Reflections on light

Developing new methods for producing anamorphic sculpture

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Keywords: Anamorphosis, oblique, catoptric, ray tracing, reflective, holographic, real image, virtual image, rendering, sculpture, installation, perspective, history of art, Hydroforming

Abstract

This paper presents novel catoptric anamorphic sculptures made possible by the development of bespoke software. The authors detail the production of a catoptric anamorphic sculpture involving a concave mirror and examine the audience's experience. The reflections the mirror creates are described as being 'holographic'. This effect is known as a 'real image' and only occurs using a concave mirror. Through interviews with participants, the paper reports on the audience's experience of the real image. This new approach to anamorphic sculptures extends past work dating back many centuries. The authors present the digital tools they have developed to facilitate anamorphic artistic production and extend the limits of what has been achieved in the past. They end with an outline of future work, including glass lenses, and propose using video projection mapping.

Introduction

This paper presents novel catoptric anamorphic sculptures made possible by the development of bespoke software. We begin by looking at past anamorphic artworks and how they developed into contemporary practices. We then present our anamorphic software, the pipeline we developed to produce the data simulations for our sculptural works and the works themselves. The techniques we have developed enable the exploration of many types of catoptric anamorphic sculptures.

The word anamorphosis derives from the Greek ἀναμορφόω, which translates as "transform". Anamorphosis is understood as a distorted projection or perspective. This distortion can be corrected from a specific vantage point [1].

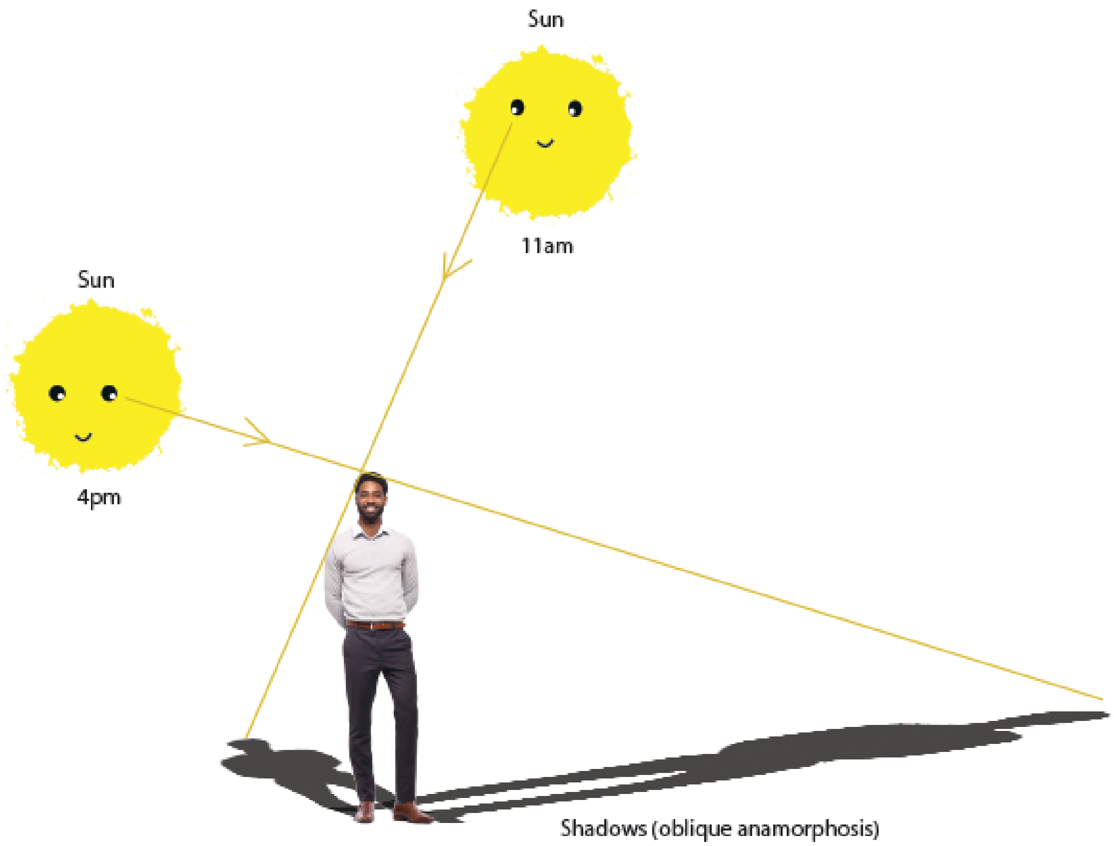

Fig. 1. Shadows cast from the sun at different times of the day (Copyright Louis Pratt 2022)

Perspective (oblique) and catoptric (mirror) are the two classified forms of anamorphosis in art. A simple way to understand oblique anamorphosis is to imagine your shadow cast by the sun. This shadow might appear compressed or elongated at different times of the day, as depicted in Fig. 1. This projection of a shadow onto the ground exemplifies oblique anamorphosis. These distorted shadows can be corrected if the viewer is at an oblique vantage point to the shadow.

Fig. 2. Shadows cast by tourists as seen from the Eiffel tower. (Copyright Elliot Moore 2007, licensed under the Creative Commons)

This perceptual phenomenon can be controlled, which means that an image can be presented to the audience as correct from a specific vantage point. At the same time, it remains distorted from a different vantage point.

Another kind of anamorphosis is catoptric or mirror anamorphosis. In catoptric anamorphosis, the image is reconstituted via a curved reflective surface. Common examples include placing a conical or cylindrical mirror on top of the drawing or painting to transform a flat distorted image into an undistorted image (Fig. 3). Contrary to oblique anamorphosis, the corrected image can be perceived in various forms from many different angles rather than a fixed perspective as for oblique anamorphosis. This facility of catoptric anamorphosis is clearly demonstrated in the interactive Wolfram Demonstrations Project [2].

Fig. 3. is a particularly intriguing historical example of catoptric anamorphosis, where the phenomenon is used to conceal the image of the exiled British Prince Charles Edward Stuart. This ‘secret’ image was painted on a wooden board used to serve drinks. When a mirrored cylindrical drinking cup was placed correctly on the tray, the drinker

could then toast to the exiled Prince and the Stuart family. The controversial image would be obscured without the mirrored cylinder, keeping the secret safe [3].

Fig. 3. Secret portrait of exiled prince Stuart, around 1750. Image courtesy of the West Highland Museum

In the case of mirrored (catoptric) anamorphosis, only conical and cylindrical (convex) reflective surfaces have been used in art, to the best of the author's knowledge. In the context of art, oblique anamorphosis has been extensively explored in painting, sculpture and installation. Fine examples are the works of Robert Lazzarini, Tim Noble and Sue Webster, Felice Varini and many others. For this reason, we chose to focus on concave catoptric anamorphic work, as we couldn't find any examples of sculptural works that used concavity.

Background

Jean-François Niceron (Paris, 1638) treatise, La *perspective curieuse* (Curious Perspectives), outlined methods for producing anamorphic distortions[4]. Even prior to this historical documentation of anamorphosis being produced, artists had already explored anamorphosis. Arguably, one of the most famous examples is by Hans Holbein the Younger, with his painting *The Ambassadors* (1553), which hangs in the London National Gallery (Fig. 4).

Fig. 4. Hans Holbein the Younger, ***Jean de Dinteville and Georges de Selve ('The Ambassadors')*** *1533 © National Gallery, London*

This painting is one of art's first examples of anamorphic distortion [5]. The bottom centre of the picture features a curious form, an anamorphic distorted skull. The distortion can be resolved when the artwork is viewed from the left slide and the viewer looks upward at the painting. One theory is that the painting was commissioned to be placed at the top of a set of stairs.[6] Holbein knew the location and angle at which it would be viewed. With this knowledge, he produced an anamorphic skull that would look correct from the vantage point of the stairs (oblique anamorphosis). This effect could have seemed magical at the time of painting, considering that the formal understanding of anamorphism was produced 80 years later. This effect would have amplified the memento mori concept, expanding on the vanitas tradition of the time.

In the 21st century, contemporary artists have applied oblique anamorphosis to sculptural works. The dramatic oversized hyper-realistic work of Evan Penny is a good example that demonstrates that the artist understands oblique anamorphosis but, in this case, doesn't allow the viewer to have the satisfaction of resolving the distortion. The work has a 'shear' applied to the sculpture. A 'shear' means holding one coordinate fixed while the other coordinates are shifted. This is evident as the feet of the sculpture are fixed while the rest of the form shear to the side. Penny understands instinctively that humans recognise the human form as it should appear. This is a quality that amplifies his hyper-realistic rendering form, challenging the viewer's perception.

Fig. 5. Evan Penny, "Jim Revisited" (2011). (Copyright Even Penny)

There are many other examples of artists employing oblique anamorphosis to achieve novel sculptural distortion in various media. The common contributing factor in producing these sculptural works is the new and developing suite of digital tools common to 3D software packages that assist in the complex computation of the geometry of the forms. For example, a lattice deformer would be an ideal digital tool to help produce Even Penny's work.

Artists have also explored catoptric anamorphoses, such as in the works of Yung Hee Jo and Jonty Hurwitz. In Yung's 2014 work Fig. 6, aptly named *About Looking*, the artist tackles catoptric anamorphosis with a sculpture rather than a 2D image [7].

Fig. 6. Yung Hee Jo, About Looking, 2014(details coming)

With the use of digital tools, Yung produced a distorted 3D form of Aphrodite based on the curvature of a convex mirror. When the audience looks at the sculpture in the mirror, it appears correct. The artist amplifies the effectiveness of this work by rendering the 3D form in a marble-like finish, referencing the original marble sculpture by Greek sculptor Alexandros of Antioch [8].

While there are many compelling examples of how artists have applied oblique and catoptric anamorphosis to sculpture production, it is crucial to understand the limits of what has been produced to date. To the author's knowledge, there are no examples of sculptors approaching reflective concave and multiple non-uniform catoptric anamorphoses, nor the use of lenses and the combination of numerous different media such as water and glass. For these reasons, we focused on creative opportunities to tackle the problem of concave mirrored surfaces.

We sought a repeatable process that would allow us to explore multiple different sculptural forms, reflective and refractive materials and the relative positioning of each in real-world installations. We outline our approach and describe the resulting artworks in the following sections.

Anamorphic software

The foundation of our anamorphic software is ray tracing [9]. Ray tracing is digitally calculating how light behaves to produce an image in the rendering process for computer graphics. Fig. 7. illustrates basic ray tracing and what the viewer might see while looking at a sculpture in a regular mirror. The rays of light bounce off the statue and the mirror before reaching the eye to be perceived.

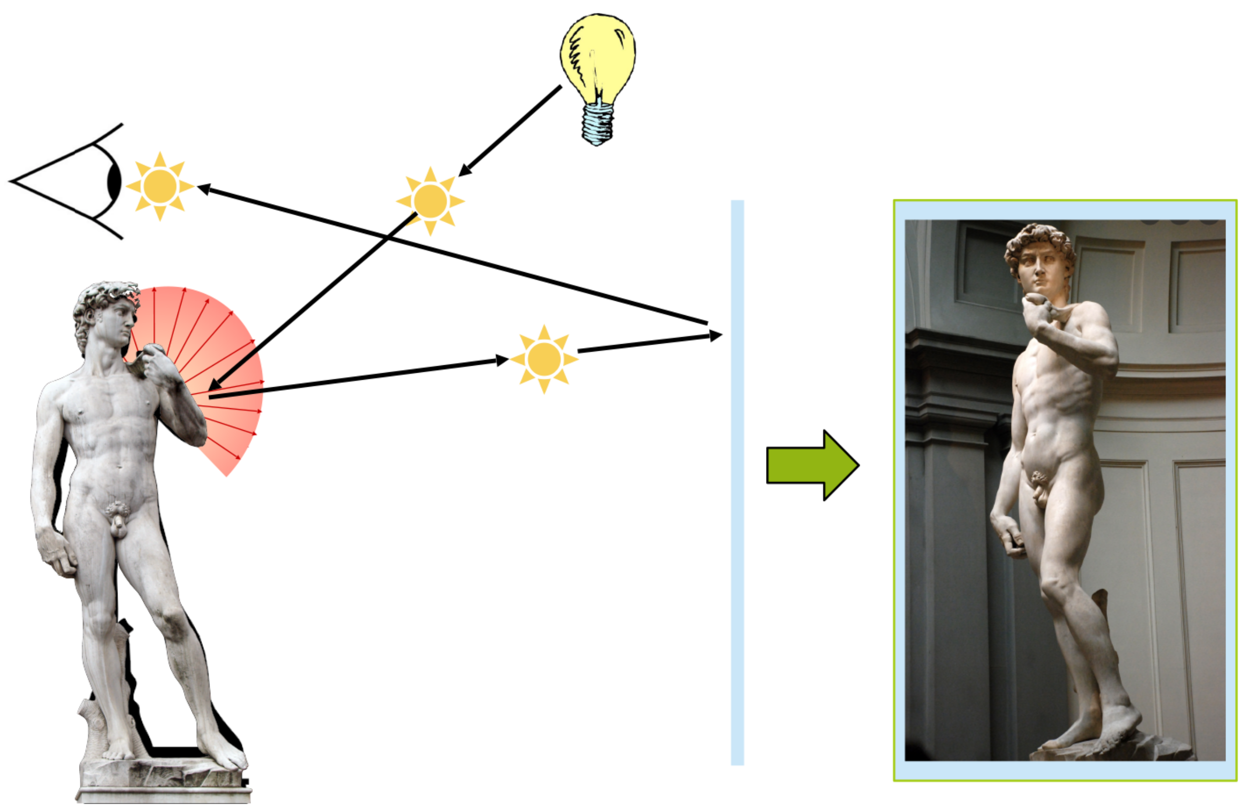

Fig. 7. Shows a standard mirror and how light rays hit the viewer's eye. (Copyright Nico Petroni 2021)

The process we employed for our anamorphic software was to backwards render, which essentially means deforming the 3D geometry to produce a specific target image in the mirror. This process is the reverse of a typical ray trace render, where an image is produced from 3D digital assets in the scene. This rendering is similar to the approach of De Comité [10], who developed methods for 2D artworks only.

Our method of backwards rendering provides the ability to simulate the optical effects of many different reflective and transparent media and specify the appropriate distortions to apply to the shape of the sculpture to ensure that audiences will perceive the undistorted form.

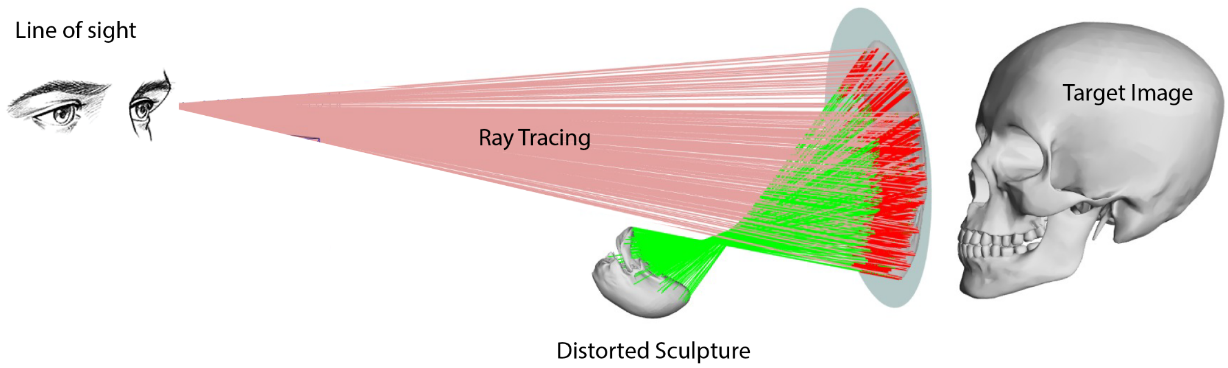

Fig. 8. Anamorphic software showing rays tracing with a concave mirror with the desired target image at the back (Copyright Louis Pratt 2022)

Fig. 8. Is a screenshot from our anamorphic software showing its calculations to produce the distorted sculpture that is corrected by the concave mirror. The undistorted skull is the target image which is the viewable reflection. We can manipulate this object in scale, rotation and position. The ray-traced photons are colour-coded pale pink, red and green. Red indicates the bounced light angle of incidence, and the green travels to the final position of the form we could produce. Pale pink shows the light rays reflected in the audience's eyes.

For our installation to be effective, it was necessary to adjust several parameters in our anamorphic software to correctly compute the distortion and position of the sculpture to achieve the corrected target image. These parameters include the viewer's location, the mirror position and orientation, and the input sculpture data that produces the reflection. After these parameters are fixed, it is possible to adjust the distorted sculpture's location to tweak the physical sculpture's scale and position as a function of our software.

Pipeline

As outlined in the introduction, we sought a repeatable and efficient process that would allow us to explore multiple anamorphic sculptural works. Initially, we focused on concave mirrors for two reasons. Firstly, no recorded examples of concave catoptric use in art have been identified in the literature. Secondly, concave mirrors magnify the reflected image, meaning a smaller sculpture could produce a larger reflection. A smaller sculpture, in turn, is faster and cheaper to produce, allowing for more experimentation and prototypes and accelerating development.

We re-rendered the results using the Arnold render (a ray tracing renderer) to test the software proofs, but any ray tracing renderers that can calculate the rays of light on reflective surfaces would suffice. We were able to prove time and time again that our bespoke backwards rendering software was correctly deforming the 3D data. This corrected reflection gave us confidence that we could account for the distortion of the concave reflective surface and resolve it. The next step was to fabricate all these elements and test the results in the real world.

Concave mirror

The fabrication process proved more challenging than expected. Acquiring a concave mirror at any scale was problematic and may explain why concave catoptric anamorphosis has not been explored significantly in art. To resolve this issue, we researched a process developed in the 1950s known as hydroforming, which uses pressurised water to shape metal [11].

We developed a hydroforming tool to inflate stainless steel into a dome, which we could polish into a concave mirror. Stainless steel was an ideal material for this project because it is durable and can be mirror polished. However, we have discovered that even the slightest deviation in the surface will be magnified in the reflection. The best practice is to add protective backing to the dome to ensure the optical qualities of the reflection.

Fig. 9 is a schematic we followed to produce our first hydroforming tool. This initial test tool created a 300mm stainless steel dome. This dome was then 3D scanned and used the data in the bespoke backwards rendering software we developed to calculate the distortion of the sculpture, which the concave mirror would visually correct. This link shows the large-scale tool inflating the stainless steel sheet into a dome. https://www.instagram.com/p/CORfIU7hr30/

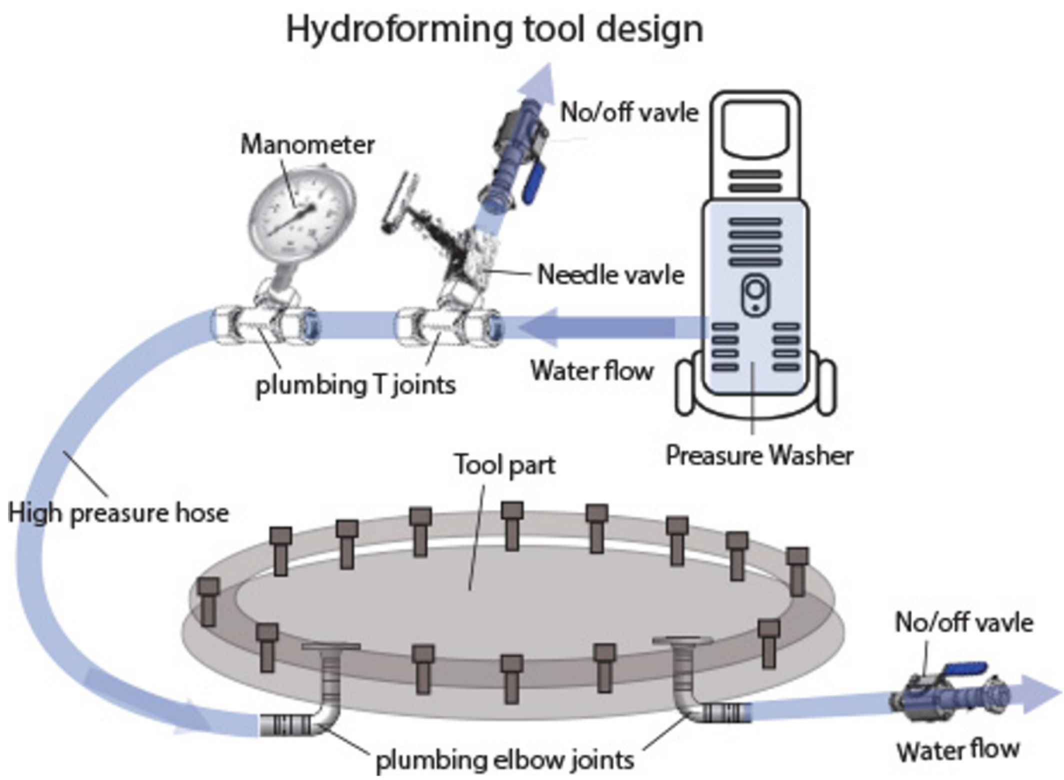

Fig. 9. Diagram design of the Hydroforming tool used for dome fabrication. (Copyright Louis Pratt 2022)

Artwork

The motifs we choose to work with for these initial projects link to vanitas and anamorphic traditions. We focused on human-centric representational forms because we felt the audience would recognise and identify with these more than with abstract forms.

Critical to the success of this prototype was positioning the distorted 3D form relative to the concave mirrored dome. These real-world elements needed to match the simulation as close as possible for the audience to perceive the undistorted form. In our case, this was particularly challenging as the dome and the sculpture needed to be suspended for the reflection to appear at a height suitable for viewing by standing audience members.

We built a life-size digital set-up with a grid, which showed the location of the concave dome, and where the deformed sculptures would be, as shown in Fig.10. This digital set-up was recreated in the real world with the grid placed on the floor in the same configuration as the digital grid to locate the forms to the mirror dome. This grid solution was helpful because we needed to remain flexible in the testing stage to support experimentation and refinement.

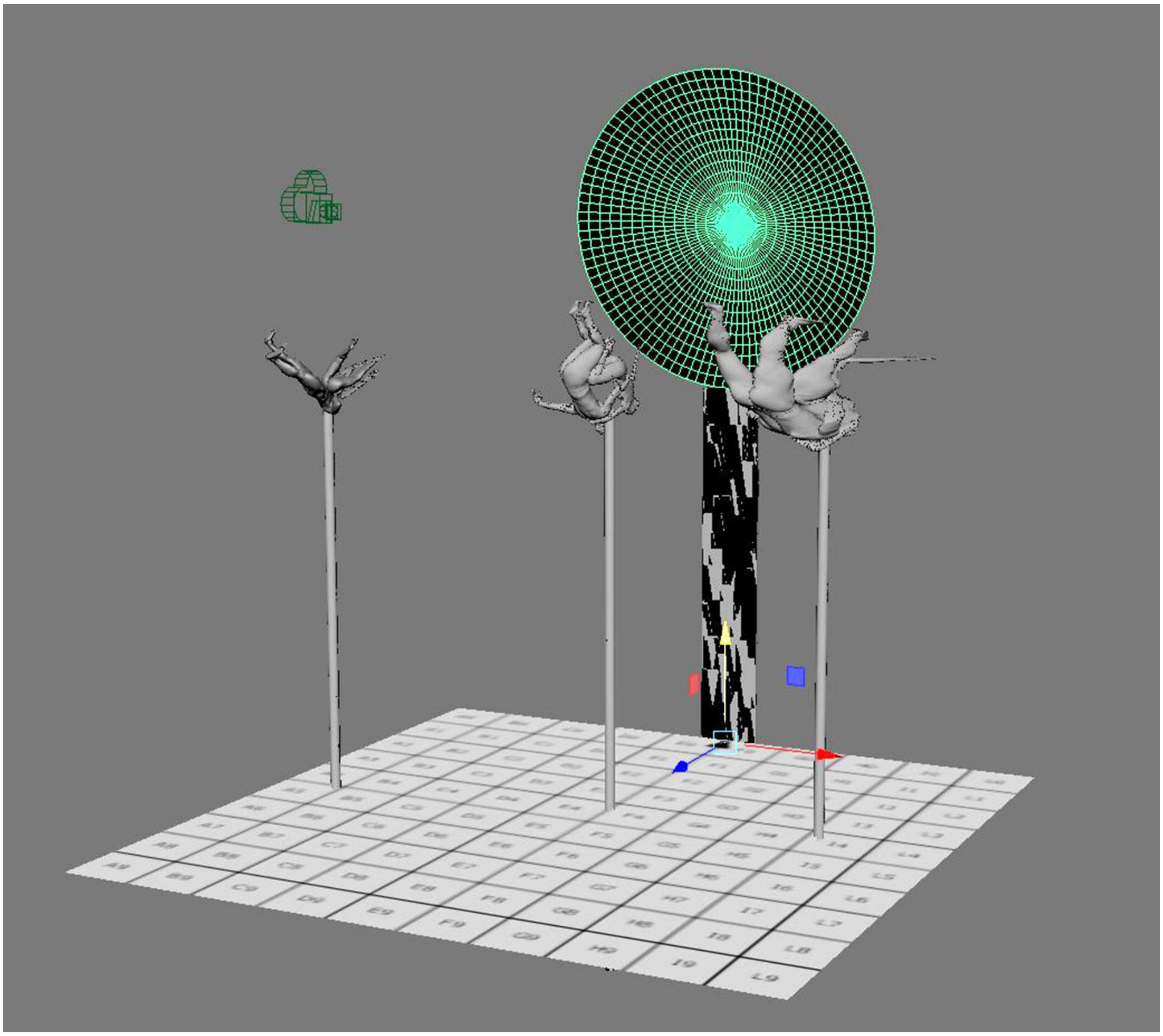

Fig. 10. Digital grid for locating anamorphic sculpture to the mirrored concave dome, same grid setup in the real world. (Copyright Louis Pratt 2022)

This flexibility led to another small but critical development: tilt the mirror dome 15 degrees to the floor. Tilting the mirror allowed control of the sculpture's height and reflected image. This adjustment enables an unobstructed view of the undistorted reflected image and the distorted sculpture. This small change had a significant impact on the viewing experience. Tilting gives us control over the relationship between the deformed sculpture at the reflection, which helps place the work in the installation. This tilting makes it possible to remove the deformed sculpture from view altogether and only present the reflected image.

Our first successful prototype worked as predicted; however, we noticed the reflected image appeared to be ‘holographic’ in that the reflected image seemed to float in front of the mirror. This visual experience was a quality we couldn’t initially explain but was sufficiently intriguing that we increased the scale of the dome to augment the holographic experience. We set up an installation at the University of Technology Sydney for a research study, with a mirrored concave dome of 1000 mm (39.37 inches) and a distorted sculpture of a skull and hands. We experimented with many kinds of data, testing different locations. However, we settled on this combination partly in homage to Holbein's work and because the skull shape works well compositionally within the circular dome shape. The hands were part of another test, and we collaged the elements together. That this was possible means, the concave mirror is forgiving and doesn’t require perfect precision.

Fig. 11. Image of the anamorphic sculpture lower-left corrected with a concave mirror. (Copyright Louis Pratt 2022)

Fig. 11. is an image of the initial prototype installation. As predicted, it demonstrates how the reflection shows an undistorted image of the distorted (and upside down) skull and hands sculpture (shown at the bottom right of the image). Note that the in-person 'holographic' experience of the image in the mirror doesn't fully translate to a flat photographic image. This quality of the installation means it has an experiential dimension that requires the audience to be in the room.

Audience Study

To examine the audience's experience, we invited fourteen people to view the artwork individually or in groups of two and discuss their experiences afterwards in a short interview. The interviews were audio-recorded and later transcribed for analysis. When asked to describe the experience, the general response was that the installation was magical, otherworldly or illusionary.

Three participants are active visual arts professionals with significant experience with innovative art installations. The remaining participants were students and staff of the university. All participants indicated that they had not previously seen a reflected image of this type. The audience consistently called the reflected image holographic, although most subjects knew they were seeing a reflection and, therefore, technically not a hologram. Most participants understood that the reflection was related to the distorted sculpture and the mirror though they couldn't explain how this installation worked. This perceived relationship of the distorted sculpture to the reflection formed an important sense of wonder for the audience.

The reflection produced by a concave mirror is reversed and moves opposite a standard plane mirror. This opposite movement is an entirely new experience of a reflected image, while the viewer still understands their moment modifies the reflection. From these novel qualities, the audience responded with surprise and intrigue. The keyword descriptions of the installation were ***"holographic, magical, illusionary, innovative, otherworldly, hovering, disbelief and mysterious".*** The subject matter was selected to amplify this experience.

Laws of optics

To understand the installation's surprising holographic quality, we need to look to physics. This 'holographic' quality can occur only with concave mirrors where the reflected image appears in front of the mirror. Concave mirrors can produce two types of reflections: ‘real’ and ‘virtual’; none are holographic. Technically, holograms are produced by a split coherent beam of radiation, such as a laser and have nothing to do with reflections [12].

In the case of a plain mirror (a standard flat mirror), the reflected image is called ‘virtual’ and appears behind the mirror. Conversely, the ‘real’ image appears in front of the concave mirror. To perceive a ‘real’ image in a concave mirror, the viewer needs to be behind C (edge of curvature) with an object placed between C and F (focal point), as is shown in fig. 12. The edge of curvature is a position determined by the concavity of the dome. An easy way to understand the edge of curvature location would be to imagine the dome as a complete sphere. The edge of curvature is the other side of that imagined sphere opposite the dome. The focal point is where the light rays cross each other, flipping the image upside down [13].

A concave mirror can present a ‘virtual’ and ‘real’ image depending on variables. This quality is specific to a concave mirror. If a person is behind C, their reflection appears upside down, though if they walk toward the mirror past F, their appearance is magnified and upright. This reflection transformation demonstrates that a concave mirror image can produce both a ‘real’ and ‘virtual’ image. A simple way to determine if the image is ‘virtual’ or“‘real’ is to note if it is upside down and appears in front of or behind the mirror. Virtual images always appear behind the mirror.

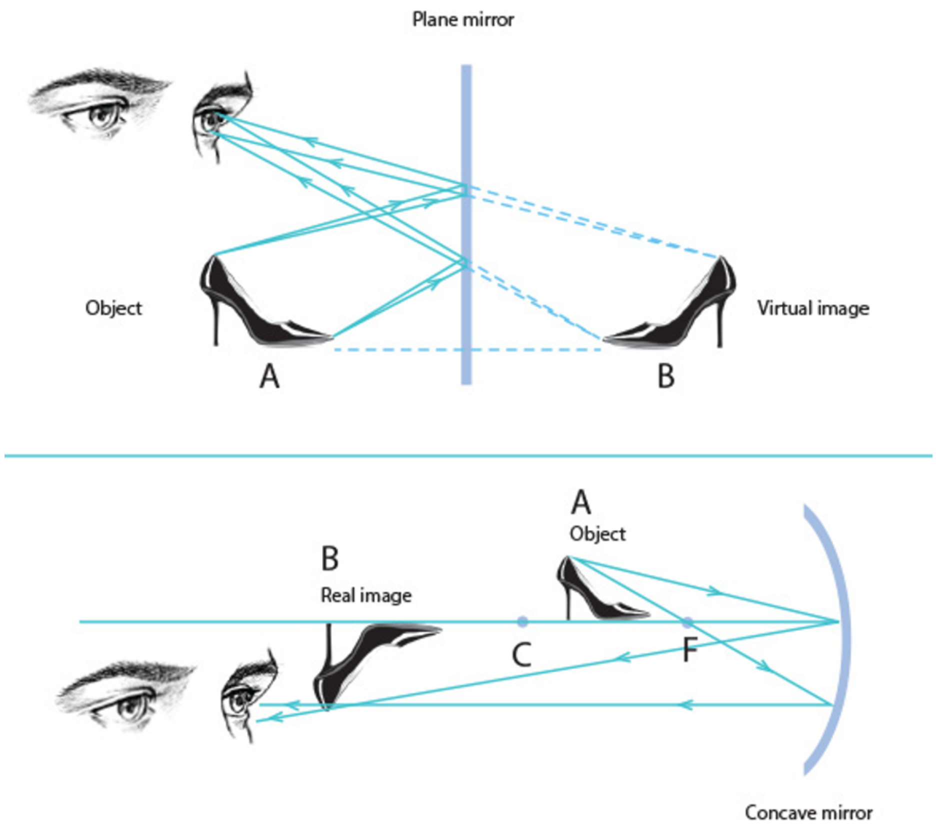

Fig. 12. Diagram of plain and concave mirrors, detailing "real" and "virtual" images. (Copyright Louis Pratt 2022)

While physics explains the 'real' image occurs in front of the concave mirror, this explanation is mainly unknown to the general public as it's not commonly experienced in daily life. For this reason, our test audience described the 'real' image as holographic.

From our experiments, we know that if we change the placement of the work, we can produce subtle changes in the reflection. For example, if the distorted sculpture moves further away from the reflective dome towards C, the image becomes noticeably smaller and more focused. However, it loses much of the holographic effect of being able to see different sides of the sculpture. The closer the object is to F, the larger the image and the greater the holographic effect, although the image can appear out of focus. All these qualities are modified as the viewer changes their position. The diagram in fig. 12 shows how the rays converge on the 'real' image, which appears in front of the mirror. This location in space is where the audience perceives the 'real' image [14].

These qualities could be altered by the level of concavity of the mirror. A greater concavity will change how close the "real" image is to the viewer as the locations of C and F have moved closer to the mirror. We plan to explore these effects soon.

A Very Dutch Ghost

This work references Dutch artist Vincent van Gogh's painting *Head of a Skeleton with Burning Cigarette* (1886) [15]. While this is a direct reference, it also pays homage to Holbien and the vanitas tradition. The goal for our first completed artwork was to simplify it and make it easy to install.

We exhibited this work at both Nanda\Hobbs Contemporary art gallery and Sydney Contemporary Art Fair in September 2022. The Nanda\Hobbs exhibit was in a dark room with one spotlight illuminating the deformed sculpture (see Fig. 14). This dramatic installation contrasted with the Sydney Contemporary Art Fair, which was presented in a brightly lit room. Fig.13 depicts how the contrasting installations appeared. In both exhibits, the direction of the audience approach was controlled to ensure the reflection was perceived first. We believe this is crucial to this installation's success, allowing the 'real' image to be explored before the sculpture and mirror.

Fig. 13. Install image of "A very Dutch Ghost" at Sydney contemporary (left) and Nanda Hobbs (right) (Copyright Louis Pratt 2022)

Both exhibits generated significant attention. At the art fair, queues lined up to see the work, intrigued by the effect of the ‘real’ image and equally impressed once they realised the deformed sculpture was accounted for in the concave mirror. The work has achieved commercial success with sales during the art fair and beyond.

Fig. 14. Install at Nanda\Hobbs. Detail of distorted sculpture (left) install view (right) (Copyright Louis Pratt 2022)

Unfortunately, for this paper, the full effect of the ‘real’ image effect can not be conveyed through images or video and is a personal experience for the viewer.

Future artworks

We see considerable potential and are motivated to explore further works. A complex concept we are considering is the integration of video projection mapping. This idea would involve mapping the video to an anamorphic distorted sculpture (hidden from the audience) showing the “real” image with the applied animated video projection. This installation concept would produce an animated ‘real’ image and open up exciting possibilities for animated anamorphic works.

Another area for further exploration is working with lenses and other transparent materials that refract and distort an image. Fig. 16 shows how our software can account for the refractive distortion and resolve it sculpturally when viewed through glass spheres. These 3D printed hands are modelled from Michaelangelo’s 1512 painting *The Creation of Adam* on the Sistine Chapel ceiling, demonstrating that we can successfully compute these refractions. Using a lens for anamorphic correction has not been applied in sculpture to the best of our knowledge.

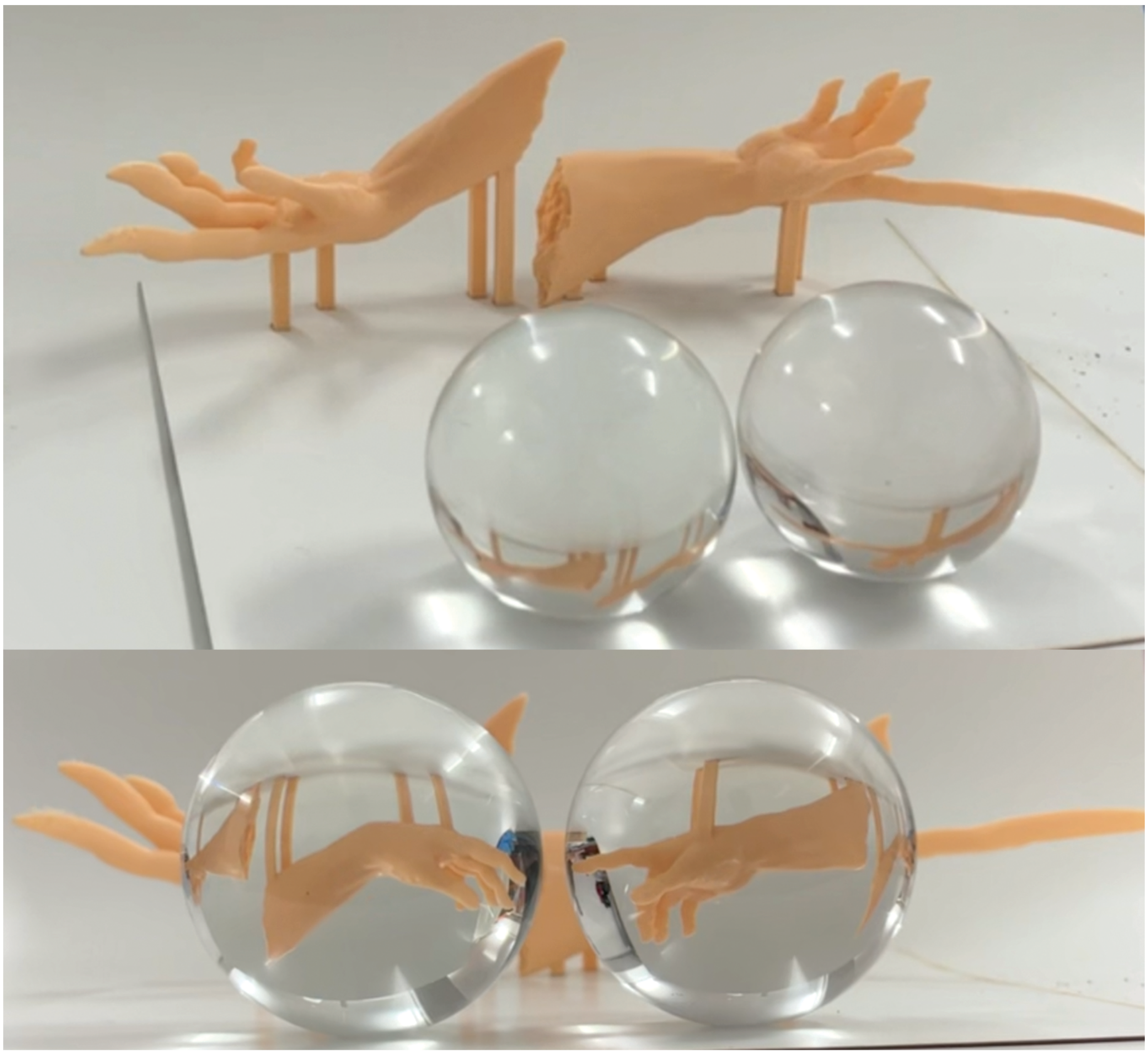

Fig. 15. Two views of the same sculpture, 1. Above 2. Looking through the glass spheres resolves the distortion of the hands. (Copyright Louis Pratt 2022)

Conclusion

The initial goal of this research was to explore catoptric anamorphosis with a concave mirror. We developed software that facilitates rapid experimentation and exploration of various sculptural forms and their placement concerning arbitrarily shaped mirrors and refractive materials.

The artistic focus was to explore evocative representational forms that reflect the anamorphic and vanitas traditions in art history - Holbien's '*Ambassadors*' being the seminal example of both. In creating artwork using our approach, we inadvertently produced a 'real' image that creates a 'holographic' effect that our test audiences perceived as highly unusual and compelling. This novel experience helped amplify the experience of our art installation.

This amplification of the artwork via the 'real' image pushed us to add humour to give the work a broader appeal and bring it into a contemporary dialogue, which is why 'A Very Dutch Ghost' is based on the Van Gogh painting.

We believe there is considerable potential for further creative and technical exploration in this area and are motivated to continue creating new works and refining our methods. These artworks are not strictly visual as they have an experiential quality since the "holographic" quality is not fully captured by video or images.

In conclusion, we have presented a new approach to sculpture by tackling concave reflective anamorphosis, thereby adding to the canon of art in vanitas and anamorphic works. We also refreshingly demonstrated, to ourselves and our audiences, how the laws of optics can still seem mysterious when viewed in a different light.

Illustrations

Fig 1. Shadows cast from the sun at different times of the day (Copyright Louis Pratt 2022)
Fig. 2. Shadow. (5 October 2022). In Wikipedia. https://en.wikipedia.org/wiki/Shadow
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Fig. 4. The Ambassadors, Hans Holbein the Younger 1553 (CopyrightThe National Gallery, London)
Fig. 5. Evan Penny, "Jim Revisited" (2011). (Copyright Evan Penny)
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Fig. 15. Shows two views of the same sculpture, 1. From above and 2. Looking through the glass spheres resolves the distortion of the hands. (Copyright Louis Pratt)

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Biographical Information

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Nico Pietroni is a Senior Lecturer at the University of Technology Sydney. His research focuses on concepts and practical algorithms for creating and manipulating digital shape representation. Nico is especially interested in how geometry processing intersects with artistic modelling and digital fabrication. His primary goal is to push the boundaries of current industrial production pipelines by exploiting the theoretical foundations in geometry processing. This includes mesh parametrisation, surface abstraction, and global optimisation applied to the entertainment industry, digital fabrication, and architectural geometry.