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S. Campana, D. Ferdani, H. Graf, G. Guidi, Z. Hegarty, S. Pescarin, and F. Remondino (Editors)

Exploring Anamorphoses in Immersive Virtual Reality on the Web: Design and Challenges of the Anamorphic Gallery of Anamorphoses (AnGA)

S. Menconero[†1], C.F. Amadei[1], G. Gosti [1], B. Fanini [1]

[1]National Research Council (CNR), Institute of Heritage Science, Italy

Abstract

In the field of art, anamorphosis is a perspective technique that produces two-dimensional images or three-dimensional installations whose form can be correctly perceived from a single viewpoint (the perspective projection centre), while appearing distorted and sometimes incomprehensible when viewed from other positions. Anamorphic devices work by disrupting the physiological visual process, altering perception and stimulating the viewer's cognitive processes aimed at recognising forms in an interactive and dynamic manner. This physical and mental engagement makes the experience emotionally and intellectually stimulating, as it requires the effort to reconfigure the image and unveil its true meaning, creating a personal connection with the artwork. Despite the potential of immersive Virtual Reality (iVR) for experiencing anamorphic works due to their interactive and dynamic characteristics, as well as the unparalleled creative freedom offered by the virtual environment, the scientific literature has not extensively explored this field.
Our contribution aims to propose the design and creation of a VR experience centred on the theme of anamorphosis, developed using the ATON framework within the H2IOSC project. The experience, titled Anamorphic Gallery of Anamorphoses (AnGA), is divided into two parts. The first part involves the exploration of an anamorphic space where the user must locate the perspective projection centre, the only point from which the anamorphosis appears undistorted. Once positioned at this point, the anamorphic environment gives way to the virtual environment generating the perspective projection. This virtual environment is a gallery showcasing various types of anamorphic devices (planar and spatial anamorphosis, tabula scalata, catoptric anamorphosis). Thus, AnGA has the dual purpose of providing users with an anamorphic experience and illustrating the main anamorphic mechanisms and their long history.
The paper also addresses the challenges posed by binocular vision in exploring anamorphic spaces in iVR, which is based on perspective projection from a single centre and, theoretically, achieves maximum effectiveness with monocular vision.

CCS Concepts
• ***Computing methodologies*** → ***Virtual reality;*** • ***Applied computing*** → ***Fine arts;*** • ***Information systems*** → *Web applications;*

1. Introduction

In the realm of art, anamorphosis is a perspective technique that produces two-dimensional images or three-dimensional installations whose correct form can only be perceived from a single viewpoint, while appearing distorted and often unintelligible when observed from other angles. There are several types (Figure 1):

- **Planar anamorphoses** are created on flat surfaces, such as a painted canvas or sheet of paper. Typically, these feature a recognisable frontal image containing an element in anamorphic projection that rectifies when viewed from a lateral perspective. Alternatively, the entire composition may be constructed in anamorphic projection, appearing distorted when viewed frontally but correctly proportioned when seen obliquely.
- **Spatial anamorphoses** can be further divided into two categories: those in which a two-dimensional image is fragmented and projected onto planes of varying distances and orientations, and those where a three-dimensional form assumes a recognisable shape only when viewed from specific angles.
- **Catoptric anamorphoses** exploit the reflective properties of

† sofia.menconero@cnr.it

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mirrored surfaces—whether flat, concave, or convex—causing the image to reassemble through reflection.

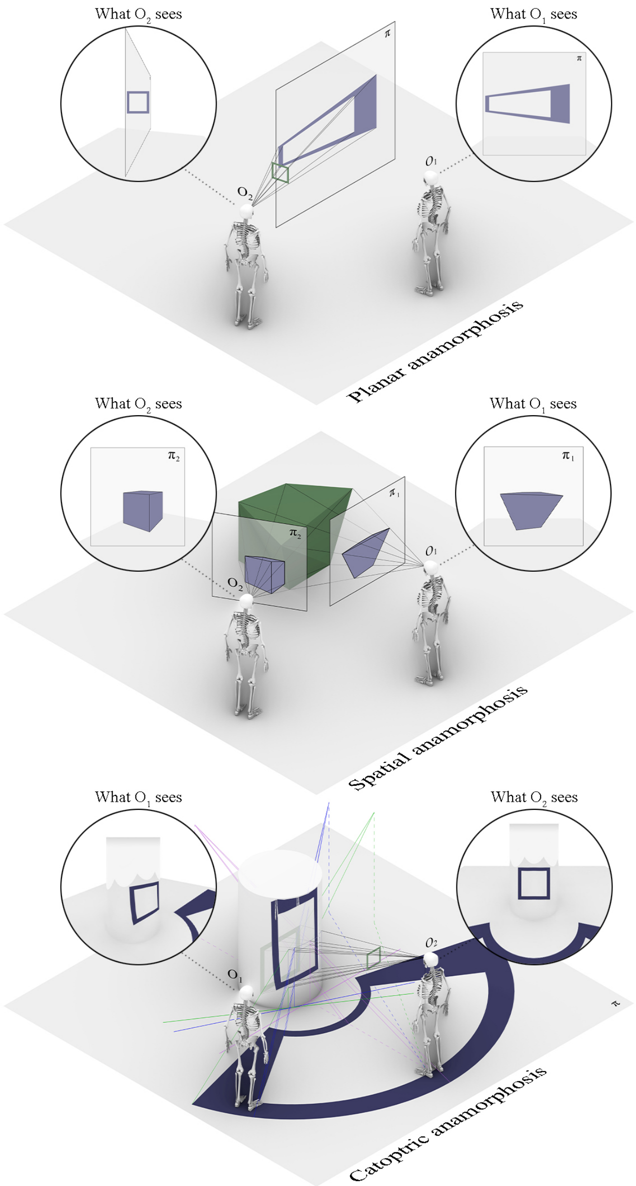

Figure 1: *Geometric principles underlying the construction of planar, spatial, and catoptric anamorphoses. Green indicates the true form of represented objects, blue shows the perspective image in generic (O_2) or privileged (O_1) viewpoints (Authors' elaboration).*

Anamorphosis stands as one of the most striking examples of the positive interplay between art and science over the centuries. Its long tradition began with Renaissance perspective experiments, peaked in 17th-century theoretical treatises, and continues to influence contemporary artistic expression [Bal97]. The term anamorphosis derives from Ancient Greek, originally meaning 'to transform' or 'regenerate' (ἀναμορφόω), from which the noun 'reformation' or 'regeneration' (ἀναμόρφωσις) is derived. The word was introduced in the 17th century by Athanasius Kircher [Kir46] and Gaspar Schott [Sch57], though the technique's origins trace back to the Renaissance. Leonardo da Vinci, in the *Codex Atlanticus* (1515), produced the earliest surviving experiments, while Piero della Francesca, in *De prospectiva pingendi* [dFca], first described its geometric principles with scientific rigour, anticipating theories that would only be fully understood a century later. The most famous example of anamorphosis in art is the skull in Hans Holbein's *The Ambassadors* (1533), where the distortion carries a symbolic *memento mori* meaning [Kem92]. In the 17th century, Jean-François Niceron [Nic38] systematised the technique, explaining how to deform an image using a perspective grid and creating monumental works, such as the mural of St. John the Evangelist in Rome's Trinità dei Monti convent (1639). Shortly thereafter, in the same mirrored corridor, Emmanuel Maignan painted an anamorphosis of St. Francis of Paola in prayer and detailed its construction in his treatise [Mai48].

What unites anamorphoses throughout their long history is a uniquely dynamic and innovative perceptual experience. Anamorphic devices disrupt physiological visual processing, altering perception and engaging the viewer's cognitive mechanisms in an interactive, dynamic act of recognition. This physical and mental involvement makes the experience emotionally and intellectually stimulating, as it demands effort to reconfigure the image and unveil its true meaning—drawing upon subjective sensations and memories. In this way, anamorphosis fosters a personal connection with the artwork, evoking an intimate epiphany that can yield profound satisfaction [Pag24].

Despite the potential of virtual reality (VR) and immersive virtual reality (iVR) for exhibiting anamorphic works—given their interactive and dynamic nature, as well as the unparalleled creative freedom of virtual environments—scientific literature has yet to explore this field in depth.

Our contribution aims to achieve three objectives:

1. To create a virtual space enabling users to experience a fully anamorphic environment.
2. To curate a gallery of anamorphic artworks showcasing their variety and, as a deeper exploration, their long history.
3. To examine the challenges of iVR-based web exhibition of anamorphic spaces and propose possible solutions.

These goals are pursued through the design and development of an experience titled *Anamorphic Gallery of Anamorphoses* (AnGA), implemented using the ATON service as part of the H2IOSC project. ATON is an open-source framework designed to present and enable interaction with 3D models through standard web browsers across multiple devices, including smartphones, tablets, computers, and XR headsets [FFD*21].

Beyond its research goals, the project also pursues educational and cultural objectives. Anamorphosis, as an application of Descriptive Geometry—a subject taught in certain secondary school programmes and further explored in university disciplines such as Architecture—provides a unique opportunity to bridge abstract geometric concepts with direct perceptual experience. Understanding Perspective is often challenging for students, as it requires moving from theoretical rules to experiential vision [Ver10, MCC24].

Through AnGA, learners can actively explore the relationship between the perspective artwork and the observer, who acts as the projection centre. This makes the experience both enjoyable and formative, encouraging interdisciplinary engagement with art, science, and digital media for students and general public.

2. Related works

The study of anamorphosis—the deliberate distortion of perspective requiring a specific vantage point or optical device for correct interpretation—has evolved significantly with advancements in digital technologies, while maintaining a long-standing tradition in art and geometric-projective theory [DRB21,MCC24]. This section examines current research across four key domains: digital creation tools, contemporary art and advertising, gaming, and iVR applications.

The construction of both analogue and digital anamorphoses has been revolutionised by 3D modelling tools. Within digital 3D environments, it is possible to easily replicate the projective conditions comprising a centre of projection (viewpoint), a surface intersecting the visual rays (picture plane), and an object to be represented. By selecting an extreme foreshortened viewpoint or a complex, reflective intersecting surface, an anamorphosis can be generated. In the field of Descriptive Geometry, NURBS modelling software such as Rhinoceros enables the graphical simulation of projective processes [Pag24, Ara21], even on non-planar, mirrored, or highly complex surfaces, through computational design supported by tools like Grasshopper [DPPIS15, DPP20]. Similar research interests have emerged in Computer Graphics [dCG15], extending to 3D object anamorphosis [HC07] and applying anamorphic projections for alternative purposes, such as enhancing eye contact in video conferencing [RBKS13].

These digital tools have accelerated the creation and dissemination of anamorphoses, allowing artists and designers to experiment with complex distortions that would be challenging to compute manually. However, most contemporary anamorphoses, while likely conceived digitally, remain faithful to traditional fabrication techniques. Notable examples include the remarkable works of Felice Varini [Var], Georges Rousse [Rou], and Truly Design [Tru]. The latter, an Italian crew based in Turin, created one of their most experimental catoptric anamorphoses for the 2019 Milan Design Week. In *More Than One Thing* (Figure 2), what appears as a flat composition from the privileged viewpoint is, in fact, the reflection on a square-based mirrored pyramid, projecting a design that is drawn across the walls, floor, and ceiling.

In advertising and music entertainment, experimentation has involved integrating anamorphoses into video formats. Examples include OK Go's music video for *The Writing's on the Wall* [OKG], as well as campaigns by Honda CR-V [Hon], Lacoste L!VE [Lac], and Vodafone NZ [Vod] (Figure 3).

Regarding the use of anamorphic devices in digital environments, the most widespread application lies in gaming, which also incorporates other types of non-perspective-based optical illusions. Scientific literature on this topic explores various aspects. Scholars have examined the phenomenon of spatial manipulation and defamiliarisation in digital games, drawing upon post-phenomenology

Figure 2: *Truly Design, More Than One Thing, Milan, 2019 (©Truly Design).*

Figure 3: *Top row: Screenshot from OK Go's The Writing's on the Wall music video; Second row: Screenshot from Honda CR-V advertisement; Third row: Screenshot from Lacoste L!VE campaign; Bottom row: Screenshot from Vodafone New Zealand advert.*

and developmental psychology, concluding that games with non-Euclidean spatiality challenge real-world spatial epistemologies acquired in early childhood [Bac20]. Others have analysed the spatial potential in the relationship between surrealism and architecture through gaming experiences [GÖ24]. The interest in spatial manipulation has led to the creation of *Spatial Chef*: a game which focuses on player interaction with virtual environments through body movements and an iVR gaming experience [SLKP23]. While spatial ambiguity is central, there is no explicit anamorphic intent or illusionary purpose. The theme of illusion reappears in studies proposing workflows for game designers to incorporate optical illusions into their projects [WXW*21].

Existing research consistently references *Superliminal* [Sup] as a first-person puzzle game integrating optical illusions and perspec-

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tive tricks. Though not only strictly anamorphic, it employs 'forced perspective'—a technique exploiting the ambiguity of monocular (screen-based, non-HMD) representations where depth cues are incomplete, making objects appear simultaneously large and distant or small and near (Figure 4). Similarly, *Viewfinder* [Vie] relies on perspective manipulation, allowing players to map 2D images from photographs into the 3D game space, creating new geometries and layouts.

Figure 4: *Screenshot from Superliminal videogame trailer showing generic and privileged viewpoints.*

Returning to pure anamorphosis, we observe that in some cases, the design output remains in virtual environments, while in others, digital design serves to produce anamorphoses for real-world viewing. The former category includes the *Anamorphic Gallery of Anamorphoses* (AnGA), detailed later. Unlike the aforementioned games, AnGA functions as a virtual museum and anamorphic experience accessible via iVR through web browsers. Leveraging the updated architecture of the ATON framework, scientific communities requiring online 3D models and 360° panoramas can now develop customised web applications with ease.

3. The AnGA Project

The *Anamorphic Gallery of Anamorphoses* represents an innovative VR experience designed to engage users with the concept of anamorphosis through two distinct yet complementary approaches: firstly, through immersive first-person exploration of a purpose-built anamorphic space—later referred to as the 'anamorphic box'—and secondly, through interactive engagement with curated anamorphic artworks accompanied by narrative explanations.

This section systematically outlines the design and development process of AnGA, which was structured around five key implementation phases:

1. Three-dimensional modelling and texturing of the virtual gallery environment;
2. Creation and texturing of exhibited anamorphic artworks;
3. Comprehensive lighting design and implementation for the virtual scene;
4. Development of the introductory 'anamorphic box' installation serving as the experience gateway;
5. Final technical implementation and deployment within the ATON framework.

The project employs cutting-edge VR technology while maintaining strong connections to historical anamorphic traditions, creating a bridge between classical perspective techniques and contemporary digital media. Each phase was carefully executed to ensure both technical precision and optimal user experience, with particular attention paid to the accurate representation of anamorphic effects in a virtual environment.

3.1. Gallery architecture

The architectural design of AnGA was conceived as a photorealistic simulation of a physical exhibition space. The virtual gallery comprises a single 8×10 metre chamber featuring four structural columns that demarcate an ambulatory from a central double-height atrium (approximately 8 metres in height), with 'natural' illumination filtering through overhead apertures (Figure 5). The architectural form and spatial configuration were dimensioned to accommodate and enhance the anamorphic artworks described in the following sections. Particular attention was given to ensuring that each piece had adequate space to include its intended privileged viewpoints. Furthermore, the ambulatory layout allowed for a multiplication of surfaces with varied orientations—walls, ceilings, and pillars—on which two site-specific anamorphoses were effectively integrated. The ambulatory also suggests a natural path for the viewer to follow, while leaving the central area of the room free for the installation of a three-dimensional anamorphosis.

The architectural modelling employed NURBS (Non-Uniform Rational B-Spline) surfaces within Rhinoceros 3D, with photorealistic texture mapping applied to simulate authentic material properties: herringbone parquet flooring; serpentine green marble column cladding and architectural details; white or green-tinted plaster wall and ceiling finishes (Figure 6). The space incorporates two site-specific anamorphic installations intrinsically linked to the architectural geometry, which will be examined later in this paper.

The technical workflow progressed through several key stages:

- The NURBS-based architectural model was exported in polygonal OBJ format;
- Automated tessellation converted the continuous NURBS geometry to discrete polygonal mesh;
- The resulting model was imported into Blender for advanced lighting simulation and refinement.

This methodological approach ensured optimal geometric accuracy while facilitating the subsequent lighting design process, maintaining fidelity to both the conceptual design and technical requirements of the virtual environment.

3.2. Anamorphic artworks

The AnGA exhibition presents six original anamorphic installations that explore diverse approaches to perspective manipulation. The creation process for these works involved a meticulous two-stage methodology: initial verification of the anamorphic effect using Rhinoceros' NURBS-based projection tools, followed by detailed 3D modelling and texturing in Blender.

Every installation incorporates one or more privileged view-

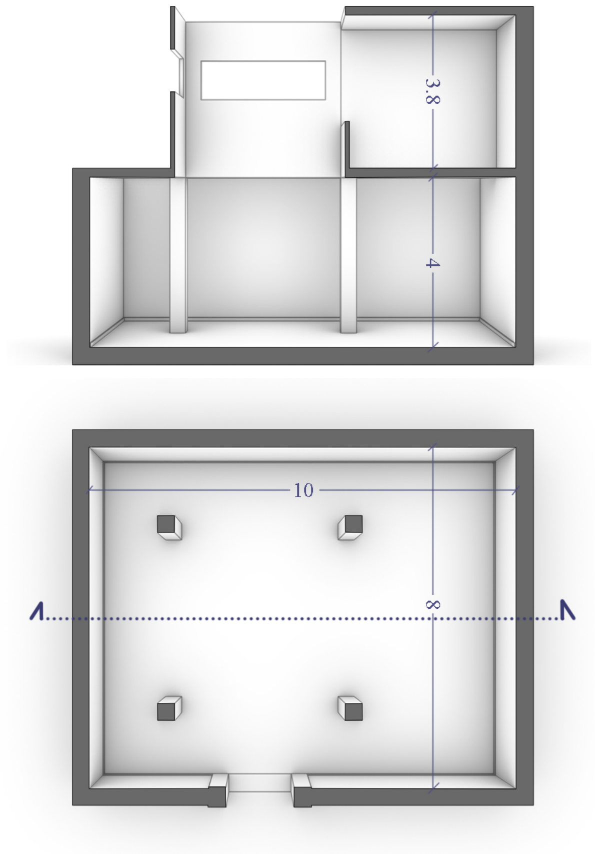

Figure 5: *Perspective section and floor plan of AnGA's architecture. All measurements are in metres (Authors' elaboration).*

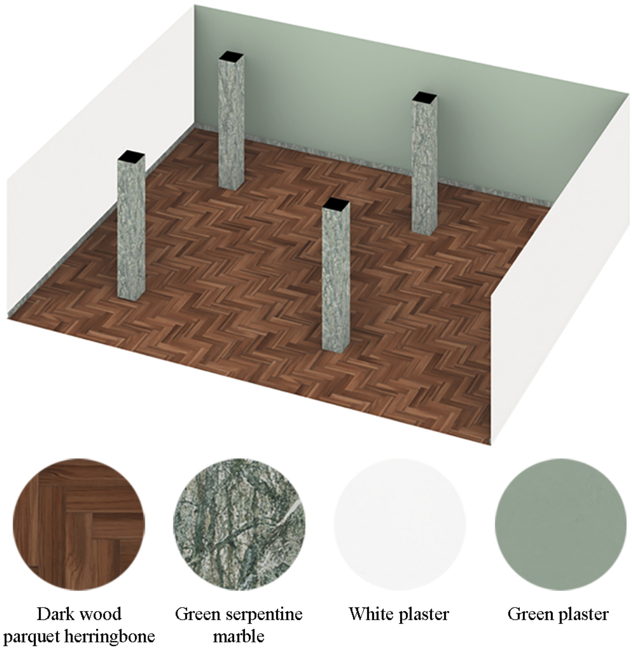

Figure 6: *Materials reference chart for AnGA's architectural textures (Authors' elaboration).*

points that are essential for experiencing the intended optical illusions. These carefully calculated vantage points enable the distorted images to resolve into their proper proportions, revealing the hidden imagery that remains concealed from other perspectives.

All anamorphic artworks are inspired by historical or contemporary physical devices. They were designed following the geometric principles summarised in Figure 1, though these are not discussed in detail here. The decision not to replicate existing artworks was based, on the one hand, on the need to design and position the privileged viewpoints in ways compatible with the architectural layout, and on the other, on the intention to demonstrate that it is possible to design original digital anamorphoses as effective as their physical counterparts. Moreover, existing historical and contemporary works are often subject to copyright restrictions by the original authors or holding institutions.

To streamline the creation process—while maintaining full manual control over all perspective projections—generative AI was employed to produce some of the images applied to the devices, as will be described later. The use of generative AI, explicitly acknowledged in the in-depth content accessible during the VR experience, served as a means to democratise creative expression and enhance productivity [MEV25], enabling the rapid generation of high-quality images tailored to the desired visual characteristics. These images were nonetheless further refined to fully meet the aesthetic, narrative, and technical requirements of the perspective devices.

These works collectively demonstrate how traditional anamorphic techniques can be reinterpreted through contemporary digital tools, maintaining historical connections while expanding the possibilities of perspective manipulation in virtual environments. The technical implementation carefully balanced perceptual impact with computational efficiency, ensuring optimal performance in the Web3D presentation format.

3.2.1. Welcome to the AnGA

Welcome to the AnGA (Figure 7) is the first site-specific anamorphosis that directly engages with the architectural space. It consists of a projected welcome message for the gallery. The projection centre (with known coordinates) is positioned near the entrance door, and the projection spans planes with different orientations.

From a technical standpoint, the text was projected onto the textures of the involved planes by rendering it from the privileged viewpoint and adjusting its size and proportions to match the undistorted texture image using image-editing software (Photoshop).

This type of anamorphosis is frequently employed today in advertising; however, architectural-scale mural anamorphoses have a long tradition, dating back to the outstanding examples created by Niceron and Maignan at the Convent of Trinità dei Monti in Rome [DRB21].

Figure 7: *Welcome to the AnGA artwork from privileged (left) and generic (right) viewpoints (Authors' elaboration).*

3.2.2. Always Together, Eternally Apart

Always together, Eternally apart (Figure 8) is an example of *tabula scalata*, also known as pleated perspective, turning picture, or channel anamorphosis. The work consists of two pieces created on vertical prismatic slats with a triangular cross-section, each displaying portraits of different figures depending on the viewer's perspective.

The digital construction involves fabricating the physical support—comprising the slats and frame—followed by mapping alternate faces of the slats onto textures corresponding to each portrait. Due to their unique ability to display two portraits that can never be observed simultaneously, the devices were inspired by the 1980s film *Ladyhawke*, as was the work's title. The portraits of the woman, the man, the hawk, and the wolf were generated using AI (Adobe Firefly), based on descriptions of the characters' physical traits and a style mimicking oil paintings.

Tabulae scalatae have a long history: they appear in 17th-century treatises, and two exquisite examples depicting the pairs Christ/Mary Magdalene and Saint Francis/Saint Clare are preserved at the Museum of Sacred Art in San Gimignano (Siena, Italy) [MM23].

3.2.3. The Apple

The Apple (Figure 9) is a classic planar anamorphosis, the first typology to be conceived historically. When viewed frontally, the work depicts Adam and Eve in their traditional iconography, with the forbidden fruit tree and the serpent. However, from a sharply foreshortened right lateral perspective, what initially appears as an indistinct reddish shape at the couple's feet resolves into the perfectly proportioned form of an apple.

The painting was created using generative AI (ChatGPT and Adobe Firefly), drawing inspiration from Flemish art, and manual graphic editing steps were added. To project the apple onto the canvas, the same method employed for *Welcome to AnGA* was applied: a proportionally correct rendering of the apple was generated from the foreshortened viewpoint, using the canvas section as a reference for subsequent perspective distortion in Photoshop. This work echoes the *memento mori* motif in Holbein's *The Ambassadors*.

3.2.4. Ce n'est pas un crâne

Ce n'est pas un crâne (Figure 10) is a catoptric anamorphosis of the *tabula scalata* variety, thus combining the previously described slatted mechanism (here using horizontal rather than vertical slats) with mirror reflection. Unlike vertical slat double portraits, this catoptric *tabula scalata* permits simultaneous viewing of both representations: one direct and one indirect via mirror reflection.

The production process follows the same methodology as previously outlined. Particular care must be taken in determining both the angle between opposing slat faces and the mirror's inclination, ensuring both images appear correctly from the privileged viewing position. The skull illustration was generated using AI, again simulating an oil painting style.

This exhibited device pays homage to history's most famous anamorphic skull—that concealed in Holbein's *The Ambassadors*—while simultaneously referencing Magritte's surrealist *oeuvre*.

3.2.5. Dodecahedron

Dodecahedron (Figure 11) represents the second site-specific anamorphosis designed to interact with AnGA's architecture. This work creates the illusion of a hollow dodecahedron suspended from the ceiling at the room's centre. The projection spans three planes with distinct orientations, employing the same methodology as the first described work.

The dodecahedron serves as a tribute to Descriptive Geometry—particularly its branch concerning representational methods, where contemporary research into perspective now encompasses anamorphic studies. Simultaneously, this Platonic solid references the contemporary artwork of Truly Design.

3.2.6. Free-form Cube

Free-form Cube (Figure 12) presents a spatial anamorphosis. What appears as an arbitrary form from most viewpoints resolves into a perfect cube when observed from a specific vantage point, with its visible faces rendered in distinct colours. The oxymoronic title highlights the form's inherent duality.

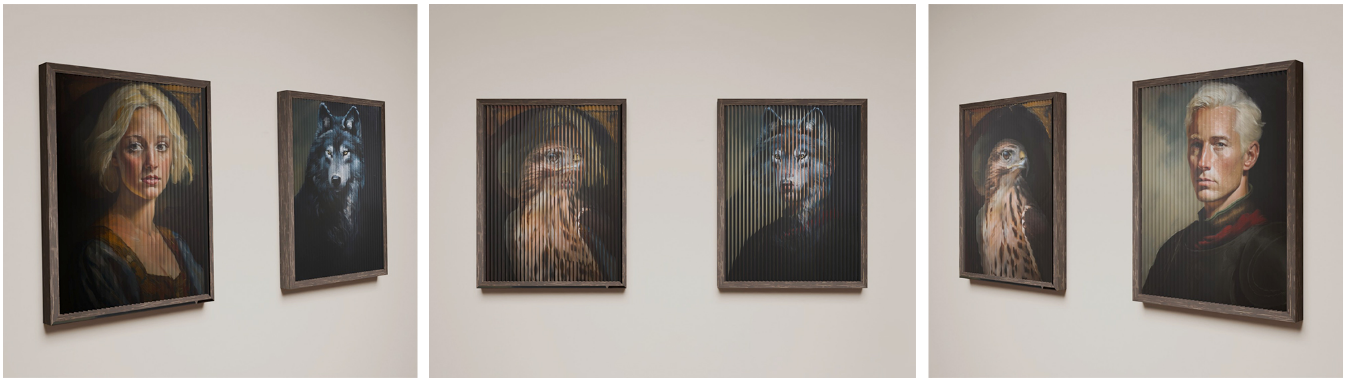

Figure 8: *Always together, Eternally apart artwork from privileged (left and right) and generic (centre) viewpoints (Authors' elaboration).*

Figure 9: *The Apple artwork from frontal (left) and lateral (right) viewpoints (Authors' elaboration).*

Figure 10: *Ce n'est pas un crâne artwork from privileged (left) and generic (right) viewpoints (Authors' elaboration).*

The work's realisation involved: 3D modelling of a cube; selection of an optimal viewing position; and strategic displacement of selected vertices along visual rays extending from this viewpoint (the projection centre).

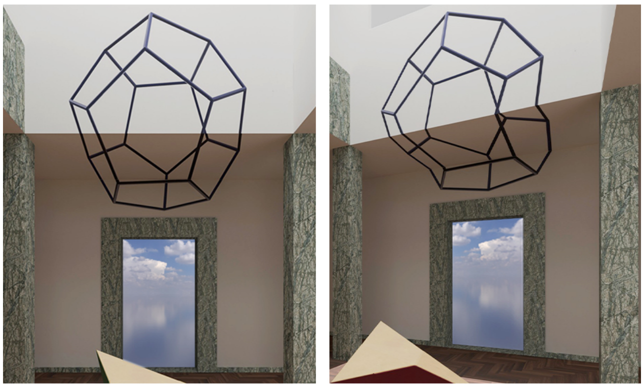

Figure 11: *Dodecahedron artwork from privileged (left) and generic (right) viewpoints (Authors' elaboration).*

This construction ensures the original cube's apparent contour and two-dimensional projection remain intact when viewed from the designated position. While the face colours maintain the illusion, the shadows remain deliberately inconsistent as they derive from the object's true, distorted form.

3.3. Lighting design

Given the choice of a Web3D-based experience, we implemented baked lighting directly onto textures to reduce real-time rendering demands.

The architectural model and its artworks were assembled in Blender for lighting design:

- A zenithal Sun light filters through the ceiling's central aperture, illuminating the *Free-form Cube* at the room's centre. This creates the object's characteristic ambiguous shadows when viewed from its intended vantage point.
- An Area light matching the ceiling opening's dimensions enhances illumination of the upper floor.
- Each wall-mounted artwork features a Spot light replicating standard exhibition lighting.

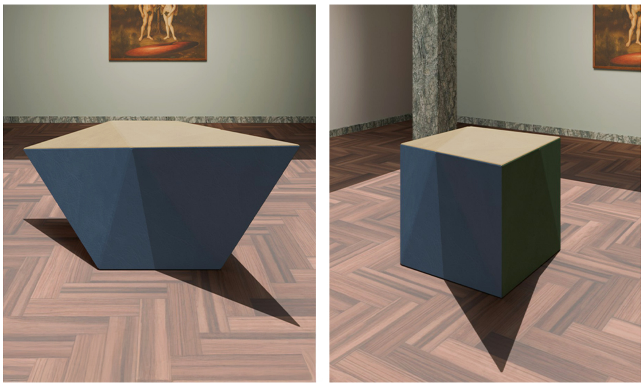

Figure 12: *Free-form Cube artwork from generic (left) and privileged (right) viewpoints (Authors' elaboration).*

- For optimal viewing of *Always together, Eternally apart*, two additional Point lights were placed near the *tabulae scalatae* to mitigate shadowing in the inter-slat recesses.

Following light placement and intensity calibration, we baked all scene components (lights, ambient occlusion, textures, and materials) onto the 3D objects' textures using Blender's Bake command. This approach yields a 3D model conceptually analogous to photogrammetric outputs, where textures inherently capture all lighting conditions present during acquisition.

3.4. Anamorphic box

A final creative phase involved the construction of the 'anamorphic box'—a rectangular-based right prism composed of five faces and positioned near the entrance to AnGA. This is a fully anamorphic space: although formally consisting of a simple volume, it simulates the spatiality of the entire gallery. Such spatial coherence is perceptible only from a specific viewpoint. Although the anamorphic box was the last element to be created—being generated from perspectival images of the gallery—it is the first element encountered by the user at the start of the VR experience.

The box's dimensions (3×4 metres with 3m height) were calibrated to achieve an optimal compromise between maintaining the anamorphic illusion and providing sufficient virtual space for natural locomotion.

The five interior surfaces display a projected reproduction of AnGA's complete interior architecture and artworks (Figure 13). The projection centre aligns precisely with the entrance doorway's centre point and the privileged viewpoint for *Welcome to the AnGA*. From this vantage, the anamorphic box and AnGA's 3D space appear identical.

The experience begins from a different viewpoint within the box, deliberately disorienting visitors in a perceptually non-Euclidean space. Only one element remains coherent from this initial position: the inscribed quote "Nothing would be what it is because everything would be what it isn't"—a reference to Disney's *Alice in Wonderland* adaptation. This text guides visitors toward a yellow floor circle marking the privileged viewpoint's location (Figure 14).

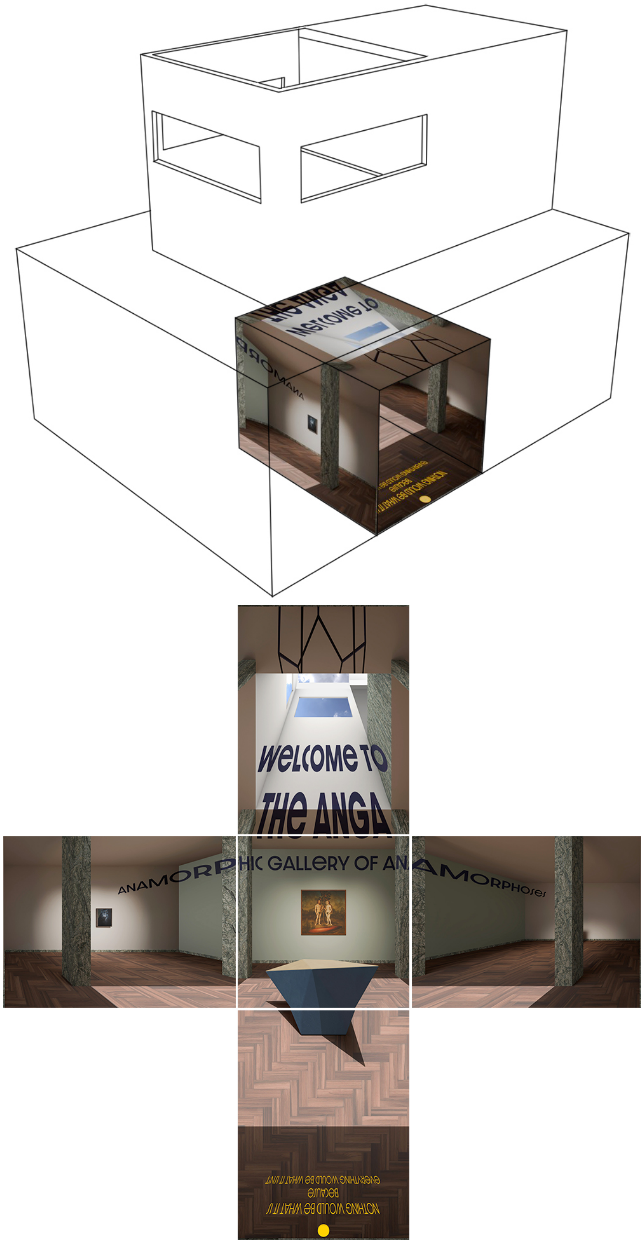

Figure 13: *Position of the 'anamorphic box' within AnGA's architecture and development of the five faces with respective anamorphic textures (Authors' elaboration).*

The aim of the anamorphic box is therefore to immerse the user in a fully anamorphic space, challenging their perceptual stimuli to the fullest extent.

3.5. Scene implementation in ATON

ATON is a framework accessible to everyone for presenting and interacting with 3D models, scenes, and 360 panoramas directly on the web. It is designed to meet the growing demand for 3D

Figure 14: *Interior view of the 'anamorphic box' from a generic viewpoint relative to the room's anamorphic projection but privileged for viewing the yellow text (Authors' elaboration).*

digitization in Cultural Heritage. It requires no installation for end users since a common web browser is sufficient to access interactive content, automatically adapting to any device (smartphones, tablets, computers, museum kiosks, up to AR/VR devices). Key features to interact with 3D contents include measuring tools, semantic annotations, virtual tours creation, immersive AR/VR presentation, real-time collaboration with other remote users, advanced illumination tools, simulation of complex materials, and much more. Furthermore, it offers different navigation modes: orbit, first-person, device orientation—besides various features for viewpoints management. By embracing international standards and formats, ATON can be easily integrated with other platforms and services [FFD*21].

The development of AnGA was carried out within the NRRP (National Recovery and Resilience Plan) project H2IOSC, which led to substantial improvements in ATON's architecture, User eXperience (UX) and User Interface (UI), that will be discussed in separate papers. The ATON architecture supports the accelerated development and deployment of custom web applications to incorporate custom logic, UI and additional functionalities. AnGA served as an experimental case study for such custom web applications.

Prior to implementing the scene in ATON, the 3D models of both the architectural structure and the anamorphic artworks were optimised using purpose-built tools. These tools performed format conversion from OBJ to glTF, along with geometric optimisation and texture compression. Through this process, the models were reduced to approximately 10% of their original file size.

Following compression, the models were imported into ATON.

A surreal background composed of clouds and reflections was integrated into the environment, visible exclusively through the ceiling aperture in the central hall and the entrance doorway. This effect was achieved by mapping an equirectangular image onto a spherical enclosure surrounding the entire scene.

Furthermore, predefined viewpoints (PoVs) were established, each corresponding to the privileged viewing positions of the various anamorphic works.

4. The AnGA experience and its challenges

The VR experience of AnGA [AnG] begins with users positioned at an arbitrary point inside the anamorphic box. From this viewpoint, the surrounding space appears intentionally distorted, with only a single coherent element: the quotation "Nothing would be what it is because everything would be what it isn't", which directs users towards a yellow floor circle. During this initial phase, participants explore a perceptually non-Euclidean anamorphic space through natural walking (where physical space permits). Upon reaching the circle, users turn to discover the previously ambiguous architectural elements resolving into the coherent structure of AnGA's main hall. At this point, the anamorphic box dissolves, revealing the full 3D environment containing the anamorphic artworks.

Users may then freely navigate the space either through teleportation to marked floor discs or via interface-selected automated movement to privileged viewpoints (PoVs). Reaching a PoV triggers explanatory content about the corresponding anamorphic technique. The experience remains consistent across desktop, mobile, and iVR platforms in terms of content delivery.

Some guidance on how to navigate the experience is provided through 3D panels, particularly at the beginning—when the user first enters the VR space—and during the transition from the anamorphic box to the fully realised 3D gallery.

This research introduces novel iVR web-based implementation, presenting unique challenges in two key areas: (1) WebXR technical challenges, and (2) anamorphic projective principles.

4.1. WebXR technical challenges

Mirror reflections in iVR (particularly for the catoptric anamorphosis) required developing a custom shader within the custom web app.

The ATON framework implements a fixed viewpoint height above the virtual floor plane, normalising user eye-level regardless of physical stature. While this standardisation facilitates precise privileged viewpoint (PoV) alignment for anamorphic viewing, spatial coordinate drift—including vertical displacement—may occur due to tracked area misconfiguration and other factors. We mitigated this issue through predefined PoVs ensuring accurate x,y,z positioning. This option allows users to move from one PoV to another directly via an interface button. Notably, we contend that teleport navigation offers valuable cognitive engagement by requiring users to actively identify optimal viewing positions.

4.2. Anamorphic projective principles

Anamorphoses are constructed according to geometric-projection principles that rely on the one-to-one relationship between the centre of projection (viewpoint), the perspective image (as received on the retina), and the represented object. To preserve this relationship—and for the observer's eye to be deceived by the illusion—it is necessary to view anamorphoses with one eye only.

The binocular vision problem—well-documented in literature [Gre97, HAOT21]—presents fundamental constraints. While desktop/mobile displays circumvent this issue by presenting a single image (subsequently interpreted binocularly), iVR inherently provides stereoscopic vision.

Preliminary laboratory testing conducted on AnGA revealed that most anamorphic works remain perceptually effective in iVR. The notable exception is the *Free-form Cube* spatial anamorphosis. This configuration corresponds to what Kilpatrick [IK61] defines as an "equivalent configuration" and aligns with the "confounded ambiguity" theorised by Richard Gregory [Gre09]: from the constrained viewpoint, the free-form shape produces the same retinal image as a regular cube and is therefore perceived as such—at least when viewed on a desktop or mobile display.

After prolonged exploration of the gallery space—particularly after moving around the *Free-form Cube* installation—when the observer returns to the privileged viewpoint and uses both eyes (i.e. under stereoscopic vision), the illusion breaks. This is due to the presence of depth cues, particularly convergence. This is a classic example of physiological depth cues, based on proprioceptive feedback related to the eye orientation when focusing on an object. Specifically, convergence refers to the angle formed by the two optical axes, which increases as the object gets closer. The effectiveness of this cues diminishes rapidly with increasing viewing distance or, alternatively, under monocular vision [CV95].

However, simply closing one eye removes depth cues, allowing the distorted form to resolve into a perfect cube—despite inconsistent shadow rendering.

5. Conclusions and future developments

The *Anamorphic Gallery of Anamorphoses* represents an innovative approach to cultural heritage valorisation, showcasing the centuries-old interplay between art and science. By digitally reinventing this Renaissance technique, the project explores the potential of anamorphic devices in contemporary contexts, demonstrating how immersive technologies can reinterpret traditional perspective illusions. Unlike current applications primarily focused on gaming or physical installations, this virtual museum maintains an educational and exhibitive purpose while incorporating interactive elements, thereby enhancing public understanding of these complex perspectival techniques.

A key strength of AnGA lies in its web-based, multi-device accessibility, which democratises the anamorphic experience by eliminating the need for specialised hardware. The ATON framework facilitates fluid exploration across desktop, mobile and VR headsets, broadening access to diverse audiences. Furthermore, this approach demonstrates how VR can effectively preserve and disseminate art forms rooted in scientific principles, fostering dialogue between tradition and innovation.

This paper aims to initiate a research trajectory on the perception of anamorphoses in VR. Due to space constraints, it is limited to the first phase of this journey—namely, the design of the anamorphic gallery. Given the unique nature of such artworks, this phase required in-depth discussion. Nonetheless, we considered it valuable to highlight some of the key challenges that this kind of experience must address, particularly those related to WebXR technology and to the perception and physiology of binocular vision.

Future research directions will include behavioural analysis of user interactions with virtual anamorphoses, with a particular focus on the underlying cognitive and perceptual processes. Such investigation could employ Interlumo—another tool developed within the H2IOSC project [FG24]. Interlumo is a suite of services designed for researchers and professionals aiming to study and understand large volumes of interaction data generated by remote applications, public or lab-based installations, virtual or physical spaces, online web apps, and more. It is structured into three components: capture, processing, and inspection. The first allows for the collection of substantial amounts of interaction data in numerical form from remote applications; the second enables the aggregation and analysis of user behaviour patterns through analytics; and the third supports the visual/immersive inspection of such data, facilitating advanced interpretation directly through a standard web browser.

Integration with studies in visual perception and neuroaesthetics may offer novel insights into the neural processing of these illusions in immersive environments, with potential applications across both artistic and educational domains.

Equally relevant will be the assessment of the experience's educational potential by engaging students and evaluating, through the use of Interlumo alongside traditional methods of user experience evaluation, their level of involvement and their understanding of the concept of anamorphosis.

Positioned at the intersection of art, science and technology, AnGA stands as both an innovative cultural experience and a testing ground for future interdisciplinary research. The project preserves historical artistic techniques and recontextualises them through cutting-edge digital media, suggesting new paradigms for cultural heritage engagement in the digital age.

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