ARTISTIC RECONSTRUCTION AND VISUALIZATION UNCERTAINTY

A Thesis

by

AICHA BOUJNIKH

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Chair of Committee,	Ergun Akleman
Co-Chair of Committee,	Kevin Glowacki
Committee Member,	Felice House
Head of Department,	Tim McLaughlin

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ABSTRACT

In this thesis, we present an approach to create artworks and animation through design principles used for uncertainty visualization. To demonstrate this approach, we use 3D models with reflective surfaces to simplify the rendering process. The creation of these works uses 3D computer graphics to develop these works of art according to research on uncertainty visualization and sculptural art.

In the first stage, we develop a work flow to create 3D objects that is computationally inexpensive to allow for quicker iterations throughout the process. In the second stage, we take a look at color mixing and using environment maps to better reflect colors off the 3D objects. In the third stage, we composite 20 layers of separate 3D objects together to obtain a final result. As shown in images and animations, this three-stage process creates an illusion of multiple transparent objects. The results create a beautiful and interesting new type of artwork.

DEDICATION

To my family and friends.

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I would like to thank my chair of committee, Ergun Akleman. Thank you for all your help and knowledge throughout this entire process. My committee members Felice House and Kevin Glowacki, thank you for your patience and suggestions that have helped enrich my thesis. Staci Dunn has been the most helpful throughout my entire experience in graduate school, thank you for being there when I need help or to chat. And to everyone at the Visualization department for their support and help during late nights working in the lab, they're always the best with company.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

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All work for the thesis was completed independently by the student.

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NOMENCLATURE

2D	Two Dimensional
3D	Three Dimensional
DVR	Direct Volume Rendering
TF	Transfer Function
HDRI	High Dynamic Range Imaging
IBL	Image Based Lighting

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1. INTRODUCTION AND MOTIVATION

1.1 Motivation

The goal of this research is to develop new approaches to create abstract art works and animations. In this work, we demonstrated that the concept of uncertainty visualization can be used to create such art works and animations.

Visualization uncertainties always exist in a surface, volume, flow, and multi-dimensional data set coming from a wide range of parameters [1, 2, 3, 4, 5, 6, 7]. Visualization of uncertainties in a data set is an important problem that requires conveying the data based on the facts, therefore, it is more than a simple addition of some visual elements.

When presenting data, most of the time it is easier to omit the areas of uncertainty, as a quick solution to avoid confusion about the data. The lack of representation of these uncertainties are attributed to difficulties in developing easier methods to define and characterize uncertainty. [1] Another challenge with visualization uncertainty is many representations are in 2D graphs and images. Since representing uncertainty in 2D is important, then is should be important to represent uncertainty in 3D visualization [8]

In 1997 article, Approaches to Uncertainty Visualization, there are four main principles of defining visualization uncertainty. The method must give information about the geometry and it's uncertainty in every part of the surface. The information should be intuitive and easy to understand, this will avoid confusion from viewers as well as experiencing visual fatigue. Since this information is difficult to display as a static 2D image. By presenting visuals in 3D will allow real-time viewing from different positions. Finally, the uncertainties should be non-distracting. Presentation of all variables, along with uncertainty, are cohesive. [1]

Along with these principles and a comprehensive analysis of previous visualization uncertainty techniques. A new set of principles can be developed to create and present uncertainties better in 3D visualization. Inspiration from contemporary sculptures will also help develop these new principles. By understanding aspects of sculptures such as forms, materials, and interaction with lighting. This will create stronger and interesting visuals.

The creation of these visualizations will use tools and methods in 3D computer graphics. Through the rapid development of 3D computer graphics and software, mimicking environments and materials in a digital space quick. This motivates quicker iterations and experimentation of more design techniques that presents visualization uncertainty.

1.2 Introduction

In this research, we present a new approach to create abstract art works and animation by visualizing uncertainty. It should be noted that we do not use real data in this research. Instead we use 'non-real data' that is artificially created as fuzzy 3D shapes. By visualizing this artificial data that consists of fuzzy shapes, we will develop a new method of uncertainty visualization that can provide contributions from both technical and artistic point of views. However, we do not focus on uncertainty visualization problems in this research. We only use the new uncertainty visualization approach to create art forms that resemble works of some of the contemporary sculpture artists. Although, this new approach can potentially be useful for uncertainty visualization, we do not yet investigate that technical aspect in this thesis.

Our process begins with analysis of previous techniques to show uncertainty in visualization. Since most of the previous research only uses 2D visualization, there will be further analysis in medical images which use uncertainty visualization techniques for doctors to reach a stronger conclusion of their patients diagnosis. The use of transparency is exploited to help define images better. [5] These ideas will help better translate the 2D techniques to 3D. To develop these 3D objects, contemporary sculpture artist will serve as inspiration for developing visually interesting 3D forms. Because the earlier analysis reveals the use of transparency is used as an advantage to visualizing uncertainty, we will specifically look at glass, plastic, and textile sculptures [9, 10, 11, 12].

To implement the methods, we will design random generations of 3D objects to represent 'artificial data'. The methods are then applied using global illumination, reflective surfaces, and environment maps. The use of animation is to exploit the surfaces through the reflection of the environment maps and show different perspectives of the 3D object. The 3D renderings are applied to a digital compositing software to control the transparency of each layer. The final composition shows all the different layers of each 3D object as one. The areas that have multiple layers appear as a solid, which shows as a commonality in the 'artificial data'. This research uses computer graphic software as tools. 3D procedural modeling is done in SideFX Houdini. Shading and rendering is done with Pixar's Renderman. And the digital compositing is done in Adobe After Effects.

The thesis is organized as follows. Section 2 details background information on previous techniques used for uncertainty visualization. Section 3 analyzes contemporary sculpture artists and their techniques to developing their artwork. Since the materials and shape are constructed in 3D digital space.The focus is primarily on plastic, glass, and textile art. This helps create a less computationally expensive work flow. Section 4 presents the methods to designing and developing the 3D visualization. Section 5 presents the final compositions and the process of developing each 3D object and environment maps. Section 6 summarizes the methods found and discusses potential future work.

2. BACKGROUND AND LITERATURE REVIEW IN UNCERTAINTY VISUALIZATION

This section discusses the background of uncertainty visualization and the previous research completed on the subject. The techniques from this section are used to experiment with the technical design of the 3D objects and their final composition.

2.1 Literature Review

The primary goal of uncertainty visualization is to provide a complete visual representation with uncertainties that is informative, intuitive, non-distracting, and interactive.[13] This helps users to interpret the information and the visual presentation can help aid in data analysis and decision making.We address these issues with various techniques to find the best way to visualize uncertainty without the user experiencing visual fatigue or confusion.

Approaches for visualizing uncertainty proposed by [14, 15] offer three possibilities. Side-by-side images, which displays one image with certain data and another one with the uncertain data. Composite images, which displays data together with the overlay of contrasting visual variables. Sequenced images, adding another variable, time, to sequence images frame by frame to show visual changes. Each of these possibilities present their own visual graphic challenges, which determines that side-by-side images require areas with certainty to show as darker saturation were the most effective. [16] This is also the same conclusion for side-by-side images with the use of color to signify areas of certainty and uncertainty. Compositing reduces the number of images to interpret simultaneously, while sequencing requires more visual cues to bring attention to the user the changes over time.

A study surveyed two of these techniques using an urban growth model to test visualization uncertainty. Static comparison (also known as “side-by-side images”), and toggling (also known as “sequenced images”) were tested on participants on the effectiveness of the information presented with uncertainty. They did not test compositing images stating, the disadvantage of 2D compositing is the ’overload’ of information. This could decrease the ability to understand the display to differentiate uncertainty from the other variables. [3] One of the questions on the survey asked participants to look at images with a single color scheme, using shades of the hue red, to represent uncertainty. Another image presented used a bi-color schedule, with areas of certainty in red and uncertainty in blue. The survey shows that groups preferred a single color scheme to bi-color with static comparison but equally preferred single color and bi-color schemes with toggling.

These studies primarily focuses on 2D visualizations, this can be difficult when translating to 3D visualizations. The details in 2D are harder to capture in 3D. One study approaches this challenge through medical imaging. [5] Direct Volume Rendering, or DVR, has been a tool routinely used for medical data sets in clinical work. The risk of the lack of information on any uncertainty presents visual challenges that DVR could not yet visualize. Including uncertain information, in a non-distracting way, allows more efficiency and accuracy when making diagnosis. They also approach presenting the uncertainty through animation called probabilistic animation. The authors note the most important idea is that a sequence of renderings is an effective representation that cannot be done with a static image. Since DVR is already familiar to the user, by adding the animation component to these renderings, the uncertainty information is easier to notice. Animation provides an alternative way to study uncertainty quickly. Another approach they found was by using compositing as a way to define the areas of uncertainty. By using an MR renal angiography, the traditional renderings made it difficult to define the thin tissue areas. By desaturating the uncertain regions with probabilistic DVR, the Transfer Function, or TF, gives physicians a better way to explore with the presets and images are clearer when the areas of uncertainty are clearly presented.

Another technique by Johnson and Sanderson that was implemented is instead using the previous method of desaturation, the areas of uncertainty are blurry. Since blurring is a natural cue to the eye that something is imperfect and will bring attention to the user. Since humans naturally follows these subtle changes, areas of uncertainty can be defined efficiently. Along with blurring, the images created fuzzy surfaces to the 3D models as another visual cue of uncertainty. The areas of low uncertainty are well defined, while areas of high uncertainty are fuzzy in appearance. This provides a visual foundation that is both informative and intuitive, the areas of uncertainty are defined and provides all the information without visual fatigue. [8] Johnson and Sanderson push this idea further by adding transparency levels to the models, the areas with the highest uncertainty are given more transparency. An underlying polygonal mesh is also added to create a smoother and appealing look.

The techniques that have a higher success rate both in 2D and 3D seem to have some level of transparency or desaturation. Compositing the images on top of each other could risk 'overloading' the viewer with too much visual information. This technique is an advantage that needs more iteration to avoid visual fatigue. A final technique to test is animating the 3D objects. This will have a greater advantage over 2D visualizations and give viewers more information from the movement of the objects. The areas of uncertainty definition are quicker to identify and will reduce the visual overload caused by compositing the layers together.

3. RELATED WORKS IN CONTEMPORARY SCULPTING

This section discusses the arts works from contemporary sculptors, whose sculptures serve as inspiration for us to develop new approach. We attempt to use lighting and material to mimic the visual effects of these sculptures. Understanding the artistic intents of these sculptors helps us to create digital pieces that is visually interesting and non-distracting to viewers.

3.1 Plastic Sculptures

In her 2018 paper, "Plastic Explorations", Weiling He addresses transforming plastic 'waste' into sculptural art as displaying it in a variety of contexts. Through different design explorations, He develops a variety of structures using only plastic. In a collaboration with Ergun Akleman and Chengde Wu, they explore the possibility of using plastic water bottles to create deltahedra forms. [10] These forms were easy to create with common materials such as tape or rubber bands. The triangular faces created structural stability and the clusters of deltahedrons creates a beautiful overall form.

In *Para-site*, she observes the material properties of the plastic. She notes the convexity, flexibility, perforation, and transparency of the plastic. [9] By exploiting these shapes that come from these materials, she is able to design non-representative objects to exaggerate shadows and translucency. She notes that creating a disconnect from the original shape of the plastic material and avoiding any representational meaning in the final outcome allows freedom to manipulate to the material for a visually interesting piece.

In another of her explorations, *Cloud Igloo*, He uses opaque volumes to fill an interior space. The bottles are strung together into clusters of random sizes, these clusters are added to the architectural space and more clusters are added on. The final piece appears to be clouds filling the interior space. Lighting is spaced out randomly throughout the interior, areas with little cluster or material allows light to show through and areas with more clusters created shadows. This presents a variety of transparencies and shades that creating an aesthetically beautiful piece to experience.

With all of He's plastic explorations, this piece has more improvisations to give way for the volumes and voids to inform and create the overall piece.

Since these works of art exist in our physical 3D world, these pieces are easy for viewers to experience the pieces and the forms are palatable to the human eye. The transparency and layering of the plastic materials creates light and shade, which is easily understandable to those viewing these pieces of art. This follows the idea of developing intuitive and non-distracting pieces that can be easily shown and understood by the viewer. These concepts created by He can be translated to developing 3D volumes that communicates uncertainty visualization in an aesthetic and easy to understand way.

3.2 Glass Sculptures

Artists that use glass as their artistic medium used the material to create interesting organic sculptures. When a light shines on the transparent material, the 3D forms are visually interesting with a sense of depth to hold the viewer and explore the material and forms that can be viewed from any position.

Marvin Lipofsky was an experimental glass artist. His designs are energetic and gestural. These biomorphic shapes, were developed by cutting, grinding, sandblasting, and acid-washing the material. As these sculptures hardened, they hold Lipofsky's gestural and energetic techniques. [17] The extensions, protrusions, and elongations of the sculptures show his fluidity and movement through the glass-blowing process. Many of his pieces, captures Lipofsky's gestural and energetic work.Many of his pieces contains a limited color palette, such as hues of blues and greens. The organic forms, each unique from the other, show the many curvatures and almost cloth-like material. When the light shines through the sculpture, there's more depth in the interiors and looking through the front folds and how it interacts with the back part of the sculpture. The colors within the folds respond according to the lighting and color of the folds behind it and the light makes the piece appear to be floating cloth. [18] His work remains an expression of movement and energy that will stay frozen in time. [19]

While Lipofsky was known for his organic and gestural works. Stanislav Libenský, with his wife Jaroslava Brychtová created geometric and structural glass works. Their work uses solid colors of glass and casting techniques to create geometric shapes. [11] The cuts on the outer surface break the light up, the depth of the glass. The natural color of the glass created recesses into the sculpture for the viewer to look into.

The casting techniques used on *The Kiss*, Libenský uses solid glass color to show a gradation of light and shadow in his sculptures. When the light shines through the sculpture the areas of glass have layers on top of one another create a darker shade of color. The areas with less glass layers, for example on the face, are a lighter shade of red, bringing the viewers attention directly to the face. The burst of light on the surface show the light-shadow relationship from the transparent glass. [12]

3.3 Textile Sculptures

While glass and plastic volumes create transparent surfaces easily. The use of textile art can also create a similar effect but on a larger scale. French textile and environment artist, Edith Meusnier takes advantage of large spaces to build her sculptures. She re-uses plastic ribbons in her work so that the sculptures are weather-proof in the outdoors. [20] The delicate, fine weaving shows a fragile piece that is transparent but the depth of the sculpture is limitless. Because these pieces are in nature, changes in the sculpture can occur from the wind and changing light, making the design of the sculpture itself change constantly.

Each of Meusnier's sculptures are either braided into trees or stand alone within nature. The various points at which a viewer can experience the piece creates and almost interactive piece where viewer can experience the sculpture from any point of view, or according to the position of the viewer.

Overall, these techniques used by each artist regardless of their chosen art medium shows imperfection and a natural man-made look. The forms that are each created are not precise or perfect, each piece of artwork have natural imperfections that occur with each materials. Their organic forms, light, and transparency gave the sculptures a sense of depth and made visually beautiful works of art that is appreciated by the viewer.

4. METHODOLOGY

This section present the technical aspects of our uncertainty visualization approach. We also present a work flow that is computationally inexpensive to allow quicker iteration and experimentation. The approach will further refine a work flow according to a set of principles to create visuals with uncertainty.

4.1 Procedural Modeling

This section will define *procedural modeling* as it is a general term used in computer graphics. For this research, the term *procedural modeling* refers to creating multiple generations of 3D models from preset rules. SideFX Houdini will be used to develop multiple generations of 3D objects. Since many different generations are needed for research, modeling each object individually would consume too much time. By using procedural modeling, models are created quickly and the models are organically made with out too much interference.

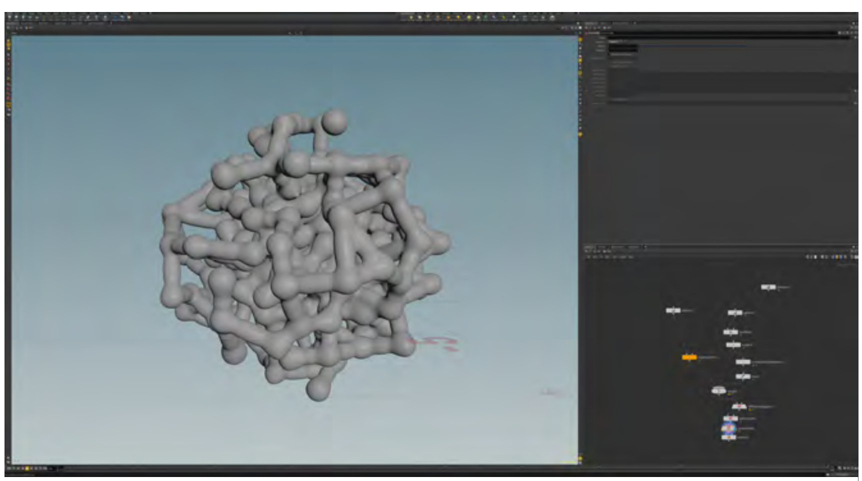


Figure 4.1: Example work flow on SideFX Houdini

Taking inspiration from the sculptural artist, there is some randomness that happens with developing their sculptures. For example, when studying glass sculptures there are natural curves and dents that can be difficult to manually model. This add to the overall 'artistic' look of these pieces as it avoids the objects from becoming to rigid or perfect, which can displace the viewer and violates the principle of non-distracting visuals.

4.2 Lighting and Reflective Surface

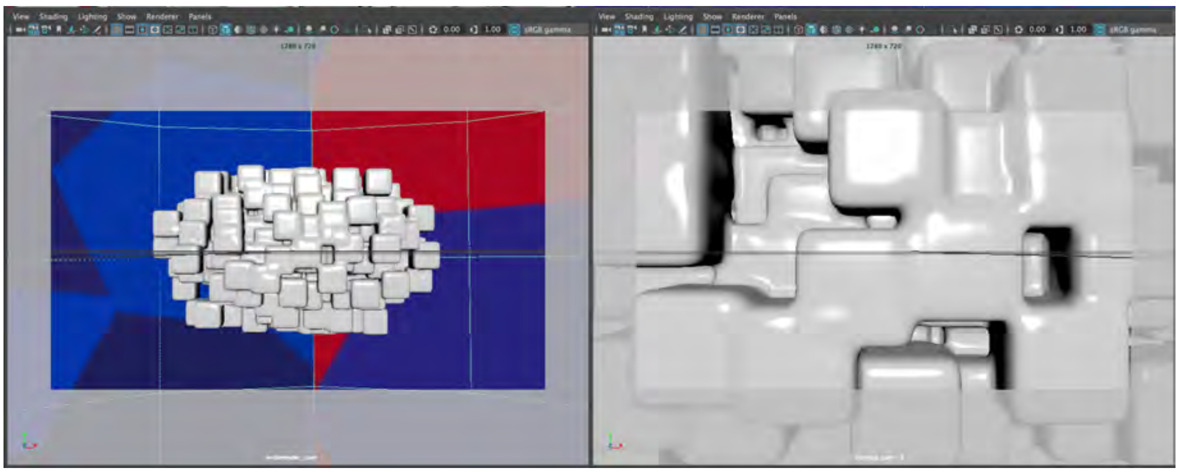


Figure 4.2: Example work flow on Autodesk Maya

After developing multiple generations of models, adding lighting and a reflective surface to the 3D objects using Pixar's Renderman to render the images. Since using a reflective shader will not be as computationally expensive as using a glass shader, the frames will render quicker and simplifies the overall rendering process. If the refractive objects are very thin, regardless of the index of refraction, the rays do not bend. Therefore, for thin objects, the main global illumination term is the reflection. Transparency can simply be achieved in the compositing stage using α. The amount of reflection is normally determined by the Fresnel equation, but we can also assume that the Fresnel term is always one. As a result, the rendering can be simplified into two stage process.

1. Render each object as a perfect mirror using an environment image and assign each rendered image I_i an appropriate α_i.

2. Composite images in post-processing using their α_i values.

Image Based Lighting (IBL) is place into scene to add light variation on the reflective surfaces. High Dynamic Range Image (HDRI) is an environment map, which is based off of interior or exterior photographs in 360 to wrap around the scene. The reflection of the colors from the HDRI on the 3D object surfaces add visual interest to the piece. Some maps are selections are based off of high or low contrast of the photograph and which one creates interesting rendered images. This helps define areas of uncertainty and creates a whole cohesive piece that is non-distracting.

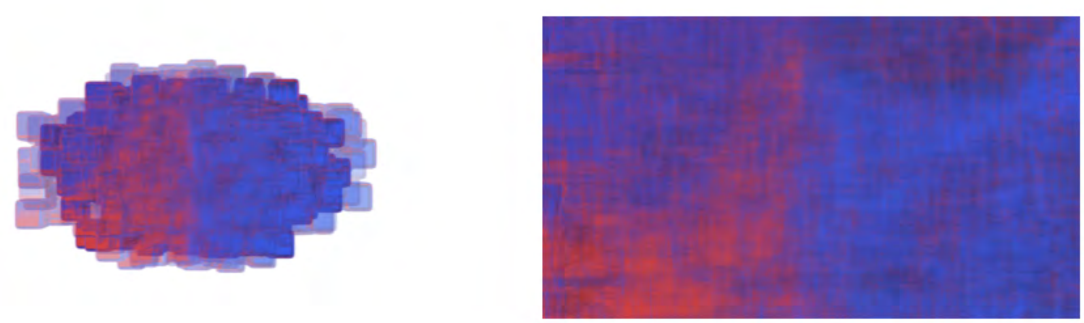


Figure 4.3: Final render with lighting and reflective surface

4.3 Animation

As mentioned earlier, from the research on using animation as technique for it's effectiveness in showing visualization uncertainty. With 2D static images, animation is included using sequencing or toggling. Images are added frame by frame to show the visual changes over time. This technique quickly creates visual fatigue since viewers need to remember the previous image and be aware of the new visual cues. The advantage of these 3D models is using an animated rotation of the objects. Experimentation with the animation is necessary with the transparent objects in compositing to avoid 'overloading' information is based on previous research.

Figure 4.4: Individual layers are animated

4.4 Compositing

Finally, in Adobe After Effects every layer of the 3D object renders are composited together. The key issue with compositing, to assign appropriate α_i values to each image I_i. Assume that our goal is to mix images I_i with weights w_i as follows:

$$I = \sum_{i=0}^{N-1} w_i I_i$$

where $\sum_{i=0}^{N-1} w_i = 1$. In our case, we usually choose equal $w_i = 1/N$. Let us assume that images are stacked based on their indexes as I_0 being background image and I_{N-1} being the top image. Then for $w_i = 1/N$, we can easily compute that

$$\alpha_i = \frac{1}{i+1}$$

Note that it is always possible to compute α_i for given set of w_i. We can also directly compute image mixing without using α_i. The main advantage of using α_i, visualization are directly computed in a compositing system. Results can be manipulated directly in post production stage.

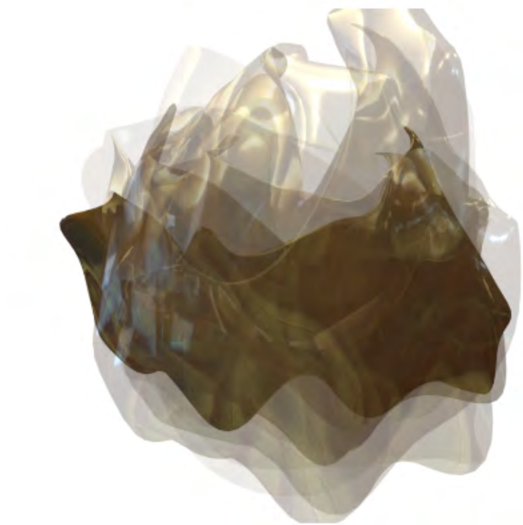


Figure 4.5: Final composition of each layer (with animation)

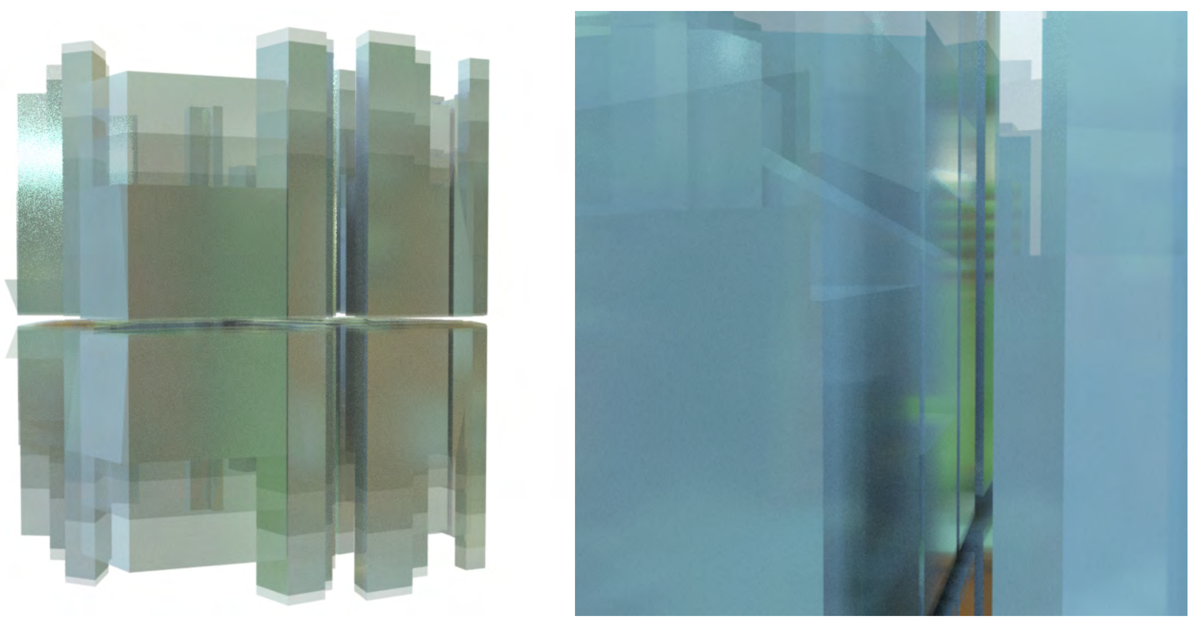
In conclusion, through the analysis of previous visualization uncertainty studies that the use of transparency, color, compositing, and animation are the basic principles implemented in this research. The development of the 3D objects will be procedurally modeled to recreate the natural and organic forms of sculptural art. Global illumination with reflective surfaces uses less render time, which helps creating renders quickly to provide quicker iteration and experimentation. After final 3D objects are made they are animated on a 360 turntable. Each layer has a specific percent of opacity which mixes the colors of the reflections from the environment maps. All together, this creates an interesting piece that avoids ’overloading’ the viewer with too much information and provides visual cues of the defined areas of uncertainty.

5. IMPLEMENTATION

This section discusses implementing all that has been learned from research and experimentation. Each composition have progresses in design from one another the more we understand about the design process. The final compositions are a culmination of the research from this thesis and a set of principles to designs these pieces through uncertainty visualization.

5.1 Initial Compositions

At the beginning, the models are made individually using Autodesk Maya. The initial models are simple geometric forms that do not have added complexity. Instead of procedurally generating each layer, the 3D objects are scaled up and down randomly. Only five layers are made in the beginning since developing a large number of layers individually was time consuming. These layers were to test original predictions for the final piece of the models.



(a) Wide shot (b) Close shot

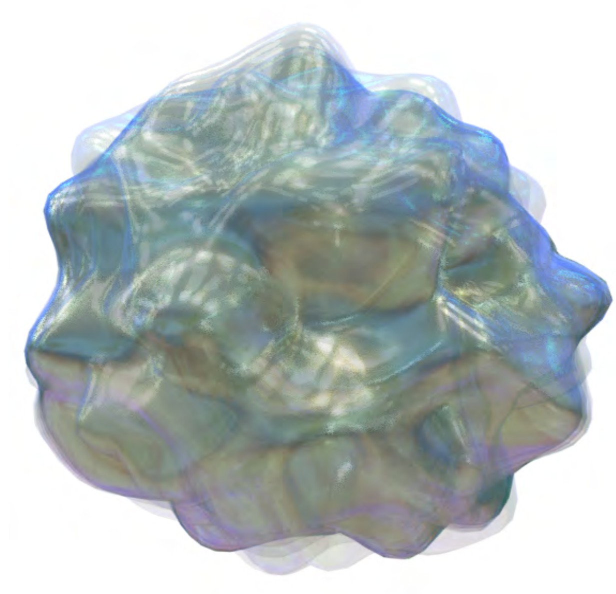
Figure 5.1: Initial tests of compositions

The use of different camera positions are to look at the final compositions from two different views. The wide shot shows the full model and give context with the 360 turntable. With the close up shots, the images became more aesthetic and every frame became an artistic image. When continuing with these iterations, the background is cropped out to avoid giving any spacial context that are already shown in the wide shot.

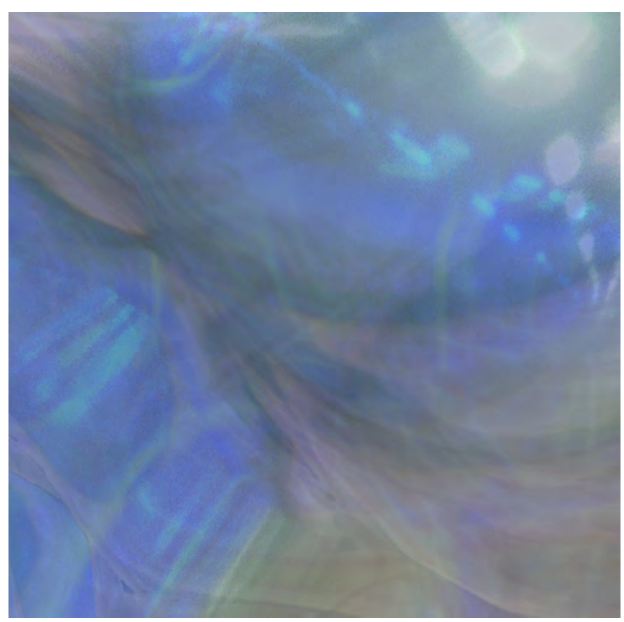
The color palette from the environment map did not seem to look as interesting on the geometric design, shown on 5.1. The sharp corners prevent the lighting to fall on the reflective surfaces and the colors did not appear as interesting. The next iteration uses organic forms to see if the colors are more interesting since it falls on curved forms without corners.

5.2 Procedural Modeling

The design principles created from the initial compositions and previous research from the sculpture artists, organic forms are developed through procedural modeling. After transitioning to SideFX Houdini, creating multiple layers took less time than individually modeling a single layer.



(a) Wide shot



(b) Close shot

Figure 5.2: First procedural model composition with organic forms

This technique took less time to create and allows more experimentation with the forms. As seen in Figure 5.2 the colors on the organic forms are much more blended than the previous iteration. The multiple layers of each model in their final composition is reminiscent of plastic sculptures. Each layer appears as if it is a thin plastic wrapping the solid form in the middle. The close up shot is shown without any background information. The colors blends with the light reflections look as if it is a stand alone photograph. The animation shows the reflective light dancing on the surfaces making the motions of the models much more interesting.

By using cloth simulations, this allows organic shapes to form - inspired by Lipofsky's work. This gave little room for control over the final model, which helps create natural and organic shapes without too much perfection. The process for developing these cloth simulation models is a grid with a triangulated mesh is dropped on another model, shown in Figure 5.3. The collision of the grid and the model creates the look of cloth modeled around an object. This process is done 20 times to create a large variety of different models for the final composition.

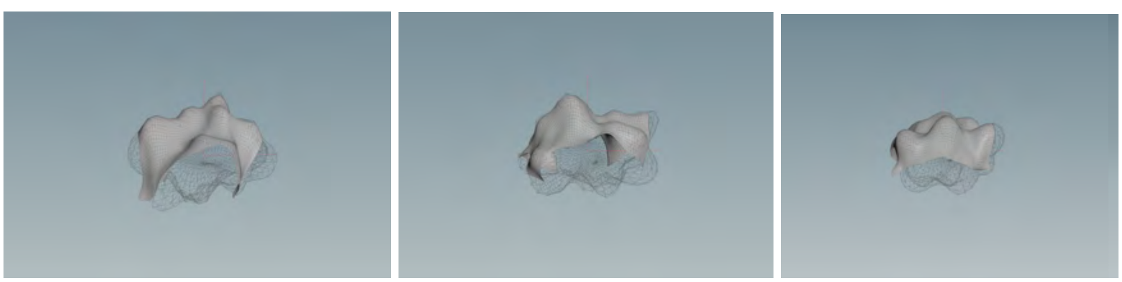


Figure 5.3: Process for creating cloth-like forms

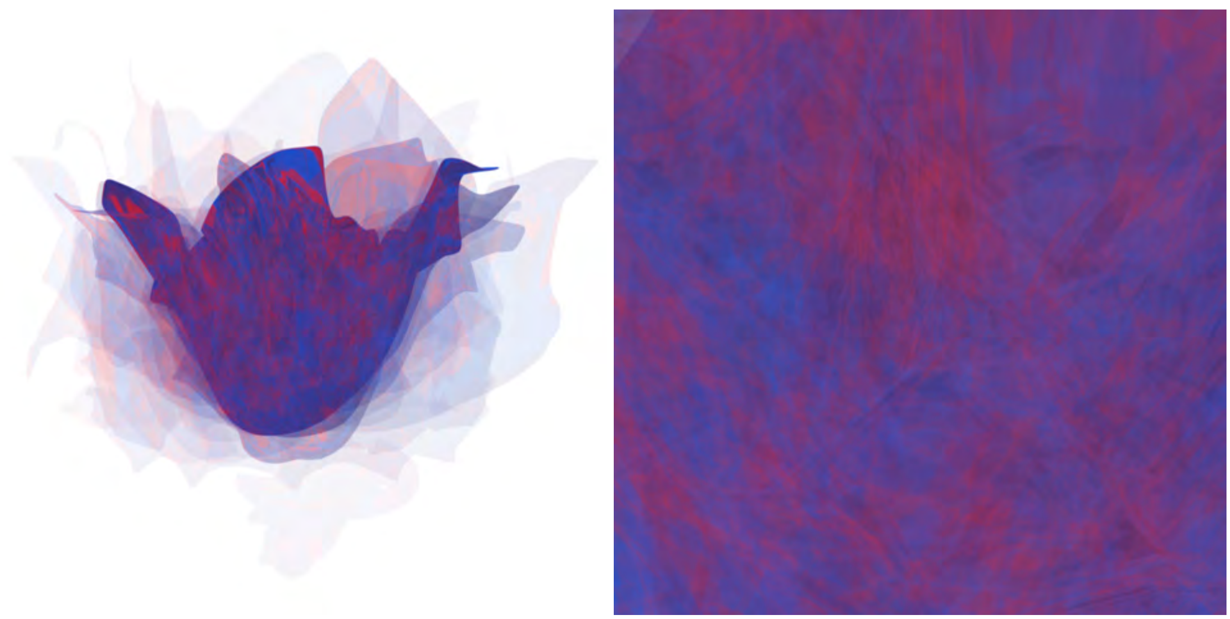
After simplifying the process of generating more layers, creating new designs allows for quicker iterations and better models. Since the final step in the design process requires layering 20 generations on top of one another, the final design of the models are not enclosed as seen in previous iterations. If every generation was an enclosed model, as seen on Figure 5.2 the models appear to be all the same. These designs took away from the creation of multiple designs. The cloth simulation model is open to be able to see the interior of the model, the final composition created more interesting looking models with various shapes and reflections bouncing off one another.

5.3 Iterations

Once the process of modeling is refined to save time, next we decided to look at the HDRIs. The reflections of the colors on from the HDRIs were not as aesthetically pleasing as originally planned. The colors mixing of the HDRIs are flat and the final composition with 20 layers appear solid. So, we develop an HDRI using a randomized pattern with one shade of red and three different hues of blue. When the reflections of the model mix the colors, the final appearance will be a shade of purple. The mixing of colors in the final composition pushes the visualization further in compositing with transparency.

Figure 5.4: Intial iteration of mixed colors for HDRIs

With the original procedural model(shown on 5.3, the render of the final composition is rendered with a single HDRI to test the initial theories of color mixing. There is some color mixing on the final composition with 20 layers. As predicited, the center shows more color mixing with the purple shade, as predicted, the wide shot of the composition seems interesting. But the close shot appears too noisy and distracting, contradicting the original uncertainty visualization design principles. Especially with the 360 turntable animation, when viewing the animation, the overall piece is visually confusing and causes visual fatigue.



(a) Wide shot (b) Close shot

Figure 5.5: Intial iteration with mixed colors HDRI

Now that we have an understanding of the appearance of the mixing colors on the final composition, another test creation of color mixing to further push the aesthetics of the colors from the reflective surfaces of the models. we decided to create 20 separate HDRIs, each model renders with its own HDRI. With a new pattern, each layer creation has the hue increase by 10. As shown in Figure 5.7, the design of the patterns remains the same with only the hue changing. This generates 20 HDRIs for the 20 models. The time it takes to individually place the HDRI and render does take time. However, the time saved from procedurally modeling makes up for the time, since this is the final stage before the final composition.

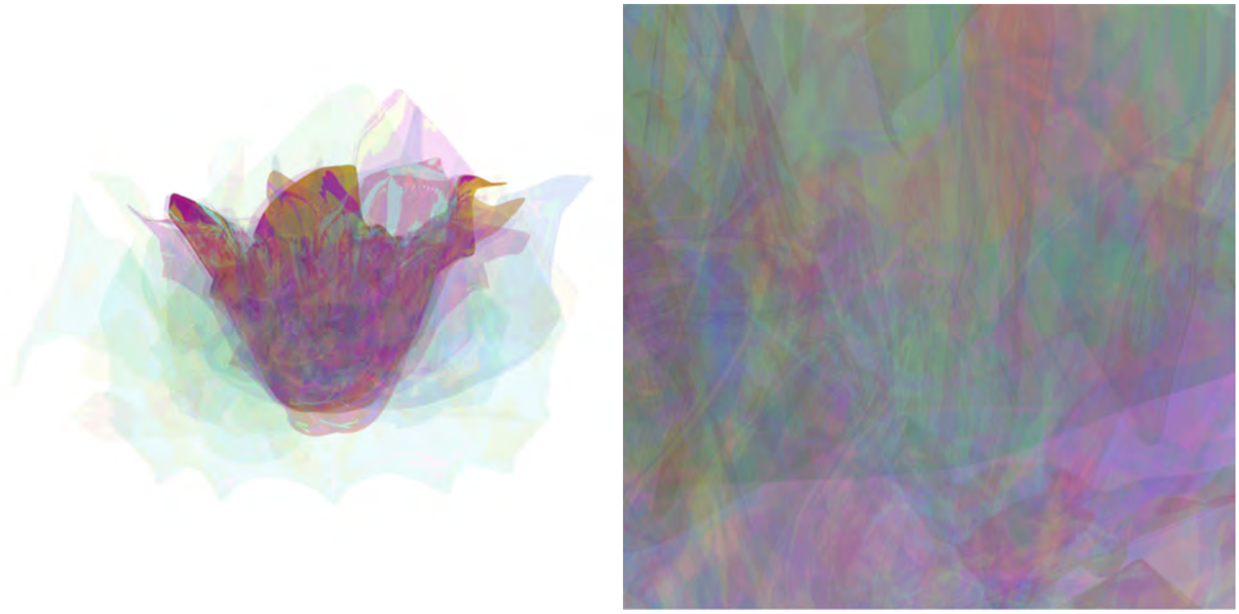
The final composition for this piece is much more aesthetically pleasing. The colors blend together beautifully without creating visual fatigue, as seen in the previous composition with color mixing. Both the wide shot and the close shot images are visually interesting with the colors reflecting off of the models and blending together with the transparencies. The form at the center

Figure 5.6: HDRIs for each of the 20 layers

of the piece, shown in Figure 5.7a, mixes each layer together without one layer taking over. The animation shows the colors dancing across the reflective forms and when paused at any moment of the 360 turntable, displays a beautiful static art piece.

With these initial tests for the final composition with the different HDRIs, more creations of the models are to develop more iterations with different forms. The next form uses tubes growing out in random directions to form a final organic looking form. This design idea is to test if maybe smaller surfaces will reflect the HDRIs differently, as opposed to the cloth-like model with large surfaces. With the color mix HDRI (as seen in Figure 5.8) the pipes had no effect on the color mixing, it still appears to be noisy and visually confusing. Even with the close shot on Figure 5.8b, the colors mixing together appear flat with no reflective surfaces showing through from the lighting.

Another test uses the multiple HDRIs on the pipes. The results are much more similar to the mix color HDRI, the colors mix too much in the center, which looks noisy and distracting. The exception to this composition is that the reflections show much better than the other composition that is flat. The pipes that jut outside the center forms, seen in Figure 5.9b, look interesting with the colors mixing and the reflections showing, giving the pipes a more 3D appearance.



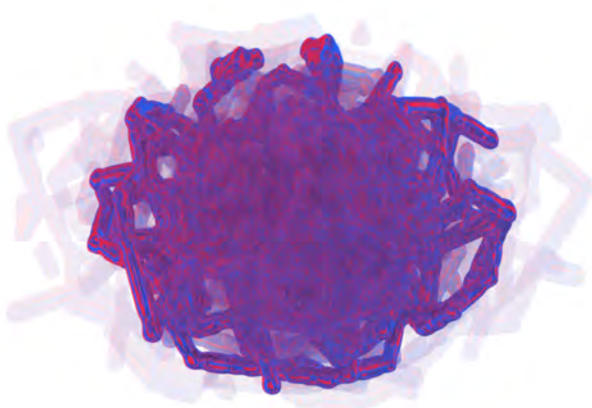
(a) Wide shot

(b) Close shot

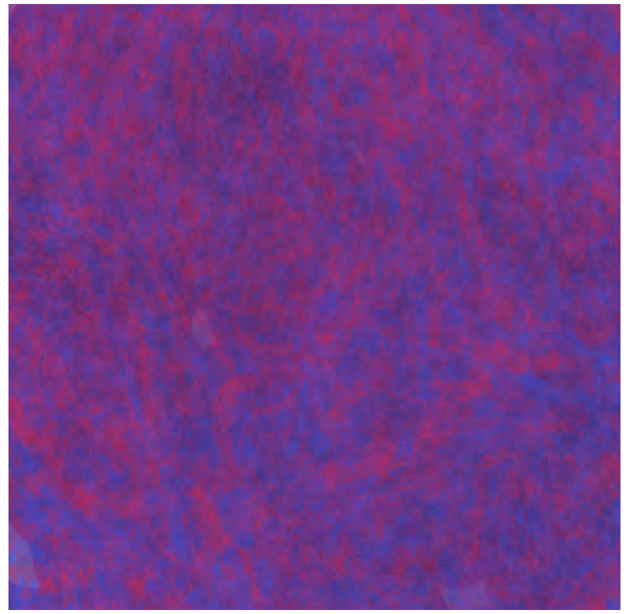
Figure 5.7: Final composition using 20 HDRIs

With the final model, we decide to study what forms were successful for the final compositions. The multiple hue HDRI was more successful in the compositions and made visually interesting compositions than the mix color HDRI. With this in mind, we decide to move forward with the multiple hue HDRI. The forms from the previous iterations show that the models need a larger surface, this will help with the colors mixing from the HDRI and prevent them from being too distracting. With procedural modeling, organic forms can be easily made and experimentation can occur to reach the forms needed for a successful final composition. The use of cubes on the final model, as shown in Figure 5.10a, the rounded cubes overlap one another depending on the size of the cubes. Each layer is changed with the amount of cubes and sizing.

The final composition is successful and takes everything learned from the previous iterations, along with the design principles of uncertainty in visualization. The colors blend together with the mixing in the center leaving a sphere form. It also appears that both the close shot and wide shot are aesthetically beautiful (see Figure 5.10. By using individual HDRIs for each of the 20 layers, the different colors are each represented in the final composition. Naturally the blending adds more



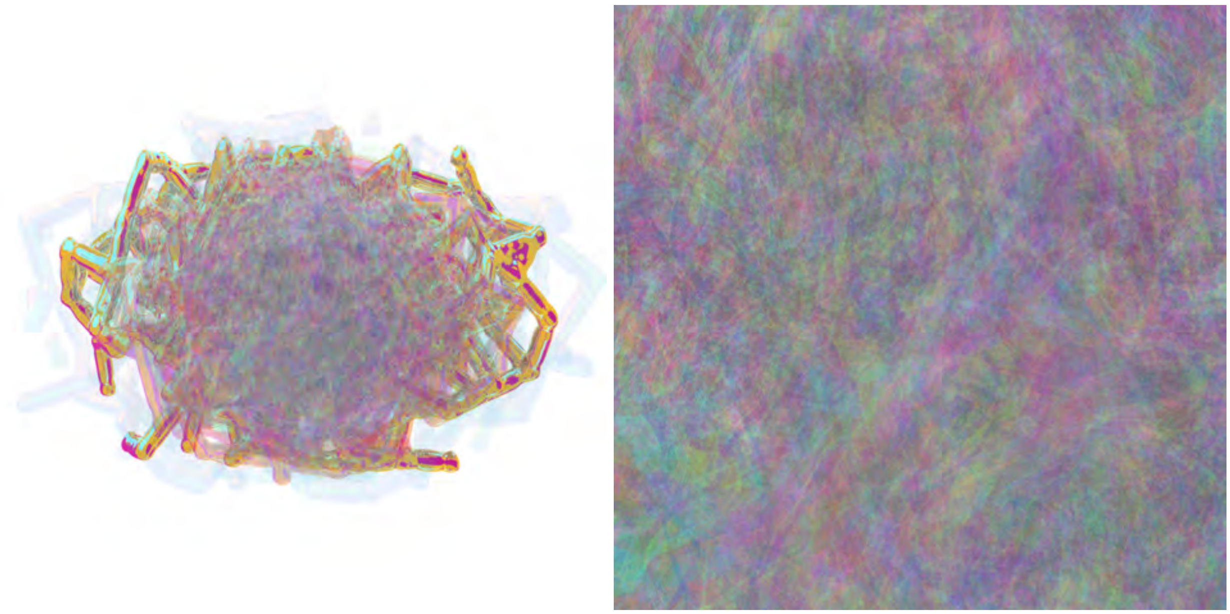
(a) Wide shot



(b) Close shot

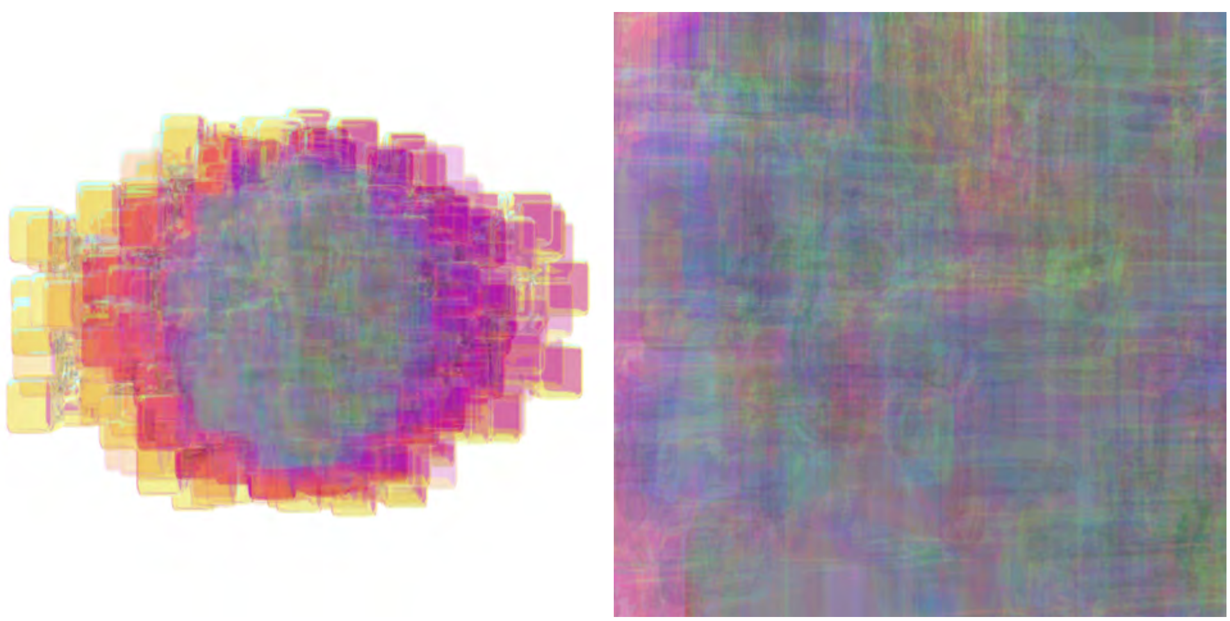
Figure 5.8: Multiple hue HDRI on different model shape

colors, making the whole piece cohesive.



(a) Wide shot (b) Close shot

Figure 5.9: Iteration using multiple hues HDRI



(a) Wide shot (b) Close shot

Figure 5.10: Cubic formation using multiple hues HDRI

6. CONCLUSION AND FUTURE WORK

The study of both previous visualization uncertainty and sculptural artist help develop a set of design principles that is used to create visually interesting works of art. The experimentation through the design process further refined the design and define what is needed for the artwork to be considered successful.

The main advantage of this approach is that the resulting images look visually appealing. Since reflections are depended on eye position, when we move the objects or camera, reflections also dances on the surfaces of the objects. This motion defines the shapes of the collection of shapes. This preliminary conceptual study is really an art project that demonstrates the potential of this approach for visualization of the data that can be expressed as a collection of 3D surfaces. For actual validation of the method, there is a need for using real data and user studies.

6.1 Results

Through the analysis of previous uncertainty in visualization research, the use of transparency, color, compositing, and animation are the basic principles that are followed throughout this conceptual study. The development of the 3D forms use inspiration from glass, plastic, and textile sculptural artist to further push the design of the forms. The organic shapes help give a sense of depth, while the surface reflections help bounce the light and colors from HDRIs to create a non-distracting and easy to understand art piece. The animation helps with viewing these pieces just like you would when looking at sculpture art.

6.2 Future Work

In the future, this workflow needs to be more streamlined to avoid constantly shifting between softwares. If the procedural models are made is Houdini, then we can use Houdini Engine to export into a real time gaming engine such as Unreal. When exporting the procedural models through Houdini Engine the parameters that are used to create the models are also exported. This would allow more artistic control further down the design process. If models can be changed through out the entire project then design iteration could happen quicker. Because these works of art are animated for to look at on a screen, another way to experience this artwork is through virtual reality. There's more movement and observation that could happen in virtual reality, which falls in line with the sculptural arts and how we experience them in the physical world.

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