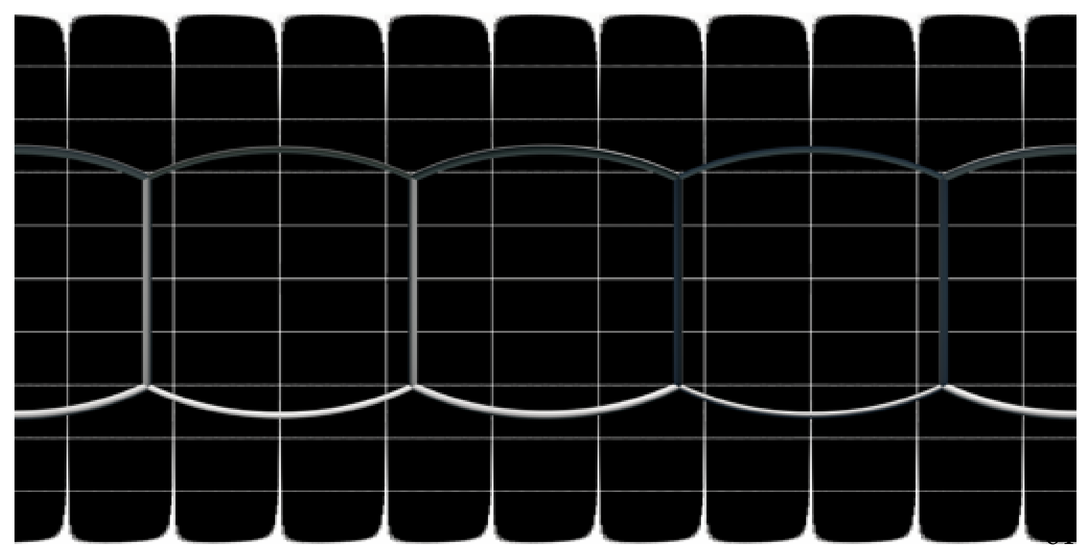


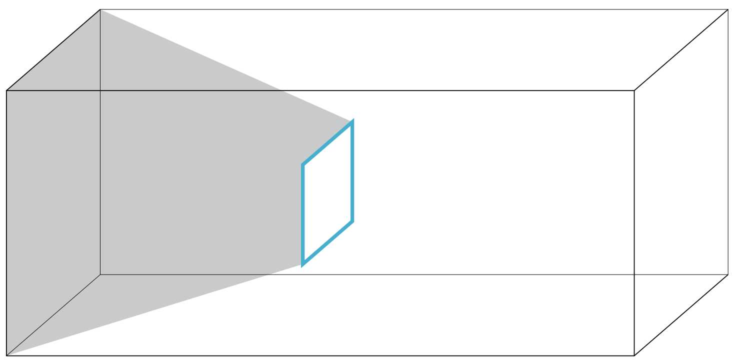




Above: Spherical and square grids, as viewed from an external reference frame

Below : Spherical and square grids as viewed from a self-scalar reference frame - spherical frames become more regular and ‘natural’



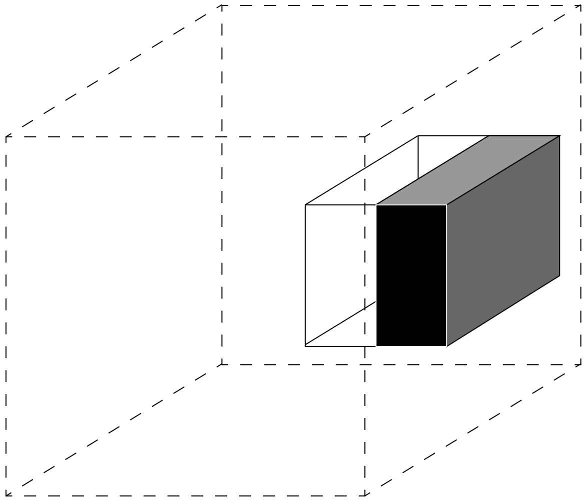


DIS-MATERIALITY

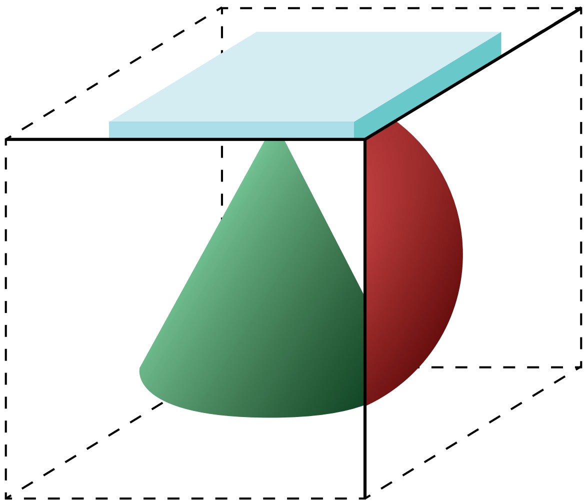
How virtual reality reacts with sense of matter.

The reaction of the human understanding of weight, solidity, inertia to the visual deception of the virtual.

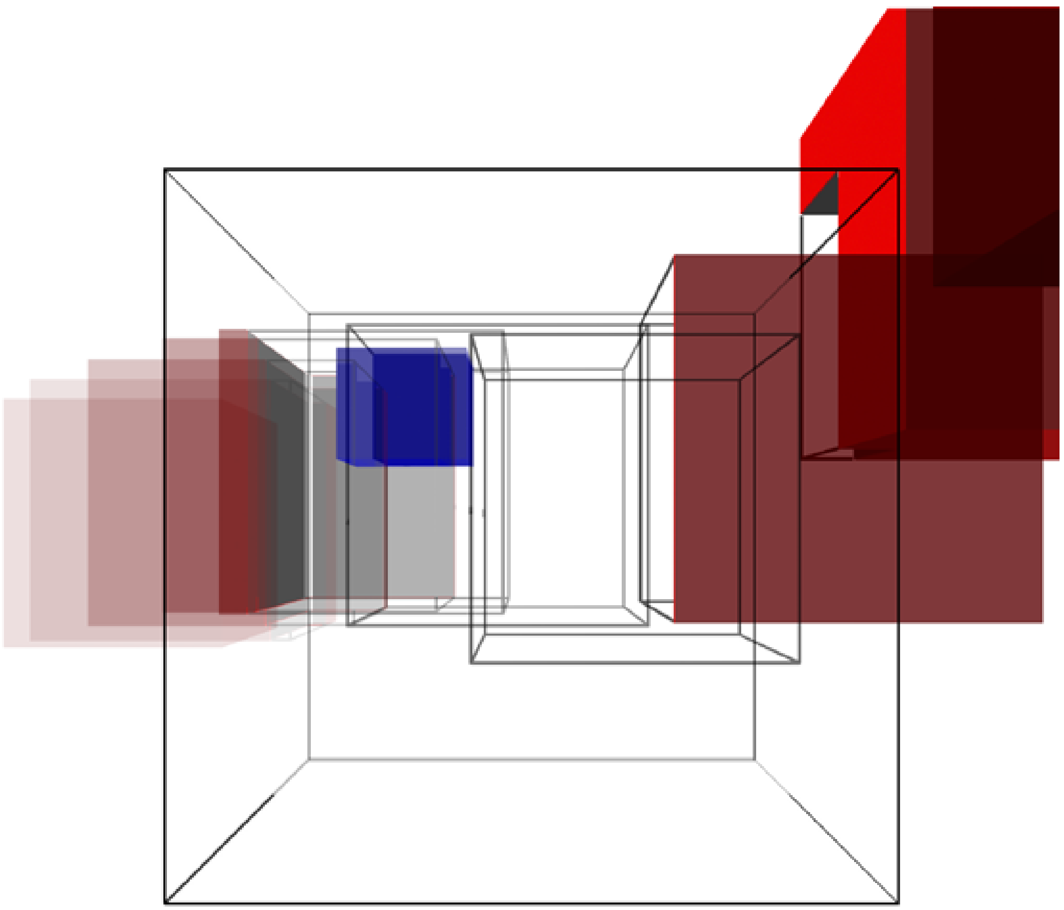
The ability for two things to occupy the same place at the same time.

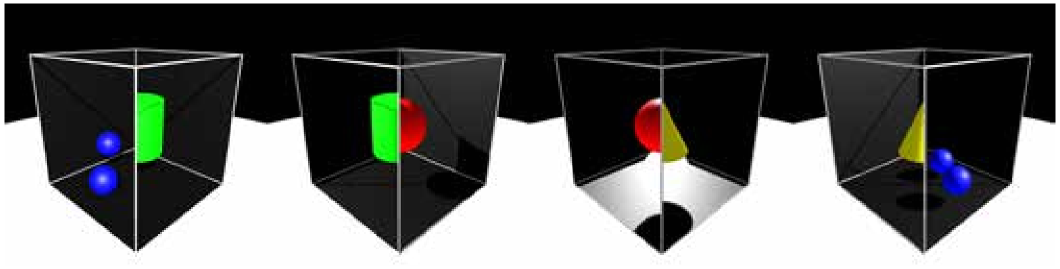


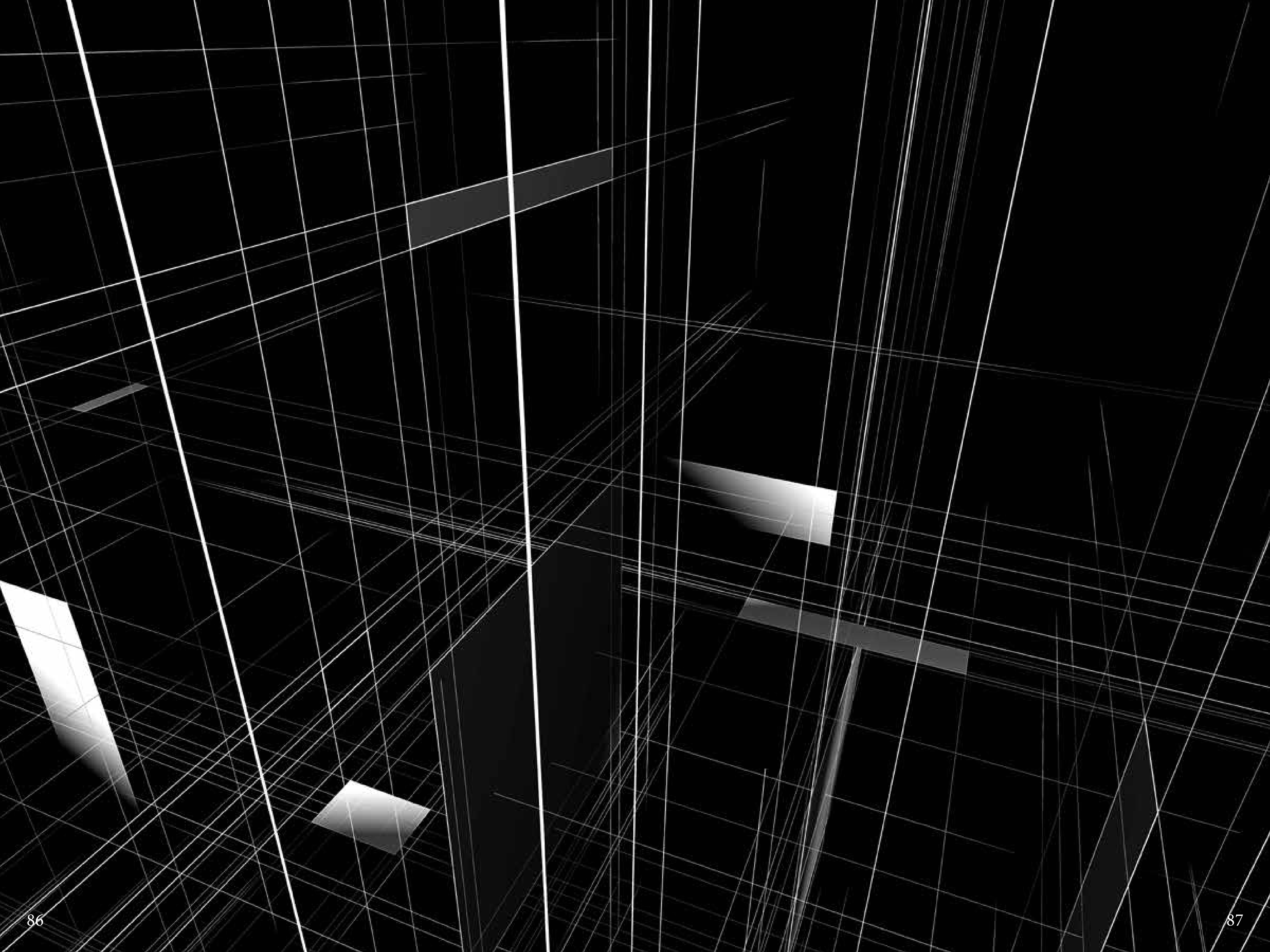
Clipping volumes illustrated the dis-materiality of objects



The contents of the box depend on the position of the viewer, allowing for multiple objects to exist in the same place, and allowing multiple viewers to have different experiences within the same drawing







“An architectural drawing is as much a prospective unfolding of future possibilities as it is a recovery of a particular history, to whose intentions it testifies and whose limits it always challenges. In any case a drawing is more than the shadow of an object, more than a plie of lines, more than a resignation to the inertia of convention.”

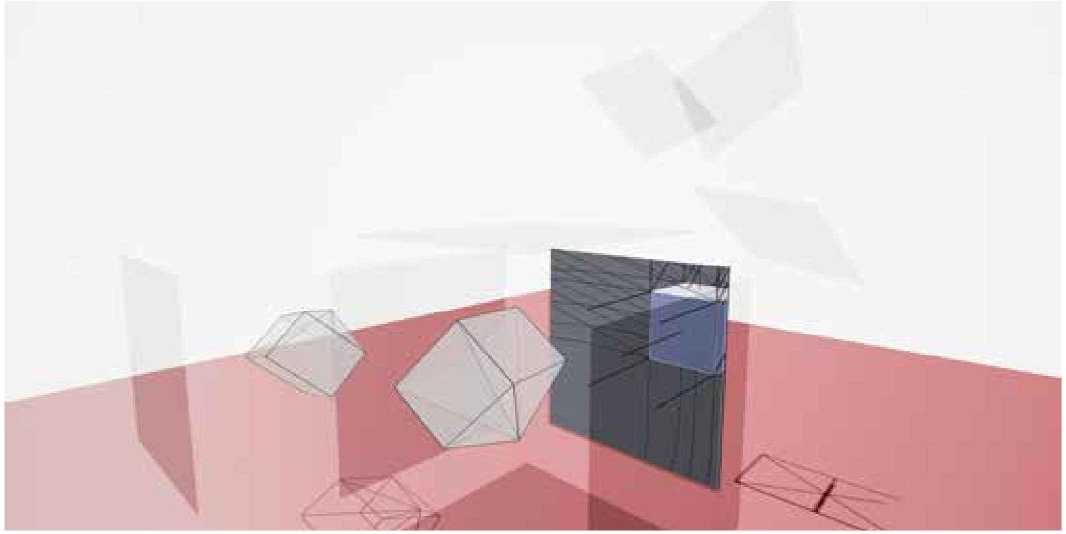
- Daniel Libeskind

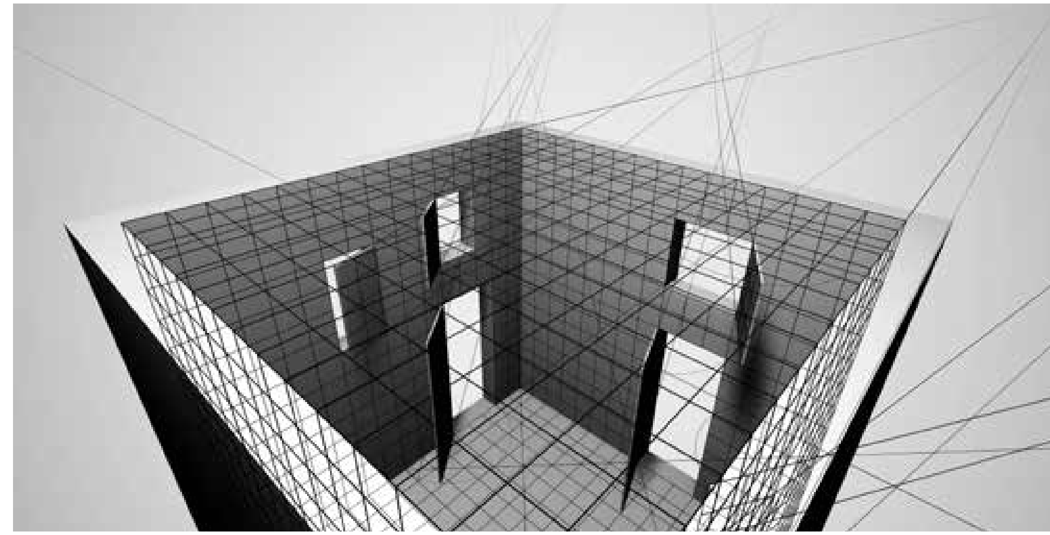
06 - PRAGMATICS

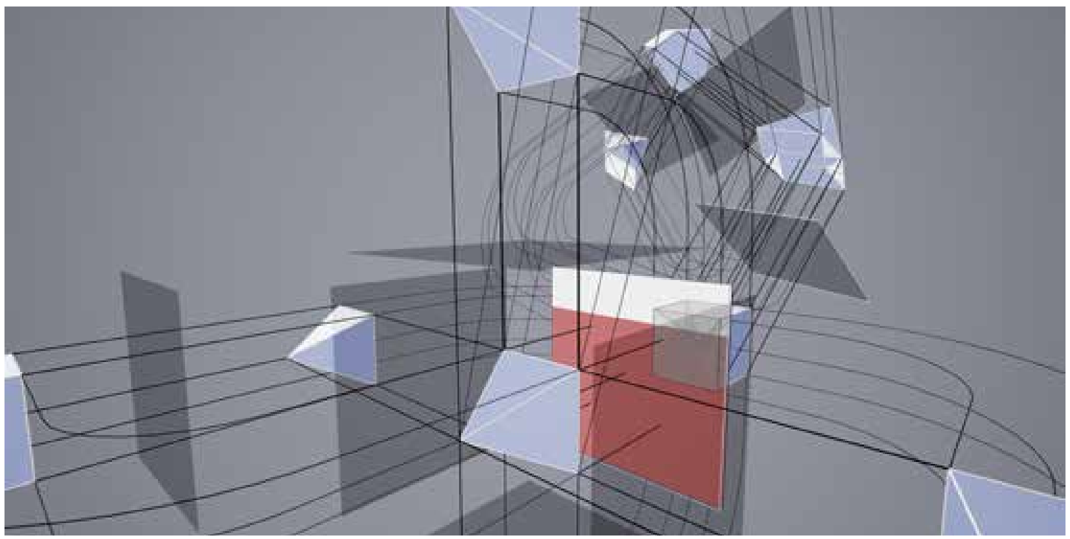
In the coming years, architects will have to collectively develop new conventions and communal understandings about virtual reality in order to use it to its full potential as a mode of visual representation.

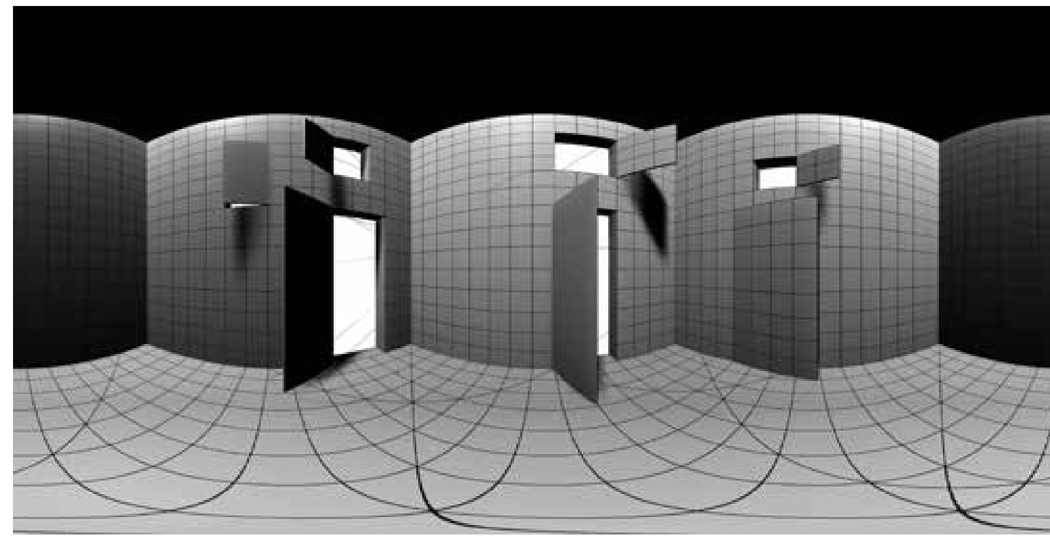
This thesis is not intended to provide solutions and answers, but rather to use design to begin the discussion around the question that began this thesis: **How do new constructs of architectural representation made available through Virtual Reality influence our perception of space and our relationship to the built environment? How will this altered perception affect the architecture that we design?**

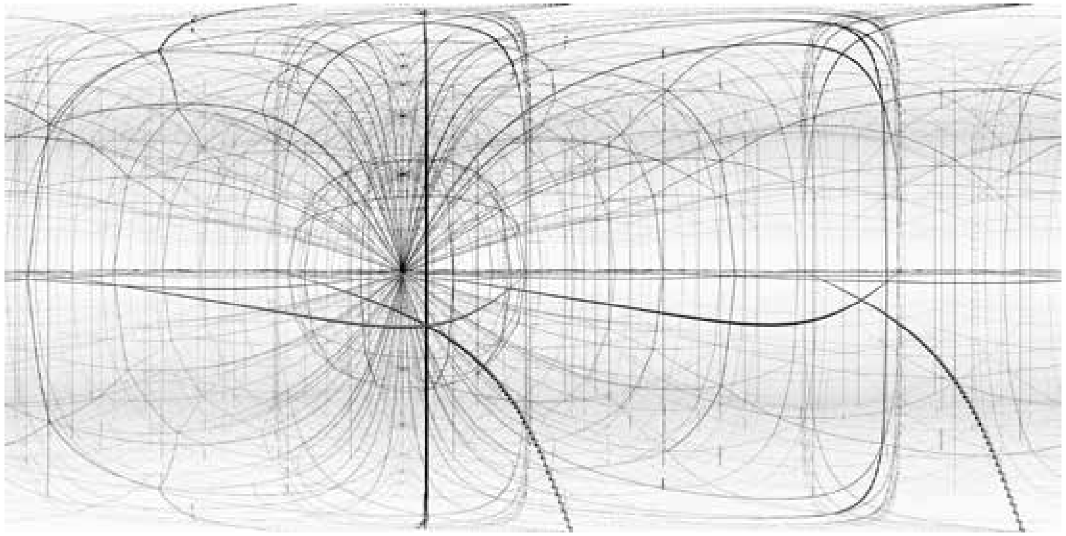
This is just the beginning. Virtual reality will become a common and important tool in design. The nature of the changes it will produce are uncertain and beyond what we can currently imagine. I expect and hope the contents of the latter parts of this thesis will be mostly irrelevant within a few years. It is crucial to start the process now, so that we can help define what that nature becomes.

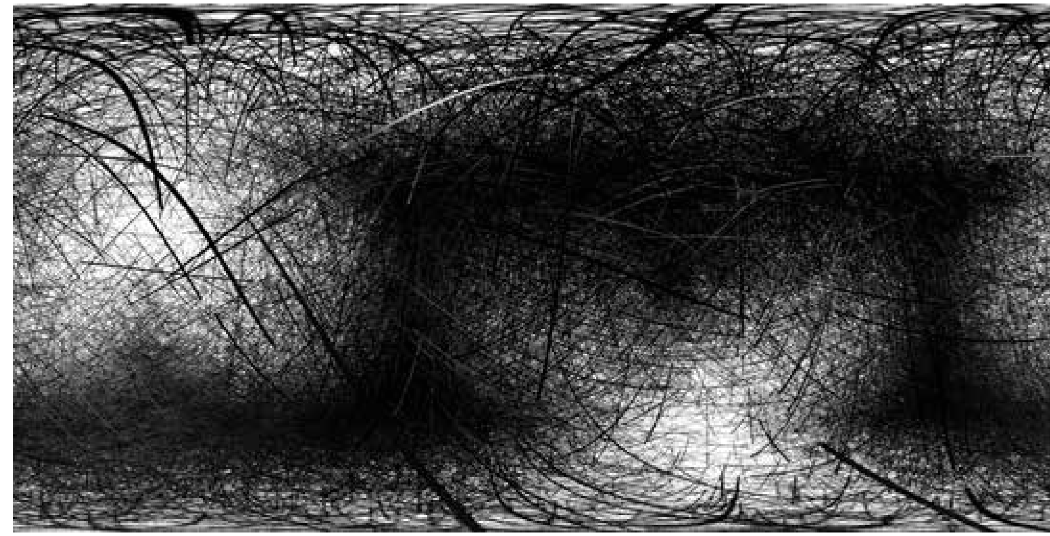


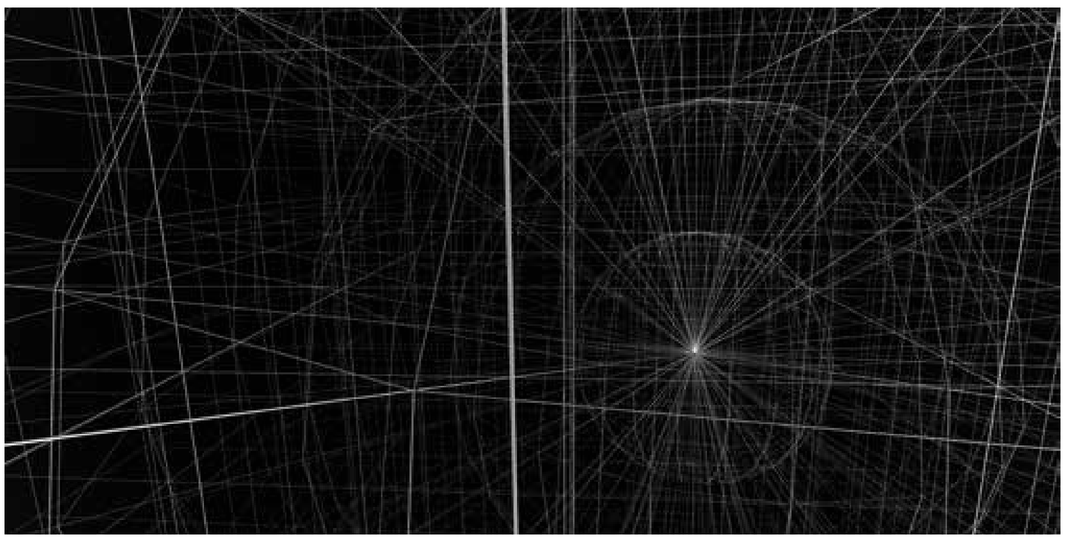


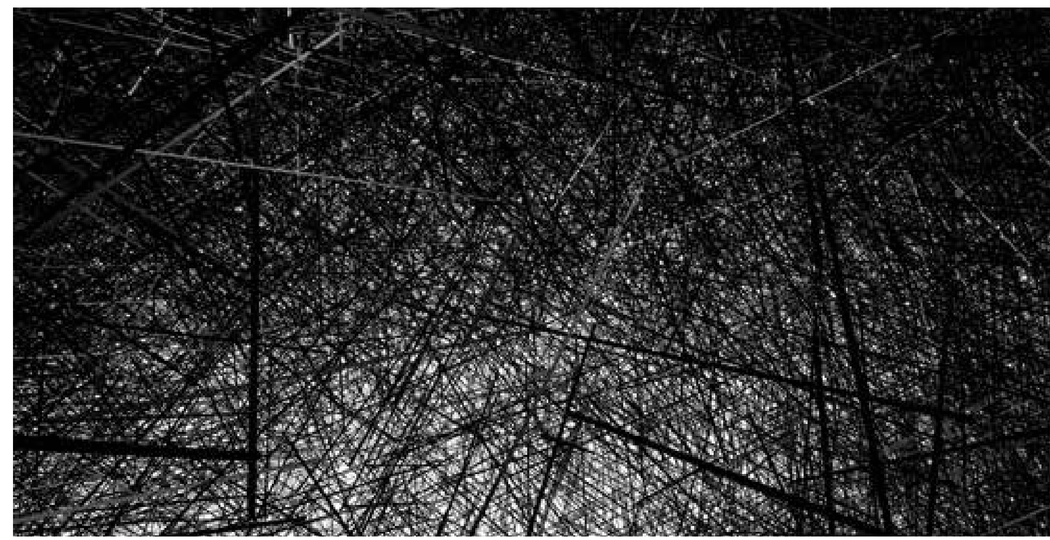


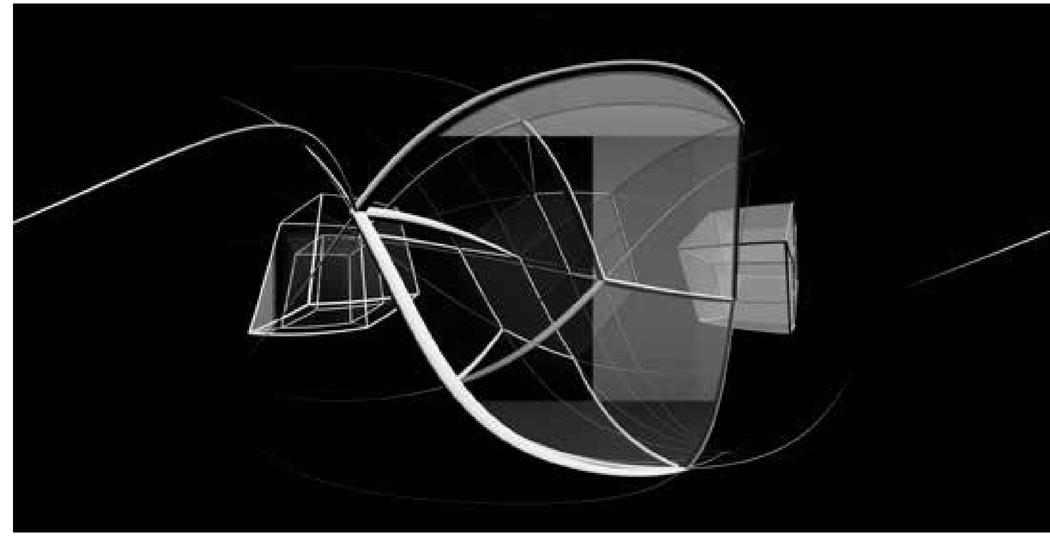


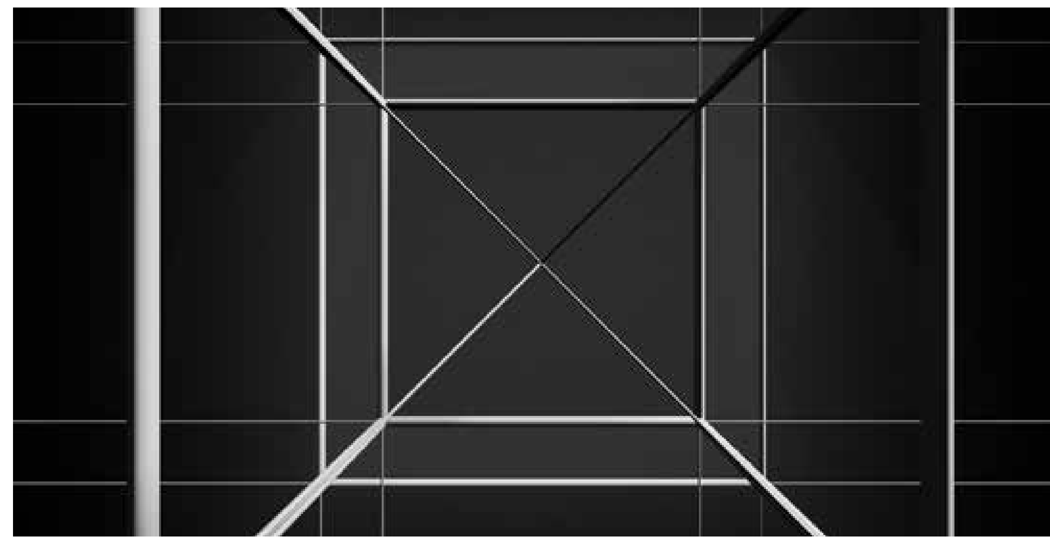


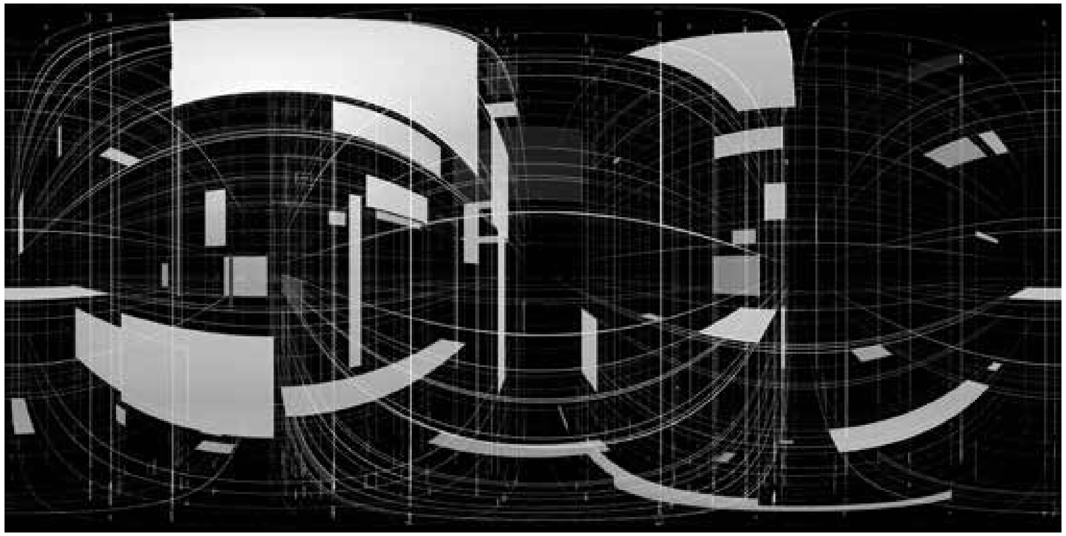


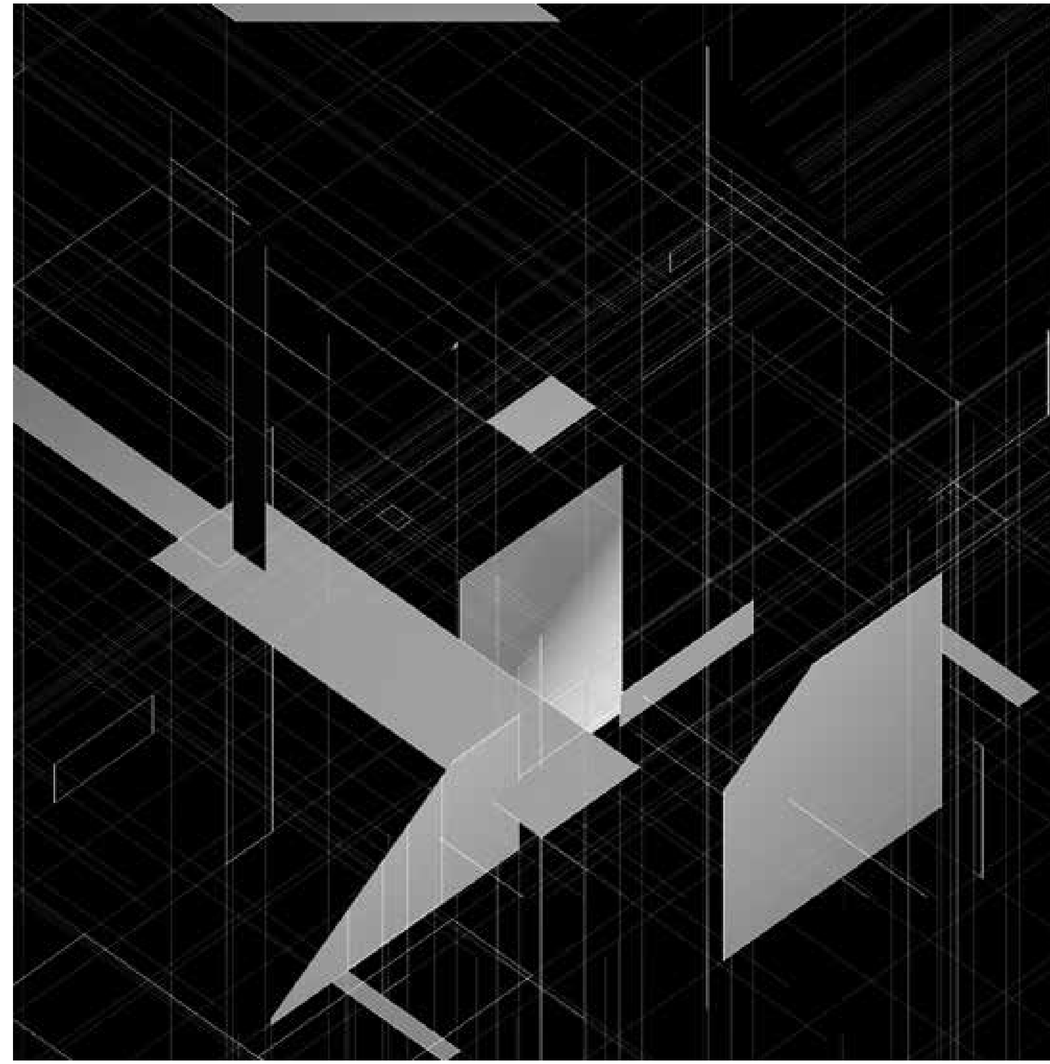


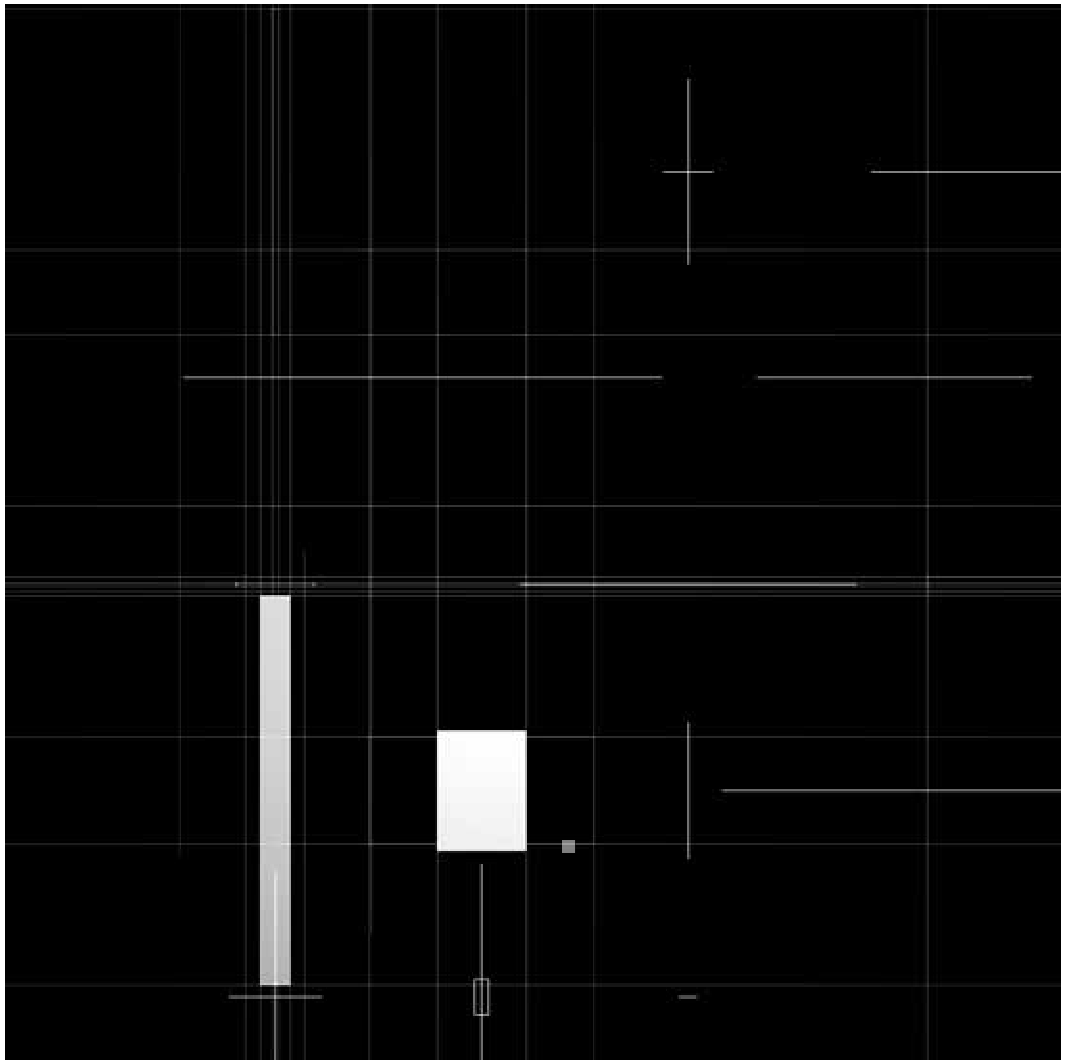


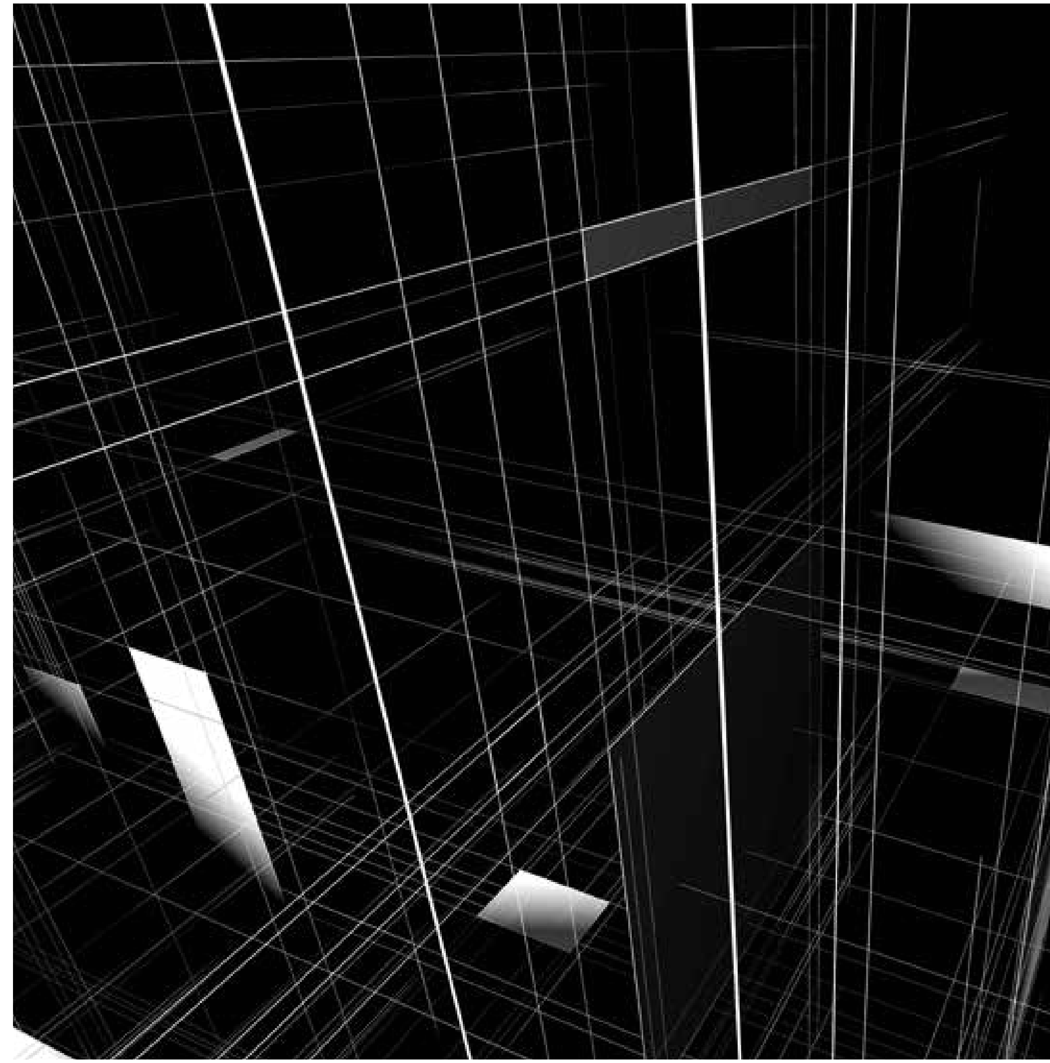


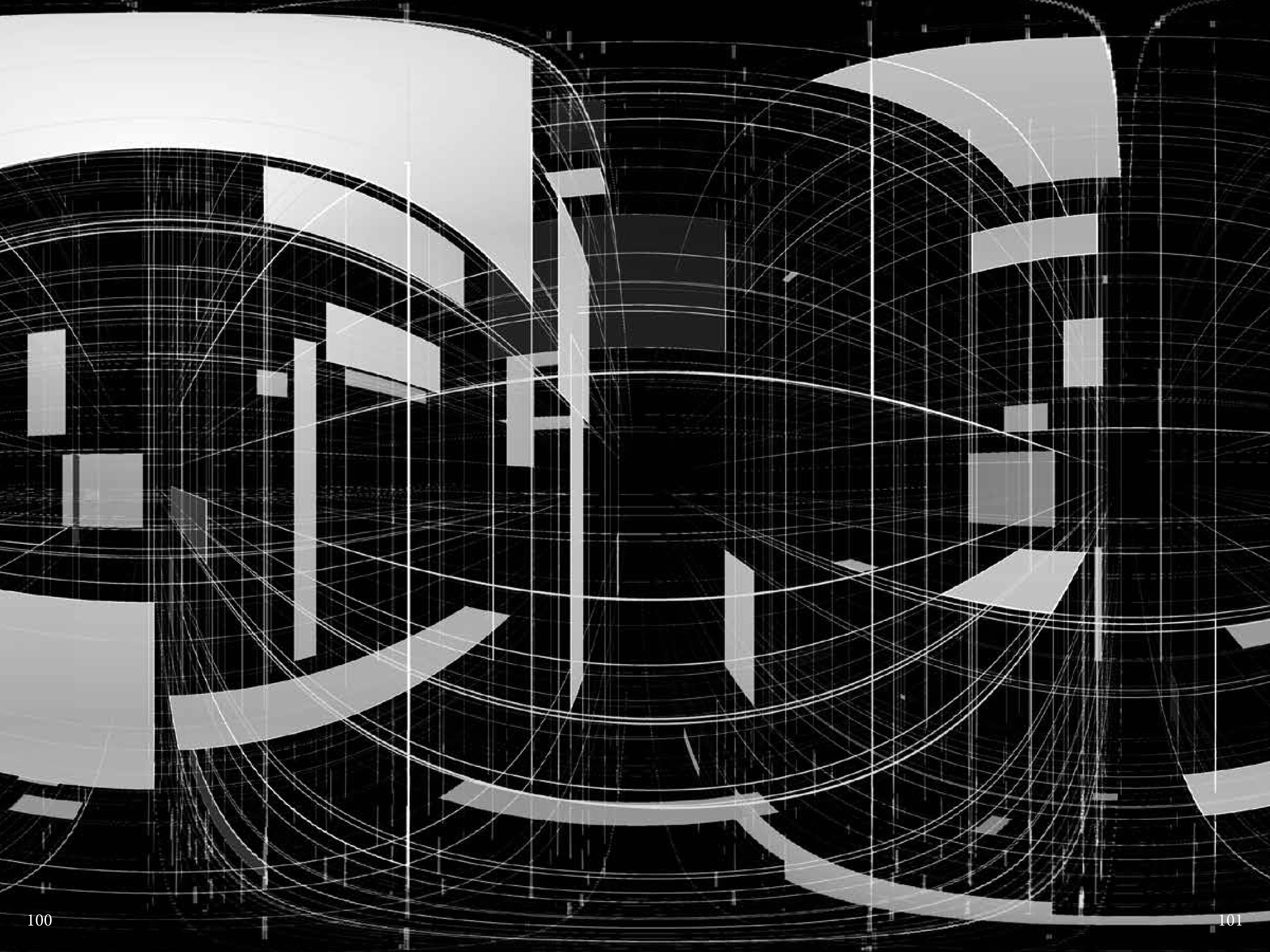


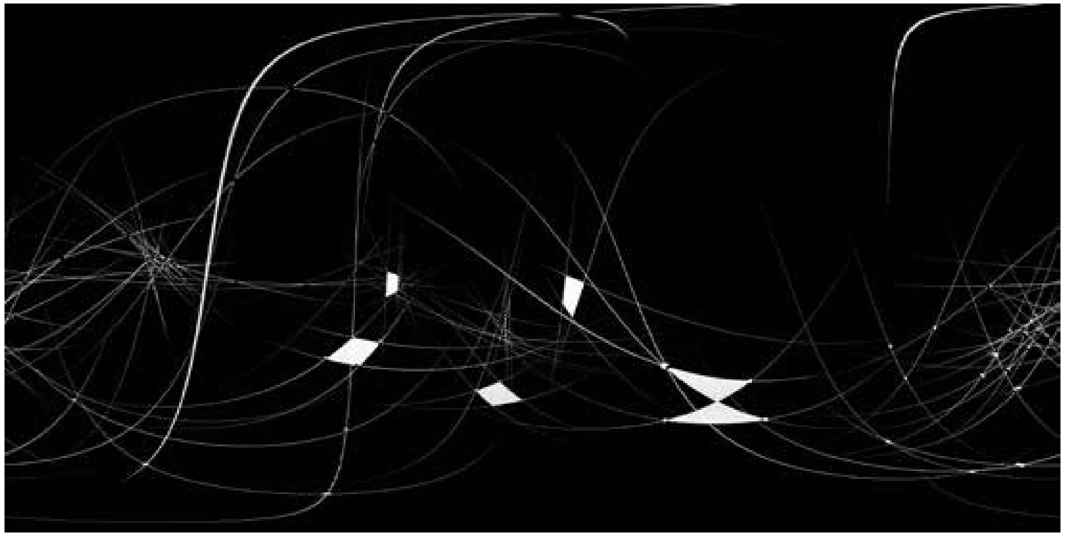


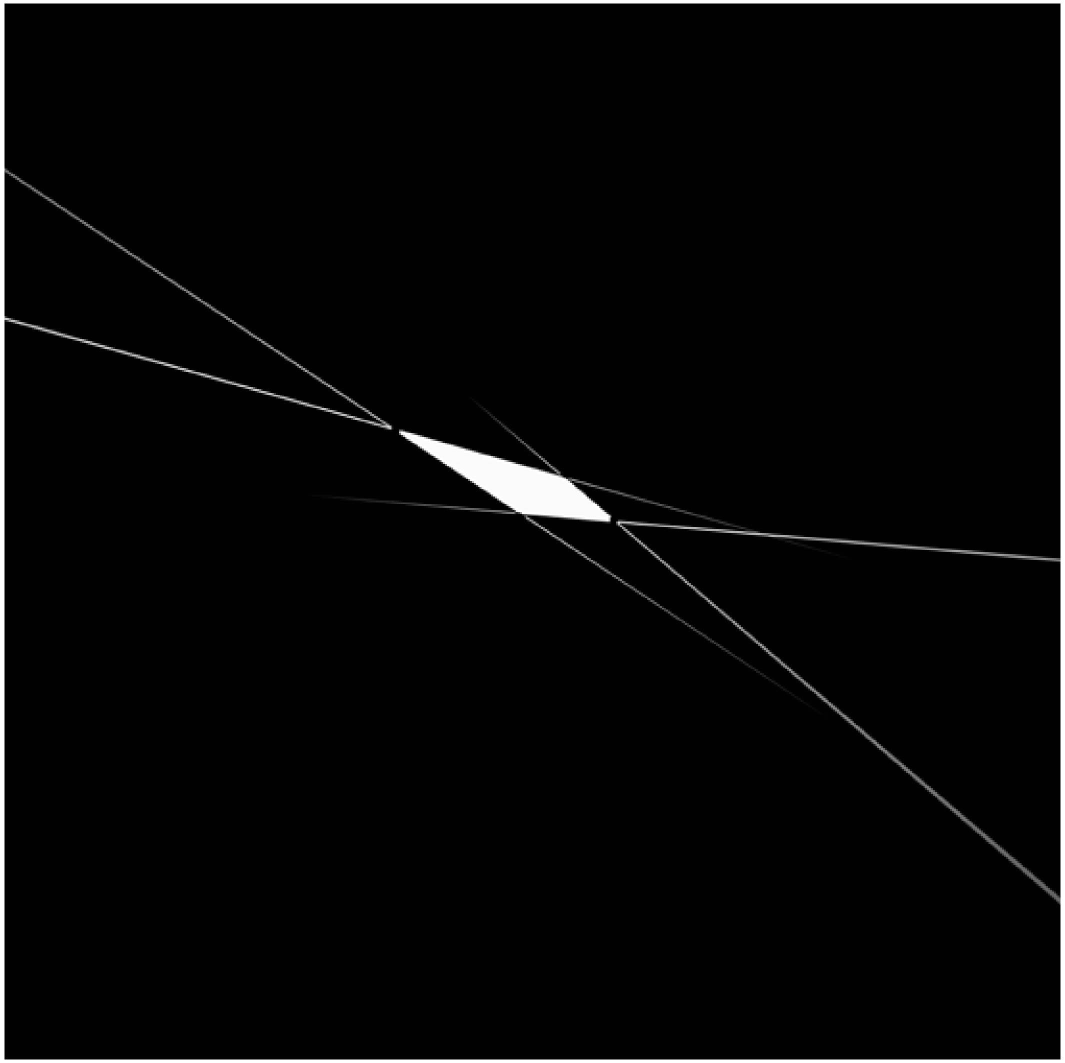


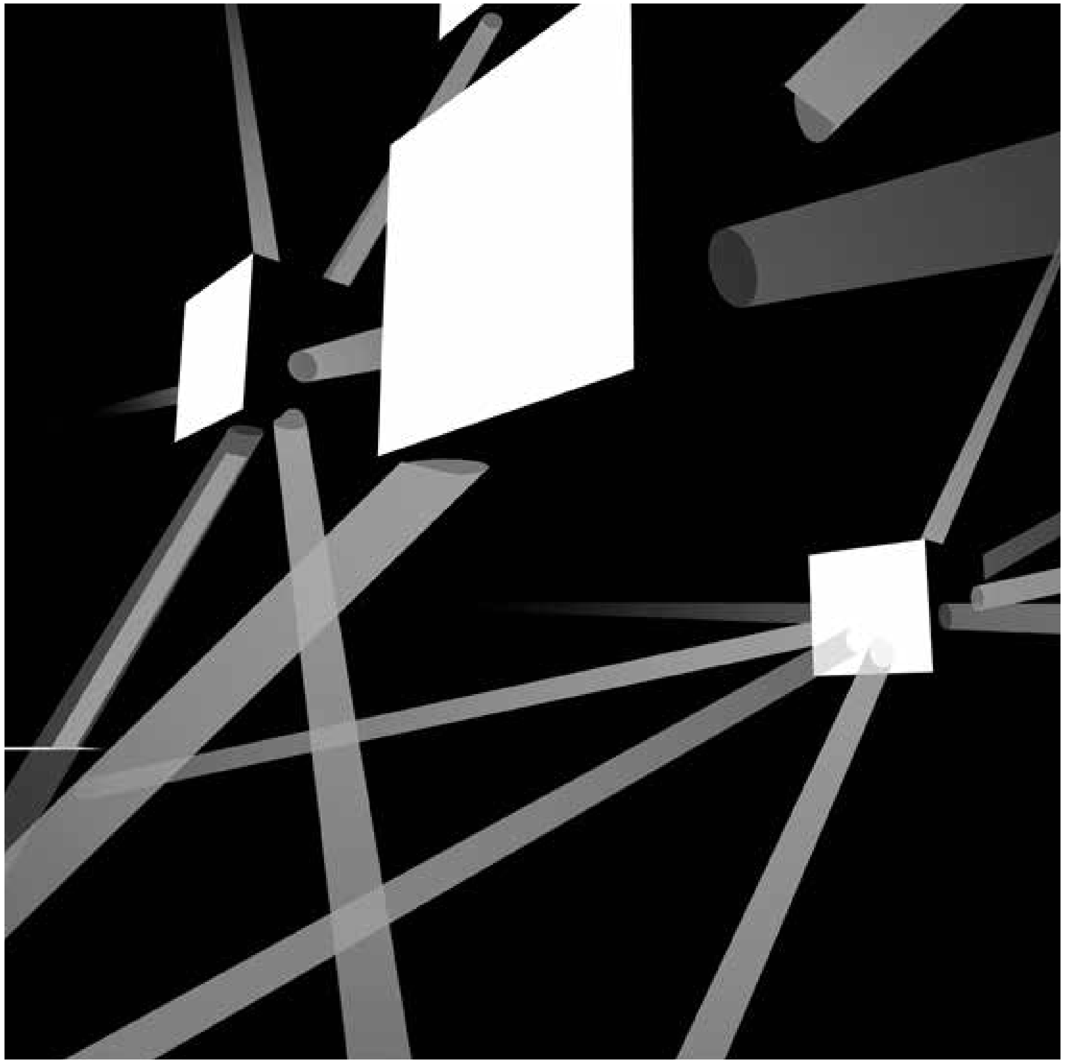


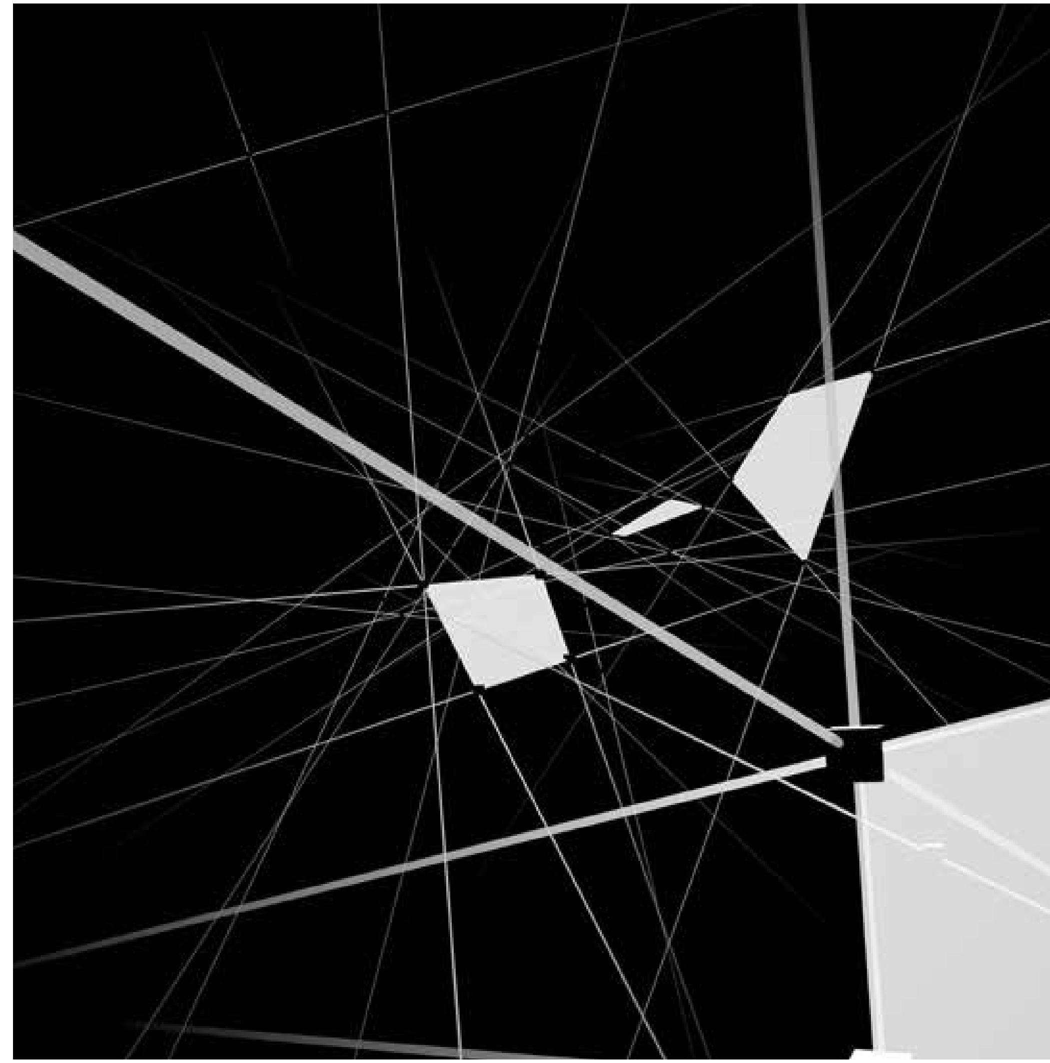


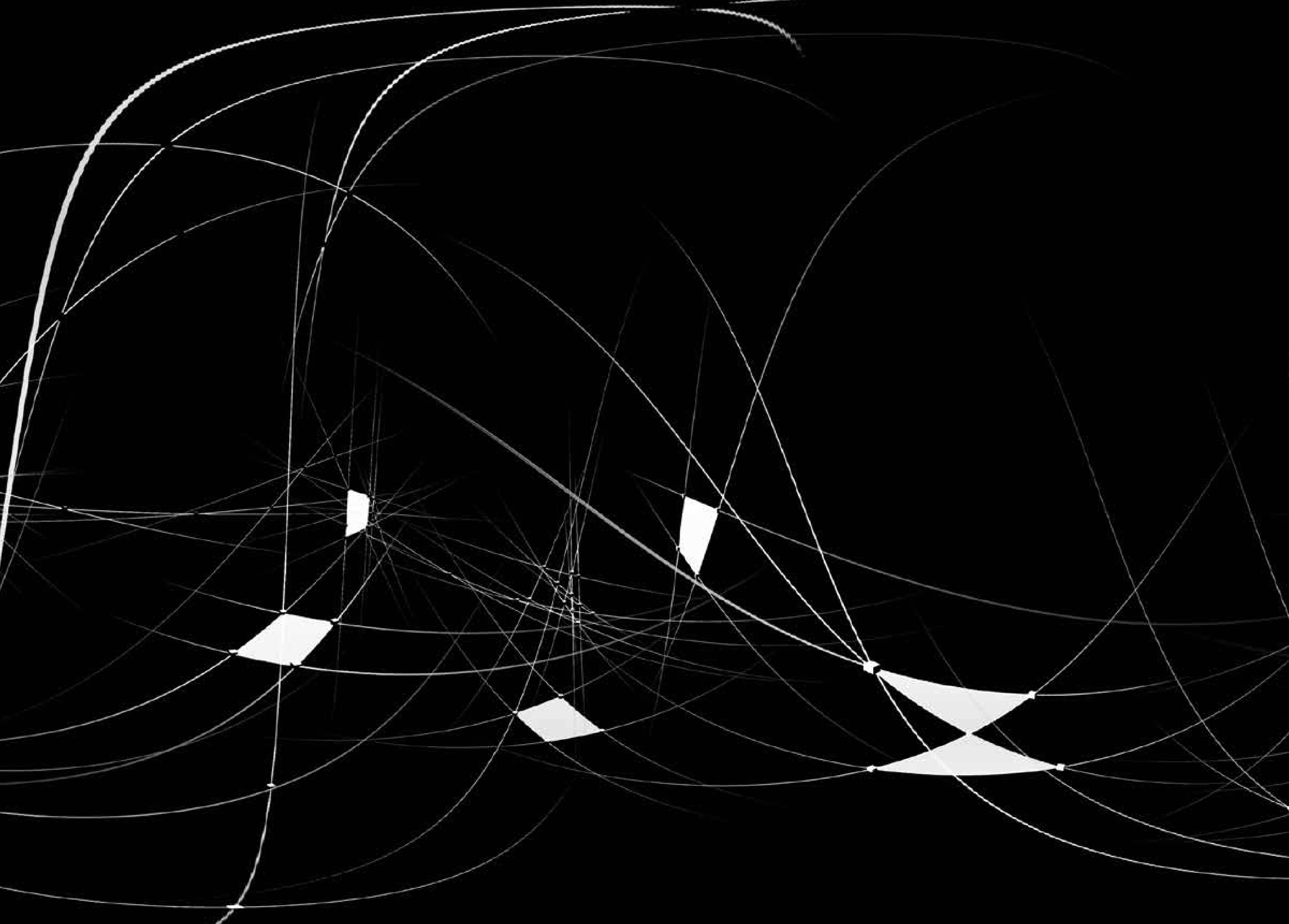












Testing virtual drawings
Seth Byrum (left) and Chris Morse (right)
Photo by Brian Hong

Testing virtual drawings
Alex Jopek (left), Chris Morse (center), Chris Chown (right)
Photo by Brian Hong

Interim Review 1, September 21st 2016
Martin Miller, guest critic (left); Luben Dimcheff, advisor (center); Chris Morse (right)

Studens experiencening virtual drawings at Interim Review 1, September 21st 2016

Interim Review 2, October 26th 2016
Andrea Simitch (left top), Dasha Khapalova (left bottom),
Jeremy Foster (centetr), Chris Morse (right)
Photo by Alex Jopex

Interim Review 2, October 26th 2016
Andrea Simitch (left), Jeremy Foster (centetr), Chris Morse (right)
Photo by Alex Jopex

Final Review, December 6th 2016
Marc Swackhamer, Heather Roberge, Chris Morse,
Aleksandr Mergold (standing, left to right)
Donald Greenberg, Caroline O'Donnell (seated, left to right)
Photo by Alex Jopex

Final Review, December 6th 2016
Caroline O'Donnell, Aleksandr Mergold, Chris Morse (left to right)
Photo by Alex Jopex

A1 - REFERENCES

Alberti, Leon Battista (1453) On Painting

Akin, Omer and Eleanor Weinel (1982) Representaiton and Architecture

Ayers, Phil (ed) (2012) Persistent Modelling: Extending the Role of Architectural Representation

Carpo, Mario (ed) (2008) Perspective, Projections & Design: Technologies of Architectural Representation

Evans, Robin (1997) The Projective Cast

Galison, Peter (1997) Image and Logic: A Material Culture of Microphysics

Kittler, Friedrich (2009) Optical Media

LaValle, Steven (2016) Virtual Reality

Perez-Gomez, Alberto and Louise Pelletier (1997) Architectural Representation and the Perspective Hinge

Picon, Antoine (2010) Digital Culture in Architecture: An Introduction for the Design Professions

Picon, Antoine (2003) "Architecture and the Virtual: Towards a new Materiality?"

Scheer, David Ross (2014) The Death of Drawing: Architecture in the Age of Simulation

Witt, Andrew (2010) "A Machine Epistemology"

A2 - TECHNICAL INFORMATION

The final content for this thesis was presented through Virtual Reality, and is therefore not possible to fully document in a book. Virtual drawings were created using Unreal Engine version 4.15 and were developed for use with the HTC Vive Virtual Reality system.

The project files for this thesis are available in a Github repository:

https://github.com/cwmorse/VirtualDrawingThesis2016

The repository contains two versions, an executable and a project folder. To run the executable, download the zip file, unzip and run VirtualDrawing_CM.exe

The project files require Unreal Engine 4.15 to run, and have not been packaged to run independently without the Unreal Engine editor.

In addition to the Unreal project files, the github repository also contains digital content from the thesis presentation including a PDF file, two brief videos, and a digital copy of this book.

For help using Github to access the project files, see their help website at:
https://help.github.com/

For help installing Unreal and running a project, see their documentation at:
https://docs.unrealengine.com/

(all links current as of March, 2017)