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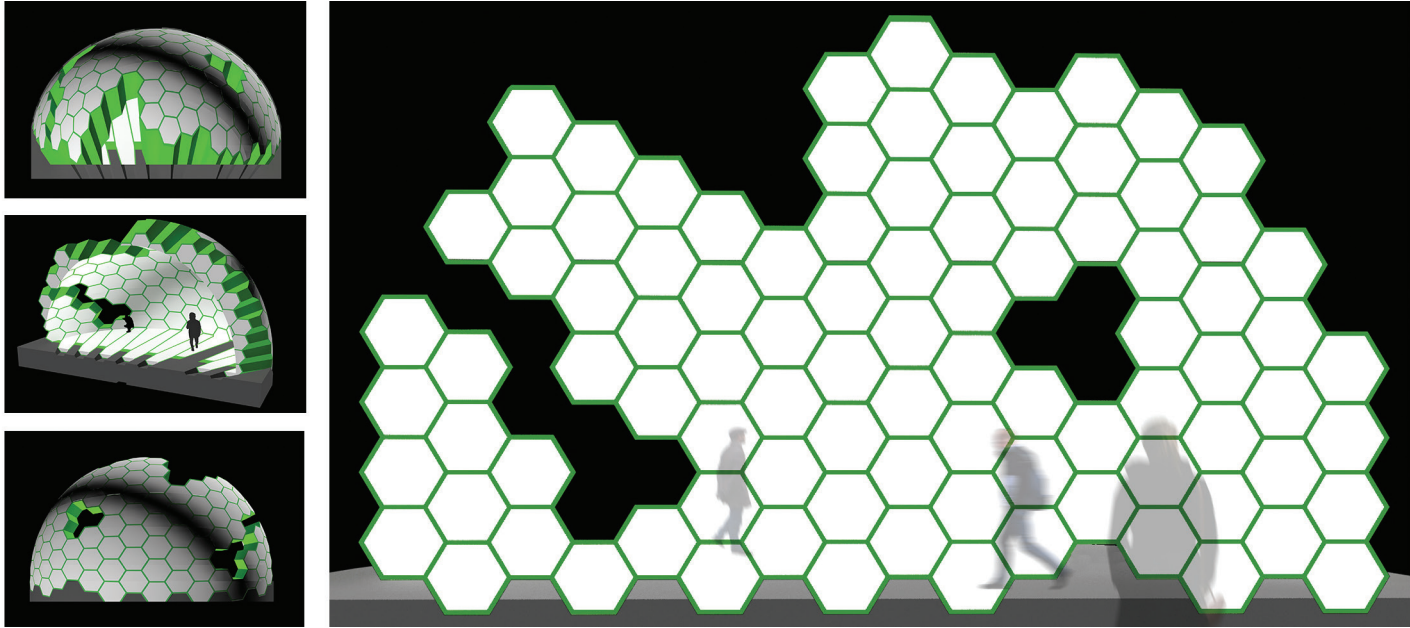
Optically Illusive Architecture

Producing Depthless Objects Using Principles of Linear Perspective

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1 Pavilion, a space where depthless architecture is depicted.

ABSTRACT

Architecture is a discipline with a long history of engagement with representational techniques borrowed from the arts such as painting and drawing. Historically, these techniques enable artists to translate three dimensional space into a two dimensional medium while architecture tends to work in reverse using the latter to express yet-to-be-realized projects in the former. This investigation leads to specific methods of linear perspectival representation that manipulate our perception of spatial depth such as trompe l'oeil and anamorphic projection. Referencing these methods, we introduce the concept of an optically illusive architecture. While referencing a wide range of visually deceptive effects, we focus on synthesizing two-dimensional patterns into three-dimensional objects for the purpose of producing a depthless reading of three-dimensional space.

In this paper, we outline optically illusive architecture and look at the initial stages of a design experiment that attempts to bring the perception of flatness into a three-dimensional object. This is achieved by building a simple algorithm that reverses linear perspectival projection to produce two-dimensional effects through a three dimensional physical object. We analyze the results by comparing the two- and three-dimensional projections against one another from varying points of view in space and speculate on the possible applications for such a design.

INTRODUCTION

Sight functions as our dominant sense when engaging the geometry of three-dimensional space. By extension, our visual perception of the geometry of space plays a major role in shaping our behavior within it – and playing with our perception of space becomes a primary mode of architectural design. Toward this end, we want to import the quality of flatness into architectural space (Figure 2).

Linear perspectival representation in architecture has historically been used to approximate an individual's visual perception of geometrically discrete objects in space. At the same time, a subset of perspectival representation focusing on optical illusions in art offers us the possibility of manipulating our visual perception by exploiting discrepancies between the image of an object and the actual object itself. Key components of linear perspective include defining a specific point of view, specifying the geometry of a picture plane and projecting vectors from specific moments of an object to said point of view while passing through the picture plane. By manipulating the geometry of the picture plane (treating it as a topological surface, for example), the viewpoint assumes the role of a gate that switches or augments the perceived characteristics of the architectural object or space. We introduce the concept of "Picture Volume" as opposed to picture plane and it allows us to ask those tectonic and architectural assembly questions that were almost left unanswered by previous projects and experiments.

The effect we are interested in producing consists of making an object appear flat when in reality it is not. It would be disruptive to manipulate people's perceptions and expectations of space by means of optical illusions. Assuming that the form of a city relies on the architecture between generic and specific environments, we are introducing a new specific space that is disruptively embedded into a generic context. In other words, it is - to some extent - reprogramming a space in a way that objects have disruptive effects beyond themselves.

In order to unpack this concept, we define our version of optically illusive architecture. We follow by briefly analyzing three specific optical illusion techniques with their corresponding results: trompe l'oeil, anamorphic projection, and forced perspective – all derivatives of linear perspective. We go on to extract

components of each of these methods and abstract them into a generative script. This script is then used to generate an optically illusive design that we evaluate in terms of flatness. We conclude by outlining future opportunities for an optically illusive architecture.

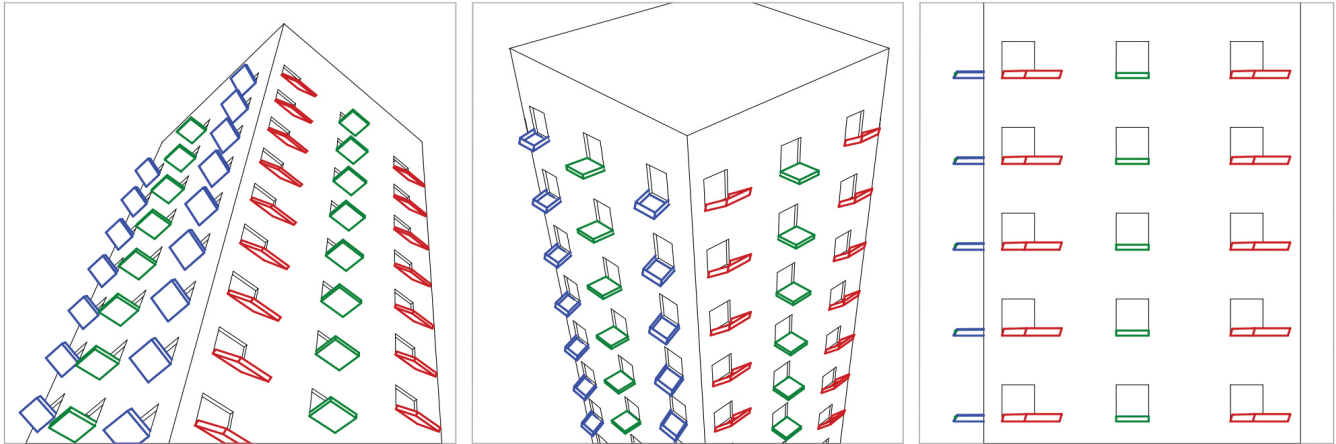## OPTICALLY ILLUSIVE ARCHITECTURE (OIA)

Broadly speaking, optically illusive architecture (OIA) is simply an architecture that appears to be different than it actually is

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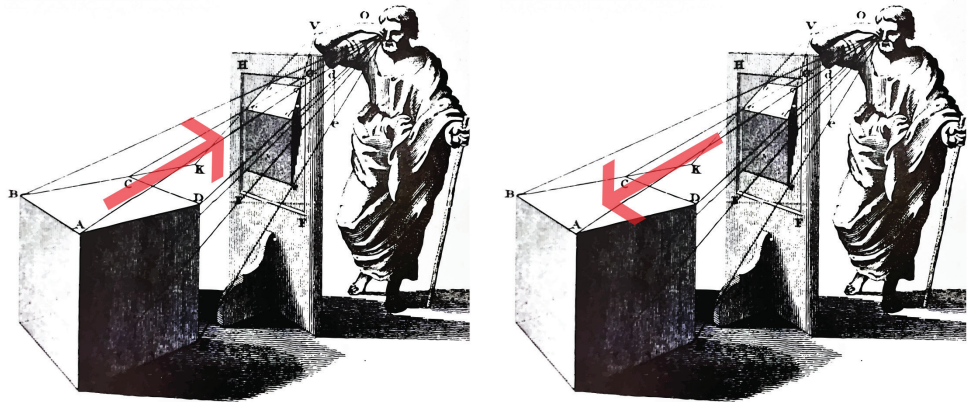
by means of combing particular illusory methods. One possible effect in OIA is the ability to add the illusion of dimensionality to objects – what we will call super-dimensional objects. An example of a super-dimensional object can be seen in Figure 3 where all balconies are level and consist of a surface parallel to the ground plane. However, from a specific point of view, the red and blue balconies appear to be sloped toward or away from the ground. Here the balconies are still perceived to be three-dimensional objects but in a way that appears to be doing more than their actual physical form.

Depthless objects (3D objects that appear to be flat) are also subsumed under the notion of optically illusive architecture and will be the focus of this paper. Unlike the previous category, the visual characteristic in this type conveys a two dimensional (flat) quality of an object when viewed from a certain point whereby the three-dimensional attributes of the object or space are suppressed. Unlike super-dimensional objects, depthless objects appear to be doing geometrically (or dimensionally) less than their actual physical form (Figure 4). Using techniques described in the methodology section of the paper, we will explain how principles of linear perspective helped us to achieve both

2   A demonstration of pictorial perspective, Brook Taylor, New Principles of Linear Perspective (1811) Left: the historical question for three dimensional representation. Right: our question –given an image as an input, how can we convert it into a three-dimensional object that looks flat?
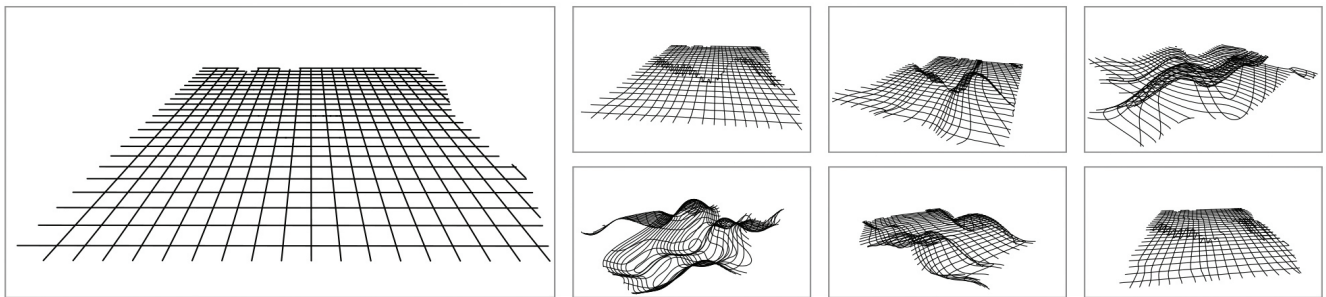
3 Optically illusive architecture with super-dimensional attribute.

super-dimensional and depthless effects in a design experiment.

Trompe l'oeil
Literally translated as deceiving the eye, the goal of Tromp l'oeil in practice is to hyper-realistically imitate the dimensionality of

Artists often practice trompe l'oeil murals on building facades to create fascinating three dimensional illusory spaces. Mexico City's "Quetzalcoatl" by John Pugh (2016) and "A Handful of Keys" in New York by William Cochran (2005) serve as clear instances of the application at scale and point to the potential

4 Optically illusive architecture, depthless object.

objects in the absence of dimensionality beyond a 2D surface. The effect is designed to deceive the viewer, calling into question whether or not he/she is looking at an actual object. To achieve this, a high level of delicacy in details, light control and an extreme precision in color shades are incorporated to make the two-dimensional work achieve the appearance of three-dimensional characteristics. The difficulty in sustaining the effect of tromp l'oeil is its dependence on being viewed from a single point in space. Once the viewer moves away from this point, the three-dimensional characteristics recede and the two-dimensionality of the painting becomes evident.

One of the best examples is Pere Borrell del Caso's Escaping Criticism (Figure 5). The flawless depth of three-dimensional space is perceived only when the viewer is directly in front of the work – thus exerting a kind of ordering agency into the space it inhabits. Trompe l'oeil is not limited to small canvases.

that architecture and urban space express when paired with this technique.

Anamorphic Distortion
Anamorphic distortion is one of the main categories of perspectival optical illusions in the field of art and architecture. More precisely, oblique anamorphic distortion refers to a distorted object (2D or 3D) that reconstitutes its actual form when viewed from an acute angle. It can also be interpreted in another way: oblique anamorphic distortion occurs when the normal vector of the picture plane is not parallel to the vector extending from the viewer's eye to the picture plane. Holbein's 1533 work, The Ambassador (Figure 6), is a clear example of this anamorphic technique. The diagonally distorted image of a human skull in the red frame only appears properly when seen from an acute angle to the upper right side of the painting.

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5   Escaping Criticism, Pere Borrell del Caso, 1874.

6   The Ambassador, Hans Holbein, 1533.

7   Forced Perspective.

Another approach in anamorphic distortion is to employ *non-flat* picture planes. Figure 4 is an example of a *non-flat* picture plane with details provided in the methodology section.

Forced Perspective

Forced perspective plays with the apparent scale of objects

through their relative positioning within a Euclidean *visual cone* (Wright 1983). We mentioned in the very beginning of the introduction that, our visual perception collects data from our circumscribed space. Thus, our understanding of object sizes is mostly formed by their surroundings. As a result, a thoughtful set-up of objects with various sizes and distances to the view-point overrides our three-dimensional perception. A common practice is to involve a human in the scene in order to manipu-late our dimensional perception of the space we are looking at. The interaction of humans and objects can result in innumerable examples of forced perspective illusions (Figure 7).

Having reviewed these three illusory methods, we summarize them in a table in order to address how they could possibly mani-fest in a built environment (Table 1).

Project Brief

The combination of 2D and 3D spaces culminates in a wide diversity of empirical projects in arts, architecture and computer graphics. Within this context, we attempt to verify whether or not a built environment can deliver a sense of flatness when viewed from a specific point in space. By means of linear perspective, we represent a two dimensional pattern on a three dimensional medium. This is a reversal of the historical practice used by descriptive geometry described as *the art of passing from three dimensional space to graphic space* (Migliari 2012).

Related Precedents

Research has been conducted on various aspects of perspectival drawing that point to weaknesses in current systems of repre-sentation while exploiting their deficiencies in order to produce novel illusory effects beyond the artists' canvas and into the space of the real world. We argue that the scale and materi-ality of architecture make it an ideal medium through which to continue this lineage of representational exploits.
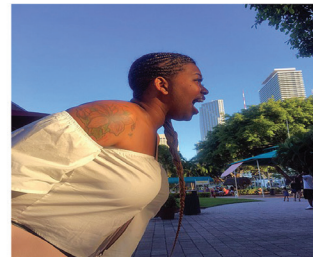
New systems of graphical representation (Correia and Romao 2007) and techniques for measuring distances in a perspectival drawing (Salgado 2003) constitute investigations into latent metrics within systems of representation. It has also been argued that linear perspectival representations are a human invention and are less than optimal means for human perception (Berdinski 1997; Anderson 2007). Trompe l'oeil has been addressed as the core concept of a number of projects, such as designing with images in an augmented reality environment (Schneider et al. 2007).

Anamorphic distorted projection functions as a focal subject in a multitude of instances. In a recent project (Jovanovic et al. 2016), robotic arms have been utilized to automatically generate an

Illusory Technique	Defined Viewpoint	Attributes
Trompe l'oeil	Yes	Hyper Reality
		• Represents 3D object on a 3D medium: Statuary
		• Represents 3D object on a 2D medium: Painting
Anamorphosis	Yes	Oblique Picture Plane:
		• Represents 2D & 3D objects on a 2D medium
		Non- Flat Picture Plane or Multiple Picture Planes:
		• Represents 3D object on a 3D medium: OIA
		• Represents 2D object on a 3D medium: OIA; (Depthless Architecture)
Forced Perspective	Yes	Manipulating Spatial Perception
		• Represents 3D object on a 3D medium: Photography, Movie Making

Table 1 Evaluating the perceived flatness. Optical illusion techniques and their attributes

anamorphic projection on a curved wall. Other research focuses on anamorphic projection on more complex surfaces and offers a refined technique not only to design, but also in manufacturing process (Di Paola et al. 2015).

There is also a wide range of mathematically-oriented approaches to perspectival representation. Amongst others, this includes projects that make three dimensional shapes from point clouds (Berger et al. 2016), urban reconstruction based on images (Musualski et al. 2013), and attempts to convert 2D shapes to 3D objects (Wei 2005). Laurentini (1994) shifts to classical practices of descriptive geometry by intersecting two visual cones each with a different silhouette in order to generate a novel three-dimensional shape. *Shadow Art* is another relevant project that deals with multiple visual cones and their intersection (Mitra and Pauly 2009). In this project and several similar installations (Tim Noble and Sue Webster), the result is an object with multiple meaningful shadows where a source of light is placed at the vantage point and the viewer observes shadows rather than the object itself.

Research on sketch-based modeling also involves perspectival drawing techniques such as mapping 2D freehand drawing to a 3D model (Olsen 2009). However, unlike our project, in these modeling techniques, initial 2D sketches are usually interpolated by a smooth mesh using a topological mapping algorithm.

Other branches of science also focus on optical illusions. Among them are research works that were initially conducted for non-architectural purposes - only afterwards becoming recognized in the field of architecture. One of the most well-known projects is called *The Ames Room*; first introduced by an American ophthalmologist Adelbert Ames for non-architecture studies in 1934. Specifically, it is a clear example of anamorphic forced perspective based design in the world of optical illusions (Ittelson 1952).
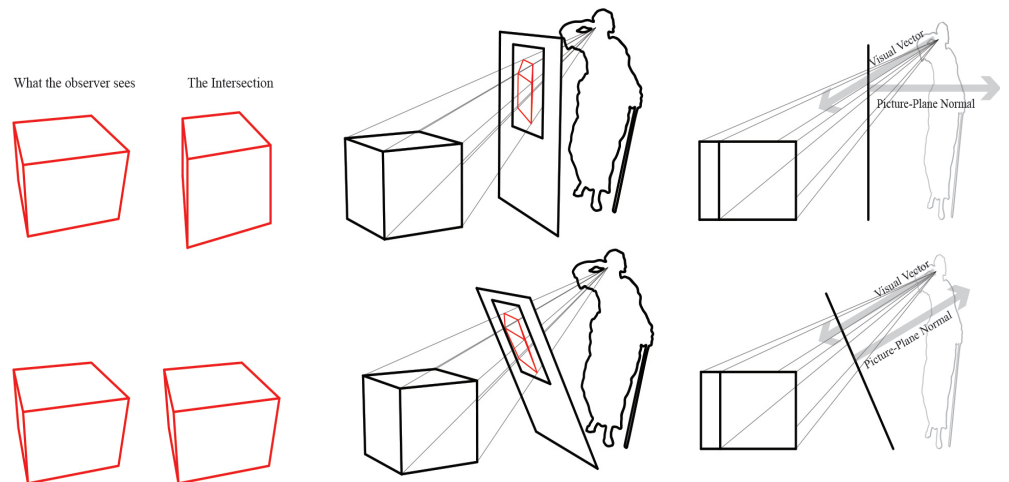
METHODOLOGY

As mentioned earlier, the elements of linear perspective are limited and explicit: object(s), a picture plane, a viewpoint, and vectors that extend between them. Nonetheless, a number of research projects suggest more elements may be at stake (Salgado 2001). Our method derives from Leonardo da Vinci and Alberti's classical definition where there are vectorial paths (representing actual rays of light) extending from each and every visible point in a Euclidean space to a single point of view. We trace these vectorial paths between the object and the observer and intersect them with the picture plane(s). In *Leonardo's window* illustrated by Brook Taylor, straight lines represent these paths (Figure 2) (Anderson 1992, 2007 and Wright 1983). The intersection of these lines and the picture plane provide the points corresponding to the visible points in the space. This is how linear perspective is drawn, however, there is a mysterious clue behind *Leonardo's window*. The picture plane is not perpendicularly placed toward the observer's viewpoint. In other words, the normal vector of the picture plane is not parallel with the visual vector extending from the observer's viewpoint to the picture plane (Figure 8).
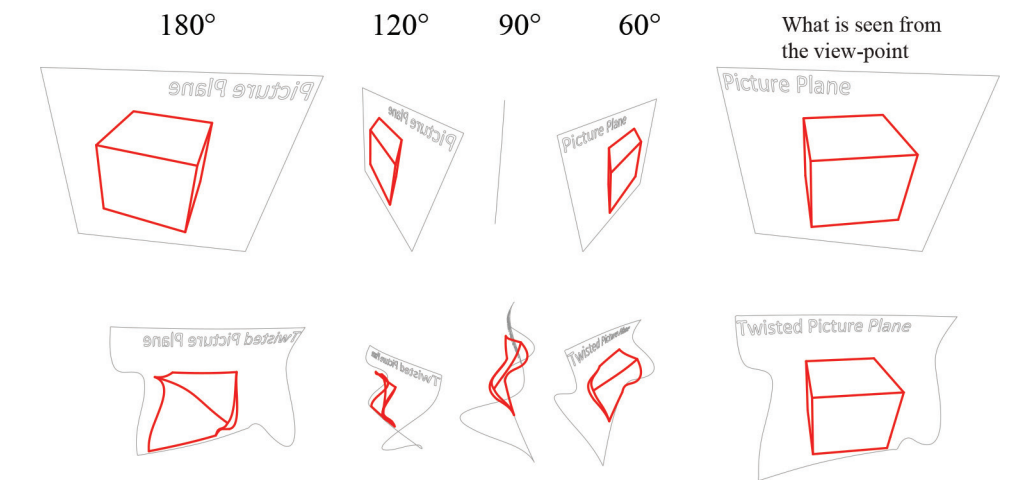
Drawing perspectives on picture planes that are not perpendicular to the observer's eye triggers the anamorphic approach of our design where we deform the picture plane surface. When the virtual rays of light intersect with the deformed surface, the image does not change from the perspective of the fixed

viewpoint. Nonetheless, the perspective has been generated in a three dimensional medium. As a result, the images in *flat* picture plane and in the *twisted* picture plane look fundamentally different from any point in the space except one particular viewpoint from which they were drawn (Figure 9).
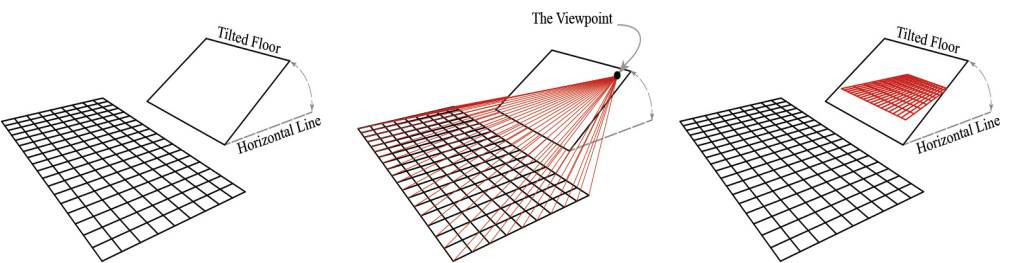
Such an approach to linear perspectival representation can cause extreme optical illusions when skillfully employed. In *The Ames Room* (Ittelson 1952), the idea of optically illusive architecture is explored through a simple tilework pattern projected across an oblique picture plane (Figure 10). The result appears to be an ordinary floor tilework when viewed from the initial vantage point. However, when viewed from any other position, its actual trapezoidal outline is revealed when the floor normal vector becomes parallel to the viewer's visual vector. Due to the tilted floor, the trapezoidal shape of the room appears to be rectangular in perspective – the intended visual deception. The illusion becomes even more extreme when two figures walk alongside the farthest edge of the trapezoidal slanted floor providing the effect of shrinking and growing figures (Figure 11). The Ames room thus combines aspects of anamorphic distortion and forced perspective in order to achieve a dynamic special illusion between a variety of objects and inhabitants.
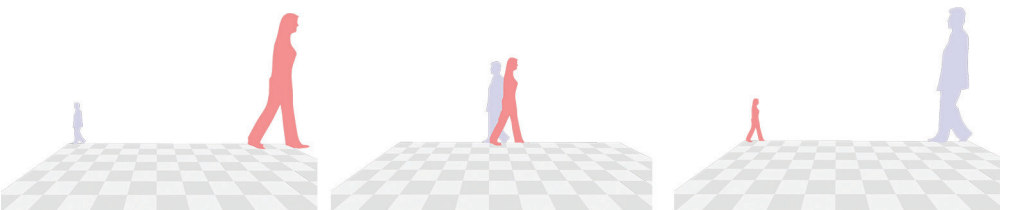
What the observer sees   The Intersection

180°   120°   90°   60°   What is seen from the view-point

Picture Plane

Twisted Picture Plane

Tilted Floor   Horizontal Line

The Viewpoint

Tilted Floor   Horizontal Line

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8   What the observer sees never changes, as opposed to the perspectival representation (the intersection) that depends on the picture plane position.

9   Top: the image on a flat picture plane. Bottom: the image on a twisted picture plane.

10   Optically illusive architecture, depthless objects.

11   Two figures walk alongside the farthest edge of the trapezoidal slanted floor providing the effect of shrinking and growing figures.

To explore these observations further, we built a code both in Rhinoscript and Grasshopper that compiles abstracted techniques from tromp l'oeil, anamorphic distortion and forced perspective into a useable design tool. The script functions between three inputs: (1) a picture plane, (2) a set of viewed objects and (3) a vantage point. The script then generates a new object representing the initial object when viewed from the vantage point (Figure 12). Multiple picture planes can be input at once in which case, any point on the object correlates to multiple corresponding points on various picture planes and all the points between them. This provides the opportunity to materialize not only the curves on each picture plane, but also the space between the curves (Figure 13). Our reason to introduce the concept of "picture volume" lies in this fact; to have the ability to volumetrically materialize the intersections. We therefore substitute the multiple picture planes with a volumetric picture plane, which is in fact a three-dimensional object.


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RESULTS

Our approach to linear perspectival representation reverses what has historically been practiced for centuries and helped us contextualize an object that is deep in space but appears flat and could practically serve as a publically accessible privileged space. We therefore end our design experiment by introducing a pavilion patterned with volumetric hexagon cells generated by the script (Figure 14). As discussed earlier in this paper, the three critical elements of linear perspectival representations are: the object, the picture plane and the vantage point. Here we list these elements as: the pattern, the object and the vantage point while the object is simultaneously both the object and the picture plane. In fact, we take two elements and merge them together to benefit from their characteristics in one shape. The intention is to produce the perception of two-dimensionality in a three-dimensional environment or what we call "three-dimensional flatness." This contradictory term clearly depicts the
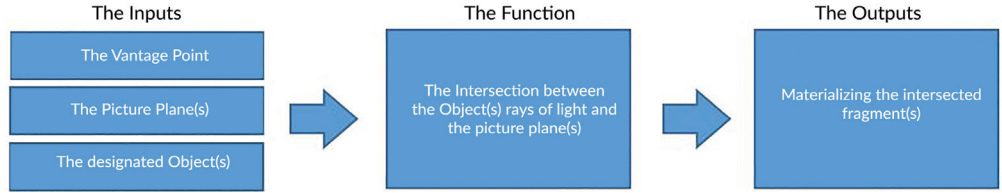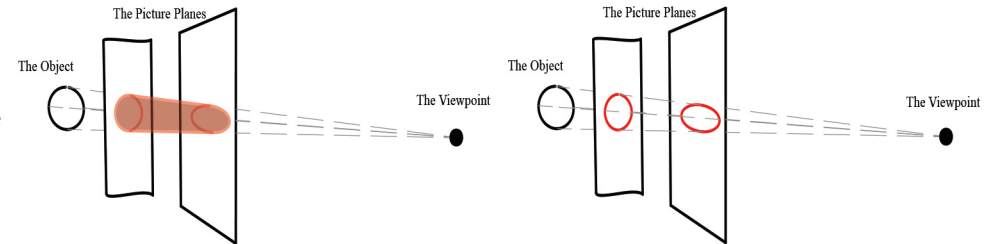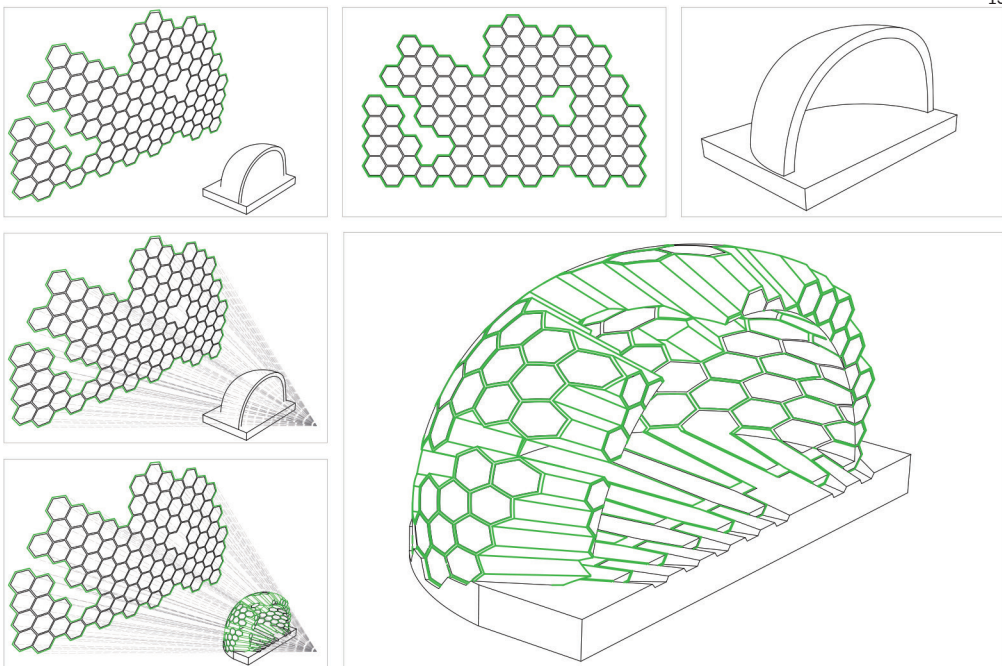
12 The diagram depicts the workflow in the code.

13 Materializing curves and materializing space between curves.

14 The Pavilion, patterned with volumetric hexagon cells generated utilizing Rhinoscript.

concept of an optically illusive architecture. Knowing that the orientation is crucially important both for the viewer and for the architecture, the object orientation can be read from any point in space but one certain view-point through which the orientation disappears (Figure15).

We look for interdependencies between the Pavilion and its surrounding space to guide its audience to the view point. Accordingly, the Pavilion guides the audience more accurately in spaces that are oriented, especially in a linear or axial aspect and

is more likely to communicate a broader range of audience in the environment (Figure 16).

We also evaluate the perceived flatness of the design by deviating from the designed vantage point while looking for a kind of visual threshold where the illusion of flatness falls apart. Toward this end, we run a method simulating the difference between what might be ideally perceived as flat and the essence of three-dimensional object obtained by projecting the pattern back to the resulting Pavilion from the initial vantage point. If the two patterns overlap completely then they are deemed identical and thus achieve perceived flatness. By shifting the vantage point laterally and re-projecting the pattern, flatness is lost and a kind of double vision effect is produced (Figure 17).

Having put the result into a context, we are now able to analyze whether there are benefits or negative consequences in doing such projects. This project is aiming to produce a *publicly accessible privileged space* as a potential benefit of our project. Well-known precedents in this regard are anamorphic chuck drawings on the streets that produce a 3D effect on a 2D surface. We are doing the process in reverse and producing a visually two-dimensional effect on a publically open 3D built environment.

CONCLUSION

We began our research with the fact that perspective drawings and paintings have long been utilized to represent the three dimensional world on a two dimensional canvas and asking, "what if we reverse this process?" Curiosity toward an illusory approach to architecture led us to study three optical illusion techniques that rely on the principles of linear perspective which we then applied to a generative script and the production of a physical object. The result was able to produce in a limited instance the possibility of producing the effect of three-dimensional flatness, an optically illusive architecture with both three dimensional and two dimensional characteristics (Figure 18).

Future Work
Our research opens up a parallel opportunity to develop the

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15 The orientation disappears coinciding with the perception of flatness.

16 The axial orientation of the space helps communicate with a broader range of audience compared to radially oriented or non-oriented spaces.

17 Evaluating the perceived flatness.

18 Top: Pavilion, the space where a depthless architecture is depicted. Bottom: digital fabrication provides a valuable opportunity to evaluate the precision of our design.
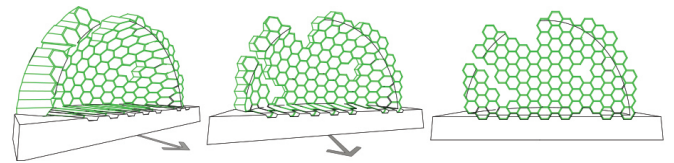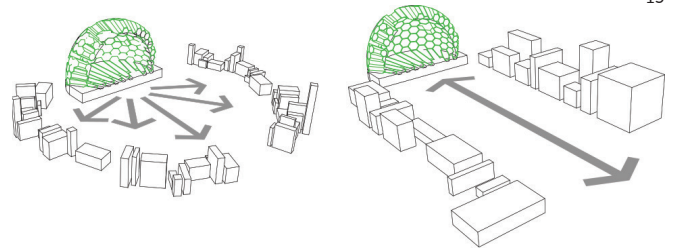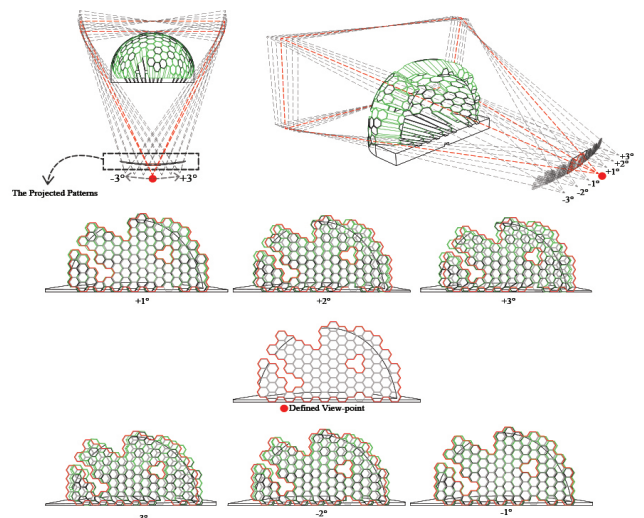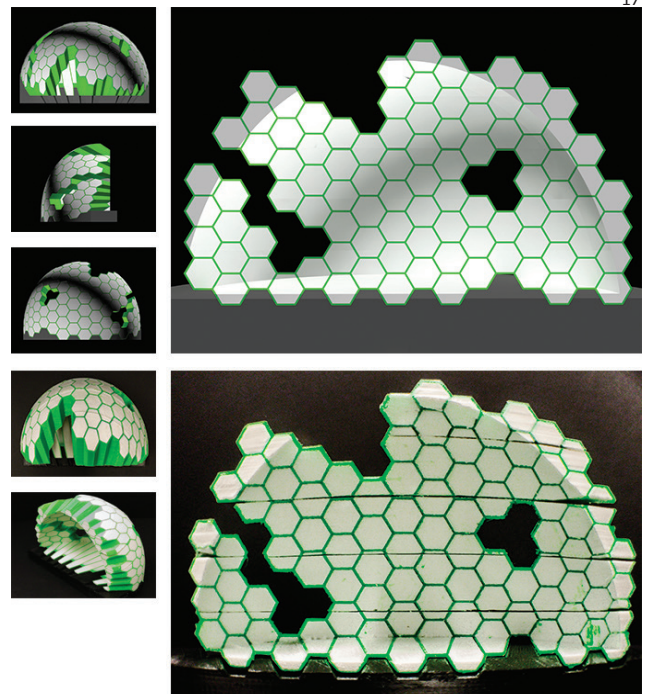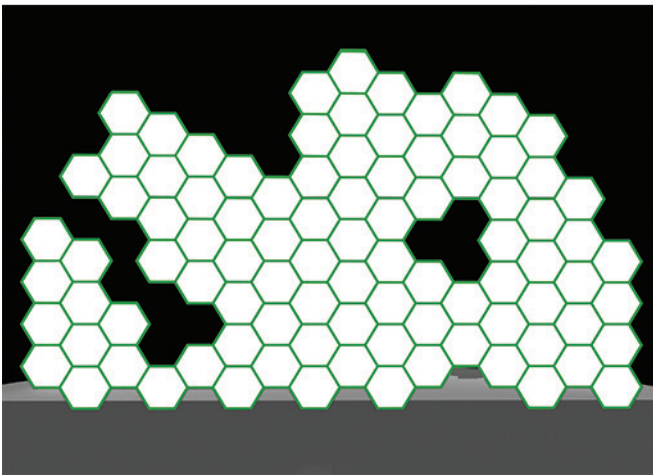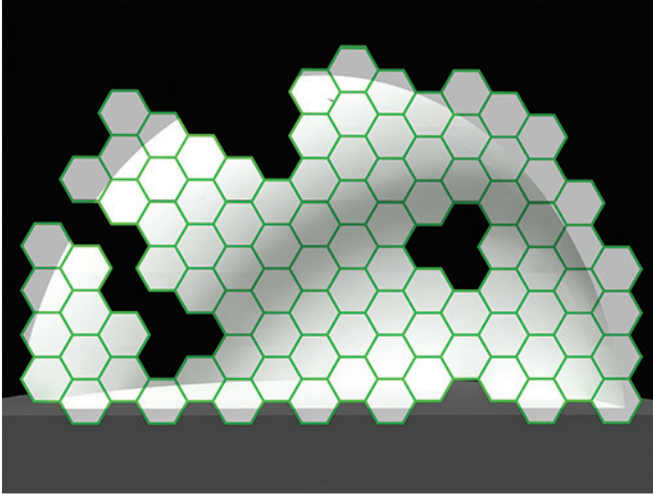
19 Shade elimination enhances the perception of flatness.

study in the following directions. First, we will explore in more detail new effects in architectural representations made possible through various materials used in the context of additive manufacturing. Second, we will turn our focus to human behavior and performance when experiencing three-dimensional flatness at scale. This social direction is aimed at addressing the relation between people's perception of spatial qualities and their behavior in the space. Having conducted the research through technical and design oriented path, we believe three different concerns should be satisfied to generate a robust and preeminent result of flatness: 1. geometry, 2. shadow elimination and 3. curvilinear perspective for visible spaces outside the cone of vision. In this paper, we addressed the geometric aspect of our research. In future technically-oriented work, we will be focusing on light exposure and techniques for eliminating unwanted shadows that reveal the three dimensionality of the space (Figure 19). We will also be studying the elements of curvilinear perspective to be able to decode and reverse the effect when viewing through a wide angle lens such as a fish-eye lens.

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IMAGE CREDITS

Figure 7: top left, G.Elser, 24 March 2008, http://www.panoramio.com/photo/8806082

Figure 7: bottom left, Andrew Kilpatrick, personal photos, 21 June 2007, Transferred from en.wikipedia to Commons, The original uploader was Ajkilpatrick at English Wikipedia

Figure 7: top right, Vincent Lock from Houston, United States, 3 July 2008, holding the eiffel tower,

Figure 7: bottom right, Daniel Di Palma, own work, 26 June 2017, Forced Perspective - Downtown Miami

All other drawings and images by the authors.
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Joshua M. Taron is an Assistant Professor of architecture at the University of Calgary Faculty of Environmental Design where he runs the Laboratory for Integrative Design (LID). His current research focuses on structurally intelligent swarms as an alternative to conventional wholesale building demolition by grafting complex morphological assemblies into existing buildings. This work is done in partnership with a variety of disciplines such as computer science, structural engineering and city planning. The work has been published internationally and orients itself toward finding new ways of revitalizing and sustaining the already-built environment.

Usman R. Alim received the MSc degree in Computer Science from the Rochester Institute of Technology in 2007, and the PhD degree in Computer Science from Simon Fraser University in 2012. Since 2012, he has been with the Department of Computer Science at the University of Calgary where he is currently an associate professor. He is the director of the Visualization and Graphics Group (VISAGG) which focuses on addressing a diverse range of fundamental and applied problems in Data Visualization and Computer Graphics.