Unsuitable Objects: Disrupting Photorealism in the Digital 3D Scan through Art Practice.

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UNSUITABLE OBJECTS:

DISRUPTING PHOTOREALISM IN THE DIGITAL 3D SCAN THROUGH ART PRACTICE

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Keywords: 3D scanning, art practice, digital cast, digital indexicality, disruption, reality capture, unscannable surface, photorealism, scan-artworks, scanogram.

Abstract

3D scanning technologies are shaped by photorealistic ideologies drawn from photography and computer graphics. However, photorealism is a belief that privileges photography as a “factual” representation of reality; it is not an inherent quality or attribute of digital capture technologies, but a technical-cultural concept imposed upon them. Through artistic research, this PhD thesis critiques the assumptions about photorealism embedded in commercial 3D scanning practices and non-critical approaches to the technology. Creative methodologies provoke 3D scanning to capture areas of solid colours, reflections, transparency, and cluttered interior architectural surfaces, all of which current commercial practices advise against. Scan-artworks explore the effect of three new categories of unscannable surface and environment on the photorealism aesthetic standards applied to reality capture. These disruptions remind us that 3D scanners are not cameras, and scanned models are, unlike computer-generated imagery, not naturally photoreal. The thesis documents novel types of disruptions formerly considered flaws or errors in 3D scanning, that present new ways of considering the distinctions between what scanners perceive and what we perceive, offering new perspectives on the relationship between 3D scanning and digital indexicality.

Note on the research by practice.

The research-by-practice includes three categories of 3D scans: colour, space, and mirror and glass scans. These “scan-artworks” featured in an accompanying exhibition and can be viewed at the links below and image examples throughout the thesis:

- Three PDF portfolios of scan categories (included with the thesis).
- Original 3D scan files on sketchfab.com:
    - colour scans (includes the methodology case study data)
    - space scans
    - mirror and glass scans
- 3D scan showreel of artworks and studies
- A list of artworks and images of the exhibition held as part of the PhD by Practice can be found in Appendix 1 and Appendix 3
- The illustrations in the thesis by the author are clickable links to the individual 3D scans

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Chapter 1: Introduction and critical practice review

1.1 Introduction

In November 2016, I attended *Mistaken Me in 3D*, an experimental portraiture 3D scanning workshop at The Photographers Gallery, London, led by Matthew Shaw of ScanLAB Projects. This workshop introduced me to advanced 3D laser (LiDAR) scanners and deepened my interest in researching the often-striking visual realism of 3D scanning, an interest that I had developed through a previous research project. In that previous work, I researched the use of early short-range 3D scanners to digitise objects for computer animation (Wallin and Stephens, 2013). I therefore had some experience with Reality Capture, a term encompassing various types of 3D scanning technologies; however, the *Mistaken Me in 3D* scanning workshop offered a new perspective. Instead of using the scanners in the way they were designed to be used, in this case, to produce digital portraits, we were encouraged to experiment with these professional scanning machines by using mirrored surfaces to distort our portrait scans, to provoke the 3d scanner to produce “errors creatively”. This technique tricked the scanner into creating misshapen, mirrored copies, much like the infinite reflections seen when standing between two opposing mirrors. This simple yet effective technique challenged the concept of a 3D scan as a perfect digital copy (Figure 1 and Figure 2). The scans showed that the 3D scanner read reflections as actual three-dimensional space. While the workshop highlighted how capturing something as ordinary as a reflection, reality capture could be prompted to record previously unseen aspects of reality.

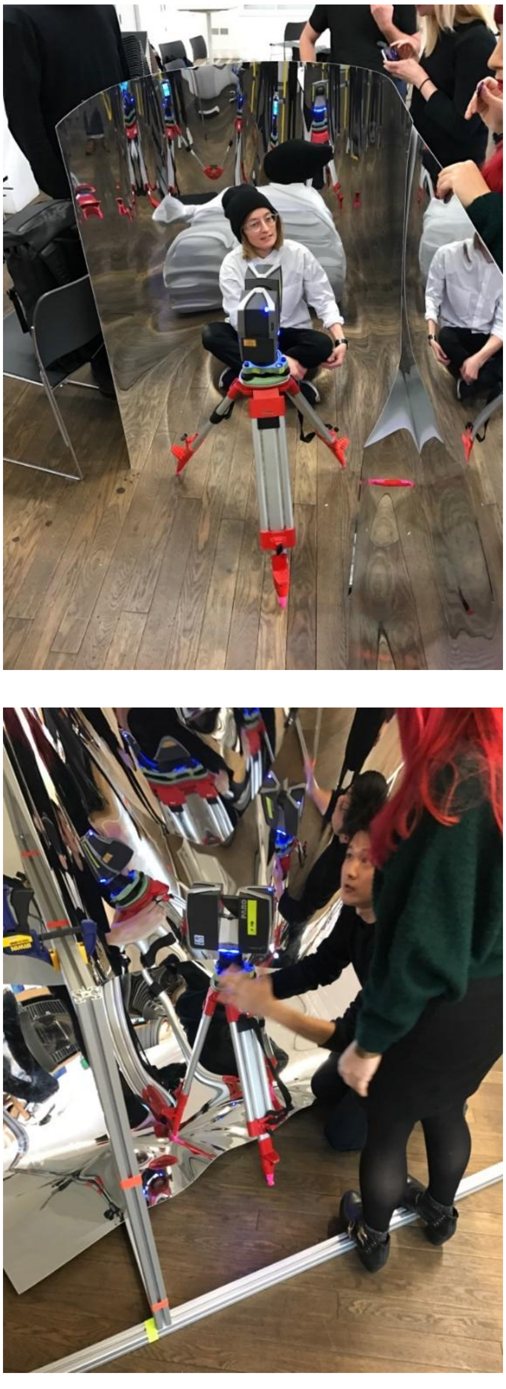

Figure 1. Laser scanning workshop 'Mistaken Me in 3D*' (2016)*

Figure 2. LiDAR point cloud images, 'Mistaken Me in 3D' *workshop (2016).*

In the workshop, a mirror was used to deflect and bend the operation of 3D laser scanning to make infinite reflected scan portraits. The mirror was also a method to directly challenge perceptions of 3D scanning as a medium that always captures visual resemblance that is truthful and objective, a direct like-for-like copy of reality. From an industry perspective, the mirrors were highly disruptive to the scanning technology; they were effectively unscannable due to the multiple distortions and reflections they caused in the scans. However, the workshop showed that new kinds of outcomes were possible, that the nature of the mirror could be captured in a scan, not in the way that we see a mirror reflection, but as a spatial realm that could be navigated in virtual three-dimensional space on the computer. The LiDAR scanner treated the mirror reflections as a genuine recording, but as Shaw explained in the workshop, these readings by the scanner would probably be discarded in the typical day-to-day uses of laser scanners as anomalous, unwanted readings. I considered that this observation could lead to discovering new knowledge in reality capture. There was an opportunity for a research project; if I could identify existing or even new unscannable surfaces, I could explore the fringes of the technology and uncover new scanning behaviours seemingly at odds with a photorealistic industry-driven perception of 3D scanning. As such, the *Mistaken me in 3D* workshop experience inspired my development of this research project and thesis.

The phenomenon of unscannable surfaces in 3D scanning is known in the field but has yet to be studied in detail, leaving a gap in the available literature. Whilst knowledge exists about the behaviour of difficult-to-capture surfaces and laser scanning, other kinds of scanning, namely photogrammetry scans, which reconstruct geometric 3D models, have not been investigated in this way before.

Photogrammetry, along with other types of smartphone 3D scanning applications, is thus the main focus of the practice-led scans of the thesis. Therefore, the scans of this project contribute new knowledge in this area, particularly on exactly what scans of materials and surfaces that disrupt and resist 3D scanning look like. The research adds to the evolving contemporary debate on 3D scan realism in digital imaging. This realism, I argue, is grounded in photographic realism, manifesting in the 3D scanning industry as a type of scanned photorealism. My research identifies how the concept and practice of photorealism are dominant in scanning, where photorealism has become a standard or ideal by which 3D digital scans are evaluated. Photorealism is linked to reality capture technology because it is intended for screen display, like other digital media, and its data is filtered through a standard of photorealism on screen. It is rendered using 3D software that generally employs perspective, lighting, and virtual cameras which follow the operation of actual cameras and photography, and it is these systems are used to visualise scan data. 3D scans are also contextualised by their application in industry, primarily for photorealistic animation in video games, digital visual effects in films and architectural visualisation. Here, the photorealism of the photograph serves as a crucial reference point, and (as I examine in the thesis) the terminology of photorealism has thus become linked with digital 3D scans. However, there are marked differences between how scanners capture objects and surfaces and what this data looks like in its raw form, and scans are then viewed or reworked to be used as photoreal assets conforming to a standard of photographic realism.

Linking 3D scans to photorealism is strange because photorealism cannot be scanned or captured directly from physical surfaces. In computer-generated images, photorealism is a verisimilitude of pictures and models created to resemble photographs. Photorealism is a belief that privileges photography as a “factual” representation of reality; it is not an inherent quality of scanning technologies or the surfaces they capture, but rather a technical-cultural concept imposed upon them. At the same time, reality capture is seen as a precise medium that parallels photography as an objective form of mechanical capture. Uncritical associations between 3D scanning and photography frame images of 3D scans and the operation and use of scanning technologies in photographic terms. Consequently, my research establishes how 3D scans are viewed and marketed as photoreal assets for photoreal environments within 3D software. At the same time, by using creative methodologies to scan various types of unscannable surfaces and present this data through a portfolio of scan-artworks and models, the research problematises photoreal interpretations of scanning technologies in response to the terminology related to reality capture as it is used in the industry. The research, therefore, reacts directly to photoreal interpretations of scanning through new kinds of digital scans of unscannable surfaces that do not always produce photorealistic outcomes

The thesis explores the central claim that 3D scanning technologies and the models they produce are influenced by photorealistic ideals and standards derived from photography and computer graphics. Concepts of photorealism and its practical application in scanning are part of the research into contemporary scanning practice. This practice-led research examines disruptions to photorealism that naturally arise when scanning certain reflective or transparent surfaces, solid colours, as well as intricate architectural structures and negative shapes. This is significant because it reveals how this 3D scanning research contradicts the technology's established perceptions and applications. The scans show that these disruptions are not random errors but rather consistent readings that illustrate how the technology perceives the world quite differently in these contexts, how it offers alternatives to what the camera or the human eye perceives, challenging the photoreal ideas and practices that have become entrenched in its operation.

The commercial 3D scanning sector recognises that challenges, such as unscannable surfaces, such as glass or solid dark colours, can hinder the photorealism of scans. These disruptions are often viewed as realism faults or problems to avoid or correct. But what if these errors were genuine readings? What does the 3D scanner perceive in these contexts? My PhD research contributes to this field, not necessarily in a completely novel area, as the challenges of difficult-to-capture surfaces are already recognised, but by offering a systematic and extensive exploration of specific categories of unscannable surfaces. This is achieved through a methodology that employs creative scanning practices to provoke and investigate the medium repeatedly.

Furthermore, the research is supported and framed by critical-theoretical inquiry and interdisciplinary contextualisation. This framework includes a state-of-the-art review of contemporary commercial and artistic 3D scanning practices. It examines related photographic media theory regarding photographic realism and indexicality. This photographic theory, along with digital media studies on computer photorealism, is combined with a selection of key contemporary art historical contexts that illuminate parallels seen in 3D scanning. Through the lens of scanning practice, this “critical framework” enables the thesis to consider the dominance of computer photorealism as an aesthetic and/or ideal mode of representation in reality capture. It (re)visits ongoing questions about indexicality in digitality, particularly in the context of 3D reality capture. This contextual, theoretical research, along with the practice-led scans conducted for the thesis, will address the main research questions posed in the thesis.

The three main research questions this PhD poses are: What can the practice of 3D scanning unscannable surfaces, spaces, and materials reveal about disruptions in reality capture technology? This first question focuses on scanning surfaces that disrupt shape and form, affecting the overall visual resemblance of the scan to its subject. It aims to open an area of research that questions or undermines the perceived photorealism of the 3D scan through objective observations. One suggestion is that these disruptions may provide insights into a developing area of capture, revealing how, in these specific instances, 3D scanners view the world differently than the human eye and cameras. What do the disruptions reveal about the scanner's perceptions and the aesthetic structure of reality capture in these situations? I am interested in the working practices involved in 3D scanning and the theoretical aesthetic implications of hard-to-scan surfaces.

The second research question asks: What is the relationship between reality capture, photography, and the photorealistic image or model? This philosophical inquiry prompts research into how cameras and photographs have shaped our perception of reality. There is a profound cultural, technical, and ideological investment in perspectival imaging and photographic media, which is now seemingly being extended to new technologies of reality capture. However, 3D scans are not photographs; scanners are not cameras. They are machines that collect measurements and images as spatial data, producing 3D models and point cloud data rather than capturing images of perspectival space. Scans digitise the layout and surfaces of the scene before the scanner; they are three-dimensional digital copies of objects and environments. Still, 3D scans are often presented or perceived as two-dimensional perspective renders on screens that can resemble photographs. Connections between scanning and photography exist through the use of cameras and photographs in scanning, as well as with pioneers in the field who draw parallels between their 3D scanning work and photography. Photogrammetry scans (a primary focus of this thesis) use photographs to build 3D scans, which are marketed as photorealistic computer models in commercial scanning due to their photographic qualities. This has resulted in 3D scans being perceived as photorealistic in a non-critical manner, or without a complete understanding of the technology. For example, some laser scans can look similar to black and white photographs, a parallel that ScanLAB discusses in talks on their own work. They note how the operation of their scanners and the scanned images they produce evoke the aesthetics and function of early photography, commenting that the scanner is part of the evolution of photography. The relationship between scanning, cameras, photographs, and 3D computer models is complex, as photography and reality capture are intertwined in specific scanning contexts and technical processes[1].

The third research question examines the 3D scan as a digitally indexical sign, asking: How does 3D scanning prompt us to (re)think the index in digitality? This question explores how 3D scanned models function as indexical signs and whether reality capture reinstates the index as a foundation of digital realism in 3D modelling. 3D scanning, like photography, is essentially a capture technology. Traditionally, indexical realism has supported the credibility of photographs as captured sign-images that point to the object in front of the lens. Unconscious visual comparisons between scans and photographs and direct photographic remediations

[1] For example, photogrammetry creates scans from collections of photographs, which are then reconstructed into 3D computer models that can be further developed and manipulated.

and framings of scans as images on screen further draw these comparable media together. Conceptually, the photographic index has often been likened to a process of moulding or imprinting. In this context, 3D scanning can also create digital moulds and replicas, offering a similar potential. Unlike photographs, which are two-dimensional images, 3D scans capture shape, form, surface colour, and texture. The three-dimensional nature of reality capture conveys a sense of physical presence. This sense is comparable to how photographic theorists have likened the indexicality of photographs to a physical transfer; this concept may likewise be applied to reality capture.

Indexicality in 3D scanning may serve as an antidote to the perception of the digital image as an entirely malleable medium; however, critical questions remain to be explored. For instance, are scans as computer models equally malleable and subject to manipulation? Do indices in digital scans consistently manifest as a photorealistic resemblance? Are resemblance mismatches created by unscannable surfaces still considered indexical? If they do not accurately represent what the object looks like to us, what are they depicting? These questions will guide exploration and reflection throughout the thesis, informed by the scanning research practice and applying developing theories of indexicality in the field and from other media.

The structure of the thesis is arranged around four chapters and a conclusion. This first chapter serves both as an introduction and review of contemporary scanning practice in the evolving field of reality capture. It establishes key themes and relevant critical literature. The second chapter outlines the creative methodology developed in response to how artists research and work at the limits of new technologies, and how artworks can embody ideas about medium and process. It outlines a method for the 3D scanning practice part of the project, developed through a case study on scanning solid colour shapes. The method aims to use artistic experimentation to challenge photorealism in scanning. It does this by creatively exploring gaps, faults, and limitations of new scanning technology, while focusing on two categories of unscannable surfaces that are discussed in chapters three and four.

The third chapter explores the capture of interior space as the first of these categories. 3D scanning is often used to document buildings, and this chapter, along with the scans conducted for it, examines challenging architectural structures that are difficult to capture. The outcome is the digital capture of negative space, a novel category of disruption, where scans act as indexical digital casts. The fourth chapter investigates the 3D scanning of mirrors and glass surfaces. Transparency and reflections create some of the most problematic unscannable surfaces. This practice is frequently avoided when aiming for photorealism in commercial scanning. The scans in this chapter intentionally critique commercial practices by diverging from established principles in the field. The results show that it is possible to scan these surfaces, but that metals and glass exhibit unexpected behaviours as their optical effects shift and change when the 3D scanner moves around them to create a scan. Additionally, new types of 3D scans are introduced in this chapter, showing specific glass scans functioning more like photograms than traditional three-dimensional captures.

Various reality capture technologies are utilised throughout the thesis, but a strong focus remains on affordable and democratised versions of 3D scanning (again, not investigated at this level before). These include smartphone-based photogrammetry (3D scans generated from stitched photographic viewpoints converted into digital 3D geometric models) and short-range handheld hybrid LiDAR laser scanners found in more recent Apple iPhones and iPad Pros.

Returning to this first chapter, which establishes the existing knowledge available, it analyses and explains current 3D scanning techniques while identifying how and where 3D scans are utilised in computer graphic photorealism. The chapter highlights the pioneers and researchers in 3D scanning who are pushing the boundaries of scanner capabilities and questioning the representations in 3D scan images. Rather than using reality capture purely as designed- a machine for creating and copying the world- here, the 3D scanner is a creative tool to investigate surfaces and interpret space. Researchers writing on 3D scanning and artists working with the technology are exploring deviations from established photoreal commercial workflows. These pioneers are investigating the aesthetic potential of visible and non-visible light 3D scanning technology. They uncover new scanned views of the world and, in turn, propose innovative ideas about the possibilities of data scanned from reality. I review both pioneering 3D scanning projects and the everyday industrial applications of 3D scanning, establishing a dialogue between these two fields.

I critique the marketing ideologies and instrumental fantasies embedded as photoreal assumptions about commercial scanning technologies in most non-critical writing and thinking in the field. This critique of knowledge in reality capture can, in turn, help illuminate potential areas for original creative research in 3D scanning, primarily focusing on hard-to-scan surfaces and spaces. Photorealism, photographic realism, and indexicality theory are key to this thesis because I hypothesise that 3D scanning technology is framed and remediated by established concepts from 3D computer graphics, in which the photographic model is dominant. Concepts from photography and photoreal computer imagery are applied to contemporary 3D scanning. I include a review of the semiotic theory of indexicality, which has traditionally underpinned photographic realism and is now, I believe, considered to confirm the three-dimensional realism of a digital 3D scan. The following sections are both a review of contemporary reality capture projects and technology with related research in the field, and a critical theoretical framework by defining the somewhat opposing yet key themes of photographic realism, computer photorealism, and photographic indexicality.

1.2 Indexicality and photorealism

I begin by addressing concepts of photorealism and indexical realism, which are central to this thesis's research questions and themes. While these concepts and their origins will be explored in greater depth throughout the thesis, a brief overview is necessary. Starting with the term “indexicality” which originates from the 19th-century semiotician Charles Sanders Peirce. Peirce, in 1867 defined the index as a type of sign that could only be caused by its referent object as part of a typology of signs (Peirce, 1931)[2]. Indices can include images such as photographs, but more often, they do not necessarily resemble their referent; for instance, an index might be a measurement, a footprint, or smoke from a fire. In simple terms, an index is something, a sign, that results from an actual event or physical stimulus. In the context of photography, Tom Gunning describes it as:

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[2] Peirce updated his typology of the sign several times over the years. In this thesis, I reference the essays in the *Collected Papers of Charles Sanders Peirce*, Volume II: Elements of Logic, first published in 1931.

> ..the indexicality of the photograph depends on a physical relation between the object photographed and the image finally created.
>
> Gunning, 2004, p.40

The index is relevant to this study because it has traditionally been linked to photographic realism. At its core, a photograph is a unique form of visual capture of the world, created by the object positioned in front of the camera. This understanding has endured despite the adaptable nature of digital photography files. Arguably, 3D scans are created in a similar manner, by the object or surface in front of the scanner. Photography and 3D scanning, at least on the surface, are comparable media regarding the primary function of both cameras and scanners to capture reality. This research aims to determine whether indexical realism can also be applied to 3D scanning. The theorisation of the index in reality capture can perhaps be explored through similar interpretations of what the index represents as a sign, and whether a scan can be regarded as a digitally indexical sign. This is a question to examine throughout the thesis.

The other central theme of the thesis is photorealism, a term originally used to describe the 1960s art movement in which artists utilised photographs as source material to create paintings. Emphasising surface detail, qualities of light and reflection, and camera optics, often made the paintings indistinguishable from photographs. The invention and increasing use of digital media in the late 1990s led, according to digital media theorist Lev Manovich (1996), to the adoption of the term photorealism to describe computer-generated images and renders designed to resemble photographic images. Like painted photorealism, digital photorealism, or computer photorealism as it is sometimes called, is an ideology and practical methodology to create images and videos that intentionally appear as if captured through a camera lens. These images emulate lens-based effects and photographic characteristics, although they do not always simulate optical accuracy. Photorealism has become an industry standard for assessing computer-generated images on screen, and in turn, 3D scans as digital models and images on screen are subject to the same photorealistic assessments and framings.

At its core, photorealism encompasses computer-generated images that mimic real-world scenes and are presented as photographic representations. Photorealism is particularly prevalent in commercial 3D computer modelling and rendering workflows. Computer artists use software toolsets to build and model virtual geometries and textures and create models that resemble physical objects. 3D software employs physically based rendering systems that include material shaders, lighting, cameras, and models to produce photorealistic results. Even fantasy elements that do not exist in our world can be made photoreal if they interact with light and shadow in a scene, but again, they appear as if captured through a lens.[3] Eran Dinur, writing on photorealism for visual effects, games and visualisation, states:

> if we wish to create convincingly realistic digital content, we need to emulate the characteristics of photography and cinematography, rather than the way we see the world with our own eyes.

Dinur, E. 2022, p.14

[3] The computer-generated dinosaurs in *Jurassic Park* (1993) are an original case-in-point here. This early photoreal example demonstrated how computers could create “credible photographic images of things which cannot be photographed” (Prince, 1996, p.28). Industrial Light & Magic pioneered effects in this film; the audience was aware of the fantasy elements on screen but was nevertheless perceptually convinced by photoreal arrangements of light, shadow, colour, and texture interaction perfectly integrated with the filmed backdrop (Manovich,1995; Prince, 1996).

This is why 3D scans enhance photorealism, as they possess a high degree of resemblance to the captured objects. Suppliers of 3D scans to game designers, animators, digital visual effects for cinema, and architectural visualisation value digital 3D model geometries because they can be repurposed and marketed as photorealistic assets. Photogrammetry, in particular, can be incredibly effective at replacing hand-built 3D models. Mimesis in photogrammetry scans has led to their use in computer photorealism, which is even conceptualised by the industry in photoreal terms. Therefore, the project focuses on digital photorealism and its relationship to 3D scanning.

However, photorealism in computer graphics goes beyond merely applying filters or lens effects to computer-generated images. It serves as a way for evaluating the credibility and physical accuracy of digital images on screen. It does this by replicating lens effects, optical properties, and digitally simulating the physical behaviour of authentic materials and light. Stephen Prince (1996) referred to this as “perceptual realism", where digital visual effects are utilised to create perceptual cues, with elements such as lighting, texture, and depth crucial for rendering images that appear real to the viewer. Prince stated that perceptual realism in computer-generated imagery is achieved by adhering to visual conventions based on photorealism and aligning perceptually with how we experience the world. Perceptual realism has contributed to our understanding of how realism in cinema can be digitally created in what was once viewed as an indexical medium, it also provides a deeper insight into how photorealism functions, particularly when it incorporates fantastical elements that still seem believable. Photorealism in computer graphics is often determined by how much detail a digital 3D model conveys and how authentic it appears. Simply put, it serves as a standard for assessing how well the artist has modelled it.

Digital 3D scans capture remarkable shapes and details from the world. In their daily applications and informal writing on reality capture, we see how this ability to create 3D models directly from physical surfaces leads to discussions and evaluations of scanned models and 3D scanning technologies in photorealistic terms. Importantly, like the 3D computer model, the 3D scan undergoes a realist framing in which it is rendered and presented, remediated within a photoreal aesthetic or ideal. However, this perspective on 3D scanning overlooks how the medium functions differently from photography, lenses, and cameras. Disruptions in 3D scanning caused by certain materials, surfaces, and spaces directly challenge the prevailing notion of the 3D scan as a photorealistic replica. These disruptions are a key focus of investigation through the practical scans conducted for this project. The implications of these scans for a deeper understanding of reality capture as a medium, with its aesthetic character and differing technical abilities of the camera to record the world in new and unexpected ways, are explored in detail in chapters 3 and 4. Before that, this introduction will examine definitions of reality capture and its operational mechanisms.

1.3 Evolution of reality capture

The invention of the term "Reality Capture" can be attributed to the software corporation Autodesk, which described reality capture as “the process of scanning an object, building, or site and producing a digital model” (Autodesk, 2018, 0:13). Reality capture is an umbrella term that defines several different variants of 3D scanning technology. Today, this term is often replaced by the more commonly used phrase 3D scanning. Scans are three-dimensional spatial coordinates, colours, and texture data captured from the physical world and reconstructed as digital model replicas. Sometimes called digital twins, scans comprise geometric computer models and point clouds; they are close digital copies of objects or environments. A point cloud is a collection of millions of laser measurements of points on surfaces, representing a dense cloud of the scanned environment. Photogrammetry scans are geometric models, digital wireframe geometries made from triangles or polygon faces, which can be displayed within 3D modelling software on the computer screen. They are constructed in the same way as standard 3D models on the computer. As coloured versions of these scans, the models are usually covered in captured textures, although points in a LiDAR point cloud can also be colourised.

3D scanning incorporates several capture methods and is a technologically evolving field. Unlike photography, where the main differentiator is whether the photograph is digitally or chemically fixed, 3D scans can be captured using infrared lasers, photographs, or projected images. Scans made from laser measurements create point clouds, while overlapping photographs are used to reconstruct geometric 3D computer models in photogrammetry. There are several variations of 3D scanning technologies, and these continue to evolve. Some, like Leica or Faro LiDAR laser scanners (Figure 3 and Figure 4), are high-end and expensive, accurate within millimetres; others, like photogrammetry, can be free to use, easily accessible, but still provide precise visual results (Figure 5 and Figure 6). Despite technological variations, all scanning technologies are connected by the same operational goal to capture three-dimensional copies.

Figure 3. A FARO Focus LiDAR scanner at a crime scene.

Figure 4. A Leica ScanStation LiDAR surveying scanner.

Figure 5. Photographs from various angles of a pot for 3D *reconstruction via photogrammetry.*

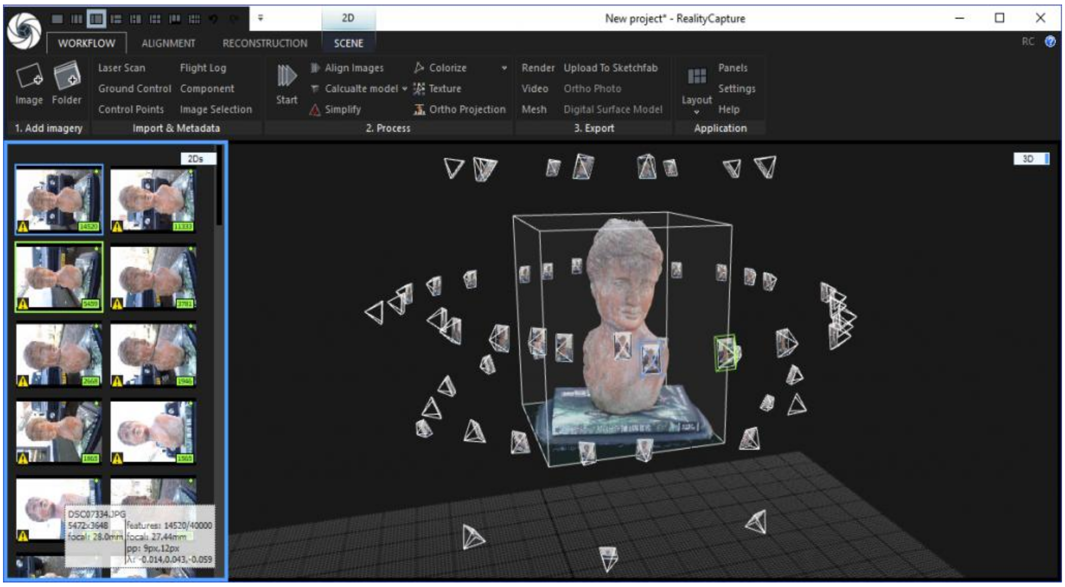

Figure 6. Photogrammetry software displaying a 3D *bust scan.*

Understanding its origins and development helps illuminate not just how 3D scanning works as a technical process, but also what it fundamentally is as a way of seeing, recording and interacting with the world. 3D scanning has evolved from traditional physical surveying methods and tools that historically required manual measurements of landscapes and architecture. According to scanning manufacturer Faro, these tools included “tape measures, piano wire, plumb bobs, and laser range finders” to produce single-point measurements (Faro, 2023, para. 1). This toolset and surveying process form the basis of what 3D scanning was developed to accomplish 3D scanning, conceived to digitise these manual surveying processes, started in the 1960s with the first “attempt[s] to accurately recreate the surfaces of various objects and places” (Edl, Mizerrák, and Trojan, 2018, p.1). Early scanning used projected light patterns to analyse the shape of surfaces. However, porting a scanned copy of a physical object into the computer did not come until the mid-1980s. By this point, computers had developed enough to support sophisticated 3D models, as Edl et al. point out:

> With the advent of computers, it was possible to build up a highly complex model, but the problem came with creating that model. Complex surfaces defied the tape measure.
>
> Edl, Mizerrák, and Trojan. 2018, p.3

Edl, Mizerrák, and Trojan describe 3D scanning as a capture technology that produces accurate digital replicas of real-world objects, which emerged in the late 1990s. At this time, physical pointers on arms (contact scanning) were utilised to create 3D digital meshes of busts and other objects based on collected measurement points. These points were input into the computer as data, transforming into vertex points around which a wireframe 3D model could be constructed. In 1992 Professor Marc Levoy at Stanford University, with a group of research students, set up a "project to build a 3D fax machine", a laser scanner for the "description of the externally visible surfaces of an object" (Levoy, 2006, para.2). Levoy foresaw technologies for scanning and their potential uses, which are now widespread. Levoy's first 3D scanners were developed in collaboration with Professor Greg Turk, who created a scanning process called range imaging. This early laser scanner projected a red laser to analyse depth and surface contours, which they described as an "inexpensive and accurate means for digitizing the shape of three-dimensional objects" (Figure 7), (Turk and Levoy, 1994, p.311). To produce a "seamless description" of an object in the round, range imaging required several scans of the same object from different angles (Levoy, 2006, para.1).

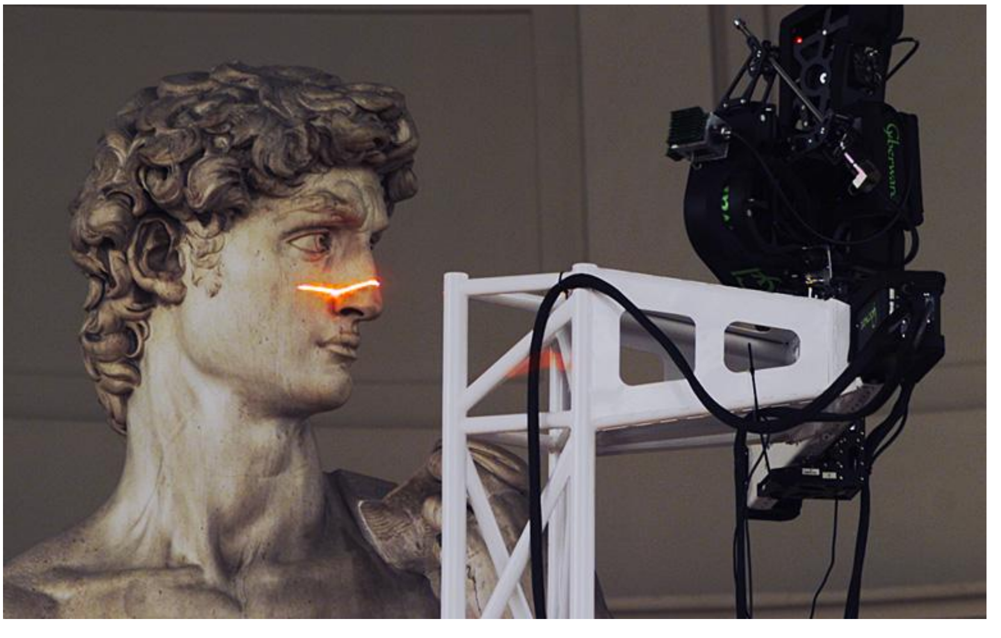

Figure 7. The Digital Michelangelo Project (1998)

This method was famously used to 3D scan a terracotta model rabbit known as the Stanford Bunny. The scanned Bunny file later served as a test file for many computer-generated effects and remains in use today. This scanned model is part of the history of computer graphics.

Turk and Levoy's innovations in 3D scanning would define what a 3D scanner is and the concept of a scan as a digital replica. They established test cases and research projects for scanning, including *The Digital Michelangelo Project* (1997-1999), which advanced the development of high-resolution 3D scanners capable of capturing "chisel marks smaller than a millimeter" made by Michelangelo on sculptures in Florence (Levoy, 2003, para.6). This groundbreaking project also marked the first capture of coloured surface textures, which were applied to the reconstructed digital model. It was the first notable use of 3D scanning to create detailed replicas for scientific investigation and cultural heritage conservation. This project demonstrated the non-contact nature of the scanner, which replaced invasive casting procedures to produce an exact facsimile as a permanent digital record of Michelangelo's sculpture[4]. Turk and Levoy were interested in scans as digital replicas of physical sculptures. Today, reality capture is utilised in various commercial sectors, including surveying and architecture, but Turk and Levoy can be credited with establishing the concept of capturing three-dimensional facsimiles. Their project set standards for 3D scanner operation, offering valuable insight into the technology's development and the reasons behind its invention.

In 2000, Greg Turk reflected on his scanning invention and noted the limitations of 3D scanners, particularly their inability to capture certain surfaces:

> It is important to note that for an object to be visible to the camera of the range scanner, its surface must reflect the red laser light. A black object

[4] The advantages of digital facsimiles of sculptures over physical plaster copies or even original artefacts are that digital copies do not decay or become damaged over time.

> cannot be scanned, and even a bright blue or green object may not scan well if it reflects little in the red wavelengths. Furthermore, very shiny (specular) objects can sometimes cause parts of the object to be indirectly illuminated through reflection, resulting in false depth readings.
>
> Turk, G. 2000, para. 4

This early example shows how flat colours or mirror-like surfaces disrupt a scan, causing what Turk called “false depth readings". Turk commented that he chose the bunny to scan because it had a non-shiny, dull matte surface, which made it well-suited for his new scanning technologies. Its texture allowed for a close geometric copy and preserved visual detail resembling the object. This shows that from its inception, 3D scanning has encountered disruptions when scanning shiny finishes, reflections, transparency, and solid-coloured materials, all of which continue to pose challenges for scanning and photoreal framings of the technology.

In many ways, Turk’s thinking still holds in scanning today; the surfaces he describes as problematic for scanning and scan resemblance are still viewed as such. However, when scans are made of these unscannable surfaces, they can also be interpreted differently. Rather than viewing scan readings as errors, they could be seen as accurate recordings of how light behaves in the scene. Is the capture of a mirror a reflection, as 3D space genuinely false? Capturing such reflections may open new possibilities for visualising mirror behaviour in 3D space. The challenges posed by featureless colours, reflective materials, and transparent surfaces in 3D scanning have not been significantly explored, and the concepts in this field have remained mainly untested since the research conducted by Turk and Levoy in 1994.

First noted over 25 years ago, the effects of these unscannable surfaces on scan resemblance and mimesis are acknowledged, but they are primarily worked around or avoided. A comprehensive investigation of the visual distortions and disruptions created by unscannable surfaces, particularly fractures and anomalies in photorealism, often dismissed as technical errors, has yet to be undertaken. Unscannable surfaces provide an opportunity for a deeper understanding of 3D scanning as a unique form of digital perception, a new way to encounter and represent reality.

1.4 Publications on reality capture

After examining the evolution of reality capture technologies, the following section identifies key texts on the aesthetics of reality capture that I reference throughout the thesis. These publications explore central themes of the thesis, including:

- The challenges presented by unscannable surfaces and the disruptions they create.
- The connection between reality capture, photography, and photorealism.
- The idea of the digital index in 3D scanning.

These texts examine current working methods and contribute to theoretical discussions in the field. They will also help shape the conceptual and aesthetic developments in 3D scanning practice and artworks created for research.

One active area of research in reality capture lies within computer science. It primarily focuses on the technical advancements in visual accuracy, fidelity, and resolution enhancement in 3D scanning. Computer science research on disruptive surfaces (such as reflections, transparency, and dark colours) addresses these surfaces' effects as challenges to be resolved to achieve a digital replica as close to the original subject as possible (Angheluţă and Rădvan, 2020; Chen et al. 2007; Gupta et al. 2012; Ihrke et al. 2010). This research seeks to eliminate geometric and visual flaws. Scanning research and development in this field are shaped by the working practices and methodologies of 3D computer modelling. 3D scans saved as geometric model data are effectively subject to technical mediation through computer graphics techniques of photorealism. Ongoing developments in computer science related to geometric and visual photorealism in reality capture establish a foundation for commercial 3D scanning. However, by capturing typically unscannable surfaces, my research responds to and reveals the photoreal ideals, standards, and outcomes that seem to overshadow alternative and distinct ways of scanning the world.

Scientific advancements are essential for understanding how the field technically approaches incremental improvements to the resemblance of 3D scans. Although this area is not the primary focus of my arts-based project, we should not ignore significant developments, such as Turk and Levoy's scanning inventions, which have propelled the field forward. Projects like *The Digital Michelangelo Project* illustrate the intersection of art and science in 3D scanning, showcasing how enhanced scanning fidelity can reveal new insights in conservation and art historical contexts.

Compared to scientific research and development in 3D scanning, publications on the aesthetics of reality capture, scanning, and its emerging relationship and use within the arts are more limited. Publications by researchers including Shaw and Trossell (2014), co-founders of ScanLab Projects; Adam Lowe (2020) of Factum Arte; Peter Ainsworth (2020); Patrizia Di Bello (2019); Geoff Manaugh (2015); Jussi Parikka (2021); Danielle Willkens (2019); and Tom Milnes (2021) are all leaders within the field. Their research investigates how reality capture reacts to distinct material and spatial contexts and connects to other capture forms, including photography. They explore how scanning, utilising sensors and lenses, capturing parts of the electromagnetic spectrum that exceed the human eye's capabilities and visible light photography. This research critically engages with themes like the photographic framing of LiDAR scans, photorealism and scanning, surface resemblance and its connections to resolution, the impact of unscannable surfaces, and 3D scans as indexical traces. These papers are particularly relevant to this thesis and are referred to throughout the writing.

1.5 Contemporary 3D scanning practice

Understanding various scanning technologies is essential to supporting the practice-led aspects of this research, which involves 3d scans of unscannable surfaces. This understanding will enable me to illustrate how my 3D scan research responds to existing practices and, in some cases, builds upon the work of other researchers in the field.

In addition to researching the aesthetics of reality capture, I will examine relevant areas of contemporary 3D scanning practices using photogrammetry and LiDAR. First, I aim to establish the main scanning technologies that all reality capture users use. Then, through the lens of these primary scanning technologies and practices, I will identify and analyse several key scanning projects and organisations in the field. We have established that the two primary technologies are LiDAR laser scans, created from millions of measured points, and photogrammetry scans derived from overlapping photographs[5]. A third type of scanning, known as depth-scanning,

[5] LiDAR stands for Light Detection and Ranging. LiDAR scanners emit pulsed laser light, which is used to measure distances from the scanner to a surface in front of it. The light reflects back to the scanner, creating a point cloud of precise three-dimensional data regarding the shape, size, and layout of objects and terrain. LiDAR is employed in surveying and mapping.

uses infrared structured light projections, such as stripes or grid patterns, to analyse surface topography. Depth scans are short-range, while long-range LiDAR can reach several kilometres. Photogrammetry can work at different scales; for example, it can capture a vase on a turntable or a mountain from a drone camera.

LiDAR and depth scanners sometimes include an additional visible light camera to capture colour information through digital texture maps. In contemporary smartphones, depth sensors are novel, inexpensive 3D scanning technologies that can quickly combine camera colour with depth-scan data into one capture. Apple describes their iPhone laser sensor as a LiDAR scanner. However, this is sometimes disputed compared to the traditional capabilities of LiDAR long-range high-resolution scanners, which provide detailed captures. However, on a smaller scale, Apple LiDAR can quickly capture detailed 3D scans of interiors and architecture.

1.6 Photogrammetry

Photogrammetry, sometimes called photo scanning, is a 3D scanning process that utilises photographs taken from various angles around an object. Points in the photographic data sets are triangulated to construct 3D models. Unlike LiDAR scans, photogrammetry produces 3D data representations in both forms of point clouds and geometric 3D models. 3D models are the primary outcome of photogrammetry scans. While LiDAR typically results in a monochrome collection of points, photogrammetry can create full-colour models that closely resemble their physical counterparts. Photogrammetry is suitable for both small and large objects, whether in a studio setting or on location. It is particularly effective for capturing street architecture, natural forms, human figures, or any static item with a rough, non-shiny surface. Theoretically, there is no limit to the resolution of a photogrammetry scan; it can be generated from hundreds of photographs. However, taking a few dozen photographs from all angles of an object, with adequate diffuse lighting and no harsh shadows, will yield a good result. Factum Arte, featured in this thesis, has extensive experience with photogrammetry (2023, para. 1). They provide a definition:

> The technique has a number of advantages over traditional 3D scanning technologies, including the possibility of recording colour information at the same time as 3D data. Photogrammetry is also inherently "portable" – in most cases the equipment (camera, tripod, flashes) can fit into a small camera bag, making it a particularly useful tool for recording at remote or dangerous sites.
>
> Factum Arte 2023, para. 2

Photogrammetry is very good at capturing worn, patinaed objects. Results will closely resemble the original form, as demonstrated by the rock and mineral 3D scan examples I captured (Figure 8 and Figure 9). This ability has led to its use in architecture, cultural heritage preservation and archaeology (Ivsic et al. 2021). Photogrammetry is particularly important for creating copies or "facsimiles" of museum pieces or other cultural historical items, where scanning continues a tradition of physically making plaster casts in a digital form (Turnbull 2016, V&A 2016). However, despite the detailed digital replicas enabled by photogrammetry, it is not infallible. Capturing unscannable surfaces with photogrammetry leads to many capture anomalies. Initial research shows how photogrammetry interprets mirror reflections and transparent glass differently than we or a camera perceive them. (Figure 10 and Figure 11). For example, when scanning interiors, photogrammetry recognises windows as balloon-like extensions, and mirrors as additional actual spaces (in the scan) beyond the physical location captured. When scanners encounter mirrors or windows, the 360-degree nature of photogrammetry results in reflections shifting and changing as the camera moves. This creates many varying views, a moving reflection that challenges photogrammetry to define the surfaces as static objects[6].

Figure 8. Photogrammetry scan of a piece of Malachite by the author.

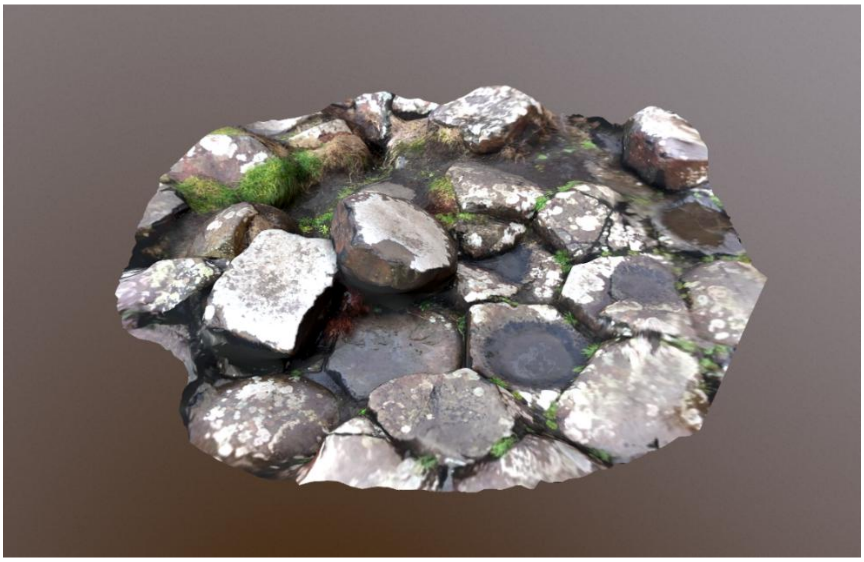

Figure 9. Photogrammetry scan, The Giants Causeway, Northern Ireland. Scan by the author.

[6] I discovered how photogrammetry seeks to capture reflections as static textures in scans I made of chrome and glass spheres observed in **Error! Reference source not found.** and **Error! Reference so urce not found.**.

Figure 10. This is a photogrammetry scan of a group of glass jars. The glass is disrupting the capture. Scan by the author.

Figure 11. Polycam interior scan, showing how the scan attempts to capture the exterior space beyond the windowpane (detail). Scan by the author.

Photogrammetry assumes that surfaces are covered in diffuse, unmoving textures; it uses points of contrast on the surface to track and reconstruct the 3D scan. Non-reflective or transparent materials work predictably, but mirror and glass materials can create a malformed outcome because the scanning technology cannot easily find points of similarity in a reflection; it is unsure where the surface begins and the reflection ends (Figure 12). Disruption caused by mirrors and glass affects other types of scanning, which is often corrected later in 3D software. 3D scans are typically edited to remove errors; they are modelled in post-production. Examples of uncorrected photogrammetry scans of mirror and glass surfaces are challenging to find. Understanding what photogrammetry captures in this context is crucial to my research.

Figure 12. Polycam interior scan showing how the scan attempts to capture the 'inside' of a bathroom mirror (detail). Scan by the author.

Unlike LiDAR point clouds, photogrammetry generates digital 3D models that integrate seamlessly into 3D modelling and rendering environments.

Photogrammetry scans are typically reconstructed as 3D polygon model files, similar to those employed by 3D modellers, making them valuable assets in extensive photoreal scenes. Consequently, photogrammetry has been characterised as a technique for creating “photorealistic 3D models” (Ivsic et al. 2021, p.2). Ideas about the potential relationship between photogrammetry, other types of scans, and photorealism are discussed in more detail in Chapters 3 and 4 of this thesis. However, in this introductory chapter, we begin to see how contemporary 3D scanning commercial practices aim to use scanned assets for digital photorealism. Scanned assets can be found online in libraries like Quixel Megascans, Polyhaven, or 3D model communities like Sketchfab.com. Quixel closely associates its 3D scans with photorealism, declaring its library contains “18,000 photorealistic scans” (Unreal Engine, 2023, 1:35) (Figure 13). Quixel is a prominent scanning organisation in the field of digitisation for computer graphics content. They search for scattered debris, rocky and rough surfaces, natural landscapes, organic forms, grungy, rusty, corroded surfaces, and worn architecture, all to be scanned and replace traditionally hand-modelled and textured assets. Quixel employs photogrammetry to capture our physical environment for highly photorealistic scans. Founder Teddy Bergsman states that Quixel’s mission is to “capture the entire world; we want to build a library out of everything that exists in real life” (Unreal Engine, 2019, 0:09) (Figure 14). Like Google Maps and Street View, the Megascans platform represents a substantial three-dimensional mapping and acquisition initiative for computer animation, visual effects, and gaming art[7]. Individually, the Megascans evoke the image of specimens in digital jars. When considering Quixel’s mission to scan the world, one sees that

[7] https://quixel.com/megascans/home/

they treat the planet as a “standing reserve” – a term coined by Martin Heidegger. (1954, p.17).

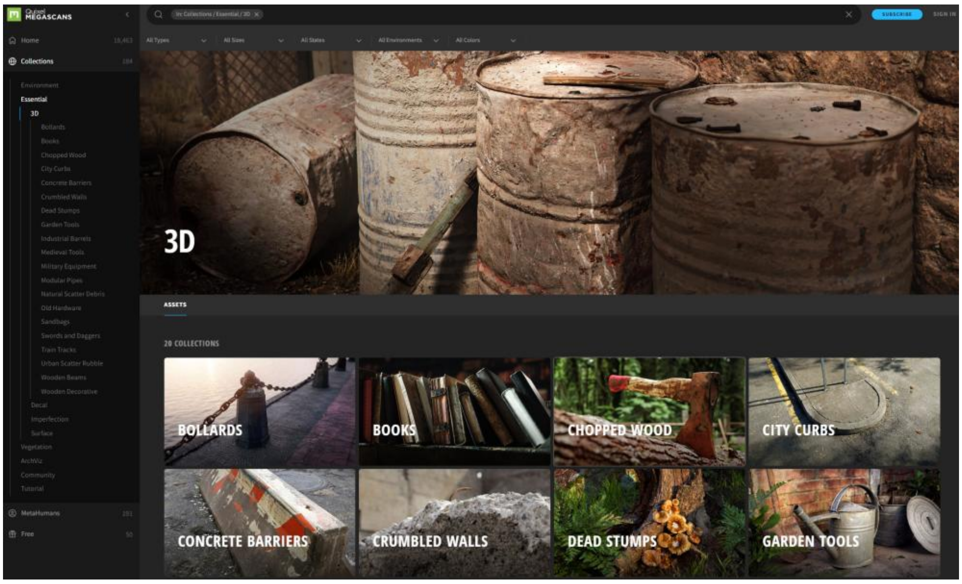

Figure 13. The Quixel Megascans online library.

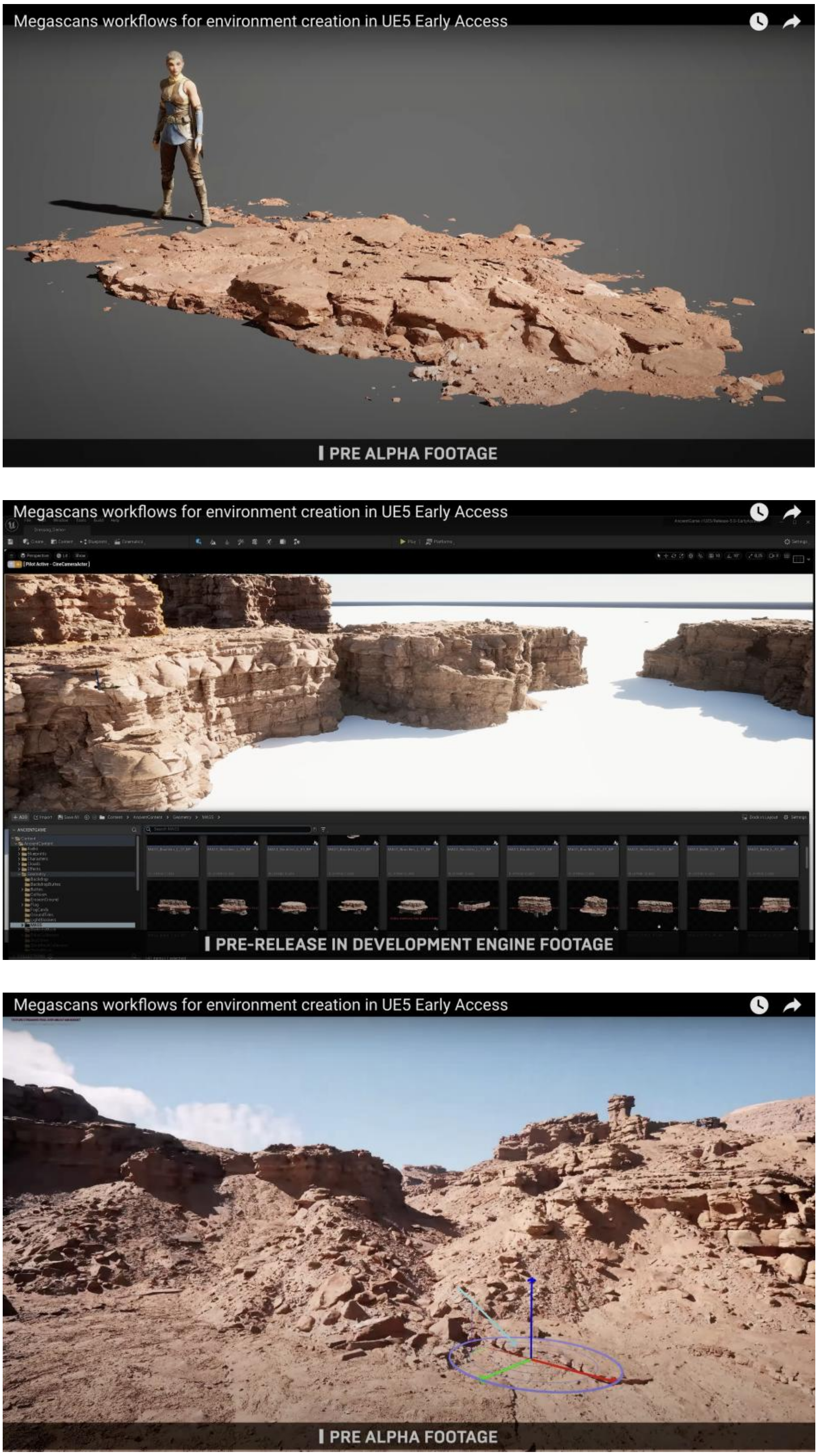

Figure 14. Quixel Megascans photorealistic world-building workflow in Unreal Engine 5.

Quixel boasts global scanning teams, making anything and everything in the world a potential commercial asset to be captured and stored as a digital resource, catalogued, and classified into ready-to-use sets and libraries. Quixel's association with computer photorealism is established. Bergsman states that photorealism is now “incredibly simple” because it can be created quickly using 3D scans from Quixel’s library (Unreal Engine, 2022, 0.29) (Figure 15). Marketed as a fast method for creating photorealistic scenes, where the level of captured detail meets digital photorealistic standards, this serves as a unique selling point for 3D scanning. Indeed, on their development blog, Quixel highlights its claim to photorealism in a regular “spot the difference” competition between a “real photograph” and a 3D scan. They ask, “One of these images is a computer render, and the other is a real photograph. Can you tell which is which?” (Waqar, 2023, para.1). This illustrates how photogrammetry scans are becoming a significant source of photoreal aesthetics that are increasingly prominent in computer-animated environments where photorealism is valued. Again, my research, conducted through practical scanning experience of unscannable surfaces, challenges prevailing ideas about photogrammetry and photorealism. It seeks to expose these photoreal digital ideologies by showing what raw captures of unscannable surfaces actually look like as digital media.

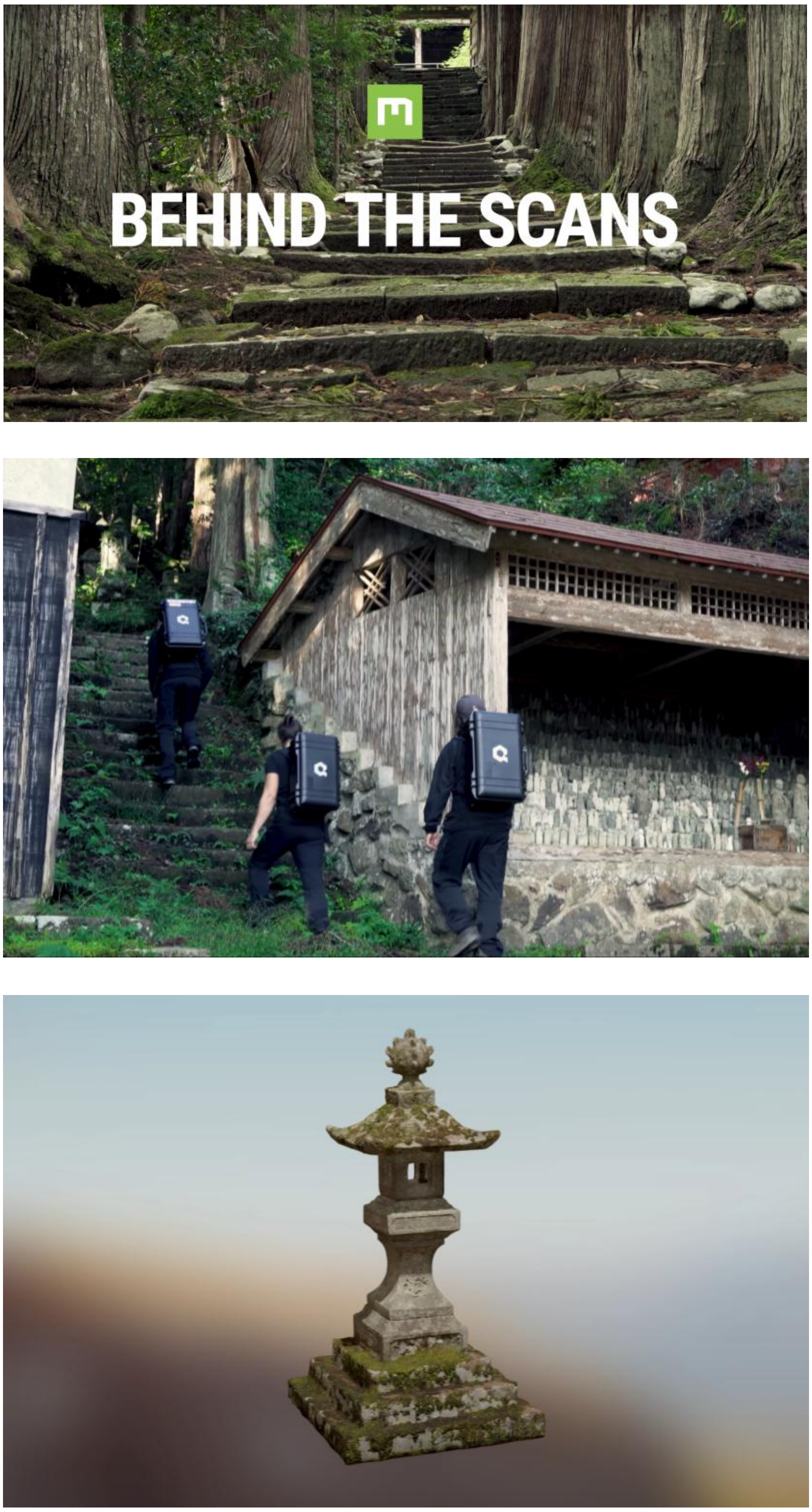

Figure 15. Quixel's film 'Behind the Scans: The Isles of Japan' (2021) showcases the Quixel team capturing photogrammetry of ancient ruins. Quixel has produced films featuring teams scanning various global locations.

However, even with Quixel, photogrammetry results are not always photorealistic in appearance. For example, Quixel does not include everything in its 3D scan library – a database search for glass objects, mirrors, or brightly coloured balloons shows that all these types of surfaces are absent (Figure 16). This is significant for my scanning research because if these surface categories are missing from arguably the largest library of 3D scans in the world, why do they not “fit” within the computer photorealism of that library? Therefore, these categories are key areas to investigate through the 3D scanning practice of this project.

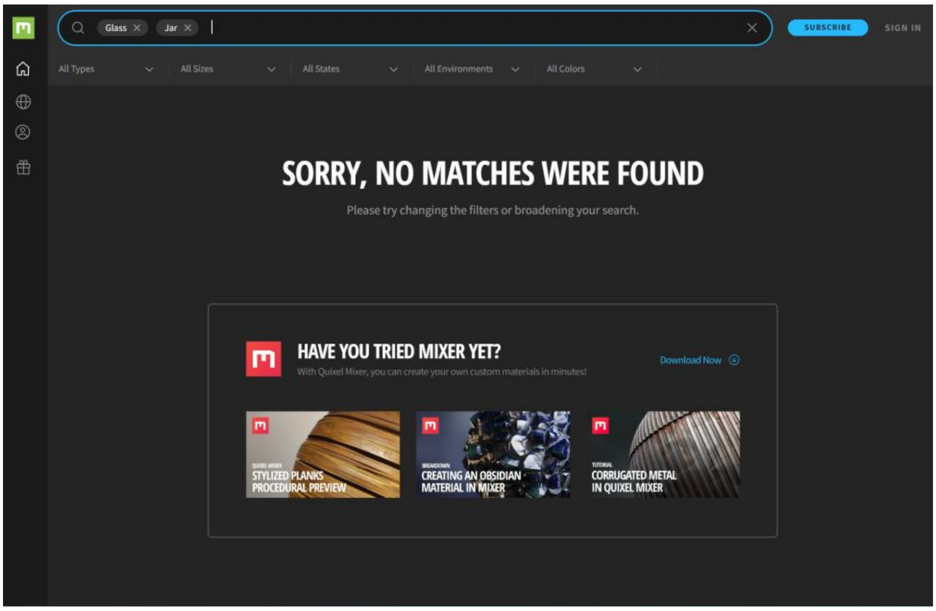

Figure 16. A search for glass, mirrored, or brightly coloured 3D *scans in the Megascans online library yields no results.*

1.7 LiDAR

Another significant 3D scanning system is LiDAR laser scanning, a widely used type of reality capture that utilises time-of-flight measurements and triangulation to map surface environments. Scanning technician Pedro Miró provides a helpful definition of LiDAR:

> LiDAR (Light Detection and Ranging) is a medium- to long-range 3D recording method that uses laser pulses to measure the distance from a scanner sensor to a target surface. The distance is calculated by determining the time it takes for a reflected pulse to be read back into the sensor. LiDAR scanners turn this information into a series of XYZ coordinates that are plotted in 3D space as a “point cloud” with often millions of points. This data can be turned into a 3D model – also known as a “geometric mesh” – in further post-processing to join the points (vertices) to each other using edges and planes.

Miró, P. 2023, para.1

LiDAR employs lasers outside the visible spectrum for humans; its scans are based on infrared measurements rather than visible light (as with photogrammetry), allowing LiDAR to operate in the dark. It is typically applied to medium to large-scale exterior and interior environments rather than concentrating on individual objects. LiDAR produces a three-dimensional map by integrating scans from various positions to capture occluded surfaces. It finds applications in surveying and architecture, cultural heritage documentation, as well as in 3D computer animation, television, and film (to document film sets for post production) (Miró 2023, para. 2; Lidar Lounge 2016, para.1). Due to its use of lasers for measurements and its precision in capturing millions of data points in a single scene, LiDAR is often regarded as both accurate and objective. Consequently, it is employed to scan and document crime scenes, survey landscapes, and serve various purposes in construction, heritage, and conservation. As a high-end form of scanning, LiDAR is seen as having an aura of truth and infallibility, as Hito Steyerl (2012) observed:

> The new technology promises all the things that documentary representation promised objectivity, and full and truthful representation of events only this time augmented by an additional dimension.

Steyerl, 2012, p. 192

LiDAR scan data is viewed on a computer screen as a point cloud, consisting of millions of spatial measurements. As an objective collection of data points, this raw data has an otherworldly appearance, characterised by a semi-transparent, ethereal, and colourless aesthetic (Miró, P. 2023, para. 2). An example of this aesthetic can be seen in the LiDAR scan of the Major Oak in Sherwood Forest by artist Mat Collishaw (Figure 17). His artwork, *Albion* (2017), uses a large-scale animation of the tree slowly rotating. Projected using the Victorian technique Pepper's Ghost, which creates the illusion of the scene floating before us as a semi-transparent, eerie spectre of a tree. Viewed in this way, the laser scan, according to Collishaw, creates a “petrified version of nature” (2023, pp. 17 and 74). Images of LiDAR scans, such as Collishaw's *Albion* projection, may initially seem distant from the computer graphic photorealism of Quixel's photogrammetry scans; however, the following sections will demonstrate how LiDAR scans have been compared to black and white photography and are influenced by photographic framing and interpretation.

Figure 17. Albion (2017), laser scan of the Major Oak in Sherwood Forest, artwork by Mat Collishaw.

LiDAR has been extensively explored by ScanLAB Projects, which considers it its primary medium. ScanLAB is interested in the aesthetic and spatial features of LiDAR, rather than its measuring and documentary capabilities (Figure 18). Led by Matthew Shaw and William Trossell, ScanLAB is the main case study of this thesis. ScanLAB are a self-proclaimed creative 3D scanning studio that is “widely published and exhibited”; they make digitising physical environments a central part of their practice (2021, para 3). They use laser scanners, which they recognise as precise scientific tools, in unconventional ways. Shaw has said they “act like artists,” challenging the limits of 3D scanning by pushing the boundaries of the equipment, employing it in unexpected contexts, and going against accepted practices (The Photographers Gallery, 2016, 00:28).

Figure 18. ScanLAB Projects LiDAR scan for the BBC One series 'Invisible Cities', (2017).

Projects like *Post-Lenticular Landscapes* (2017) intentionally foster an aesthetic dialogue between 3D scanning and photography as capture technologies. ScanLAB regards LiDAR scanning as a cutting-edge technology that enables computers to perceive, drawing parallels between scan imaging and operation and some of the earliest photographic methods and images. In this vein, they argue that 3D scanning is "the future of photography" (2021, para. 2). This observation is essential for this thesis as it helps to locate 3D scans within the related field of photographic capture and theory.

1.8 Facsimiles

Hito Steyerl wrote about new reality capture technologies and how they can be reconstructed as objects rather than images:

> 3D scanning and printing techniques are able to create material replicas of objects and situations.. Images are thus potentially replaced by objects

> that stand in for other objects. In these technologies, representation is replaced by replication.

Steyerl, 2012, p.15

This quote from Steyerl highlights another essential aspect of reality capture practice: the facsimile. The foundation Factum Arte has revived the practice of facsimile production through 3D scanning by digitising artworks for conservation and restoration. The facsimile, coming from the Latin definition of “to make alike”, is a close, indistinguishable physical (and now digital) replica of an original surface. Using scanning and photography, Factum Arte has produced large-scale physical copies of artworks and notable heritage sites, such as the Tomb of Tutankhamun in Luxor in 2014. Factum Arte used scanning to “assess, preserve, re-materialise the Tomb as a copy for tourists to visit” (Spohler, 2016). Facsimiles can be both digital and physical, and 3D printing is the most obvious example of a physical-to-digital-to-physical Facsimile. Factum Arte refers to this process as “re-materialisation,” in which they combine additive and subtractive techniques to reproduce artworks (Nathan, 2022, p.23). Re-materialising the Tomb of Tutankhamun in every detail demonstrates the power of the scan as a copying technology.

Factum Arte is at the forefront of three-dimensional digitisation; they have developed bespoke scanners such as the Veronica Scanner used in *Live* 3D *Portraiture*, an installation at the Royal Academy in 2016. This installation digitally replicates individuals from the level of resolution of 1:1, only formerly found in plaster casts, down to microns, bringing incredible scrutiny to the 3D scanning facsimile process. For founder Adam Lowe, it is not just about preserving or documenting, but about a deeper inquiry into the surface makeup of objects. Lowe’s 3D scanning conservation work has been described as an:

> ..obsession with the relationship between reality and appearance: for years he’s been trying to work out how to map the physical presence of objects, how to create an image of something that cannot be photographed but can be seen, how we understand the reality behind images. Now he has created something that allows us to look at things that cannot be seen but can be photographed or revealed through 3D scanning.
>
> Sattin, 2015, para. 4

Lowe’s approach to 3D scanning goes beyond simple technological duplication; it fosters new insights into the scanned surfaces and how the scanner interprets them. Factum Arte’s approach to 3D scanning goes beyond “slavish” reproduction; they argue that “digital techniques may be used either slavishly or originally” (Latour and Lowe, 2011, p. 275). In reference to Walter Benjamin’s well-known essay on ‘The Work of Art in the Age of Mechanical Reproduction’ (1935), Lowe suggests that digital scanning technologies can capture and transfer the “aura” of the original to its facsimile. He remarks that digital scanning “shrinks” the reproduction process, reducing Benjamin’s claimed technological gap between original and copy. Lowe tells us that the standard for visual reproduction is the photograph, but that this is a limited type of facsimile because a flat two-dimensional image does not tell us about shape or the intricacies of a painting’s surface, something that 3D scanning can do and is evidenced in the work of Factum Arte.

Lowe and Factum Arte have published many articles and reviews detailing their workflow, analysing and explaining how they judge levels of resolution and resemblance in a 3D scan as a digital replica. Their bespoke scanning workflow differs from the mass commercial digitisation by Quixel Megascans, who do not prioritise the authenticity of facsimiles or converting their scans into physical 3D prints. Factum Arte provides valuable insights into the relationship between the scan and its object and between the copy and the original. This insight is valuable when exploring the research question of 3D scan indexicality and addressing the disruptions generated by “unscannable” materials and shapes, which may result in scans that are authentic yet lack resemblance.

Another author who offers a facsimile-centred view of scanning, and an alternative perspective to photorealistic image-based renders, and photographic framings of reality capture, is Patrizia Di Bello (2018). Writing on the connections between sculpture and photography, her final chapter, labelled a ‘Digital Conclusion’, discusses digital 3D scanning. Evoking a story about an imagined late-19th-century Camera Medusa machine that could duplicate physical objects and allow users to become sculptors, Di Bello considers 3D scanning similarly as a method of three-dimensional capture operationally akin to photography. She discusses how, in Factum Arte’s *Live 3D Portraiture Show* of 2016, the scanner used was “explicitly related to nineteenth-century experiments with photo-sculpture. "[8] (Di Bello, 2018, p.114). Both technologies record the world, but the output is a physical model rather than an image. Therefore, while acknowledging connections to photography, Di Bello does not consider 3D scans as images (to be viewed) but rather as captured data to be made physical again.

Di Bello examines a genealogy of facsimile sculpture reproduction that dates back to the museum practices of the 18th and 19th centuries, which involved keeping casts of artworks. At that time, sculpture reproductions were common in

[8] Photo-sculptures were made from profiles created from photographs of numerous viewpoints that can be used to create a 360-degree copy.

museums. Today, digital 3D scans are utilised to create copies of sculptures, and Di Bello conceptually replaces the earlier physical casting methods with 3D scanned digital casts. She likens reality capture to a digital version of a plaster cast, linking traditional mould-making and casting methods to “digital casting” using reality capture technologies. The practice of digital casting is described in the book in an interview with Sculptor Barry X Ball. Ball’s practice involves scanning existing busts and sculptures and using the scan data to machine-cut versions from different types of stone. By reversing the 3D files in software so they are back-to-front, effectively a mirrored version of the original and using different materials from the original sculpture, Ball makes the viewer aware that these digital duplicates are copies but also new sculptures. For Ball, the screen-based view of the scan is an intermediary step; it is not the end goal.

Pioneers and experts in 3D scanning practices reviewed here represent a variety of approaches. Some utilise reality capture for commercial purposes, digitising the world en masse and selling 3D scans as digital photoreal models and assets. Others employ scanning technologies to capture the essence of an object, its "aura", serving as a facsimile for artwork conservation and production. Meanwhile, artists and researchers working with reality capture have explored scanning anomalies. In the following sections, we will examine how ScanLAB has surveyed unscannable surfaces, structures, and phenomena, and how their work subverts the industrial use of reality capture by questioning the idea of the scanner as a super-accurate copying machine and, in turn, the photographic framings applied to scanning. The methods of my research practice outlined in the next chapter aim, in part, to extend ScanLAB's work by exploring specific categories of capture disruption.

1.9 Photographic framing

In the previous section, we explored 3D scans as physical facsimiles. While there is a circular logic to transforming a 3D scan back into a material object, most 3D scans are more commonly experienced as digital images on screens rather than re-materialised forms. This screen-based way of viewing scans is central to my proposition that scanned data are subject to photographic framings and photorealistic 3D computer models and renders standardisation. The way we see and interpret scanned data, such as LiDAR scans, is conditioned by perspectival screen-based media that invite parallels with photography. While photogrammetry models align with photoreal computer models and renders.

The presentation of scan data as perspectival images stems from the paradigm of linear perspective used to view three-dimensional scenes since the Renaissance. In this technical and cultural context, 3D scanning as a method for recording layouts in space is visualised using perspective in computer graphics systems. Furthermore, the use of virtual cameras to view and render scan data links it to optics and modes of analogue photography[9]. Despite being a new technology, three-dimensional LiDAR data is potentially perceived and shaped by established perspectival imaging methods and lens-based media. Photogrammetry data, as textured models, is rendered according to the conventions of photorealistic computer graphics.

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[9] Virtual cameras in 3D software function are based on the same principles and settings found in physical cameras and lenses, thus mimicking many aspects of photography.

To explore how scans are visualised and “framed”, I first turn to Anne Friedberg’s book, *The Virtual Window* (2006). Friedberg traces the evolution of the frame or rectangular boundary in art and imaging systems from Renaissance art to the windows used by contemporary computer systems. She explains how the frame evolved from the idea that a painting was like a window to another world, as proposed by Leon Battista Alberti in his 1435 treatise *De pictura*. The photographic and cinematographic frame followed, and today, computer software systems, both two-dimensional and three-dimensional, operate within a window or frame. This is the same conceptual and practical perspective through which we now view 3D scans as screen images in a frame. Friedberg discusses how, despite challenges, perspectival imaging has remained dominant due to deep cultural, technical, and ideological investments in photographic media in the twentieth century, which persist today. Capturing spatial layout, dimensions, and surfaces feels phenomenologically closer to how we experience physical objects and surfaces, yet 3D scans are still rendered as flat, perspectival images. This is due to practical digital workflows, where reality capture, like 3D computer animation before it, needs visualisation rather than remaining as data on a hard drive. However, its framing leads to a photographic understanding of capture and a photorealistic interpretation and use of scan data and models.

An emerging relationship between 3D scanning and photography that goes beyond a simple framing of scan data can be observed in the work of ScanLAB Projects. Their work demonstrates precise alignments between photography and reality capture. This was first evident in what they described as the first-ever laser-scanned photoshoot for Vivienne Westwood in 2014, where a LiDAR scanner replaced a camera. Interviewed about the project, Shaw compared commented on the use of the scanner in place of a camera, observing that the current state of laser scanning to photography “back in the of the early 1800s” (Fairs, 2014, para. 7). This was because the images of the scans were reminiscent of grainy early black and white photographs, and the fact that a LiDAR takes several minutes to complete, meaning that the models scanned had to stand very still, again rather early long exposure photography. However, the laser scans revealed their own characteristics, eerie gaps appeared in the scans, resembling deep black shadows behind the fashion models. These shadows were not created by the visible light in the room but rather by the operation of the scanners, which, like a camera flash, project laser light that was occluded by the models, resulting in a different kind of non-visible light shadow (Figure 19).

Figure 19. ScanLAB Projects and Vivienne Westwood collaborate on the first laser-scanned photoshoot (2014).

This comparison of LiDAR scanning to photography partly stems from the technological development stage, where visual and operational features resemble early photographic processes. However, further connections between photographs and scans can be found. In the publication ‘Digital Doppelgängers’ (2014), Shaw and Trossell discuss how the scan is “as an evolution of the photograph, a lidar 3D scan freezes the dimensional properties of an object, space or event” (p.23). In this quote and other interviews, they propose that 3D scanning is a progression of photography and debate how scans and photographs relate and differ. They re-enact famous photographic works in 3D scanning projects, like *Post-lenticular Landscapes* (2017), a LiDAR recreation of early photographic expeditions to Yosemite Valley (Figure 20 and Figure 21). This project recreates large-scale photographs by early photographic pioneers, such as Watkins, Weed, Muybridge and Adams of Yosemite locations as digital 3D scans. Viewed anew, the non-visible light of the LiDAR scanner, the scans starkly resemble the photographs they recreate. The scans are framed next to the original photographs, allowing for a direct visual comparison.

Figure 20. The left image shows photographer Ansel Adams standing atop his station wagon in 1935. The right image, taken in 2016, features ScanLAB founders Matthew Shaw and William Trossel standing on top of an SUV, recreating one of Adams' photographs using a LiDAR scanner.

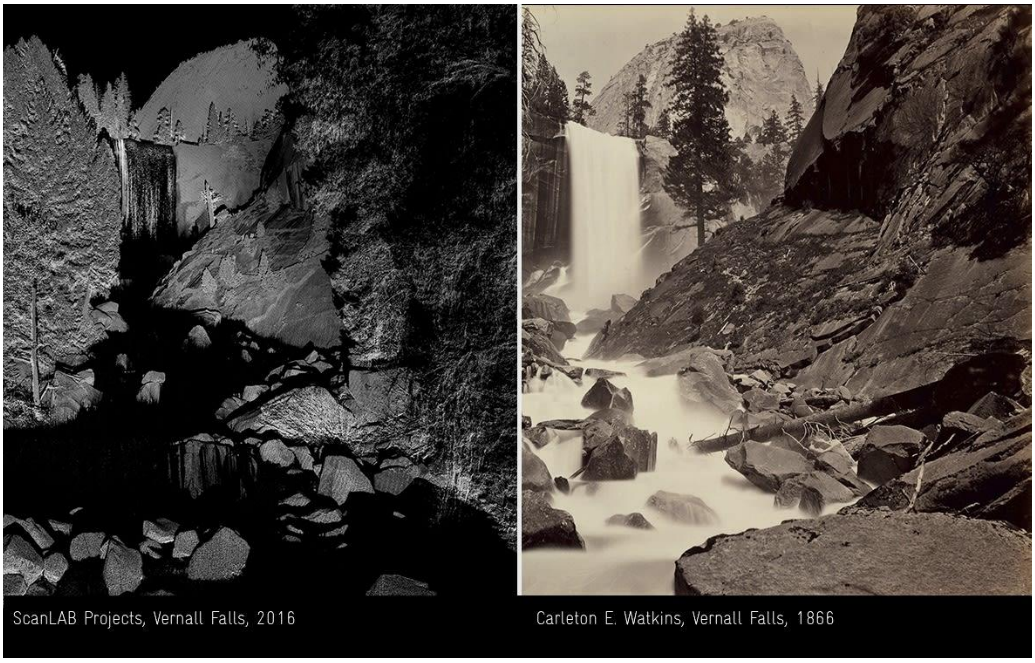

Figure 21. The left image by ScanLAB shows a LiDAR scan of Vernall Falls in 2016, recreating one of Watkins' photographs of the same location taken in 1866.

This parallel to early photography made by ScanLAB highlights similarities they observe in the bulky setup of equipment, noting that "the equipment is heavy, requires portable darkrooms (powerful computers), and is still prone to error and temperament" (Trossell 2014, para 8, quoted in Winston, 2014). The long exposure characteristic of sweeping lateral, panoramic, or 360 LiDAR scans typically results in humans being absent from the scans, similar to very early photographs. Laser scanners often lack the resolution to capture people at a distance; the few minutes it takes to complete a scan makes them intolerant of movement. As reality-capture technology becomes more compact and faster, new handheld smartphone scanners are increasingly common. Smartphone democratisation of reality capture parallels the evolution of mass-produced, inexpensive, affordable cameras and photography. However, ScanLAB continues to use LiDAR, a heavy, largely tripod-based technology. They also prefer to work with black and white LiDAR imagery, which evokes the grainy appearance of early photographs.

Despite operational or visual comparisons between LiDAR and early photography, ScanLAB has sometimes emphasised that the scanner is not a camera and point clouds are not photographs. While attending a ScanLAB workshop in 2017, I noticed several people referred to the LiDAR scanner as “the camera”. Shaw commented that it feels convenient to view the scanner as a camera (the moment of capture is like a photographic exposure), but it is a fundamentally different technical operation. He described the three-dimensional models produced by the laser scanner as more closely comparable to sculptures than to the planar image of a photograph.

Other comparisons between reality capture, cameras, and photography by ScanLAB highlight scan artefacts are similar to “double exposures on traditional camera film”, however, they caution that scan errors are “less predictable” than film artefacts (Trossell 2014, para 6, quoted in Winston, 2014). They observed that artefacts or noise in 3D scans often originate from capturing reflective, transparent, flat-coloured surfaces or intricate architectural shapes. LiDAR and photogrammetry interpret these surfaces and structures differently (and disruptively) than lens-based capture. Noise caused by these surfaces may not necessarily be errors, but rather alternative visions of the world as seen through reality capture. Shaw and Trossell assert that recognising these errors or noise is significant because, as technology advances, they will be automatically edited out in favour of a photoreal or photographically framed standard in 3D scanning[10]. They suggest that digital flaws

[10] Shaw and Trossell from ScanLAB have often remarked in discussions and interviews that reality capture is at a “stage of development (in 3D scanning technology) comparable to the evolution of wet-plate photography in the late 1800s" (Trossell 2014, para 7, quoted in Winston, 2014).

and struggles in capture challenge dominant perceptions of photographic realism in scanning and can now inform us about what it is and how it is perceived. The noise they observe in 3D scans is perhaps like lens blur or artefacts of chemically unstable early photographs. However, scanning technology is likely, especially with the advent of artificial intelligence, to evolve in overcoming these gaps in photorealism by correcting aberrations and artefacts, which we will not be able to reproduce – and see – again. At this stage, 3D scanning offers an opportunity to explore a medium that is less reliant on traditional notions of photographic realism.

Considering 3D scanning in the photographic context described by ScanLAB can be confusing due to the technical differences and output between photography and scanning. Another perspective on the relationship between scans and photographs is provided in ‘On Seeing Where There’s Nothing to See: Practices of Light beyond Photography’ (2021) by Jussi Parikka. This work explores alternative understandings of reality capture and concepts regarding the photographic framing of 3D scanning. Parikka discusses the idea of “wi-fi seeing", where images of the world are created from transmissions, signals, and measurements. He notes that Lidar uses invisible infrared rays to generate scans from millions of measurements, without the need for visible light or lenses, highlighting that these scans are distinctly different from normal photographs.

Parikka describes this as a “post-lens” vision, an “alternative to camera-based” imaging system grounded in signals and sensors (2021, p.185). He also notes that photographic theory has concentrated more on “cameras” than on, for example, “sensors, " highlighting an apparent dominance of photographic framing in spatial imaging (Gabrys, 2016, quoted in Parikka, 2021, p. 186). According to Parikka, 3D scan imaging is part of a genealogy of sensing technologies, such as radar, enabling us to see signals as marks. He observes that signal imaging, like LiDAR, is increasingly prevalent in our digital media landscape, yet it remains “entangled” with and framed by “traditional genres of imaging and photography” (Parikka, 2021, pp. 186 & 196).

Another perspective is offered by researcher Peter Ainsworth (2020), who explores themes similar to those of Parikka. In a paper on the “scanned” space between real terrain and virtual maps, Ainsworth examines the photographic visualisation of scanned images, finding parallels between point clouds, and pixels or film grain. He notes that “the process of making scan images may well be applied to the production of photographs” (2020, p.271). However, he finds it problematic to view 3D scanning as a form of three-dimensional photography. Turning to Benjamin Bratton, Ainsworth argues:

> the function of [scan data] representation is very different [for machines]. The “image” likely remains data and is never rendered to look like a “picture” because there is no need
>
> Bratton, 2016, quoted in Ainsworth, 2020, p. 62

Ainsworth states that the key issue is how the scan data is framed as an image, which inevitably leads us to think of it in photographic terms. The photographic framing of 3D scans relies on how the data is output and viewed. According to Manovich's definition of photorealism, Ainsworth observes that the rendering of the LiDAR point clouds creates an image, which he argues frames the scan in photoreal terms. The connection between LiDAR imaging and photorealism arises from the computer program, which is “conceived towards and through photographic visualization” (2020, p.275). However, asserting that a rendered LiDAR scan is photoreal is more challenging than making the same assertion for a render of a photogrammetry scan.[11]. Ainsworth does not address photogrammetry scans directly, which can look photographic as they use photographs to make the scans. Scanned models inherit visible light characteristics, such as shading, tone, colour, and textured surface[12]. In contrast, LiDAR scans, because of their cloud-like appearance, tend not to look exactly like the actual object. However, this has little to do with how LiDAR data is photographically framed. Ainsworth notes that the photographic perception of LiDAR scans is based on photorealism rather than actual photography:

> the reference to the photographic lineage of [ScanLAB's *Post-lenticular Landscapes*] project directs our view towards a wider understanding of the computationally photographic constructed or grounded in photorealism – rather than photography as such.
>
> Ainsworth, 2020, p.280

Computer graphics rendering systems are designed to simulate light and cameras, which Ainsworth calls computationally photographic. By using these systems, we can observe that rendered scans can appear photorealistic. Ainsworth's discussion indicates a complex relationship between 3D scans, historical photography, and photoreal software tools to render digital scan images. However, as we will see, these photoreal qualities can quickly deteriorate when

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[11] A virtual camera is essential, even when observing 3D scans in virtual reality or as interactive models on screen. However, a 3D print created from a 3D scan file eliminates the need for a virtual camera.

[12] The relationship between 3D scanners, cameras, and photography is complex. Within reality capture systems, cameras and photographs serve a hybrid role. LiDAR and other 3D scanning variants can be combined with cameras and photography to produce colour scans. Photogrammetry utilises photographs as data sets to create scans.

photogrammetry encounters an unscannable surface, such as glass. This represents a disruption of photoreal ideologies, which I will further explore in chapters 3 and 4.

1.10 Photographic realism

The previous section introduced the photographic framing of reality capture data. It began to examine how and why 3D scan images are rendered as photorealistic imagery. In my experience teaching undergraduate visual effects students, I have occasionally noticed that photogrammetry scans are described as very "realistic" because they closely resemble the scanned objects in every detail. To better understand this non-critical reference to "realism," I turn to definitions and concepts regarding photographic realism and theories of indexicality introduced earlier in the chapter. When discussing photographic function and theory, I refer to the predominant form of photography, where light is projected and focused by a camera, transforming a collection of photons into a two-dimensional image that represents three-dimensional space. This contrasts with abstract, camera-less techniques such as photograms, cyanotypes, and rayographs, which are frequently viewed as clear examples of indexicality[13]. As media scholar Michelle Henning puts it:

> Photography's machinic vision is thus characterised both by a lack of selection and by light imprinting itself on the receptive surface, producing a direct recording by the camera of whatever objects are placed in front of it.

Henning, 2018, p. 13

[13] Photograms, cyanotypes, and rayographs will play a significant role later in the thesis for understanding the specific flattened 3D scan effects observed in the research practice.

Since the early days of photography, indexical realism has been considered to underpin analogue photography as a sign, wherein, without the object before the camera, the photograph would not exist. This concept stems from Peirce's semiotic model, which describes a photograph as a special type of index-icon: an index that resembles its referent. Peirce stated that most indices do not resemble their referents (for instance, a temperature reading), although he acknowledged that they may share some common characteristics (for example, a footprint). Traditionally, realism of analogue photographs encompasses both a visual likeness in the photographic image (iconicity) and the fact that it is produced by light reflected from the referent object (indexicality). According to Peirce, photographs as indices have a direct "optical connexion with the object" and the photograph serves as a sign that both records an external existence and the method of its creation (1931, p. 359). In photographic theory and philosophy, the index concept is well-known and central to a photograph's credibility.

The primary function and principle of a camera is to capture reality. It achieves this by recording focused light that reflects off surfaces in front of it. According to Henning, this represents the "having-been-there" quality of the depicted objects, and the camera as a mechanism "underwrites the photograph's believability" (2018, p.13). Henning also points out that in the two most influential books on photography, by Susan Sontag (1977) and Roland Barthes (1980), photographic realism is viewed as being based on the need for "something" to exist to be photographed. Sontag noted that cameras "capture reality," and the photograph shows that the subject existed before the camera.

> A photograph passes for incontrovertible proof that a given thing happened. The picture may distort; but there is always a presumption that something exists, or did exist, which is like what's in the picture.

Sontag, 1977, p.5

Without manipulation, photographic realism is based on how the image "points" to its referent and through its resemblance to it. Sontag stated that even the most amateurish and poorly taken photographs have a "more accurate relation to visible reality than other mimetic objects" (1977, p.6). Similarly, Barthes wrote about photographs as "likenesses" and asserted that "every photograph is a certificate of presence": it is "the thing [that] has been there" (1980, pp. 76 - 87). Barthes referred to this as the "photographic referent" which he describes as:

> ..not the optionally real thing to which and image or sign refers but the necessarily real thing which has been placed before the lens, without which there would be no photograph.

Barthes, 1980, p. 76

In 1945, film theorist André Bazin wrote a seminal paper on the ontology of the photograph, translated to English in 1960, which discussed his ideas about photographic realism. For Bazin, this realism was grounded in the automatic production of photographs as an objective medium. The referent, he stated, compelled us "to accept as real the existence of the object reproduced [in the photograph]" 1960, p.8). Bazin posited that the photograph fulfilled humanity's "obsession with realism", asserting that it "mummified time". In a similar vein to Sontag, who remarked that the photograph "is part of, an extension of [the] subject", Bazin contended that the photographic image is identical to the object photographed, asserting that "it is the model" (Sontag, 1977, p.155; Bazin, 1960, p.8). Like Sontag and Barthes, Bazin did not explicitly address indexicality in this text; however, he employed indexical language to characterise the properties of the photograph. Bazin referred to photographs as traces, death masks, marks, or fingerprints drawn from reality. He noted that photography "enjoys a certain advantage in virtue of its transference of reality from the thing to its reproduction", subtly implying that more than just the image of the object is captured (1960, p. 8). This indexical language can be observed more broadly in photographic philosophy.

Academics in photography have sought to understand indexicality by comparing photographs to physical imprints, stencils, casts, relics, and stains. However, before we can explore whether these indexical qualities exist in digital 3D scans, we must first examine the differences between analogue and digital indices by identifying relevant theories and sources on the concept of the digital index.

1.11 Digital indices

Analogue indexical interpretations of a photograph created by an object before the camera are widely recognised. Although the photograph does not take an actual impression from its subject, it has been considered akin to physical moulds or plaster casts. As we can see in Sontag's writing:

> A photograph is not only an image (as a painting is an image), an interpretation of the real; it is also a trace, something directly stencilled off the real, like a footprint or a death mask.
>
> Sontag, 1997, p.155

The concept of the photographic index as a form of stencil created by light, rather than a physical impression, aligns with the analogue nature of chemical photography. This idea originated many years before digital capture technologies were invented. The viability of digital indexicality in 3D scanning is a central theme of this thesis. However, unlike photography, scanning lacks an analogue precursor. Nonetheless, I believe that the notion of the index as a process of imprinting or casting aligns more closely with the entirely digital technologies of 3D scanning. Since the advent of digital photography and editing software like Photoshop, questions have arisen about whether indexicality can exist within digital technologies that function differently from their analogue counterparts. Therefore, it is essential to review theories of the digital photographic index before seeking evidence and considering the 3D scan as a digital indexical sign.

From the mid-1990s, new digital photography technologies prompted debates about the potential for indexical realism in the digital age. These discussions centred on how digital photography and video capture and store images as digital files, and how easily these digital images could be copied and manipulated using computers. Digital photographs could be combined with, or entirely replaced by, photorealistic computer-generated imagery that could effectively counterfeit photographs (Gunning, 2004; Henning, 2018). With this in mind, we should consider whether a "digital index" exists before revisiting 3D scanning and how this concept may be applicable there.

Author Mary-Anne Doane (2007) noted that the index has gained new value and interest in the face of the "threat and/or promise of the digital" era (2007, p.129). In the same special issue of the journal *differences*, under a section called 'Indexicality: Trace and Sign', writers including Peter Geimer, Tom Gunning, and Braxton Soderman discussed digital indices. Soderman's paper questioned whether indexicality can exist in digital images. He observed that:

> Contemporary discussions of the digital image often focus on the annihilation of the indexical status of mechanically produced images such as photographs. In light of these discussions, I wish to ask: Do digital images have their own mode of indexicality?

Soderman, 2007, p.156

Soderman's research into the indexical status of digital images parallels my question about 3D scans and indexicality. He discussed the potential loss of the photographic index due to digital camera functions and computer-generated images, which could break the connection between the image and its referent object. He explains:

> Digital images can be produced from scratch without capturing the image from the external world, and second, even if the digital image is gathered from the external world (i.e., an image captured by a digital camera), the translation of the continuous light into discrete data sets disrupts the physical connection between image and referent. In terms of the former, using digital paint and design tools (image programs such as Photoshop or computer graphics programs like Maya, etc.), one can create photorealistic images without real-world referents, thus bypassing traditional notions of indexicality.

Soderman, 2007, p.158

Understanding digital capture technology can be challenging due to its primarily automated nature; it operates like a black box. However, for this thesis, our focus is on what technology can achieve rather than how it functions. Soderman proposes a new application of Peirce's indexical sign to digital images, suggesting that a digital index can demonstrate an object's external existence without a physical connection. For Peirce, an index might simply be someone pointing at something to indicate its presence. This challenges the notion that an index must be strictly an analogue, point-to-point correspondence, as seen in the case of digital photographs, which are converted into stored data before manifesting as an image. Soderman's argument does not centre on electronic capture or digital manipulation but explores how data is interpreted in semiotic terms. He advocates for alternative indexical scenarios within software and 3D simulated models.

Soderman describes how computer models, referred to as "conceptual objects", can be digitally indexical within their systems: indexical signs that do not have a physical connection but link back to a virtual referent (2007, p.165). This alternative interpretation of the index may help distinguish the computer-generated photoreal simulation from photography and 3D scanning. Soberman argues that the conceptual index can either have a computer-generated referent within a computer system (for instance, simulated models and virtual light) or a computer simulation based on various types of collected "real-world" data. Soderman supports this idea by referencing Mark Wolf's research, which posits that a digital "perceptual index", likely an image (possibly a photograph), correlates with a physical event. In contrast, a "conceptual index" can have either a virtual or a data-collected referent (Wolf, 2000, quoted in Soderman, 2007). The conceptual index can therefore be a computer simulation founded on real-world data, such as market trends or climate change measurements.

Motion capture is a comparable example to 3D scanning of the conceptual index, a system that tracks and records movements to drive digital character animation (Allison 2011). Although no image is captured, motion capture, representing spatial-temporal data, animates a visible entity, such as a biped character, using movement data collected from an actor. Motion capture is a conceptual index because it is a non-visible data measurement driving a visible result. No matter how simple the 3D model or visibly different from the original performer the 3D character model is, to watch motion capture playback is to see an index of the person's actual movements – their human gait and idiosyncrasies come through clearly in the animation.

In *differences,* Gunning explored the relationship between the index and the digital in two papers from 2004 and 2007. He disputed the claim that digital technology and the index are opposed. He pointed out that analogue photography was often altered, and although digital manipulation is technically sophisticated, alterations in analogue photography were not uncommon. The equipment of photography itself (lens type, film stock, printing, etc.) can distort a truthful imprint of reality. In a similar vein to Soderman's text, Gunning argues:

> The difference between the digital and the film-based camera has to do with the way the information is captured – which does have strong implications for the way the images can be stored, transferred and indeed manipulated. But storage in terms of numerical data does not eliminate indexicality.
>
> Gunning, 2004, p.40

Gunning points out that trusted instruments, such as thermometers and rangefinders, which measure indexical data, convert information into numbers. Digital images and photographs are stored as a numbered collection of pixel values. The data values stored in photographic files do not look like a photograph in pure data form, but Gunning says this does "not undermine any indexical claim" (2004, p.40). Gunning and Soderman remind us that Peirce stated the indexical sign was created by or referred to something in the world. This could be an image formed by a process, but more likely, it would be a measurement or an imprinted mark rather than a resemblance. They argue that it does not matter whether photographic data is collected digitally, as both analogue and digital photographs would not exist without a referent. Philip Rosen (2001), writing before Gunning, makes a similar point regarding digital images, asserting that “it is the data of image files which are the digital ground” of its medium” (2001, p. 305). Does this suggest that the 3D computer systems and file types used to store and visualise models and point clouds represent the digital “ground” of the 3D scanning medium?

1.12 3D digital scans and indexicality

If we accept that other types of digital capture, such as photographic or motion capture data, are likely to be indexical, we can also consider the concept of digital indexicality in 3D scanning. This will be an area for my digital 3D scan work to investigate directly. However, before examining that practice in the upcoming chapters, I want to further reflect on potential contextual examples of photographic realism and indexicality, discussing them in relation to reality capture technology and examples. I believe photographic theory provides a relevant context as photography shares a similarity with reality capture as a medium that captures reality and whose images and models traditionally resemble (as Henning points out for photography) whatever objects are placed in front of the camera or 3D scanner.

We can argue that 3d scans, like photographs, possess a direct optical connection to the objects in front of the scanner, which is indexical. For example, infrared LiDAR scans demonstrate that a direct laser connection is evident in the measured values assigned to each point in the digital scan point cloud. Even poor or inaccurate digital 3D scans, point, as models and images, to their referents, aligning with Sontag’s notion of incontrovertible proof that a given thing happened. Like photographs, a 3D digital scan serves as a unique type of sign that combines index and icon, functioning as an index that resembles its referent. This description broadly applies to most types of scanning technology, with photogrammetry being a notably detailed form of scanning that closely mirrors the original. Details are represented in 3D scan files as intricate polygon wireframe models made up of millions of faces. Perhaps this captured surface detail signifies another aspect of scan indexicality? As Henning notes, this detail embodies indexicality and medium specificity for photographs.

Photogrammetry scans are produced by and closely resemble their reference surfaces. LiDAR, utilising non-visible light data, may not appear identical to its referent, yet the LiDAR scan retains many characteristics. What Barthes referred to as the photographic referent can similarly be designated as the digital scan referent in the context of reality capture, without which a 3D scan would not exist. Reality capture provides a three-dimensional representation of the referent, surpassing photography's two-dimensional capabilities. With 3D scans, we gain an objective representation in-the-round; this additional dimension further satisfies the obsession with realism that Bazin associated with photography and his notions of total cinema, capturing an essence of the object.

Bazin discussed how photographs are more than mere images; they embody qualities of the object being photographed, making them an extension or part of the “model". With 3D scans, this idea seems even more valid because scans are not just replicas but can be fully three-dimensional facsimiles, capable of becoming a 1:1 physical duplicate. Do 3D scans somehow capture a piece of the original or bring us closer to it? An analogy can be drawn from Sontag’s point about an imaginary photograph of Shakespeare. If photography had been invented early enough, a photograph of the playwright (regardless of how aged or faded it might be) would always be a more desirable memento than a painting. Sontag remarks, "a photograph of Shakespeare would be like having a nail from the True Cross” (1977, p.154). Is a 3D scan preferable to a photograph as a facsimile?

An example of the power of indexical realism in digital scan technology can be found in scans of Van Gogh's paintings. These scans of the artist's work have been transformed into unique facsimiles: perfect copies known as *Relievos*. In an interview with the director of the Van Gogh Museum, arts writer Dalya Alberge describes these enhanced 3D copies as “the closest you can get to the original without it being the original. There is a certain fascination about that” (2013, para. 10). The Museum commercially utilises the indexicality of these Van Gogh facsimiles, selling the *Relievos* at a high price. The idea is that indexical realism embodies more than a likeness of the subject; it is somehow the same as the subject. Can we think of facsimile 3D scans in the same manner? Indeed, *Relievos* are perhaps an example of reality capture technology used to inadvertently realise Bazin’s photographic sentiment of capturing the model itself. The veracity of some 3D scans is such that they are more than a visual record: not merely reflective of the world, they also seem like a “piece of it” (Sontag, 1977, pp. 4-5).

Reality capture, like photography, involves a unique process that Bazin described as transferring reality, effectively scanning and harvesting part of the physical into the virtual realm (3D scanning has been marketed in these terms). We can debate whether it truly accomplishes this, as this is a philosophical concept about scanning rather than claiming that the technology functions as a Star Trek-like transporter for moving matter. However, 3D scanning produces highly accurate replicas of objects. It shares characteristics with photography as a technology that captures or preserves a moment. Bazin referred to this freezing of time in a photograph as embalming and compared photography to the process of mummification, suggesting that the photograph itself is akin to a relic.

Bazin uses the Holy Shroud of Turin as a metaphor for photographic realism, which “combines the features alike of relic and photograph” (1960, p. 8). Perhaps we can consider the digital materiality of reality capture in similar terms. Doane (2007) also refers to the Holy Shroud of Turin, stating that the photograph shares similar qualities with the shroud, as it exhibits the “indexical status of the stain”. She claims that this is how the photograph has a “privileged relation to the referent” (2007, p.132). The Holy Shroud of Turin is a relic with form and dimension, but photographs are flat, two-dimensional images, while scans are 3D models rather than images. Can we, therefore, consider 3D scans as a kind of digital stain or relic, where some of the substance has transferred to the digital model? Relics, remnants, mould, and plaster casts are all employed to invoke the concept of photographic indexicality, exploring and explaining the semiotic qualities of photography. We can potentially draw these parallels to reality capture, even though it does not create any actual physical impression, unlike a mould or death mask, nor does the photograph.

Another way to theorise digital indexicality in 3D scanning is to utilise Soderman’s theories on perceptual and conceptual indices regarding LiDAR and photogrammetry. LiDAR laser measurements can be visualised as a perspectival image on screen; however, like motion capture, the lasers do not see but measure the layout of the scanned environment. In Soderman’s model, LiDAR serves as a conceptual index, as it is based on data visualisation. Photogrammetry acts as a perceptual index since it relies on collecting image data, which is then employed in the reconstruction of the scan, evident in the photographic textures of the scanned models. Soderman also discusses a potential shift between perceptual and conceptual indices when data transforms into an image. It seems that 3D scans may occupy a position between the two. Even if a conceptual index suggests a digital referent, Soderman’s argument is that referents can be both physical and virtual, all of which are recorded and visualised using digital systems.

Another indexical model of 3D scan data is the digital cast. Steyerl and Di Bello's definition of 3D scanning as a digital equivalent of plaster casting aligns with the indexical comparisons made between photographs and casts, which provide evidence of indexicality in photography. The concept of the 3D scan as a digital cast is investigated in my digital captures or casts of negative space. This practice, reviewed in chapter 3, was partly inspired by Di Bello’s writing, which connects digital scans to indexicality by considering them the digital equivalent of a cast from a mould. She states that scans are “indexical, directly caused by the original” (2018, p.122). Di Bello observes that these digital copies are non-invasive and potentially more accurate and detailed than traditional casts[14]. Indicating that for the 3D scan to function as an index it does not need to physically touch the referent object. Hito Steyerl described 3D scans as “remote-sensing casts of reality” and considers them indexical copies. However, Steyerl observes that when 3D scans are mediated, “fiction and indexicality merge in these objects” (2012, pp.191-202). This standard 3D modelling practice involves combining scanned data with modifications made by a 3D modeller. Similar to photomanipulation, this blending of modelling and scanning is part of the clean-up or attenuation of 3d scans. A digital modelling workflow known as retopologisation reworks heavy scan files to create usable 3D assets while enhancing their photorealistic attributes. Although digitally necessary,

[14] Factum Arte advocates using 3D scanning to produce digital facsimiles with higher detail and resolution than the physical casting methods they emulate.

retopologisation could weaken the connection between the scan and its referent, shifting it from an index to an icon as a sign.

Ainsworth also questions whether remodelled 3D scans maintain an indexical link to their referents. He argues that scans processed through “algorithmic interpretation” combined with digital manipulation in post-production may potentially dilute their indexicality. Transforming a 3D scan into a streamlined, lightweight model for computer animation, as seen with Quixel models, could result in a loss of indexicality. However, as Gunning points out, the mediation of photography is often overlooked when considering indexicality, and this perspective may reasonably extend to the intricate post-production processing and manipulation of 3D scans. The marketed aesthetics of resemblance present scans as inherently truthful and objective representations. Nevertheless, scans are frequently digitally remodelled into photoreal assets; in contrast, photography manipulation has long been an established practice. Gunning acknowledges that just as digital content can be altered or fabricated, analogue photography has been subject to manipulation since its inception (Burgioni 1999). Both the camera and the 3D scanner, as capturing apparatuses, can significantly influence the final image or scan.

We are inclined to view the camera as similar to our eyes, capturing a comparable perspective of the world. At the same time, the scanner is seen as mirroring the world in a way that reflects our own spatial experience. However, the two technologies capture surfaces in distinct ways, all of which attenuate the scan. Just as the distortion of the lens, film stock, exposure, and chemical development in the darkroom affects the outcome of an analogue photograph, the density of the lasers in LiDAR and the resolution of photogrammetry photographs all impact scan quality and detail, a potential indexicality. With photography, Gunning notes how these concerns are “magically whisked away” in favour of photography’s supposed privileged (analogue) connection to its object (2004, p.40). He suggests that with photographic fakery, “being aware of the strata of the indexical” is essential, as these elements and partial truths lend power to the image (2004, p.41). Steyerl’s similar point about 3D scanning, where frequent partial or missing data results in scans being interpreted or remodelled, merging indexicality with fiction, yet these scans are often uncritically viewed as unaltered, truthful copies. As Gunning suggests, layers of mediation in photography are often ignored in favour of an assumed indexical connection, and 3D scanning presents a similar case where photorealistic scans obscure the complex processes that shape their production. Therefore, the scans produced for this thesis will remain unaltered in their raw form; they are neither edited, cleaned, nor remodelled to fit a particular representation. However, I will investigate unscannable surface errors in 3D scanning and their impact on concepts, scan photorealism and indexical traces.

My approach to scanning reacts to the computer modelling industry's photorealistic manipulation of 3D scans. I also intend to address through 3D scanning practice whether scanning disruptions can be viewed as indexical, even if they do not correspond to the reality perceived by the human eye or camera. I will create scans that will deliberately explore the effects of mirrors, glass, cluttered spaces, and brightly coloured objects upon photoreal outcomes in scanning. 33D scanning these challenging surfaces may lead to new ideas about the nature of the digital index in areas of non-resemblance that deviate from photoreal standards.

1.13 Digital photorealism

At the stand of this chapter, I examined how 3D scans are digital files that require specialised software to open and view, and how they represent digital geometries operating within the same modelling environments and toolsets used in photorealistic computer animation, visual effects, and video games, I now turn to a closer investigation of digital photorealism itself. Commercial 3D scanning companies like Quixel and Epic Games explicitly market their 3D scans for their photorealistic quality. Since scan photorealism is a key theme of this thesis, the next section will explore early definitions and evolving research on computer photorealism. This research will inform how I will identify moments where photorealism is challenged or disrupted when scanning provocative materials and environments. My creative practice aims to explore and react to concepts of scan photorealism and question photoreal perceptions of reality capture.

The term photorealism describes the technique of creating images that resemble photographs. Digital software tools are used to manufacture the appearance of photographs. The action of cameras is virtually simulated using various types of computer-generated and manipulated imagery. However, photorealism did not originate with digital technology; it began with painting. As an art movement, photorealism emerged in America in the mid-1960s, partly as a reaction to abstract expressionism. New York gallery owner Louis K. Meisel promoted the movement by supporting a group of painters who made photographs the subject of their works. These artists depicted elements of American culture, including glass-fronted diners, camera stores, chrome fenders, ketchup bottles, and pinball machines. Utilising slide projectors, airbrushes, paints, and paintbrushes, the aesthetic of painted photorealism, like contemporary computer photorealism, was based on “photographic realism” constructed from many different photographs rather than replicating a single photograph.

The concept behind painted photorealism is the interplay between subject, image, and medium. From a distance, the painting may seem like a photograph, but the brushstrokes and paint become clear up close. Like computer scientists and artists working with digital shaders and 3D rendering, photorealist painters were intrigued by the technical challenges of capturing visual elements that only a photograph could depict, such as the fleeting optical effects of light and reflections on metallic and glass surfaces. These surfaces frequently appear in photoreal paintings, where the refraction of glass and multiple reflections between metals present a visual challenge for both photorealist painters and computer artists to represent. Computer scientists and artists exploring early 3D computer renderings investigated how to create images of chrome and glass surfaces to test the capabilities of 3D raytracer render engines. Today, students of digital 3D software learn how to convincingly render glass and metals by creating test scenes resembling those painted by photorealists.

Photorealism is extensively discussed by Jay David Bolter and Richard Grusin (2001) in the context of their theories of “remediation”, “immediacy”, and “hypermediacy” in media. Their concept of remediation addresses the evolution of new media that are based on or influenced by older ones. For example, how the paradigm of drawn linear perspective inspired the development of similar spatial systems in 3d computer graphics. They say that the digitalisation of photorealism inherits earlier painted representation and photography practices. According to Bolter and Grusin, photorealism depends on immediacy, where the viewer is unaware of the medium and taken in by the spatial illusion of the image; a photograph naturally is an example. In contrast, the concept of hypermediacy refers to when the medium becomes apparent. We can think of paint strokes or a pixilated image as examples of hypermediacy.

Bolter and Grusin view computer photorealism as synthetic photography, where photography's optical and compositional systems are simulated using 3d software. They challenge Bazin’s claim that film and photography represent the pinnacle of realism, believing that 3D computer graphics have taken on that role. While comparing painted and computer photorealism, they are not without their critiques of digital photorealism. They identify shortcomings in certain aspects of computer photorealism that fall short compared to painted versions. For instance, achieving digitally replicated naturalistic patinaed textures has consistently proven challenging. However, areas where computer photorealism shines include rendering accurate shininess, reflections, and transparency in glass and metal surfaces. Bolter and Grusin's analysis, written in 2001, may require reconsideration due to advancements in digital texture painting and rendering and changes in 3D modelling practices. Recent developments in the field of digital photorealism may further complicate the landscape. Forms of methodologies for creating computer photorealism, such as synthetic media, digital compositing, AI-generated images, deepfakes, and, of course, 3D scanning, are now all part of the digital photorealism mix.

William J. Mitchell's T*he Reconfigured Eye: Visual Truth in the Post-Photographic Era* (1994) is an earlier but significant text that discusses computer photorealism. Mitchell outlines the principles of digital perspective and virtual space, light, shading (digital materials), and rendering, which he divides into virtual shading and cameras (synthetic photography). He highlights that mid-1990s computer systems could already, in some cases, simulate photographs so accurately that observers could not distinguish them from actual photographs, which is certainly the case today:

> Synthesized images can now be virtually point-for-point matches to photographs of actual scenes, and there is experimental evidence that, for certain sorts of scenes observers cannot distinguish these images from photographs. They can successfully borrow from the photograph's mantel of veracity and pass as true records of actual scenes and events.
>
> Mitchell, 1994, p.16

To achieve this "mantle of veracity," Mitchell explains how computer scientists reinvented linear perspective systems as 3D computer software. Based on Renaissance ray tracing, this method led Mitchell to note how Albrecht Dürer's perspective machines "anticipate 3D rendering" (1994, p.155). The 3D systems used to build and render photorealistic scenes on the computer are based on older image-making paradigms.

Researching photorealism in digital cinema at a similar time to Mitchell, media theorist Lev Manovich explored the growing presence of computer photorealism in film. He published articles on digital photography, cinema, and digital media (1994-1995), addressing the implications of photoreal animation and digital manipulation on film as an indexical medium. Manovich consolidated these ideas in *The Language of New Media* (2001), defining photorealism as "the ability to simulate any object in such a way that its computer image is indistinguishable from its photograph" (2001, p.199). He noticed how photorealism is emulating cameras and photographs using software rendering systems. Manovich was clear about photoreal definitions, but I believe computer-based digital photorealism is sometimes casually confused by audiences with a more general approach to making something computer-generated look “real”. I have noticed how digital artists merge accurate simulation techniques, such as 3D rendering, or combine digitisation (such as 3D scanned elements) with entirely faked composited elements created from digitally manipulated photography and video to deliver an overall effect of photorealism in an image on screen. A combination of computer-generated image workflow that brings together different pipelines to create photorealistic characteristics. We can think of the anatomical accuracy of carefully 3D modelled computer-generated animals and fantasy creatures created in the 3D software Maya, or invisible computer photocollage used in Photoshop or compositing software NUKE to create digital set extensions in many historical or period dramas. Different digital methods are used to create photorealistic output for film and visual effects, in combination or individually. Ultimately, all parts of computer-generated images are composited to form a photorealistic outcome.

Photorealism can therefore be individual 3D renders, essentially photographic simulations, or constructed from various digital media elements, including photographs and video composited together (Mitchell called this “computer collage”), or a combination can be used. Francesco Casetti (2011) described this as “sutured reality”, a digital stitching of different types of visual media on screen into filmic coherence, the interweaving of lens-based acquisition, scanned or simulated 3D computer models (2011, p.95). With this in mind, we should note that computer-based digital photorealism is complex and sometimes made from many parts, including 3D scans.

Manovich anticipated other definitions of photorealism as mimesis by reminding us that photorealism is essentially software faking photographs:

> What is faked, of course, is not reality but photographic reality, reality as seen by the camera lens. In other words, what digital simulation has (almost) achieved is not realism, but only photorealism – the ability to fake not our own perceptual experience and bodily experience of reality but only its photographic image.
>
> Manovich, 2002, p.200

Even when presented with an image of clearly non-existent elements (such as the dinosaurs from Jurassic Park), if they existed and could be photographed, they would resemble actual creatures, such as reptiles. We accept these “unreal” images due to their spatial placement, colour, texture, and interaction with light and shadow; they adhere to a “set of realist codes” (Lister et al., 2009, p.140). These codes, known as “reality effects, " as Lister et al. point out, apply to both photoreal and hyperreal imagery. For instance, light and shadow exist in Pixar movies, yet these animations are not considered photorealistic.

Manovich also tells us why digital photorealism exists in its current form:

> It is only this film-based image which digital technology has learned to simulate. The reason we think that this technology has succeeded in faking reality is that cinema, over the course of the last hundred years, has taught us to accept its particular representational form as reality.
>
> Manovich, 2002, p.200

This echoes Sontag's earlier observation that a photograph has “become the norm for the way things appear to us, thereby transforming the very idea of reality and realism” (1977, 67). We understand the world through photography. Sontag’s point emphasises how photographic realism has shaped our perception of reality. Computer photorealism, influenced, framed, and remediated by photography, cannot rely on perfect renders that can appear too flawless or sharp to be mistaken for photographs. It must incorporate additional effects to degrade, such as grain, blur, depth of field, distortion, and chromatic aberration, to achieve a “film look. " Adding these effects helps integrate computer-generated imagery within a film plate (background).

Twenty-five years later, Manovich’s analysis of digital cinema and the behaviour of computer photorealism remains relevant. Academic writing on photorealism broadly supports Manovich’s assessment. For example, Lister et al. state that photorealism is “not so much capturing external reality as simulating another medium [which is] the visual replication of photography and cinematography” (2009, p.137). Barbara Flueckiger’s chapter on photorealism, nostalgia, and style (2015) discusses the creation of “aesthetic coherence” between filmed and computer-generated elements by adding “analogue artefacts” of lens and film (p.79 and p.90). Stephen Prince (2012) writes about photorealism in terms similar to Manovich's but critiques it as a restrictive concept that is sometimes offset in favour of other stylistic, less photoreal concerns. Prince notes that:

> photorealism is a slippery and somewhat misleading term. As an art-form of composited images, little about cinema is realistic if such a term is understood as corresponding with camera reality.
>
> Prince, 2012, p.89

Despite critiques of digital photorealism, it has become well-established and serves as a yardstick for digital mimicry (Rosen, 2001). Its practice is complex and can consist of computer-generated and filmed elements.

Reality capture introduces a new dimension to digital photorealism. Scans acquired from the world naturally possess many photoreal qualities, such as details in their surface textures and topographies. Considering the significance of this detail in the photoreal effect of the scan, we can reference Roland Barthes's theory of ‘The Reality Effect’ (1969), which examines how descriptions of minor, insignificant details in literature contribute to a sense of authenticity, creating an illusion of reality within a fictional world. While Barthes's concept was a literary theory, computer photorealism relies on creating verisimilitude from detailed (nuts-and-bolts) aspects of 3D digital models that effectively convey detail and texture. Details are crucial to photoreal 3D modelling and texturing, as including trivial, random, secondary, yet high-fidelity details on 3D model surfaces adds descriptive elements that indicate the presence of a real-world counterpart. Barthes's theory of reality effects aids in understanding the importance of integrating scanned models into a computer-generated environment, where detail and texture may be lacking or difficult to recreate in other ways, especially when photorealism is the standard in these types of digital media.

Prince also discussed how effects can be utilised to create complex sets of “perceptual cues about surface texture, reflectance, coloration, motion, and distance,” which provide a compelling means of "gluing" together synthetic and live-action environments (1996, p.33). These cues also appeal to a viewer’s experience, allowing them to “judge the apparent realism or credibility possessed by the digital image” 1996, p.34). 3D scanning, specifically photogrammetry, captures many seemingly insignificant details and imperfections. These include detritus, scattered inconsequential objects, patina, wear and tear, and the effects of light and shade, all of which function as reality effects by signifying referents. As reality influences these scanned details, they become invaluable to 3D modellers and texture artists, effectively replacing the time-consuming techniques normally required to create photoreal 3D models by hand. The key difference is that the reality effects are captured, signifying actual surfaces as indices. Nevertheless, they are treated as photorealistic because they fulfil a role traditionally served by the 3D modeller.

Quixel, who refers to their megascan collection as photoreal, effectively markets scanned models for their reality effects. Quixel’s selling point is its collection of random, aged, or worn 3D scans. It does not focus on capturing surfaces that lack typical details like plastic. Quixel employs photogrammetry because it claims to capture photorealism. Of course, photorealism is a concept and a creative practice rather than something that can be recorded directly. Still, as we have seen, Quixel asserts that scanning, particularly its scans, simplifies the creation of computer photorealism. Quixel's utilisation of its scans establishes a standard by which photorealism can be produced much more convincingly due to the direct connection a scan has to the real-world details it represents. Where previously this 3d-modelled photorealism was generated manually, it now appears that through scanning we can observe a form of what I term captured photorealism emerging. The hand-built equivalent relies on the modeller's skill, artistic interpretation, and symbolic representation. Both approaches contribute to photorealism, yet the methods and underlying semiotic relationships differ.

Bolter and Grusin’s concept of remediation is evident in the use of reality capture for photorealistic purposes. Photogrammetry scans, influenced by pre-existing media, 3D computer modelling, and its photoreal workflows and methodologies, illustrate this concept. Immediacy is also present in photogrammetry, where cleaning scans and removing errors and traces of the scanning medium creates a seamless immersive model. Following this theme, we see 3D scanning as a successor to computer-generated photorealism, as it takes on the roles previously held by 3D modelling, texturing, and rendering. A 3D scan maintains a direct connection to the captured surface, producing digital replicas that appear more photorealistic than a simulated equivalent. However, this shift from modelling or simulating photoreal qualities to scanning is not always straightforward. 3D scanning disruptive surfaces may cause artefacts that reveal the presence of the medium; this is where hypermediacy occurs. I have observed this in my scans of unscannable surfaces, where breaks in photorealism expose the scans' aesthetic structure, presenting alternate visions of reality that are indexical but do not always resemble the original surface. I will explore these surface-induced scan phenomena in the following sections.

1.14 Realism disruption: unscannable surfaces

This final section of the chapter explores what is known about unscannable surfaces, which are central to the research-by-practice element of the thesis. In daily 3D scanning practice, materials and structures that are difficult to capture are often regarded as errors or noise. These disruptions can unravel and undermine the 3D scan's resemblance to the original, challenging the notion of the digital 3D scan as a perfect or truthful copy. In the commercial marketing of reality capture, such disruptions are perceived as problems to be fixed or prevented (Einscan 2019; Matter and Form 2018; Motley 2015; Scan Dimension n.d). However, should scan disruptions be viewed as errors in the scanning process, or are they inherent characteristics of the scanned object? Each disruption raises questions about whether reality capture perceives the world like the human eye or other technical imaging methods, such as photography. The disruptions provoke inquiries about what aspects of reality the 3D scan captures. This is a key research area for this thesis.

Do reflective, transparent, solid colour, or complex architectural-shaped surfaces create errors? These surfaces are just as integral to the world as other less troublesome materials and shapes. While disruptions may appear as errors because the scan results contradict our expectations and look different (a distorted version of the scanned surfaces), they could also represent genuine readings. These perceived errors provide aesthetic opportunities for artists and researchers to deepen their understanding of the scanning medium. The errors caused by unscannable surfaces form the primary focus of my project. However, before discussing my scanning research into the behaviour of unscannable surfaces, this section examines how artists and researchers in the field have responded to a growing awareness of scan disruptions and the breaks in photorealism that they can cause.

Shaw and Trossel (2014) of ScanLAB discussed disruptions in their LiDAR scans when capturing materials like glass or solid black colours. These anomalies led them to question the idea of a 3D scan as an always truthful or perfect copy of the world. Similarly, Steyerl describes digital 3D scanners as being perceived as “a new technology of truth” (2012, p.192). Steyerl connects this perception to the professional use of LiDAR scanners to collect documentary evidence. However, despite the reputation of LiDAR for precision and accuracy, Steyerl noted the sometimes-faulty nature of 3D scanning, emphasising that a scan may not always be a visually perfect representation due to several factors. Just as Shaw and Trossel refer to scan disruption as "noise", Steyerl describes it as "wrecked" scan data from issues such as blind spots. She argues that scanned data requires digital repair work, necessitating the need for creative repair work to scan surfaces. Steyerl, Shaw, and Trossel's concerns about the accuracy of reality capture in specific situations are apparent in their discussions of how errors are digitally fixed and manipulated by a modeller to both eliminate disruptions and to conform to a photoreal standard, but are still presented as a truthful resemblance.

ScanLAB, adhering to their philosophy of experimenting with equipment in unexpected ways, regarded disruptions in their LiDAR scans as opportunities to push the limits of scanning technology. They note:

> Using a tool for its intended purpose under optimum conditions will produce a perfect, efficient result. Purposeful altering of these conditions and experimentation with “that which may not work” has been the driving point for a series of recent ScanLAB that start to bend the scanner’s perception of space or rematerialise the point cloud.

Shaw and Trossel, 2014, p. 25

Through several laboratory tests, ScanLAB challenged the belief that 3D scans are perfect replicas, examining disruptions caused by “optical phenomena” such as black objects, mirrors, and transient occurrences like “mist, smoke, explosions” (2014, p. 25) (Figure 22). They called the results the unwanted phantom signals from problem surfaces and structures, manifesting as digital noise. Importantly, these observations revealed something new about both the technology and the spaces scanned:

> ..the resulting blooms of false information, offset realities, distorted surfaces and data voids as a new form of space, only constructed when scanned.

Shaw and Trossel, 2014, p. 25

These alternate offset realities were visible only to the 3D scanners' “eyes” and were discovered accidentally during a product scan. Usually, scan noise is edited out, either automatically by software or manually in post-processing. However, Shaw and

Trossel chose to display the raw, unaltered 3D scans in the exhibition *NOISE: Error in the Void (2014)* (Figure 23 and Figure 24).

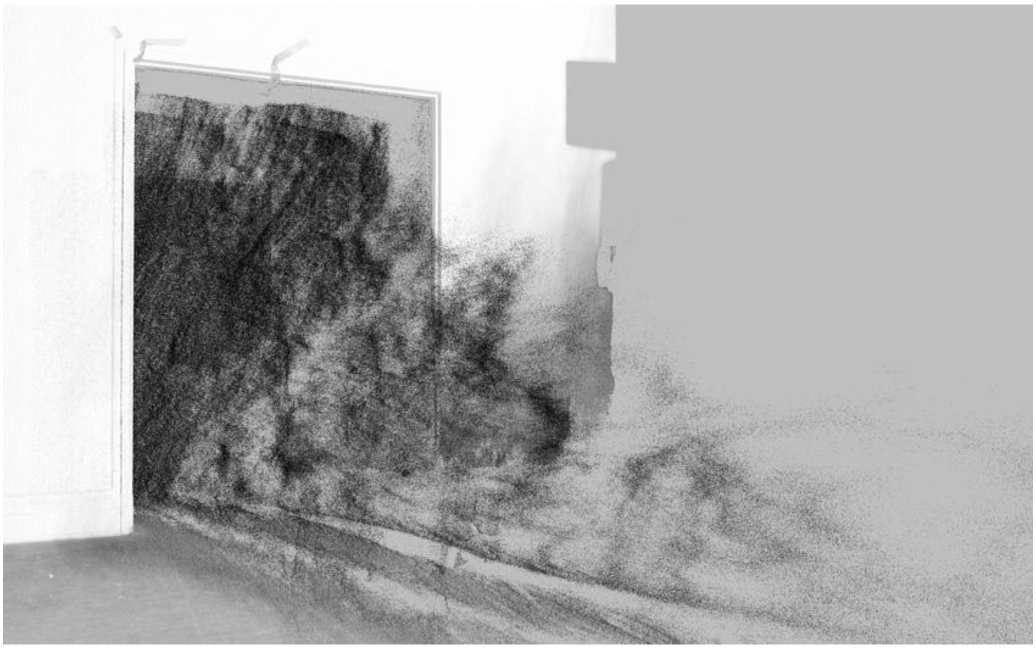

Figure 22. Scan LAB Projects experiments scanning mist.

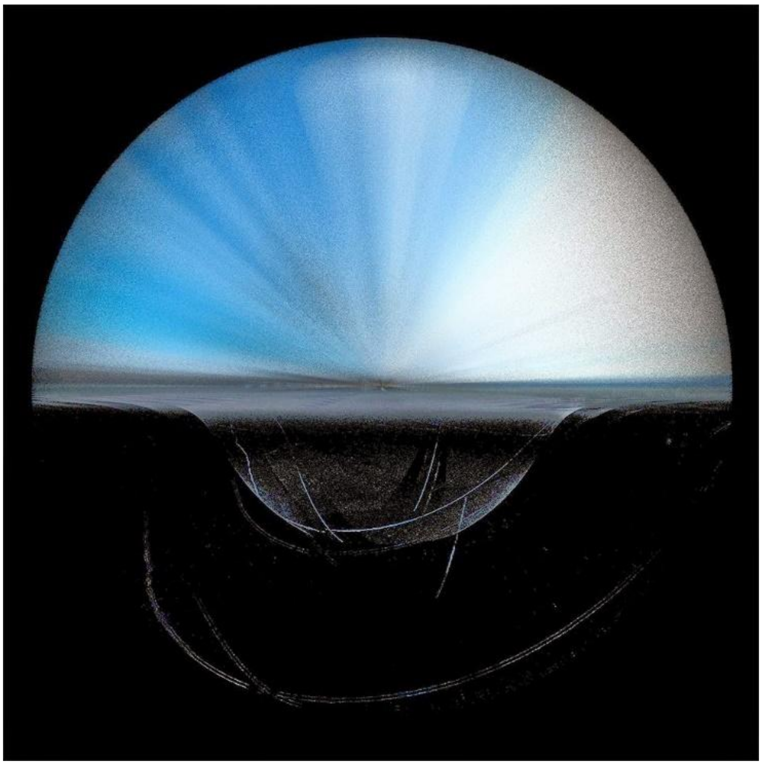

Figure 23. NOISE: Error in the Void (2013), the Surface Gallery.

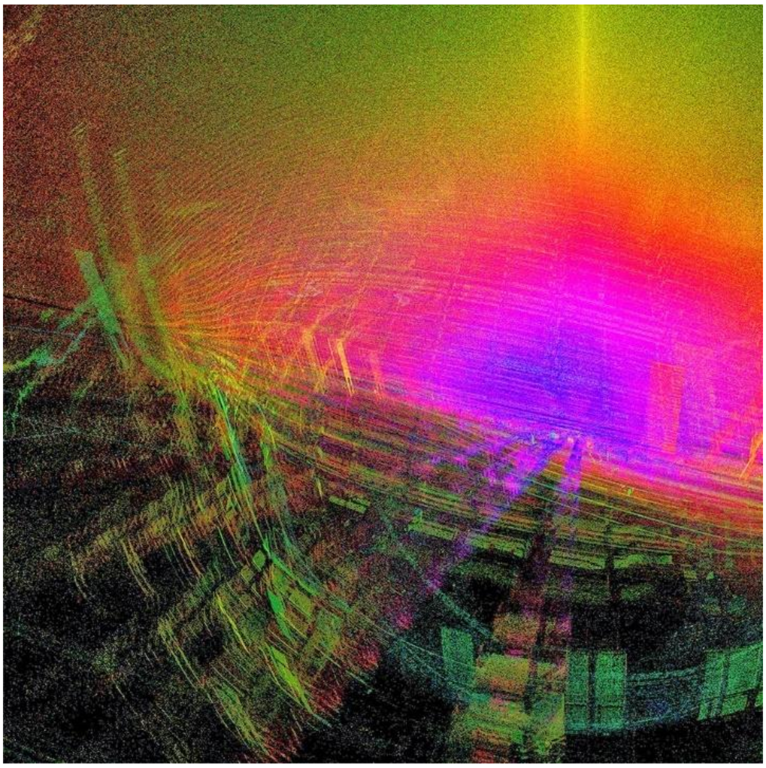

Figure 24. NOISE: Error in the Void (2013) The Surface Gallery (detail)

In ‘Digital Doppelgängers’ (2014), Shaw and Trossel discuss capturing unscannable materials and observing the noise produced by mirrors, glass, and dark colours. They include several paragraphs on unscannable surfaces, which is a significant topic. Sustained research into the effects of materials like glass using various scanning technologies, not just LiDAR, could yield different results. ScanLAB’s work is vital for this project as it initiates research into the relationship between 3D scanning technology, unscannable surfaces, and scanning behaviour. By employing innovative practices with technical scan exploration, their approach acts as a model for revealing aspects of scanning that are often overlooked (e.g., Quixel’s absence of scanned glass and mirror assets).

Disruptions caused by unscannable surfaces and materials arise as a by-product of a capturing environment. Parikka describes these as “accidents of over-seeing” laser light, where disruptive materials and shapes “can throw sensors off and lead them to perceive the cityscape in surprising, accidental ways” (2012, p.199). Architectural historian Danielle Willkens (2019) also observed scan accidents in her article on John Soane’s Museum. ScanLAB’s goal was to digitise the museum space and create digital duplicates of the artworks for virtual tours on the museum website. Willkens notes that the mirrors in the museum created an extended reality visible only to the 3D scans, suggesting that scanning the mirrors “provided the most visually compelling and unexpected results from the project” (2019, p.215).

In 2015, Geoff Manaugh analysed how Lidar scanners interpret reflective and transparent surfaces in another Scanlab project: ‘The Dream Life of Driverless Cars’. Manaugh observed that while LiDAR scanners effectively handle most solid, diffuse textured surfaces, they encounter difficulties with reflections, wet surfaces, and complex structures like scaffolding. He noted that although this poses a challenge for driverless cars navigating a built environment, disruptive surfaces also present an opportunity to perceive an alternate version of the world, one that remains invisible to humans:

> The flip side of this example is that, in these brief moments of misinterpretation, a different version of the urban world exists: a parallel landscape seen only by machine-sensing technology in which objects and signs invisible to human beings nevertheless have real effects in the operation of the city.
>
> Manaugh, 2015, para. 5

Manaugh notes how ScanLAB employs LiDAR technology to reveal not only a world of solid structures but also an alternate space “haunted by duplications and digital ghosts" “silhouettes" “aberrations” and “hallucinations” (2015, para. 5). The implication is that this version is as accurate as the other solid surfaces, as it still reflects what the scanner duly records. Willkens suggests that while accidental scanning discoveries are often perceived as scan errors, they illustrate the potential to capture more than our physical realm. Parikka noted that unscannable surfaces offer us the chance, through 3D scanning, to perceive what is otherwise invisible.

Tom Milnes is another artist and researcher of optical phenomena and 3D scan anomalies, which he describes as glitches. His works, ‘Ephemer(e)ality Capture’ and the ‘photogrammic glitch’ (2021), explore similar areas to my research by capturing unscannable surfaces and situations. Milnes's artworks are produced through what he calls “practices” in photogrammetry, resulting in images and sculptures that, due to inherent errors, challenge prevailing notions of photogrammetry as a medium that always faithfully represents the world as we visually experience it. Through a scanning practice that investigates the distortions and gaps in photogrammetry as a commonly perceived mimetic realist medium, Milnes builds upon Steyerl’s concept of blind spots and wrecked 3D data. He uses photogrammetry to capture phenomena and situations that disrupt scanning algorithms. His artworks draw attention to the inherent anomaly-prone nature of photogrammetry algorithms, which attempt to fill in absent areas, gaps, and spaces between surfaces that the medium often fails to register. In photogrammetry scans lacking this information, the algorithm produces bent, stretched geometries representing what it could not fully perceive. Milnes’s research, like that of ScanLAB, also investigates the effects of optically challenging materials such as reflections, transparency, and regular patterns on diffuse surfaces. As Milnes further elucidates:

> Photogrammetry struggles to capture certain objects and environments due to their optical nature. Transparent, repetitive, patterned, indistinct, plain, reflective, and ephemeral objects cause problems.
>
> Milnes, 2021, page 1

Through a still-life Vanitas collection of scanned objects, Milnes intentionally highlights errors in the photogrammetry process by scanning glass and reflective items. He argues that this research underscores how reality capture, a method of staged automation, often creates gaps where data is missing due to optically challenging and changing surfaces. The result is, once again, stretched geometry and blurred textures. Milnes articulates that his research seeks to:

> explore the mimetic visuality in 3D capturing technologies and issues that unpick their representational nature as being heavily mediated

Milnes, 2021, page 1

Milnes recognises how the 3D scanning workflow is framed and mediated towards mimesis, the scan as a mirror representation of the world. While Milnes does not specify the nature of the representation, I believe it is a form of photorealism, which is the driving factor behind the reconstruction of photogrammetry scans.[15]. Milnes's work with optically challenging surfaces pushes the photogrammetry process to its limits. The resulting errors reveal aspects of the

[15] LiDAR and other forms of 3D scan point clouds can also be viewed or rendered as perspectival images.

medium that are typically obscured by the largely automated procedures of processing 3D scans. In one experiment, Milnes conducts a 3D scan of a glass of water against a mirror. He observes that the “reflection of the mirror becomes not a reflection, but a window to another world” (2021, p.8). This illustrates the loss of the mirror plane in reality capture, and I have noticed a similar effect when scanning mirrors. Likewise, Willkens described ScanLAB’s mirror space scans as an accidental byproduct of the scanning process, noting that this discovery demonstrates how reality capture can interpret a reflection as actual spatial data. While Milnes regards the anomalies in mimetic capture triggered by optical phenomena as scanning glitches, one might wonder whether these are really algorithmic errors, or if the 3D scanner is genuinely “seeing” these surfaces in a completely new light?

My Phd research has developed independently and somewhat in parallel to Milnes's research; however, it also builds upon his findings by extending the possibilities of 3D scanning reflections and transparency using smartphone scanners. It incorporates numerous glass and metallic objects across hundreds of scans, allowing for a detailed survey of these scanning anomalies. Furthermore, my research introduces new categories of 3D scan disruption, including solid colour surfaces and complex everyday architectural interior environments through the disrupted capture of negative space.

1.15 Conclusion

This first chapter thoroughly reviews and analyses 3D scanning applications, cutting-edge technological practices, photoreal standards, and ideologies within the field. It examines contemporary scanning technologies, commercial practices, and innovative examples of reality capture research, establishing the thesis's technical, creative, and theoretical foundation. It consolidates relevant literature and theories on photorealism, photographic realism, and photographic indexicality. I describe how digital scans, due to their wireframe geometries and image-based textures, can be considered close counterparts to hand-created simulated 3D computer models. Both hand-built and scanned computer models adhere to photoreal standards, practices, and workflows. Similar to the digital manipulation of photographs that creates new types of photorealistic imagery, this chapter demonstrates how reality capture industry workflows and non-critical practices typically regard scanned models as malleable, wherein scans are remodelled to become digital photoreal assets. However, since reality capture is a relatively new digital medium, its digital materiality is characterised by its unique nature of digitisation, and considerable curiosity exists in the field of 3D scanning to explore and understand the errant behaviour of unscannable surfaces. Scanning these surfaces may yield insights into the behaviour of the medium (when not subjected to photoreal constraints) and inspire new perspectives of reality as seen by the 3D scanner. In contrast, the 3D scanning industry views unscannable surfaces as disruptors of the mimetic qualities they market. Interestingly, I have spoken to numerous individuals working in 3D scanning who are intrigued by the accidental alternate views of the world that unscannable surfaces present as scan anomalies, yet they find themselves unable to explore these further due to the photorealistic standards demanded by their commercial workflows. Nevertheless, focusing on unscannable surfaces opens a new research path into the 3D digital scan medium. In semiotic terms, unscannable surfaces, as disruptors of resemblance, may still be objectively truthful captures but differentiate the digital scan icon from its index. These surfaces can provoke reality capture into revealing new kinds of scan data.

The scanning industry's approaches and models of reality capture are generally regarded as photorealistic, and even with LiDAR's colourless point clouds, an underlying trend in framing and rendering this data in perspectival ways is evident. In this chapter, I have examined artists and researchers who aim to disrupt this way of thinking and push the limits of what 3D scanning can capture beyond its industrial user base. Consequently, in alignment with the thesis research questions, the next section of this thesis establishes a method for creatively provoking 3D scanning. This art practice methodology lays the foundation for my scanning research practice and ways to gather new data on existing and novel categories of scan disruption. The theories and cases discussed in this review provide context for these new scan practice results, and the research questions relating to indexicality and photorealism in reality capture have begun to be explored.

2 Chapter 2: Methodology

2.1 Scanning the unscannable

> Although the camera remains a perfect perspectivist tool, capable of copying reality in its slightest detail, it has long been recognised for its ability to emancipate itself from mere reproduction in order to detach itself from reality and produce mental images.

Baker, l'Ecotais and Mavilian, 2018, p. 13

The above quote is from 'The Shape of Light', a book that accompanied an exhibition on 100 years of abstract photography at the Tate gallery in 2018. The quote tells us how the camera and photography can be directed away from their day-to-day operations of capturing the three-dimensional world around us and towards experimental subjects that challenge, alter, or even remove the perspective of the photograph. While camera-less photographs are a further abstraction of the medium by reducing three-dimensional objects to two-dimensional shapes as we see in photograms, this history shows that photographs can be disrupted. Photographic abstraction continues to this day and can be valued in equal terms to a traditionally composed figurative photograph.

The digital 3D scan is, much like a photograph, captured from life, yet it too can be disrupted away from a figurative view of the world. Typically, both LiDAR and photogrammetry scans possess a close visual or spatial resemblance to their referent objects. We have observed that the perceived accuracy of reality capture technologies, combined with similar visual screen-based resemblances of scan models to the original subject, has resulted in scanning being framed by a photographic understanding or photographic "model" of capture. Consequently, its application in computer graphics has subjected it to photoreal standards. However, due to the increased accessibility of scanners, the notion (and practice) of scanning as a flawless copying process is subject to challenge. Mistakes and discrepancies in resemblance caused by the subject rather than the scanner's operation expose potential breaks in scan photorealism. Unscannable surfaces liberate 3D scanning from reproduction constraints. Thus, scanning mistakes and faults are the key focus of practical research in this thesis. Errors or disruptions in 3D caused by the represented objects and spaces themselves that affect standards of photorealism in scanning are valuable findings for the research practice. Therefore, the method developed here deliberately targets unscannable surfaces using 3D scanning technology to systematically provoke and explore errors and disruptions, aiding us in distinguishing between faults and accurate readings.

Developing a method that investigates the disruption of photorealistic outcomes and standards in 3D scanning involves an artistic exploration, engagement, reaction, and contemplation regarding the scanning medium. The method must research the primary types of complex unscannable surfaces, shapes, and structures identified in the research from the previous chapter. These include the 3D scanning of two categories: form and space, and material and surface. The selected categories are spatial and material, encompassing the 3D scanning of irregular and cluttered surfaces in interior architectural spaces, and a category that examines the capture of challenging reflective and transparent material surfaces, which can significantly disrupt reality capture. These materials and shapes are chosen because they resist 3D capture; knowledge in the field suggests that they are unsuitable objects for scanning.

The term “unsuitable objects” (used in the thesis main title) evolved from words such as unscannable, disruptive, unreliable, stealthy, limiting, and problematic, all of which are employed by those working with scanning to describe materials, shapes, and surfaces that are challenging to capture with a 3D scanner. As observed by ScanLAB:

> “stealth materials” that reflect or confuse the scanner’s return signal are avoided in the everyday course of scanning.
>
> Shaw and Trossell 2014, para. 13

The practice aims to investigate the impact of the most disruptive materials and shapes on the photorealism of the 3D scan using photogrammetry and hybrid LiDAR smartphone scanning. This method builds on existing knowledge from artist-researchers such as ScanLAB and other researchers. My approach extends their research by exploring scan disruption and its implications for perceptions and standards of photorealism associated with 3D scanning. Consequently, this method seeks to expand and develop some of the avenues opened by disruptive scans and the work already accomplished by pioneers in the field. By creating systematic collections of scan disruption, superficial or incomplete knowledge about how disruptive materials and shapes influence scanning can be examined far more deeply than in previous studies. The in-depth focus on two distinct categories and collections of capture aligns with chapters 3 (on irregular interior spaces) and 4 (on reflective and transparent materials).

Scans will be developed for these categories and uploaded as an online library of 3D scanned models for interpretation and analysis. The online collection of

3D models serves as the project's data, as an organised visual example of digital 3D scan disruptions that I collected. The scan collections also aim to enhance understanding of what can be 3D scanned in previously dismissed areas. The practice-led approach to creating the scans involves producing standalone scan artworks as exhibition images and renders, while employing creative methodologies to experiment with scanning different surfaces and setups. This method is intended to respond to conventional 3D scanning techniques; it will function outside the constraints of industrial utility or application for photoreal markets. Challenging or pushing the boundaries of reality capture beyond this operational comfort zone is crucial to the methodology, as it facilitates the exploration of 3D digital scan images for their own sake.

To develop this method, refine the practical 3D scanning workflow, and create a practical framework for practice-based research, I conducted a series of 3D scans focused on capturing solid colour, a disruptive surface. This pilot study aimed to test and enhance the method; thus, I opted to scan “solid colour” as a known (yet somewhat ambiguous) disruptor of scanning, while surface texture, comprising numerous colours, plays a critical role in photogrammetry scanning processes and photoreal outcomes. This initial case study was carried out earlier in the project and is documented in the following section, which examines the findings and their application in developing a method through the practice of creating 3D scans of solid colour surfaces.

2.2 Finding a method through practice: scanning solid colour

Conversations with professionals who worked with 3D scanning revealed solid colour as potentially problematic for 3D scanners to capture (Clear Angle Studios

2022; Clark and Mitchell 2021). While glass and reflections were known to be a challenge to scan, methods existed to mitigate or avoid the problems they can cause for 3D scanners. Areas of consistent colour, such as blacks, were considered troublesome when scanning manmade structures and architectural shapes (Turk 2000, Shaw and Trossel, 2014). Black-coloured surfaces often have a reflective or shiny surface, which can interfere with scan outcomes. Manufactured surfaces often include whites and greys. Due to lack of texture and irregularity, these surfaces can prove more unscannable than others. For photogrammetry, for example, a highly textured organic surface is preferable. Therefore, this initial scanning phase aimed to scan solid colour on artificial surfaces such as brightly coloured shiny plastics. The objective was to develop the art-practice scanning method and to respond to the results with some initial analysis of the 3D scan behaviour and the impact of challenging solid-colour surfaces on its photorealism. The interaction between colour and texture also became a focus of this first collection of 3D scans.

The case study of colour scans utilised photogrammetry, depth (structured light) scanning, and LiDAR smartphone applications. These scans are stored online in the Sketchfab 3D model repository[16]. The 3D scans depict differently coloured objects with regular shapes, such as balloons. The inspiration for scanning balloons arose from a chance encounter with a large cluster of balloons that had appeared to have blown loose and come to rest on a pavement (Figure 25).

[16] https://skfb.ly/oWvJx

Figure 25. Coloured balloons found in a west London Street.
Photographs by the author.

I employed my iPhone camera to create a photogrammetry scan of the balloons as they lay on the pavement. The juxtaposition of the balloons against the road backdrop resulted (in the scan) in a visual contrast between the deformed coloured balloon surfaces and the accurately captured textured surface of the pavement (Figure 26). This initial test led to further scans that explored the disruptive contrast between coloured surfaces and textured backdrops (Figure 27, Figure 28 Figure 29). This contrast emphasised the effect of solid colour on the scanning process. The extreme geometric deformation of the smooth, solid-colour balloon surfaces sharply contrasted with the relatively photorealistic appearance of the textured bricks or patinaed pavement. I felt that this striking visual combination of scannable and unscannable surfaces, encapsulated in a single 3D scan, had not been observed before in 3D scanning.

Figure 26. Photogrammetry scan of the balloons in Figure 20. Scan by the author

Figure 27. Photogrammetry scan of balloons against a wall. Scan by the author.

Figure 28. Photogrammetry scan of balloons in a gravel environment. Scan by the author.

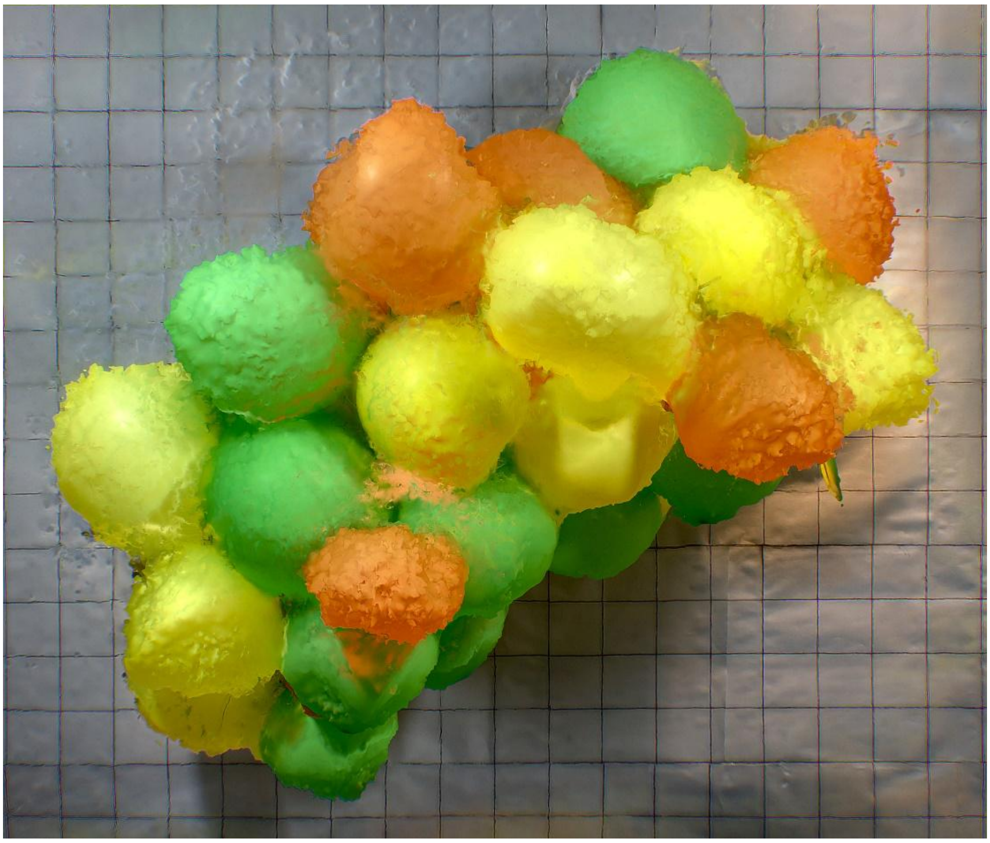

Figure 29. Photogrammetry of balloons against a grid showing ragged edges. Scan by the author.

To my eyes, the scanned representation of the backdrop environment appeared correct, but the balloons did not. They were malformed and looked as though they had been liquefied by their colour. Questions arose from this first scan, were the areas of colour accurately captured? If the area of colour disrupted the photoreal appearance of the scene, was it still actual to the subject, was it indexical? Other colour scans were full of colour-induced distortions as geometric errors, was the technology seeing a different visual outcome to what the human eye or camera captures? What can it see that is different to everyday visual phenomena of things such as a balloon or a mirror? These were inquiries to investigate further in the thesis through the practice of scanning unscannable surfaces.

These initial scans corroborated existing knowledge concerning the capture of irregular surfaces characterised by extensive colour variation; for instance, a brick can be captured nearly perfectly and remains easily recognisable. However, they demonstrated that the uniformity of a balloon, with its shiny coloured and smooth surface, entirely lacked detail, making it significantly more challenging to achieve an accurate scan resemblance. The colour and regularity interfered with the photogrammetry and depth-scanning processes, resulting in distorted digital replicas. The balloon scans resembled coloured putty or molten-coloured liquids that had blended and resolidified into irregular, shrunken forms. Separate surfaces were eroded at the edges by neighbouring colours, the balloon's usual smooth profile was transformed into a new amalgamated shape, and small fragments detached, floating as blobs of geometry in space (Figure 30). The scanned colours blended, transforming individual balloons into a singular new object. Reality capture did not differentiate between separate surfaces; instead, it perceived and reconstructed them as one. The balloons lost their distinct outlines, their shapes became ambiguous, and collections of twenty or more balloons amalgamated into a single geometric mesh. These scans represented mutable forms that shifted from recognisable shapes to loosely defined, liquid-like geometries[17].

Figure 30. Photogrammetry scan showing detached blobs of geometry (detail). Scan by the author.

The first balloon scan was effectively captured on location, scanning both the balloons and a slice of the surrounding environment. From this experience, a choice emerged between 3D scanning in the field (either inside or outside) or capturing objects in a photographic studio context. Sometimes, inadvertent scans of room backdrops were captured on location, giving the idea of disruptive interior scans as a

[17] The balloon scans reminded me of virtual liquid simulations created with 3D software such as Autodesk Maya's Bifrost plugin or Side FX's Houdini. Although produced differently, a fluid dynamics simulation can resemble the mixing of physical liquids or paints. However, achieving the desired effect in such simulations can be challenging; they can sometimes appear as a blobby mess of particles, much like the colour scans.

further category. However, for the colour scans, to capture the balloon's surfaces in the round, it was logical to also make 3D scans in the studio. I found that scanning objects individually is a practice that reflects how digital 3D models are conceptually distinct from each other, as they are usually modelled separately and without a background. The balloons were filled with helium, which floated free from the resting surface, suspended, and 3D scanned with two depth-scanning techniques (Figure 31).

Figure 31. Balloons filled with helium in preparation for 3D scanning. Photographs by the author.

The first early method was using a clip-on iPad 3D scanner called "Structure" (wirelessly paired with the Skanect 3D capture software on a computer)[18]. The second was using a depth-scanning application called Scandy Pro, which I became aware of in 2019. Scandy Pro used an iPhone 11 front facing true-depth (face ID)

[18] https://structure.io/skanect

camera and sensor, a novel approach at the time[19]. It involved pointing the face of the iPhone away from you to scan with the front-facing sensor; solid colour sometimes made it challenging to keep a scanning lock on the balloons. The Scandy Pro, results varied in quality, but the app was quick and straightforward to use, and I would class it as one of the very first smartphone 3D scanning setups.

The hand-held 3D scanning methods produced a distinct visual outcome compared to the photogrammetry *colour scans*. The balloon scanned from the Scandy Pro app had an eggshell-like appearance, with torn edges where one could observe the ruptured polygon faces and edges that constituted the model (Figure 32 and Figure 33). These images make us aware of the captures as reconstructed digital wireframe models; these are the same type of geometric 3D model that William Mitchell (1998) described as being built from rows of points, edges, and polygon faces. Here, the Scandy Pro scanned balloons, which, rather than looking like actual balloons, appeared like computer models of balloons. Parts of the scanned balloons were well-formed and intact, with a shape similar to the original balloon. Other missing areas were torn, splintered away, and fractured at the edges, revealing the makeup of the scanned models. We can see something of their aesthetic infrastructure. This structure is normally completely hidden in most 3D traditionally photorealistic 3D models and renders (Figure 34).

[19] https://www.scandy.co/apps/scandy-pro

Figure 32. Depth-scan of coloured balloons. Scan by the author.

Figure 33. Scanned balloons showing fractured geometry (detail). Scan by the author.

Figure 34. Depth-scans of coloured balloons. Scans by the author.

Tears and fractures in the scans appeared to be caused by scanning alignment issues, as the scanner had slipped due to the smooth-coloured shapes. Like the photogrammetry *colour scans*, featureless colours are more complex for the scanner to lock onto an object due to the lack of surface detail. The absence of detail caused the scanner to buzz in my hand as it gave haptic feedback indicating good and bad alignment. But unless a failed scan message appeared, it could be difficult to tell how the 3D model would be reconstructed. Scanning in the round required walking around the balloons, making sure nothing was missed or occluded and going back over the same areas. However, it was hard to know if this method improved the capture or not as multiple passes did not seem to overall affect the quality of the scan outcome. The workflow indicated that 3D scanning using smartphones as scanners was often an intuitive process of trial and error, rather than a set of scientific steps. It was the opposite to how industrial, conservation or commercial sources like Factum Arte Arte, Quixel or Lidar Lounge approach the methods of reality capture in empirical terms. I was using new smartphone reality capture applications for the *colour scans,* contrasting with the established systematic, often rigorous approaches to preparing and capturing scanned models. Here, an intuitive and organic 3D scanning method emerged that, whilst less sophisticated in its design, could still produce a photoreal resemblance.

Reflecting on the results, the colour balloons were disruptive to both types of reality capture used in the case study. The depth scans results were somewhat chaotic and fragmentary, while the photogrammetry scans were an abstracted collection of liquid-like deformations which contrasted sharply to their textured surroundings. This disruption extended to other scanned brightly coloured toy balls of different kinds, and experiments that tested the behaviour of glass and colour under the scanner using jam jars filled with watercolour paints (Figure 35, Figure 36, Figure 37 and Figure 38).

Figure 35. Photogrammetry of a bag of coloured toy balls. Scan by the author.

Figure 36. Detail of Figure 34. Scan by the author.

Figure 37. Jam jars with coloured paints. Photograph by the author.

Figure 38. Photogrammetry of jam jars with coloured paints. Scan by the author.

These results showed that capturing solid colour surfaces or liquids completely and without geometric errors was almost impossible. The outcome was down to the subject and its behaviour. If, for example, the balloons accidentally moved, the scanner captured their different positions, making me think of this phenomenon like a 3d multiple exposure [20]. The results showed fragmentation, misalignments, overlaps, doubles, gaps, molten effects, and floating parts, all characteristic traits of these early *colour scans*. There was an indication of the duplications and digital ghosts, aberrations, and hallucinations that Geoff Manaugh wrote about in his 2015 article on Scanlab's Lidar driverless cars imagery.

Anomalies in colour scans contrast a commonly structured approach to working with digital 3D data and computer graphical models. 3D scanning of a balloon is somewhat of a misnomer; such a regular shape is more suited to the precise tools of digital modelling software, making scanning these forms rather pointless when they could be easily modelled with 3D software. Comparing colour scans to other computer models emphasises the chaotic nature of these scans, in contrast to the often neat and flawless 3D surfaces in computer modelling systems. As Manovich noted, "3-D computer graphics" are "unnaturally clean, sharp, and geometric looking", which he described as a representational limitation when compared to a "normal photograph" (1996 p. 16). Since Manovich's writing, advancements in digital texture painting software combined with systems capable of handling millions of polygons (and scanned models) have significantly increased levels of realism in computer animation. This case study revealed that there are

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[20] This is because most types of 3D scanning cannot capture moving objects.

aspects of modelling that scanning struggles with, and vice versa. 3D scans are constrained by the physical equivalent of the smooth geometric regular surfaces that Manovich discusses. The current reality capture, featuring regular, consistently coloured surfaces, begins to unravel the realist function of 3D scanning.

By scanning disruptive surfaces, the method aims to push various forms of reality capture to their absolute limits, yielding results that offer insights into what the 3D scan represents and how it does not perceive every surface or shape uniformly. In these instances of scan provocation, we can observe its non-photorealistic operation, where, as Jussi Parikka (2021) mentions, “glitches” serve as a means “to understand the functions of this form of imagining of 3D scanning” (2021, p.199). Here, disruptions and equipment misuse provide alternatives to photorealistic interpretations of reality capture. Scanning unscannable materials and structures illustrates, as Parikka states, how scanning technology documents the conditions of its own existence. Like Manaugh, Parikka wrote about ScanLAB’s LiDAR scans of driverless cars, which he described as an “experimental framework” (2021, p.199). Manaugh also observed how “ScanLAB discovered that they could tweak the equipment to reveal its overlooked artistic potential” (2015, para. 8). From the outset, this thesis has drawn inspiration from ScanLAB's innovative scanning practice; however, my method differs from ScanLAB's in several respects:

- It employs innovative research methods that react to industry standards of photorealism in 3D scanning by striving to capture traditionally unscannable surfaces

- It utilises novel subject matter with an extensive focus on distinct research categories of unscannable materials and environments.

- It uses photogrammetry and cutting-edge, low-end reality capture smartphone technologies to explore scan disruptions.

The method seeks to enhance established practices while also differing from them in employing 3D scanning equipment and software to explore the disruption of photorealism in 3D scanning due to unscannable surfaces.

2.3 Art practice as a method

If the 3D scans of the thesis are to contribute to knowledge in the field, this could be achieved in one of two ways. One option would involve improving existing workflows and seeking methods to enhance the precision or photorealism of the 3D scan in these challenging-to-capture scenarios. The alternative was to question established ways of thinking and working—and consequently, the notions and standards of photorealism—in scanning by investigating the genuine disruptions that scanning lore advised strongly against. Research and improvement of the 3D scan as a digital replica have already been technically embedded in the day-to-day practices of reality capture, where workflows and software algorithms are incrementally updated to enhance accuracy and eliminate errors in likeness. Therefore, it was crucial to resist this approach to align with the project's research aims. Opting to develop a portfolio of 3D scan disruptions would examine scanning’s relationship with photography and photorealistic computer-generated images, prompting a discussion on the perceived indexicality of digital 3D scan images.

Having studied Fine Art for my undergraduate degree, I already possessed some knowledge of how artists work (which is often intuitive) and the strategies used to create works that can convey both aesthetic and conceptual outcomes. Strategies might include simply experimenting with materials, effects, or tools to understand their functions, making aesthetic judgements, reflecting on occasional accidents, and adapting practices moving forward and repeating actions to determine if an observable phenomenon is stable and problem-solving can all be part of the creative process. This was somewhat intuitive, but observing a change in the scan would trigger reflection on how that occurred, prompting an adjustment of the method to incorporate and enhance that effect. The input leading to a noticeable change could be the addition of numerous reflective surfaces or simply positioning objects closer together. While this represented a form of qualitative research, it was essential to maintain organisation and adopt a systematic approach. The organisation was provided by the categorised collections of scans. If something unusual occurred (which happened frequently), this was noted and explored later, as it was vital to adhere to the scanning strategy without deviating.

Examining the theory underpinning the practical method is beneficial before detailing how the scans are collected and organised. This theory is supported by evidence of how artists can function as researchers and artworks can serve as research outcomes. The writings of authors including Christopher Frayling (1993), Paul Leedy and Jeanne Ormrod (2010), Will Gompertz (2015), Desmond Bell (2021), and Elizabeth Price (2021) provide context and a theoretical framework for the art practice.

The notion of making as part of considering and developing ideas about new phenomena emerges from these authors. Frayling’s well-known paper examines the question, “How can I tell what I think until I see what I make and do?” (1993/4, p.5). He argues that the method employed by the artist, craftsperson, practitioner, and designer is characterised by “action which follows reflection, or reflection which follows action” (1993/4, p.4). Bell expresses a similar sentiment when stating, “the focus is on making the creative work as a vehicle for enquiry” (2021, p.20). These concepts underpin the method of 3D scanning of disruptive categories. Bell advocates the “Cycle of Reflective Practice," in which concrete experience is succeeded by "observation/analysis." This leads to "conceptualisation," which can then be followed by further “experimentation/testing/data gathering," allowing the cycle to repeat (2021, p.25) (Figure 39). This iterative practice proved immensely beneficial for crafting and generating the 3D scans, analysing them, and developing concepts in the written section of the thesis.

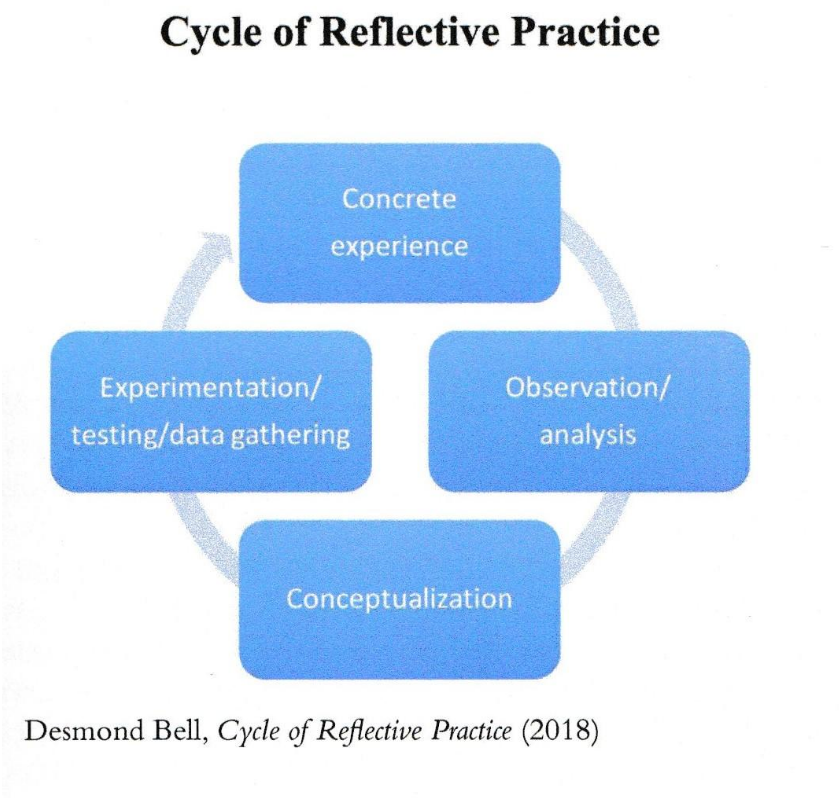

Figure 39. Bell’s Cycle of Reflective Practice.

Leedy and Ormrod (2010), who promote a research method like Bell’s cycle of reflective practice. They describe a set of researchers’ abilities to describe, interpret and reflect on the data, and to provide a context in writing. In reference to Peshkin

(1993), Leedy and Ormrod provide a guide as to these aspects of qualitative research and why they are used:

> *Description:* Can reveal the nature of certain situations, settings, processes, relationships, systems, or people.
>
> *Interpretation*: Enable a researcher to (a) gain new insights about a particular phenomenon, (b) develop new concepts or theoretical perspectives about the phenomenon, and/or (c) discover the problems within that exist within the phenomenon.
>
> *Verification*: Allows a researcher to test the validity of certain assumptions, claims, theories, or generalizations within real-world contexts.
>
> *Evaluation*: Provides a means through which a researcher can judge the effectiveness of particular policies, practices or innovations.
>
> Leedy and Ormrod 2010, p.163

This guide taught me how to deal with 3D scan data when writing about it in the thesis. Leedy and Ormrod also say that the researcher should be immersed in the subject and know what projects have been completed, as this helps distinguish between existing knowledge and what stands out as something new.

Artists naturally tend towards a more inquisitive and experimental approach “guided as much by instinctive concerns and provocations than by ratiocination.” (Bell 2019, p.23). The method of provoking reactions in scanning involves deliberately examining materials and spaces that challenge conventional thinking in the field. In this way, the method encompasses scanning the unscannable and questioning accepted scanning and computer modelling techniques. Both Bell and Gompertz discuss how art research entails experimentation, accidents, learning from failure, and being open to unexpected directions, potentially guided by the material itself. Gompertz's exploration of how artists think prompted me to view disruption as a form of creative failure, resulting from pushing something to its limits to observe the outcomes. Gompertz argued:

> Often the "new" element in really big ideas comes in the form of a disruption...That's how ideas are generated. Unusual combinations. Mixing old and new to stimulate original ideas.
>
> Gompertz, 2021, p.81

Gompertz warns that not all disruptions produce worthwhile ideas, and it is essential to be critically aware that not all 3D scans deliver results. Yet the method helps by advocating the identification of recurring visual trends in the captures. In short, this method looks for something that in an industrial context is a failure but may be valuable to this research. For example, a 3D scan featuring a visual or spatial fault caused by a disruption of material or objects might reveal how the scanner interprets phenomena, such as when a mirror is perceived as an additional three-dimensional space. Or in another example, results that look like failures in photoreal resemblance, but could also still be evidence of indexicality in the 3D scan, as when the scan maintains "accuracy" but departs from "recognisability" (Gunning, 2004, p.41).

As Bell argues, operating against the grain of accepted practice is where artists have often existed at the "avant-garde" (2021, p.145). He suggests that the forefront of creative research usually arises when new technologies are used in unconventional ways or when existing ones are repurposed. This leads to innovative relationships between art and science, and operating at the edge of a new technology can contribute new knowledge in emerging fields. Bell says this occurs when technologies for seeing, recording, and visualising space are both appropriated and developed by artists. Interestingly, Bell cites the invention of linear perspective as a quintessential example of artistic innovation. He notes that it is widely recognised that Brunelleschi’s method drew upon the earlier experiments of other artists, and that Alberti’s later codex *On Painting* (1437) formalised the linear perspective technique. Bell regards Brunelleschi’s accomplishment as a paradigm of artistic-research practice, which was informed by testing a new technology, and creative in its problem-solving approach.

Insights from other artists' works can help to interpret the results of the 3D scans of interior spaces and mirrored glass surfaces. In part, the method for analysing the 3D scans comes from comparing them to analogous non-digital media artworks. Looking at selected works from established artists proves informative; it helps identify potential lineages, guides decisions regarding scanning subject matter, and connects similar phenomena across different media to better understand the captured disruptions of the digital 3D scan categories. For example, Cornelia Parker's mirror, glass, photography and shadow artwork can assist in understanding how glass can disappear from 3D scans, but still leave a shadow, a similar phenomenon can be seen in Parker's shadow sculptures. The negative space architectural casts of Rachel Whiteread, which tell us about the nature of objects and spaces without seeing the objects or places themselves, may have parallels (and differences) to the cast-like nature of the 3D scans of space in chapter 3. The work of these artists and others is essential in comparison and developing theories about what the 3D scans in the research-by-practice are achieving. Utilising literature sources on the artwork of these artists is a method of analysis by which we may better understand the scan-artworks and data. As Frayling states, “the thinking that is, so to speak, embodied in the artefact," and viewing artworks as sources aids in revealing what is embodied in the scans of the practice (1993, p. 5).

Returning to Candy and Edmonds, who observe that the artefact is likely to be, in part, “the basis of the contribution to knowledge” (2018, p.64), I find that employing creative methodologies to explore the various scan disruptions naturally leads to considering the digital scan images and renders as artworks. These 3D scan artworks will serve to illustrate what the research has uncovered. As part of the practice-led PhD and this methodology, staging an exhibition of the scans appears to be a fitting conclusion to the practice-led phase of the research. Price (2021) emphasises the significance of exhibiting work in artistic PhD’s by practice, as it enables the artwork to express the theories embedded within it and the research. I determined that an exhibition of the 3D scan categories would will allow the work to articulate the outcomes of the disruptions visually. This highlights a contribution beyond merely storing scanned data on a hard drive. An exhibition would also facilitate space for reflection, gather feedback from peers and the public, and reveal what the research has uncovered.

The planned exhibition will be the outcome of the scanning practice. I plan for it to show key examples of different scan categories as large format 3D computer renders and animations. These will be displayed as printed images and a showreel of the 3D scans. Details in the scans that are difficult to see on smaller screens will be shown in large displays and prints. The exhibition will include sculptures of the scans as 3D printed or paper models, and portfolios (both print and digital) will further show the work. The 3D printed models of scanned interiors will highlight differences between actual architectural space and the 3D scans of it. Visualising the scanned data through artworks that exemplify the new phenomena captured, I hope to demonstrate what the research has discovered and how the images might relate to each other. I am keen for digitally scanned images to communicate their results directly as both renders and interactive 3D models online. The point of an exhibition is, therefore, to highlight the different types of disruptions captured so that they can be directly viewed.

In summary, the theoretical framework for the adopted method is based on research ideas developed by examining the work of Frayling, Bell, Price, Gompertz, Leedy, and Ormrod regarding how creative practitioners can function as researchers and how the artefacts produced can serve as research outcomes. Meanwhile, the analysis of the 3D scans draws from existing interpretations of artwork by artists addressing similar themes, along with relevant theories from the fields of photography and the computer graphical photorealistic image.

2.4 Organising and undertaking the practice

Following the review of literature and critical practice, I have established a creative methodology to explore the categories of disruption in 3D scanning. This subject matter comprises two primary categories of investigation: the 3D scanning and capture of space (negative space architectural interiors, ch. 3), and the scanning of mirrors and glass (reflective and transparent surfaces, ch. 4). The technical approach for these scanning categories is based on extensive hands-on experience with reality capture tools and software. This practical experience must consistently engage with and update technical methods to produce the scans, as reality capture can be complex. One must first understand the technology to effectively respond to established working methods and photoreal ideologies in digital 3D scanning. For instance, disrupting 3D scans through the scanning categories can only be accomplished if we know what might be considered a good 3D scan. Therefore, a commentary will run through the chapters related to established industry practices in 3D scanning. This will enable me to discover innovative and unconventional uses of reality capture, without falling back to established conventions of photorealistic production.

Other factors I will need to consider are the type of 3D scanner used and whether the scan was photogrammetry, short-range LiDAR, a depth scan, or a hybrid. Some 3D scans must be made on location, for example, with architectural interiors, while others, such as glass objects, need to be captured in a studio. The scans will be stored as navigable 3D models on the 3D model platform Sketfab.com. Sketchfab helps keep the research organised and perpetually stores the scanned data online. Each model is viewable online at sketchfab.com/florianstephens/models. A collection created for the *space scans* can be found online: skfb.ly/oWvP9. While the *mirror and glass scans* are here: skfb.ly/oWvJo. The colour scans from the previous case study are here: skfb.ly/oWvJx. The online 3D scan collections will help to sort which scan images will form part of the submission and exhibition.

This methodology has focused on the theory behind creative research-by-practice and developing the scanning methods needed to examine the thesis's research questions and themes.

3 Chapter 3: Space and form

3.1 Introduction

This chapter focuses on the 3D scanning of environments, specifically interior architectural spaces. There are two main ways of working with reality capture technologies they are object-based and environmental scanning. In object-based scanning, reality capture focuses on isolating surfaces and forms from their background, an approach that comes from 3D digital modelling, where models are created separately (Figure 40 and Figure 41). While environmental scanning captures sections of environments, such as natural and architectural spaces. Architectural scans can include both interiors and exteriors of buildings (Figure 42, Figure 43 and Figure 44).

Figure 40. Photogrammetry of a bust scanned using a turntable.

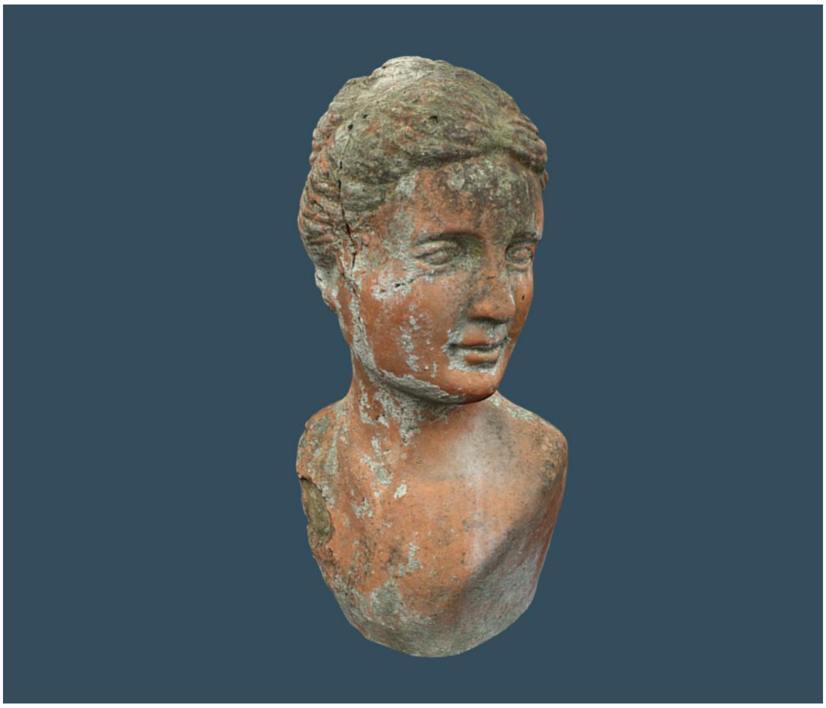

Figure 41. An image bust scan.

Figure 42. Drone scan of a Cumbrian farmhouse. Scan by the author.

Figure 43. Scanning company First Horizon LiDAR scans an interior.

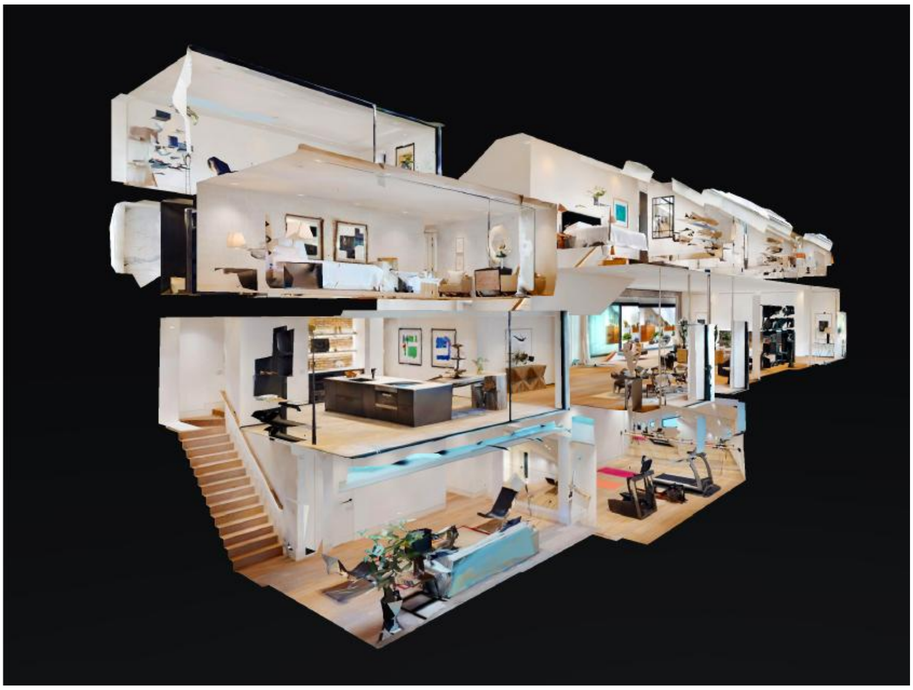

Figure 44. A Matterport scan of a building interior.

This chapter thoroughly examines the interaction between reality capture and interior architectural spaces. It investigates how complex architectural structures and cluttered interior environments can disrupt photoreal standards in 3D scanning. The practical element of this chapter, called the *space scans*, reveals a series of novel forms that seem to capture the negative space in a room or building; these scans have not been previously researched. The *space scans* invert the standard object-oriented scanning practice. They capture the background as a continuous, enclosed structure by concentrating on the surrounding space and looking outward toward walls or barriers. The result is a scan that is a negative inside-out representation, effectively serving as a digital cast of the captured space. Focusing on interior spaces and the negative, this chapter explores different ideas and working practices regarding how reality capture scans "space".

The chapter begins by illustrating how 3D scanners function as spatial recording devices, digital perspective machines that are similar in methodology yet differ in technology from Renaissance devices used to create perspectival drawings and measure layout space. It then discusses how scans of interiors can capture the negative shape of houses and other kinds of interiors, showing how reality captures and interprets space differently from human vision or conventional photography of interior architecture. Pioneering scans of architectural work are analysed for disruptions caused by unscannable surfaces to demonstrate how the scanner operates differently in these environments than with singular objects. Scans as lived spaces are also explored, considering how operating a 3D scanner leads us to view interior space in new ways. The capture concludes with a look at how the negative shapes of the space scans, as disrupted digital casts, can be theorised to be conceptually similar to actual casting and represent indexical digital traces of the scanned spaces.

3.2 Reality capture as a perspective machine

First, I want to consider how 3D scanners and reality capture technologies can be viewed as modern versions of older Renaissance perspective machines (Kemp, 1990). A 3D scanner acts as a device that records the layouts and proportions of objects and surfaces. The measurements it captures can then be utilised within the perspectival construct of virtual three-dimensional space, enabling them to be represented using digital perspective tools in 3D software. Theorising the 3D scanner in this way involves examining how it functions practically and conceptually, bringing a record of physical surfaces into virtual computer space. While there are other comparisons between scans and photographs or scans and plaster casts, this interpretation focuses on how a LiDAR scanner operates by acquiring measurements rather than images (although typically, the output of the scan is a three-dimensional image). Jussi Parikka tells us that laser scanning is a form of “wifi” seeing, as it does not use visible light or take images of the surroundings as part of the capture. It is akin to radar, but instead of sound waves, it measures and gathers coordinates from the environment using invisible lasers. A LiDAR scan can, through data, do what linear perspective and photography had only previously visualised. As Geoff Manaugh (2015) points out:

> [LiDAR is] far more accurate than anything achievable by the human eye. Capturing resembles photography, but it operates volumetrically, producing a complete three--dimensional model of a scene. The extreme accuracy of lidar lends it an air of infallible objectivity

Manaugh, 2015, para. 4

I believe the laser measurements taken by LiDAR are not unlike older types of perspectival measuring and spatial drawing devices formerly described by art historian Martin Kemp (1990) as “perspective machines”. Does this make a LiDAR scanner a form of twenty-first-century perspective machine?

To answer this, I first want to look at how a 3D scan captures spatial and image data, and how that data manifests in virtual space. 3D scans are essentially data points collected from the scanned objects and surfaces. Each point has a positional value for the three axes X, Y, and Z. This Cartesian positional data can be loaded into 3D software to reconstruct geometry models or point clouds. To view a 3D scan, it must be opened using a 3D application (such as Autodesk Maya); even if a scan is to be 3D printed, it must go through software before being output as a 3D print. The loading of scanned 3D data reconstructs it (the scan) as a virtual model. This process illustrates how scanners link the physical and the virtual, the analogue and the digital realms. Here, 3D digital computer space provides both a literal and a conceptual grounding for 3D scan data files. The loaded scan becomes a native of this virtual space. Before the invention of 3D scanning and the contemporary use of scans in place of hand-modelled computer geometry, digital 3D models were essentially simulations, representations rather than digital duplicates of the world. Now, scanners overcome this separation to build digital perspectival models and environments from actual physical layouts and object positions.

This process of taking measurements of physical objects and creating three-dimensional representations is the digital rethinking of an old idea. In place of strings, tape measures and plotting grids, we now have lasers and data points.

Instead of drawn linear perspective, there are digital 3D renderings. We can break this idea into two parts: the digitisation of linear perspective, and the digitisation of space by scanners. Experts of drawn and digital linear perspective generally accept the modern-day computerisation of the perspective paradigm.[21] Researchers in both computer-generated imagery and art history, in drawing and computing, note a link between linear perspective and digital 3D software. Media theorists such as William Mitchell (1998) see perspectival computerisation as meaningful to the representation technology as the original invention of linear perspective. While Bolter and Grusin wrote how "digital graphics extends the tradition of the Albertian window", they argued that Alberti's conceptual understanding of framed perspective is built into present-day 3D render engines on the computer (2000, p. 26) (Figure 45 and Figure 46)[22] Later Anne Friedberg described digital 3D space as a virtual window, a "digital simulacrum of perspectival space" (2006, p. 3).

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[21] Computers utilise point-projection perspective, which simulates the projection of three-dimensional objects onto a two-dimensional screen. This system involves rays being traced from points on objects to a virtual camera. The rays interact with the projection plane, the computer screen (in analogue perspective, this would have been a painter's canvas), to create a rendered 3D representation.
[22] **Error! Reference source not found.** and Figure 46 compare Alberti's single-point perspective to the perspective projection used by 3D computer software.

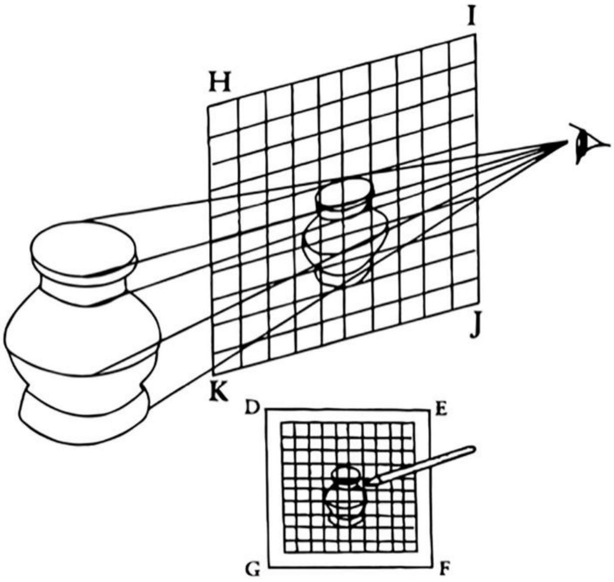

Figure 45. Leon Battista Alberti's (1435) intersection or "veil". Where points intersect a grid and are transcribed onto a square drawing surface.

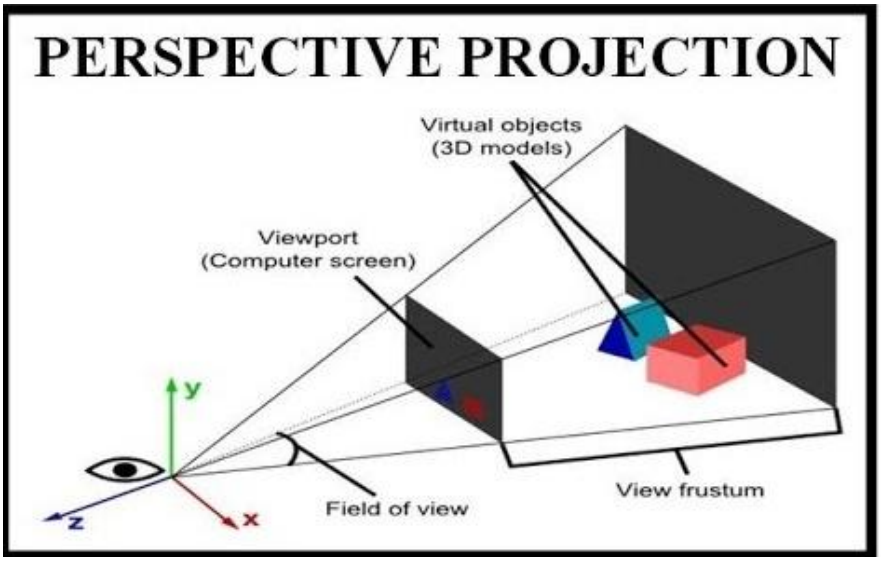

*Figure 46. Computer perspective projection of virtual (*3D*) models*

Scholars and art historians writing about analogue perspective make similar observations. Samuel Edgerton (2009) and James Elkins (1996) note how digital computer modelling originated from Filippo Brunelleschi’s linear perspective method of 1420. Lister et al. (2009), writing on the relation of linear perspective to 3D computer systems, commented that “we might even think of perspective as a kind of software” (2009, p. 117)[23]. This is a theory that Lev Manovich had broached earlier when discussing how 3D computer graphics simulate the behaviour of light and cameras; he likened computer renders to lens-based capture, which he said records a “perspectival image of the world” (2001, p.290). 3D computer graphics are linear perspective reinvented for the digital age. Without this system, reality capture would remain an unvisualised set of data measurements. We have seen how linear perspective has been digitally reinvented in computer imaging. We can now consider how 3D scanning represents a further development as part of the history of perspective.

We are familiar with the previous major capture development – photography, which, as Bazin (1960), among others, pointed out, fulfilled a psychological desire for visual realism through a mechanised and objective system. Bazin noted this desire was satisfied by knowing that the image had been created from the things in the world “by a mechanical reproduction in the making of which man plays no part” (1960, p.8). While a photograph creates a visually accurate depiction of the space before the camera, unlike the 3D scanner, it does not acquire data points as a spatial layout or reconstruct models of what it captures. The photograph is a flat representation of space; in comparison, computer perspective is a mathematical system which simulates layout. It can be navigated with virtual cameras; unlike a photograph, it has actual depth. Yet, while 3d scanning and the point projection systems in 3d computer graphics are conceptually separate, we have seen that they

[23] In their book *New Media: A Critical Introduction* Lister et al. (2003) discuss and chart the lineage of analogue and digital perspective systems from the Renaissance perspectival pictorial space to the development of virtual software and computer models. They argue that perspective is a “software” concept in computers and painting.

also work together as complementary systems. Namely, this is through the reconstruction and rendering of scanned objects so that they may be visualised using software. In a way, reality capture is an obvious next step in the evolution of the digital perspective paradigm, including the acquisition and digitisation of space. 3D scanning and 3D computer perspective rendering are separate concepts and practices, but they are closely intertwined because scanned data requires computer graphics perspective for visualisation.

This interrelationship between perspective and spatial measurement tools (acquisition) has existed before. Kemp observed the constant intersection of measurement machines and geometrical perspective in the Renaissance practice of surveying to enhance visual perspective and layout in drawing. Rather than simulating depth and dimensions, the arrangement of surfaces was recorded using a tool for turning measurements into perspectival drawings. Kemp calls this tool a "perspective machine" (1990, p. 167). He notes that in the 15th and 16th centuries, these devices were "mechanical system[s] of reproduction"; they were "instruments for recording linear effects according to projective principles" (1990, p. 167). Perspective machines invented in the period following Leon Battista Alberti's perspective window device were used by Leonardo Da Vinci, Albrecht Dürer and others to trace individual visual rays as invisible lines (sometimes actual wires) from a point on an object to a point on a 2D plane (Figure 47 and Figure 48) [24]. If we compare Dürer's well-known image (and Kemp gives other perspective machine

[24] Kemp writes that Dürer was particularly interested in the foreshortening of objects, as shown in the woodcut of draughtsmen plotting points to capture the foreshortening of a lute (1525) (fig. 24). This woodcut demonstrates the principle of a ray (or string, in this case) passing from a point on the object to an intersection on a 2D plane. This point was marked by horizontal (x) and vertical (y) strings, which could then be transferred to paper in a rotating frame.

illustrations in his book) to examples of the Lidar scanner operation (Figure 49 and Figure 50), we can see some similarities[25]. The scanning concept of a visual ray travelling between scanner and subject, measuring a distance, height, and length, appears close to the 16th-century example of Dürer, certainly in terms of its design and conceptual outcome.

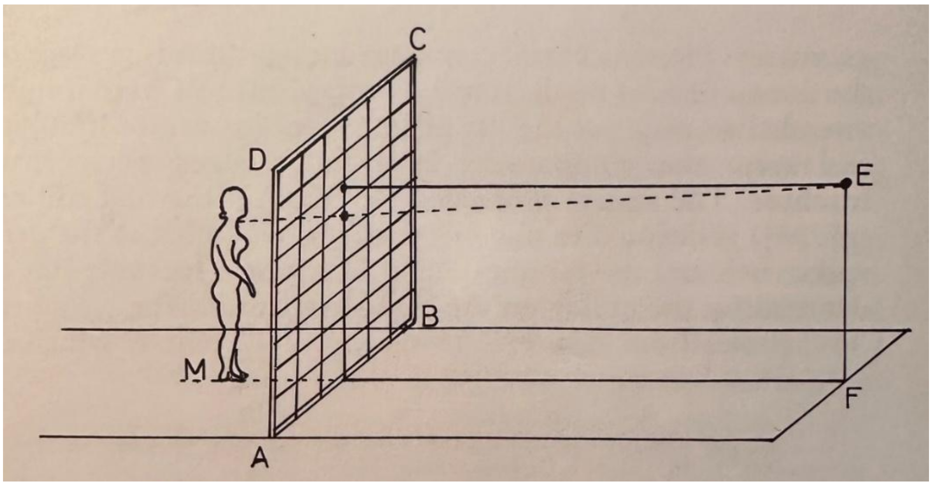

Figure 47. Leonardo Da Vinci's net system for replicating the poses of a nude via a line of sight to positions on a grid.

[25] Further visual examples of LiDAR being utilised for purposes similar to those of drawing machines from the 17th century.

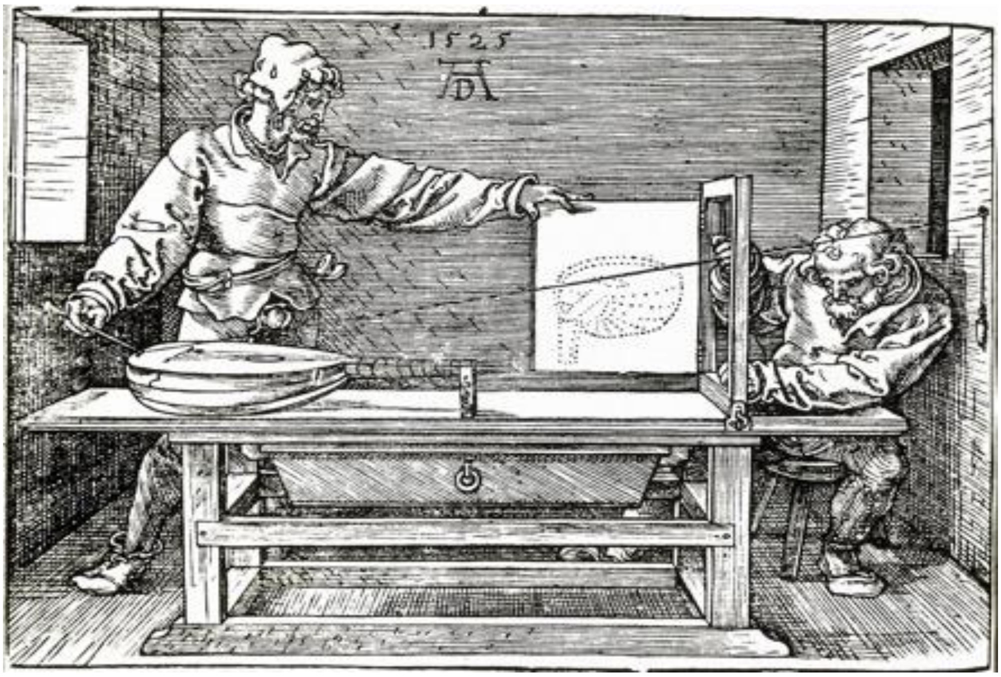

Figure 48. Artist plotting points to draw a foreshortened Lute.
Dürer engraving (1525).

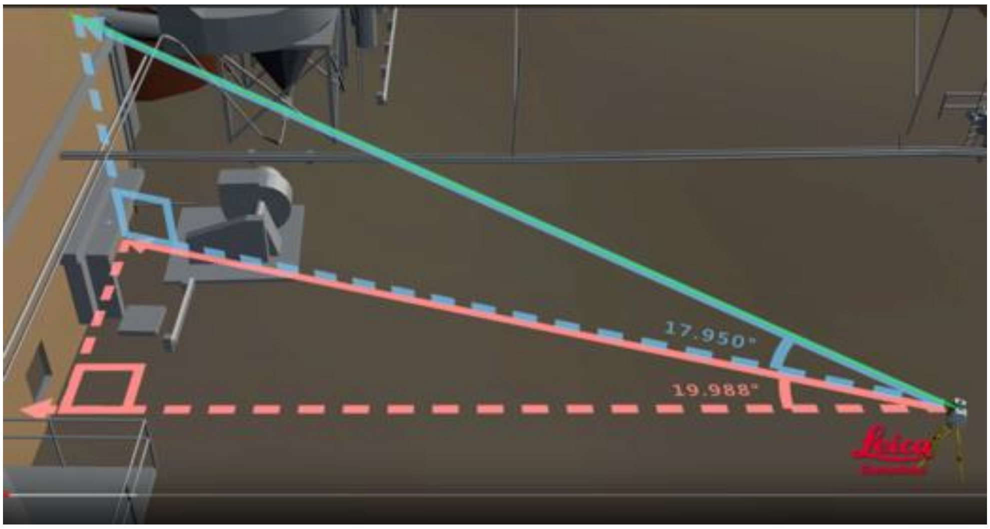

Figure 49. LiDAR scanner function

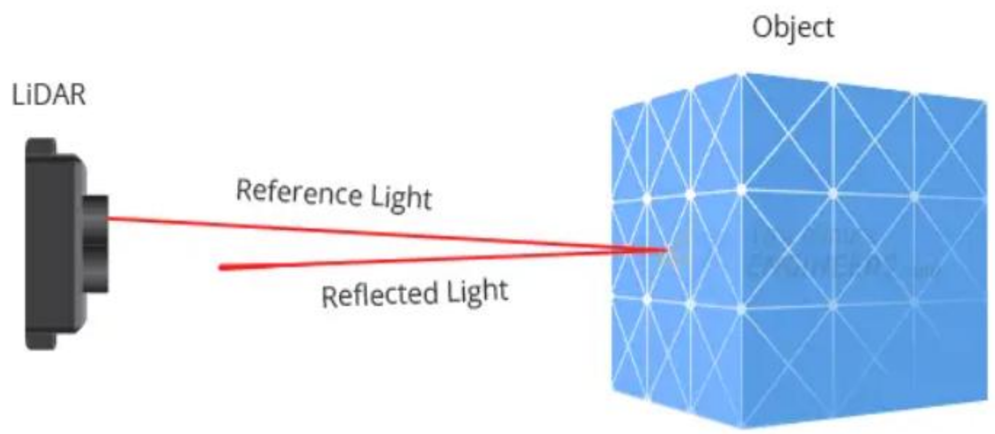

Figure 50. LiDAR scanner function.

The measurements that reality capture makes to form digital replicas could be taken in a slow, analogue way —we can think of mapmakers using triangulation. Renaissance perspective drawing also involved taking measurements. With 3D scanning, measurements that would be laborious or impossible to take by hand can be captured rapidly and computed. The point to note here is the differences between digital and analogue techniques, but both seek the end goal of a scientifically accurate measured representation of the world. Measurements that were typically taken by hand or estimated via line of sight to create perspective drawings are now being taken using the technologies of digital 3D scanning. Scans are the measurements and proportions of objects in the world. Furthermore, photoreal computer renders created from scratch in a digital simulation can now be based on digital scan data. The fact that the LiDAR scan is essentially a set of measurements also helps to underpin its indexicality.

However, despite the apparent similarities and resonance between Kemp's perspective machines and the operation of a 3D scanner, as well as the fact that both types of machines are designed to acquire and represent three-dimensional forms, there are also some crucial differences. 3D scanner recordings allow for multiple viewpoints around an object, creating genuinely navigable three-dimensionality as the scan can be rotated and examined from all angles, whereas the Renaissance perspective devices always present a static point of view[26]. While there are several variants of 3D scanning, laser scanners might seem close to the ideas behind the perspective machines of Dürer or Alberti’s notion of the “veil” of perspective, other types of scanning, such as photogrammetry, are less suited to this interpretation. Unlike LiDAR, photogrammetry techniques and software do not use a projected ray principle; instead, they analyse parallax in multiple overlapping photographs for common points in the images. From this, photogrammetry deduces 3D coordinates to reconstruct scanned objects. Therefore, the two forms of reality capture are quite different, making it harder to conceive of photogrammetry in the same terms as a Renaissance perspective machine. However, the result of a captured environment or model on a computer screen is arguably the same as a three-dimensional image on paper. No matter what scanning technology is employed, they yield similar three-dimensional perspectival outcomes to the drawings produced by earlier perspective machines.

We can think of this as a genealogy of capture and representation of three-dimensional space imaging that forms a lineage from the 15th-century linear perspective and the perspective machines in the years that followed. The later 19th century invention of photography, and the more recent development of computerised

[26] The capture of navigable three-dimensional space was evident when creating scans from the thesis because the 3D scanner needed to be consistently moved to capture multiple viewpoints.

digital perspectival space, and now with the digitisation of 3D “space” and surface made possible with 3D scanning, all form part of this genealogy. As Parikka notes:

> for a long time visuality was governed in relation to geometrics and calculation, including the perspectival calculations for painters (as famously outlined by Alberti) as well as the metrics of measurement through images for architects (also introduced by Alberti). In our context, this relates directly to the genealogy of photogrammetry.

Parikka, 2021, p.194

It is interesting to note Parikka’s reference to photogrammetry in this context. The artist Clement Valla also investigated the origins of photogrammetry in the publication ‘Surface Proxy’ (2015). In Surface Proxy, Valla wrote about the genealogy of photogrammetry as part of photography, mapping, and spatial modelling history. Valla found evidence of nineteenth-century “photogrammetry” used to produce topographic maps by triangulating points from photographs of the subject taken at many different angles. This process has been described as the “art of making measurements from images” (Paul, 2015, p.83)[27]. Valla reminds us that while 3D scanning may be a modern digital invention, it is based on the ideas and practices of older surveying and perspectival measuring systems.

The digitisation of space, layout and surface and the porting of this data into 3D computer systems, formerly the simulation model's domain, makes us consider if reality capture fulfils Bazin’s idea of total cinema, a total representation of reality. Bazin called the desire for cinema to capture more than a moving image “the reconstruction of a perfect illusion of the outside world in sound, color, and relief”

[27] Valla’s research indicates that in the early days of photography, photogrammetry measurement data collected from multiple photographs revealed that the “photographic referent was no longer situated within a single image." (Brevern, 2011, quoted in Paul, 2015, p.85)

(1967, p. 235). 3D scanning is part of successive technologies of capture that attempt, as Manovich put it, “a more direct access to reality” (2001, p.2). But just as photorealism has become ideal for computer graphics, Bazin’s myth of total cinema capture, he approaches with a degree of scepticism. A “myth of total capture” taken in the context of 3D scanning, falls apart when encountering difficult-to-capture surfaces, shapes, or indeed movement, which is particularly absent from ideas about reality capture technologies as precise and perfectly operating systems of three-dimensional representation.

Nevertheless, we have seen how reality capture is replacing many aspects of 3D computer modelling, scanning is effectively hijacking the computer modelling space, replacing some of the representational roles of the simulated 3D model, and following Manovich’s predicted model of successive technologies enabling a more direct access to reality. This is obvious as simulated and captured models share a symbiotic relationship because they have the same geometric structures and toolsets. The perspectival methods of reality capture rely on an understanding of modelling solid objects in space, usually for representation as a render on a two-dimensional surface. This understanding is closer to what is needed for perspectival drawing and painting than photography. The camera can capture only what is in front of it. Still, the 3D modeller and the painter must simulate walking around things through imagination and perspective technique, to model solid objects virtually. At the same time, the photographer typically stands in one place, while the scan usually is a 360 operation. It follows that 3D scans built from points in space have been closely aligned to perspectival traditions of realist image-making based not just on the illusion created by linear perspective but on marrying this system with actual spatial coordinates to create an accurate layout of objects. As Friedberg noted, these traditions have extended from the canvas to the computer screen, and now go further by including 3D scans reconstructed as 3D models on the computer. 3D scanning can capture spatial data as well as visual appearance, it acquires data on the layout of negative space between things, as well as the textures of those things. I argue that this makes 3D scanning a different tool from the camera; modern-day scanners are closer to digital versions of older Renaissance perspective machines.

3.3 The space scans

Having considered the philosophical relationship between reality capture, space and perspective, I will now start to examine the *space scans* of interiors made in conjunction with this chapter. The decision to scan the interior spaces of houses and enclosed rooms was motivated by common industry approaches that involve scanning an area or space. Where the scan of a room is viewed by placing a virtual camera, and the viewer back inside the scanned room. This struck me as odd because the scanning machine does not know if the scan is of an interior or an object or if the camera should be inside or outside the room. Our perception, expecting the scans to resemble a photograph or a first-person view of a room, leads to these scans being viewed internally. Although, of course, we cannot visualise a room from the outside, as that is not physically possible, but I found that when you create a 3D scan of a room or building interior, it reconstructs as a negative shape of the scanned space in the software. I became interested in exploring these negative captures because, while they seemed to offer a completely new way of looking at 3D scans, this perspective affected the perceived photorealism of reality capture in this context. Photorealism here seems to relate as much to the point of view as it does to photographic textures and the accuracy of captured models. Scanning room interiors also aligns with the scanner concept as a perspective and surveying machine, which made the capture of architecture a natural choice for the “space” category of scans. However, the cluttered spaces of domestic interiors posed a unique challenge for accurate scanning, as they appeared as potential unscannable surfaces.

I found that domestic interiors and workspaces, with their various shapes within a confined area, tested the limits of the scanning technology by presenting irregular forms. Initially, the space scans appeared to capture many qualities of physical environments; they recorded photorealistic attributes of colour, texture, detail, surface topography, and interaction with light. Coupled with the knowledge that the scans were accurate representations of length, breadth, and height, this made them convincing replicas. However, the inverted nature of these negative representations diminished their alignment with traditional photographic framings and 3D renders of similar spaces. This reduction affects their resemblance to conventional photographs of architectural interiors, influencing how the scans are perceived compared to standard photographic images. Unlike cameras and photographs, which, like our own eyes, see and capture an internal image or view of the interiors we inhabit, the scans reveal the negative space between walls, something that cameras cannot do. By focusing on the walls and floors of the scanned rooms, the space scans act similarly to cameras; yet by reconstructing this space as a negative model, they represent a previously unseen view: a reverse of the interior as a solid shape. They create a digital casting of the scanned spaces.

Despite capturing the overall dimensional accuracy of the scanned room, the space scans are not perfect replicas. They include unscannable characteristics that manifest as geometric inconsistencies from the irregular shapes of the spaces and objects within them. In the *space scans*, the provocation of the technology arises not from disruptive materials, but rather from the clutter in the rooms and the irregularity of various interior surfaces. In these scans, overlapping forms were complicated for the 3D scanner to capture separately. The condensed arrangements of objects disrupted the process, rendering them unsuitable for precise scanning (Figure 51 and Figure 52). Household items scanned in the interiors became part of the scan, altering the overall shape of the captured room. This occurred because, instead of using the scanner in perfect conditions, for example, 3D scanning geometrically clean or empty rooms, the scanner (Apple LiDAR in this case) was pushed to its limits by the complexity of the interiors combined with the objects. These interiors included a three-storey house filled with hundreds of everyday items. 3D scanning this space and the jumble of objects within it went against established scanning methodologies. The clutter caught by the scans became a significant disruptive factor, leading to several highly distorted interior scans. The scanning equipment struggled to capture the messy physical confusion of everyday life. This analogue clutter defied the usually ordered, delineated world of digital 3D software systems and geometry models, in which models are neatly separated from one another. In contrast, the dense twisted wireframe geometries of the *space scans* would likely be remodelled or classed as scan failures.

Figure 51. Negative space scans by the author.

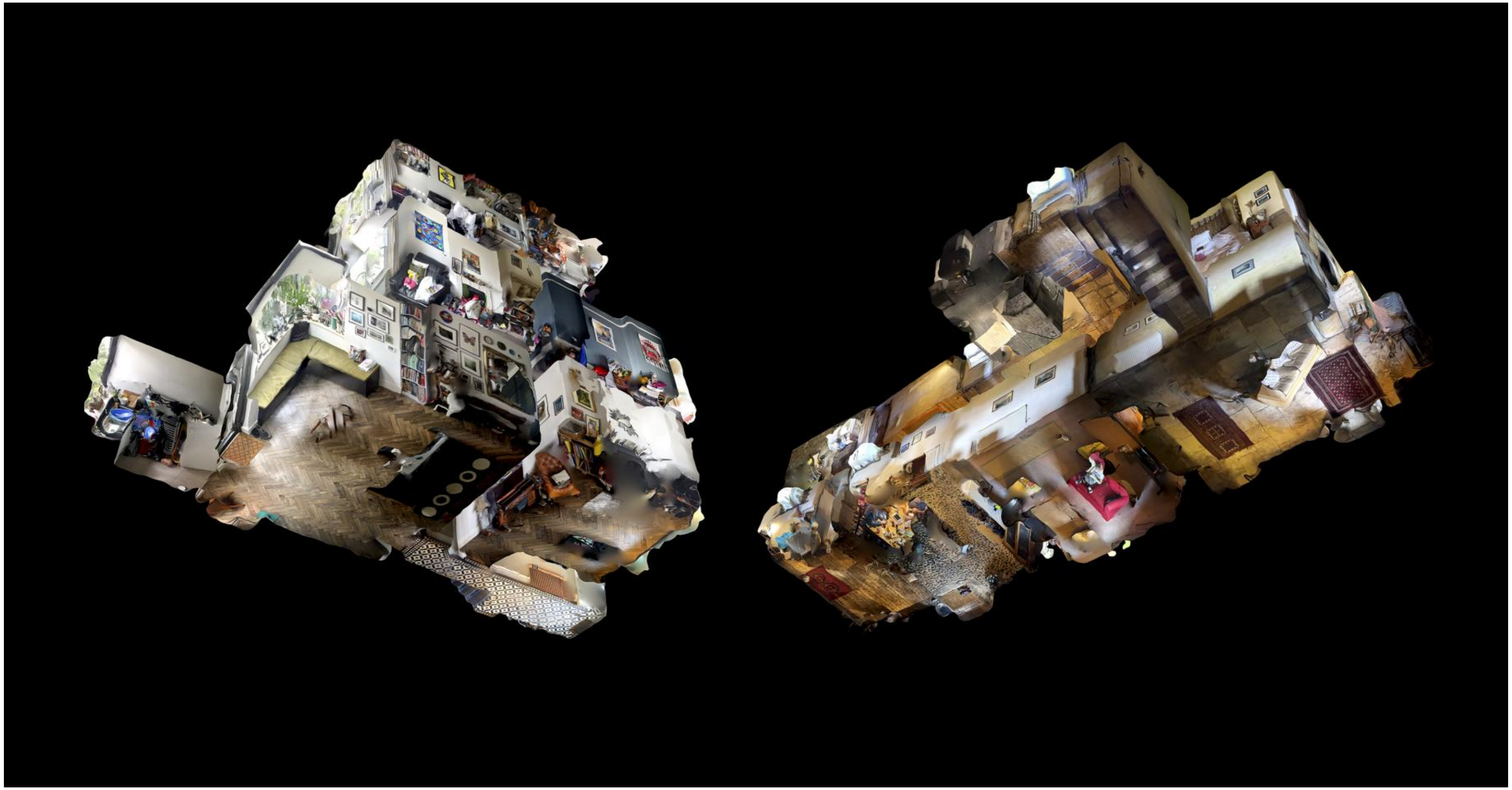

Figure 52. Two house scans, a three-storey London Edwardian terrace on the left, and a 16th-century Cumbrian farmhouse on the right. Scans by the author.

In the scans, irregular shapes, occlusions, gaps, recessions, fine details, and large surfaces, as well as mirrors (which created an illusion of additional space) and windows (which caused the scan to extend outdoors), all contributed to a confused, distorted set of images in which objects and architecture blurred and merged. When the *space scans* were viewed from the outside, the negative shape of the captured spaces was revealed. The scans showed how the rooms and houses acted as moulds, and inward-looking surfaces were captured as a reversed shape[28]. Similar to a physical cast, in which plaster or resin fills the negative space of a mould, the scans captured negative space from within the architectural boundaries. The result is a cast-like appearance; it represents a form of digital footprint of the space captured[29]. These digital casts recorded not only the shape of the room but also the items positioned against the walls, floor, and one another, all of which became entombed within the scanned “skin”. Examples of these captured negative spaces can be seen in the elevations and rotations of two 3D scanned houses (Figure 53 and Figure 54), where the empty gaps between the walls highlight the negative shapes of rooms and objects. In (Figure 55), we can see the negative shape of a bath and an inverted staircase. Similarly, in (Figure 56), minor negative indentations of tool shapes and other objects are softly pressed into the skin of a 3D scan of a workshop. In these images, the scans verge on the familiar. Yet, they appear back-to-front, inside out, and upside down, creating optical illusions reminiscent of an Escher drawing or a distorted version of Trompe-l'oeil perspective. The scans hover

[28] Opening a 3D room scan in the scanning software reveals the capture floating in space, while removing the camera from inside the scan exposes a negative view, akin to a cast taken from a mould.
[29] Unlike a plaster cast or model, all digital 3D models are simply empty polygonal shells rather than solid structures.

between views of familiar domestic imagery and unexpected gaps, distortions, and inversions—an incomplete capture of irregular spaces between objects. These scans might be considered a failure in a representational or photorealistic sense. However, they show us the negative view of everyday interior space, which is impossible to perceive in any other way. They reveal something about the materiality and aesthetics of digital capture, which I discuss in the next sections of the chapter.

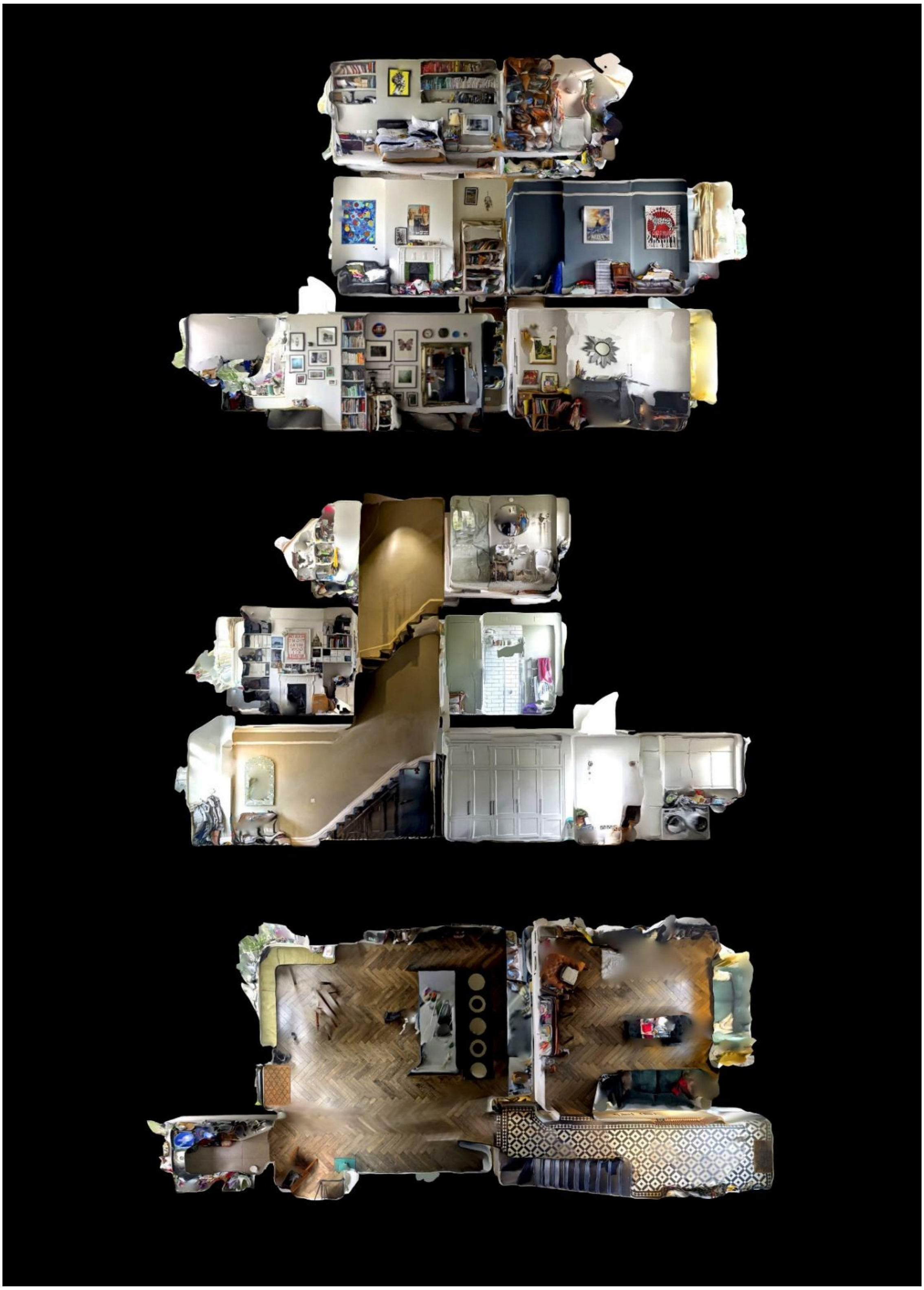

Figure 53. Three-storey London house. Scan by the author.

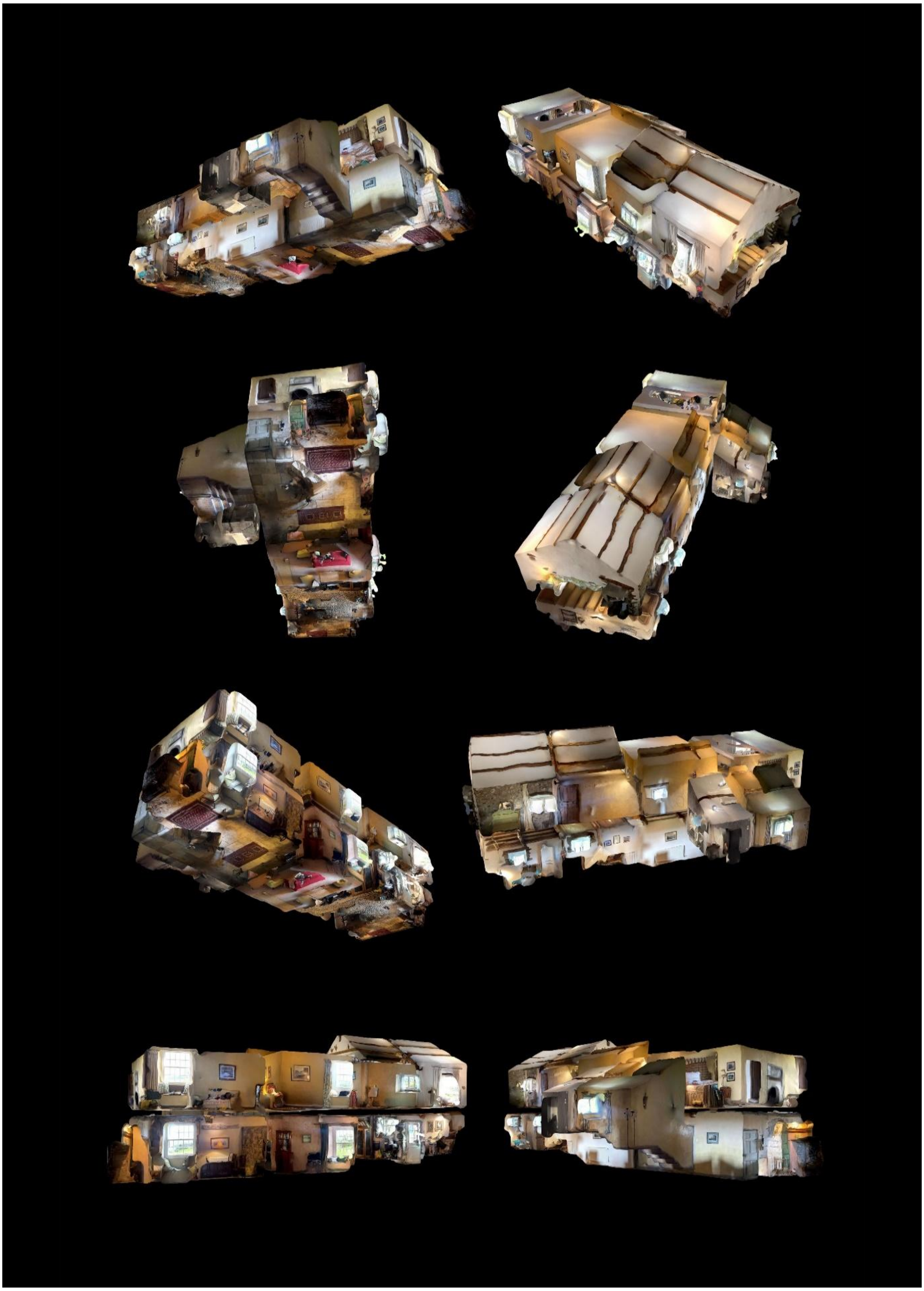

Figure 54. House rotations

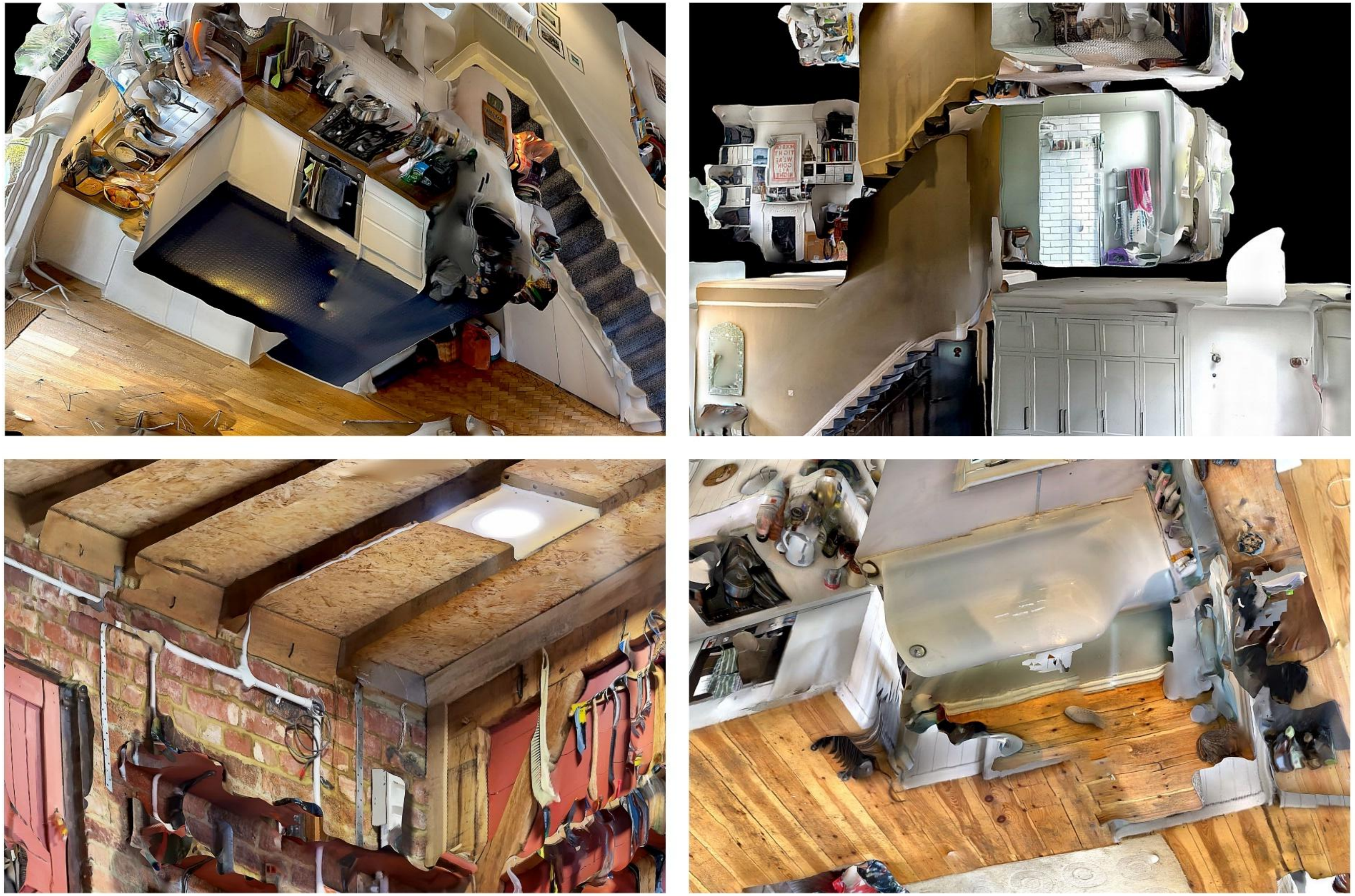

Figure 55. Negative space scans details, by the author.

Figure 56. The interior of a workshop shows objects in the "skin" of the model. Scan by the author.

3.4 Capturing interiors

The *space scans* were captured from various interiors, including domestic rooms, houses, and small workspaces like garden sheds. These interior environments were well-suited to short-range 3D scanners, which could capture 5-10 metres. The 3D scans were made by a newer reality capture technology —Apple LiDAR, available in iPhone Pro and iPad Pro devices[30]. The introduction of the Apple LiDAR sensor in 2020 marked a significant development in the democratisation of

[30] Smartphone apps such as scaniverse.com or Polycom can be used to scan interiors. They use the LiDAR sensor to obtain measurements for geometric mesh reconstruction and the device's camera to acquire high-resolution texture maps that cover the surface of the scans, thus contributing to the impression of photorealism.

reality capture, making it more accessible and cost-effective for projects like this[31]. There is an ongoing debate amongst 3D scanning professionals about whether Apple's sensor can truly be classed as a LiDAR scanner. Unlike Leica or Faro's specialist LiDAR laser scanners, which scan hundreds of metres at much higher resolutions, the Apple LiDAR sensor operates at short ranges. However, it can still achieve resolutions under 10mm. Its range limitations can be overcome by moving the scanner around the site and positioning it close to surfaces (Vogt, Rips and Emmelmann 2021)[32]. The *space scans* created for this project demonstrate that high-resolution renders, detailed large-format prints, and computer animations are all possible using these compact smartphone 3D scanners. The miniaturisation in LiDAR smartphones has been pivotal, allowing creatives to experiment with scanning outside industrial scanning workflows and challenge photorealistic standards and established working methods[33].

Using Apple LiDAR transforms 3D scanning interiors from a slow technical process into a free handheld activity, where the operator holds the device facing the wall and sweeps the smartphone scanner across the surface until all areas have been captured. Alban Denoyel (2021), co-founder of sketchfab.com and a 3D scanning pioneer, likens this sweeping movement to a "sort of spraying gesture, a bit like if I was painting with spray paint" (2021, para. 14). Spraying the surface with UV

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[31] Apple LiDAR, one of the seven types of sensors found on iPhone Pro devices, is particularly effective for scanning rooms with a range of five metres. (Apple 2022).

[32] An evaluation of Apple LiDAR for the Geosciences by Luetzenburg, G., Kroon, A. & Bjørk, A.A. (2021) demonstrated that, when compared to high-resolution scanners, the device was inexpensive, versatile, and user-friendly compared to more complex alternatives.

[33] The inclusion of 3D scanning sensors and high-resolution cameras in modern smartphones has led to the development of many capable 3D scanning apps. This has made 3D scanning accessible to anyone with a phone that supports these scanning applications. This shift from the complex procedures and sometimes prohibitive costs of laser scanning and DSLR photogrammetry to easy-to-use tools has created many high-quality 3D scans. I liken this democratisation to Kodak's invention of the Brownie camera in 1900, which brought photography to many people who previously did not have access to it.

laser light rays shows the multi-viewpoint coverage required, as the person scanning must consider the space in three dimensions. Scanning researcher Peter Ainsworth comments that this is “in opposition to the singular, monocular lens of historic photography” (2020 p.275). Ainsworth refers to the functionality and precision of the high-end LiDAR systems like those used by ScanLAB, which are usually tripod-based setups; in contrast, the *space scans* were handheld and captured entirely freeform. This eliminates the need to triangulate and connect individual scans or use tripods. The freedom of the easy-to-use handheld scanning procedure is very intuitive; technical considerations yield to the operator's relationship with the scanner and the space scan. The reality capture smartphone app encourages exploration through haptic and visual feedback to examine every possible angle. It provides a more immersive scanning experience.

Further insight into the scanning and capturing of interiors comes from comparing the digital visualisation of interiors (a common 3D modelling practice) with the process of scanning interiors. In traditional 3D modelling by building the scene and animating camera movements, the modeller simulates walking around objects virtually; here, when scanning, we physically walk through the room to create the model. Instead of the precise logical method of 3D modelling used to visualise architecture, 3D scanning resembles our interaction with interior spaces, where our eyes constantly shift and look around the space we are in. This “shifting view” is necessary to capture from many different positions and reminds us of how art movements (we can think of examples such as analytical Cubism) have rejected the single viewpoint and foreshortened perspective found in linear perspective or photography[34]. However, reality capture software ultimately edits and merges these various vanishing points when reconstructing the 3D scan into a cohesive digital model.

Another significant aspect of the *space scan*s was how they interpreted walls, floors, and objects as one. Along with the architecture of the space, other items, including chairs, tables, sofas, beds, pictures on the walls, cushions, bookshelves, and even people in the room, were captured in the geometry of the scans. A row of books or a pile of clothes became one with the walls and floor, contained in the edge, the shell, of the scanned space. All these separate forms were incorporated into a continuous digital surface. Artist and researcher Tom Milnes observed how photogrammetry has an “inability of scanning technology to distinguish between different unconnected objects” (2021, p.2). This 3D scanning behaviour of merging separate surfaces into one was originally researched by Steyerl, who said that the scanners' point of view is different because it connects two or more surfaces into one, sometimes making them “indistinguishable” (2012 p.194). Shaw, of ScanLAB, discussed similar behaviour, describing it as “the nature of the scan and its ability not to see through anything but only to survey a skin of its surroundings” (AA School of Architecture, 2015, 16.42). These observations by Steyerl, Milnes, and Shaw are also evident in the *space scans*, where rooms and objects within them are reconstructed as a single opaque skin of geometry. This action by the scanner to combine all surfaces into one form causes the scans to appear as if they have

[34] If we consider photogrammetry, which relies on numerous overlapping photographs to create a scan, each picture has a distinct vanishing point. In software, these are sometimes represented by multiple images (of the scan) framed from various viewpoints. If one was to lay out all the overlapping images, they might look a bit like one of David Hockney’s photographic collages in which objects, places and rooms are constructed via numerous photographs pieced together from different vantage points.

melted into a single amorphous shape. 3D scanning is indiscriminate in its approach; any object that touches another becomes one geometric surface. The technology does not care about perceived delineation or differences between textures and materials. When many objects are scanned in proximity, photoreal separation between surfaces breaks down.

By deliberately scanning very cluttered areas, the *space scans* increased the merging phenomenon further, resulting in an extensive combining of distinct surfaces into one. Disruption of smaller objects saw them embedded like fossils and stretched across architectural structures. Objects like beds or sofas, when scanned, altered the overall shape of the architecture, morphing rooms and buildings into new forms. , creating indents in the room geometry. This created indents and impressions in the geometry, giving the scans a surface reminiscent of furniture shapes pressed into soft clay. The amalgamation of objects led to a different interpretation of space than our experience of rooms and the movable items within them. In these digital scan images, the distinction between architecture and separate objects declines (Figure 57). In contrast to computer modelling, where a wall, sofa, or bowl of fruit would be modelled as separate meshes, the scans are unsuitable as 3D computer model assets[35]. This is because, as we have seen with Quixel Megascans, achieving computer photorealism in 3D modelling and computer animation workflows depends on clean, precise, and mainly distinct models, rather than the chaotic mixture of conjoined, malformed surfaces, colours, and messy polygons observed in the *space scans*.

[35] Usually, the 3D modelling professional cleans up and edits a 3D scan before using it in a computer animation. Modellers work to make 3D models (objects scanned) distinct from each other. Keeping models or scans separate helps the modelling and layout in the digital 3D environment. It also assists lighting, and rendering efficiency.

Figure 57. The interior of a tent with clothes captured. Scan by the author.

The *space scans* combine objects and architecture, while the simulated 3D modeled architecture is logically created, mimicking the separation of objects. Separating objects from their backdrops in the space scans would be very time-consuming and could disrupt potential indexical claims associated with reality capture in these scans. The conjoined forms and surfaces in the *space scans* reveal what raw, unedited 3D scans truly look like. This type of digital 3D imagery is rarely seen in its raw form because of the amount of post-production editing and remodelling that occurs to conform to the standards of photorealistic computer models. The *space scans* do not “fit” preconceived ideas related to photographically framed computer-generated aesthetics and 3D model construction.

We have observed that the space scans do not differentiate between individual objects; instead, they create continuous geometric structures from the landscape of the assembled interior surfaces. The interior spaces influence the scans, resulting in a likeness to these spaces in terms of colours, textures, and lighting conditions present in the environment (these attributes are represented by image textures on the models). However, as virtual copies, the scans do not share the same materials as those captured in the interiors. They lack properties such as reflectance and do not distinguish between or inherit different types of cloth-like or metal material surfaces. The absence of object separation and the limited nature of the material reconstruction in the scans reveal a shortfall in the reality of the capture. There is a parallel here between how photographs do not capture every attribute or physical quality in the world. As New Media theorists Lister et al. (2009) discuss, there are differences between photographs and their depictions. This perspective can also be applied to understanding the differences between the *space scans* and their referent spaces. Lister et al. tell us that in photography, mimetic representation depends on successful resemblance, but they caution that even the most accurate photographs differ significantly from their referents.

> [The] photograph differs from what it represents in obvious ways as a rectangular, fragile, silent, 2-D object that represents a spatially infinite, complex, multi-dimensional, noisy 3-D world. In the case of film or video, sound and movement may be added, but the distance of the image from what it represents is still great. An image of a horse resembles an image of a boat more than either image resembles real horses or boats.

Lister et al, 2009, p. 129

Like photographs, space scans perceive all interior surfaces as unified. However, reality capture enhances the ability to three-dimensionally capture the “complex, multi-dimensional, noisy 3-D world” that Lister et al. describe. This three-dimensional nature arguably replicates the world better than a photograph, making it appealing to proponents of photographic realism, who embrace the medium for its spatial and visual transference from reality (Bazin 1960). Nonetheless, this “noisy” world also presents challenges for *space scans*, which struggle with the dense mixture of shapes and colours. As Lister et al. point out, with photography, the fact that scanners do not differentiate between conjoined surfaces or accurately replicate actual materials makes *space scans* structurally quite different from the places they represent. Thus, there are limitations to the capture.

The representational limitations of the *space scans* stem partly from the inherent operations of the 3D scanner. Danielle Willkens (2019) highlights this issue in her writing on ScanLAB’s LiDAR scans of Sir John Soane’s Museum in London. Willkens observed that scan occlusion caused by objects creates laser shadows in the scans. She notes that reality capture is “like a typical camera, the scanner is unable to record data behind opaque objects” (2019, p.214). This issue can be mitigated by scanning from multiple positions to ensure all sides of an object are captured. The hand-held scanning method used in the *space scans* helped minimise occlusion, as it was relatively easy to reach around objects. However, we inevitably encounter many blurry sections, holes, stretched and mixed-up textures caused by the proximity of disorganised objects. Similarly, discrepancies in the LiDAR scans of Sir John Soane's Museum, according to Willkens, arise from different types of surface properties, which create image noise in the scans. In the space scans, the high density of objects creates a kind of object noise, where the complex arrangement of shapes leads to representational errors, repetitions, object echoes, and aberrations. The 3D scanning industry attributes these errors to inadequate equipment resolution or a need to scan objects and architectural environments separately. The anomalies in the *space scans* result from a world that is not neat or orderly, but inherently messy and spatially complex.

For reality capture to accurately represent its subject matter, it does not necessarily need to align perfectly with traditional visual representations. This is evident in how reality capture modes have evolved to encompass both object-oriented and interior room scanning. These different modes provide insight into how scanners interpret the world. Scanning tools such as Polycam (2022) and Scaniverse (2020) offer functional choices between scanning spaces and objects, with Polycam even employing Artificial Intelligence to mask out backgrounds and isolate objects[36]. These modes demonstrate how scanning technology operates based on proximity and environmental context rather than optical differences, contrasting with photography's typically singular viewpoint, which underpins photorealism.

3.5 The space scans as lived spaces

The scans of rooms, houses, and sheds are more than simple three-dimensional space mapping. Next, I want to consider how the *space scans* represent both a visual-spatial and an experiential record of the lived-in spaces captured. As we have seen, the scans give equal attention to houses and objects alike, but I believe the *space scans* are a visualisation of the experience of human spaces. Here, a well-known text, *The Poetics of Space*, by French philosopher Gaston Bachelard (1958), can help us understand how we interact with 3D scanning and further comprehend its visualisation of domestic space. Parallels can be made between Bachelard’s text, which discusses ideas about the lived spaces of the

[36] Sometimes referred to as 'Area' or 'Detail', the app Scaniverse indicates that “Area” is “Best for rooms and spaces – [using short range] LIDAR” and that the mode “Detail” is “Best for objects with texture - [using] PHOTOGRAMMETRY” (Scaniverse 2022).

“house”, and the representation of interior space we see in *space scans*. The scans are shaped by the objects in rooms and by their occupants, and they are parallel to Bachelard’s ideas and how the scan operator interacts with the space as they scan.

Bachelard discusses how we think of a house as a horizontal and vertical entity, a “geometrical object of planes and right angles” (1958, p. vii). Still, he argues that the house is a place which its human inhabitants shape, it is not a purely rectangular environment. The house is a regular space that contains many irregular objects, which alter our perception and experience of this space:

> In this dynamic rivalry between house and universe, we are far removed from any reference to simple geometrical forms. A house that has been experienced is not an inert box. Inhabited space transcends geometrical space.
>
> Bachelard 1958, P.47

The *space scans* of houses illustrate Bachelard’s philosophical discussion of the house as a geometrical box changed by the random everyday items in it. The scans show how the house is not the box-shaped form that we imagine it to be, but rather as a space confused by what Bachelard calls “human complexity, idiosyncrasy”, where the architecture is moulded by those that live in it and what is kept inside it (1958, p. vii). With the scans, we get the rough shape of the architecture, but as we have seen, this shape is softened, shaped and moulded by the mark of many different objects that have left their imprint on the “walls and floors” of the scan (Figure 58 and Figure 59). The textured protrusions of wooden furniture break up areas of a single colour, while smaller kitchen objects push out from coloured surfaces. The forms of smaller objects not large enough to be picked up in detail by the 3D scanner are seen as textures stretched across the shapes of larger surfaces, caught up in the folds and ridges of the scan (Figure 60, Figure 61 and Figure 62). They illustrate the complex mix of Bachelard's idiosyncratic human artefacts that have adapted the shape of the house scans into a unique three-dimensional representation of a lived space.

Figure 58. A semi-detached London house, rear view. Scan by the author.

Figure 59. A semi-detached London house, front view. Scan by the author.

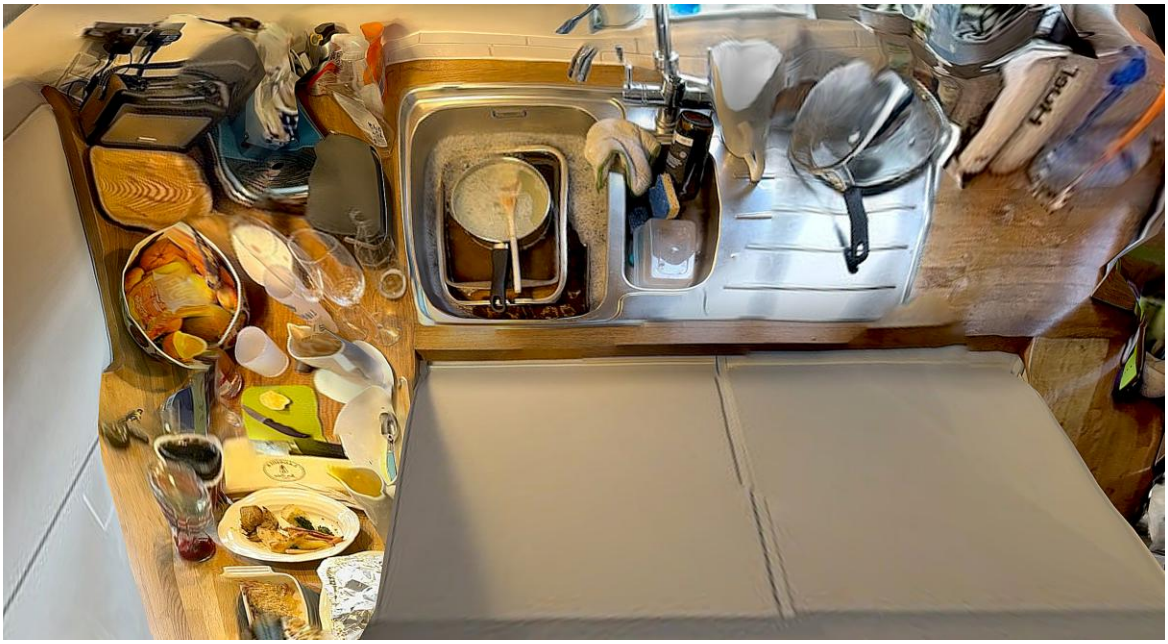

Figure 60. Kitchen detail. Scan by the author.

Figure 61. Kitchen detail. Scan by the author.

Figure 62. Detail showing stretching and softening of sharp edges. Scan by the author.

Another parallel can be found in Bachelard's writing on our relationship to the house through the act of scanning these spaces. The handheld scanner operation inside a room gives the operator choices about which parts of the space to capture. This intimate process not only captures the overall shape of a room but also requires the scan operator to negate the smaller or less accessible parts of a place or object that are generally overlooked. As the person doing the 3D scanning, I found myself wondering whether one should, for example, open a drawer, a cupboard, or a fridge door and scan inside that space, or underneath a bed (Figure 63 and Figure 64). Bachelard discusses these secondary concealed spaces within the house, and we can connect his ideas to interior 3D scanning as a process that probes beyond the limits of an internal space:

> Chests, especially small caskets, over which we have more complete mastery, are objects *that may be opened*. When a casket is closed, it is returned to the general community of objects; it takes its place in exterior space.
>
> Bachelard 1958, P.85

Bachelard's view of contained and container spaces aligns with the action of 3D scanning inside cupboards or beneath beds and tables. Not scanning these additional spaces leaves a noticeable absence in the larger model, where the chests and drawers are forgotten. However, opening a chest and scanning the objects within not only adds further areas to the scan but also creates additional disruptions in the scan's geometry, such as a jumble of crockery or a pile of clothes. This can break the rectilinear nature of an interior architecture scan, as the LiDAR cannot fully navigate around irregularly shaped objects in these hidden spaces, creating a shape that resembles plaster poured into a void but has not entirely reached every point.

Figure 63. Detail of freezer interior. Scan by the author.

Figure 64. Detail of fridge interior. Scan by the author.

Bachelard discusses the “community of objects” to be found in a “primary” space as the architecture of the interior and the objects within it. However, “secondary” closed-off spaces like cupboards raise questions regarding where the periphery of the 3d scan lies. Where are the limits of the space and scan? The computer modelling and animation approach would likely resist ignoring secondary spaces, as they can disrupt the photoreal result. Nevertheless, capturing an interior's “nooks and crannies” accurately portrays that space and our lived experiences of it.

Bachelard’s writing helps us think about our subjective perception and experiences with interior space and the deformational role of objects within the architecture captured in the *space scans.* Where objects create negative space within the rectilinear form of a house, enhancing our understanding of scanning aesthetics of buildings as cast-like concave protrusions.

3.6 Digital casts

This section addresses another central concept that runs through this thesis: the idea of a 3D scan as a digital cast. The inverted shapes of the *space scans* evoke the impression of physical plaster casts (albeit in colour), leading to my interpretation of these scans as digital casts of the negative space between surfaces. The outcomes of the *space scans* share some similarities with Rachel Whiteread's artworks, which involve casting houses and rooms. (Figure 65 and Figure 66). However, before discussing comparisons between the space scans and Whiteread's physical casts, I will first address the concept of digital casts in scans generally. Here, I will consider both positive and negative 3D digital scans as casts of space and form.

Figure 65. 'Sculptural tautology': Chicken Shed (2017), Tate Britain

Figure 66. Interior scans of garden sheds, space scan series. Scans by the author.

The first chapter identifies academics and practitioners working with scanning who have compared reality capture to other media, such as photography. At the same time, I point out the differences (and areas of crossover) between digital scans as replicas and 3D digital models built on the computer. Hito Steyerl was possibly the first to touch on the concept of scans as casts briefly, and this idea was later further explored by Patrizia Di Bello in 2018. The practice of using digital scan technologies in place of physical moulds and casts is illustrated by Factum Arte in their exhibition at the Royal Academy in 2016. Despite these interventions, the concept of 3D scans as digital casts, particularly in terms of their negative, cast-like appearance, remains somewhat overlooked in academic and artistic research.

The term “digital cast” has been used to describe scans of figurative, delineated, positive objects in the round, rather than the mould-and-cast-like process involved in 3D scanning an interior space, as seen in space scans. Digital casting also refers to scanning and reproducing objects as 3D prints or manufactured computer-machined models. Here, digital casting is the digitisation and "re-materialisation" of surfaces; implicit is the critical association of the digital cast with older facsimile methods. (Di Bello, 2018, Lowe, 2020, p.15)[37].

Digital casting is an accurate non-contact extension of mould-making, which Factum Arte liken to the processes of 19th-century plaster casting (Lending, 2020, p.58)[38]. These earlier copying technologies include photographic projections, pointing machines, and plaster casts. Here again, we see an evocation of reality capture as a form of 3D photography or photo-sculpture — essentially a machine for capturing perspective or replicating objects. Despite the differences between analogue and digital technologies, the plaster cast and digital cast are comparable because, as processes of reproduction, they can have similar physical three-dimensional outcomes.

Casting using digital capture was a prominent feature in Factum Arte's installation, *The Veronica Scanner: Live 3D Portraiture*, at the Royal Academy in 2016. The installation allowed members of the public to be 3D scanned and have a portrait that was then 3D printed as a bust (Di Bello, 2018). The exhibition displayed the workings of digital casting as different stages of mediation from scan to software and 3D printed bust. In addition to giving "cultural legitimacy to the new technology" of 3D scanning, the exhibition highlighted the differences between digital casts and photographs (2018, p.115). As a participant who was 3D scanned and digitally cast

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[37] According to UK-based 3D scanning company Superscan, the move from digital capture to casting in bronze is what they call "the new to old technology cutover stage", where we move back to traditional foundry casting techniques" (Superscan, 2023, para. 5).

[38] At the art-historical conference session *From Casting to Coding: Technologies of Sculptural Reproduction from Antiquity to the Present* in 2019, the practice of digital casting was first recognised as part of a genealogy of traditional physical reproduction methodologies.

for the exhibition, observed:

> The camera is a brutal distorter. It distorts according to the shape of the lens. A photograph is the flat representation of a convex image that takes the shape of the outermost part of the lens. This misrepresentation always disturbed me. Everyone knew what I looked like except me... Now, at least I know what I look like.
>
> Wolf, quoted by the Royal Academy 2016, para. 8

Wolf's observation regarding his digital double demonstrates that, in terms of genuine three-dimensionality, a scan can provide a more accurate representation than a photograph, which cannot capture round objects. This is discussed by Factum Arte founder Adam Lowe in his writing about Walter Benjamin's concept of the aura in the age of digital 3D scanning. Although Benjamin did not address three-dimensional reproduction, Lowe nonetheless sees parallels:

> 3D recording and 3D output methods do not feature in Benjamin's idea of mechanical reproduction where a photograph is an image that subjectively records the material world and in turn is imperfectly reproduced.
>
> Lowe, 2020, p.16

Lowe's observation considers new digital recording technologies to rethink Benjamin's ideas on mechanical reproduction. He suggests that 3D scanning can be viewed through two lenses: as a form of digital casting or as an extension of photographic reproduction. Lowe points out that the 3D scan data "can be used in different ways", either as for virtual assets (such as in video games or computer animation) or for physical reproduction of sculpture (Lowe, 2020, p.15; Di Bello, 2018).

To some extent, we have already seen this duality discussed in Ainsworth's critique of the photographic framing of ScanLAB's work. While ScanLAB produces some physical casts of their scans, their primary focus is on imaging and animation scans[39]. Their practice explores histories of photography, and I have experienced firsthand their "dialogue" with photography. I witnessed Shaw and Trussell's observe that they see the 3D scanner as "the next generation of the camera" (Photographer's Gallery, 2015, 5:17). However, Shaw has also commented on LiDAR scans (made during a workshop that I attended), he said they "were closer in kind to sculptures or statues than photographs", implying that scans could be understood in casting terms (ScanLAB Projects 2016).

We therefore have two interchangeable definitions of reality capture: one viewing 3D scans as digitally re-materialised casts to be 3D printed, and another treating them as digital reconstructions (geometric models or point clouds) visualised as images or animations and subject to photorealistic standards. This reflects how the technologies of reality capture are interacting with two genealogies of sculpture and photography. How 3D scans are "read", and how the scan data is used practically, depends on predefined outcomes, framings, and associations with different digital or older established media. As Bolter and Grusin (2000) point out in their assessment of how established media technologies and practices remediate new ones, we can see this happening with 3D scanning.

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[39] For example, in *Frozen Relic: Arctic Works (2013),* ScanLAB cast water as ice in physical moulds made from LiDAR scans of icebergs.

3.7 3D scanning negative space

The *space scans*, I propose, are a form of negative digital cast created by capturing the space between surfaces. These 3D scans invert the environment, producing digital casts that flip the spaces inside out. The result is a three-dimensional geometry covered in reversed image textures extracted from walls, floors, and furniture. To illustrate the effect of scanning negative space in this way, I re-materialised the scans through a collection of small sculptures and maquettes using paper models (Figure 67, Figure 68 and Figure 69). This process involved unfolding and printing simplified versions of the *space scans* to assemble them as physical models, which helped reveal and visually explore the internal volumes captured.

Figure 67. Simplified paper models, space scan series. Scans and sculptures by the author.

Figure 68. Simplified paper models, space scan series. Scans and sculptures by the author.

Figure 69. Simplified paper models, space scan series. Scans and sculptures by the author.

Paper models suited the 3D scans because their raw, unedited forms contain numerous holes and imperfections in the digital mesh, rendering them unsuitable for 3D printing[40]. Also, colour 3D printing can be unsatisfactory for visualising coloured scans like these.[41] These scans may be rejected due to their roughness in a commercial setting focused on precise captures.[42] Creating paper models from simplified 3D models of the scan files somewhat replicates commercial 3D scan retopologisation (simplification) processes that seek to preserve the full-colour texture detail of these scans while economising the scanned data so it may be used as a digital asset. The paper space scan sculptures highlight for the viewer both the vibrancy and detail of the textures found in the digital models, where the coloured textures on the sides of the sculptures resemble flat architectural elevations and the unusual inside-out aspect captured by the scans. As sculptures, they make us aware of the negative space captured and present inverted geometries that can be viewed above and below. This reminds us of how 3D digital scans are reality extractions that lose predefined concepts like orientation, floor, and ceiling when they enter the virtual digital void of 3D software, where a grid anchors us. One downside, however, is that the paper model process loses many macro-level intricacies of the surface details, and I continue to explore ways to fully visualise the *space scans* as physical sculptures without losing their digital materiality. Nonetheless, these paper models

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[40] Disruptions in the *space scans*, caused by features such as windows, mirrors, and the clutter of objects and architecture, resulted in folds, wrinkles, and crumpled areas within the geometry mesh of the digital scan. Consequently, most modelling standards were flawed and challenging to work with in 3D software. Defects in the topology of the geometric wireframe rendered them (in the context of computer animation or 3D printing) virtually unusable.

[41] Most scans are either 3D printed or milled using a new material that does not accurately reflect the colours captured. Although colour 3D printing is possible, it is still in its infancy, meaning it may not fully represent the colour of the digital file. Consequently, 3D prints can appear washed out and may lack visual detail.

[42] The *space scans* highlight the necessity for a scan to be a solid watertight 3D mesh if it is to be 3D printed, as any imperfections may lead to a print failure.

offer an interesting reimposition of familiar geometric shapes, such as houses or shed shapes, onto the *space scans*, which, as raw data, only roughly resemble architectural forms[43].

The space scans are covered in reversed textures, showing the insides facing outward. These textures illustrate how the scan shape was formed and moulded by the interiors and surfaces in the rooms. To understand this "negative" action further, we can consider what a physical mould represents. Curator Peter Weibel, in the exhibition Negative Space (ZKM **|** Centre for Art and Media Karlsruhe, 2019), describes a mould as follows:

> [The] mould is the solid negative impression of an object, which is used to give plastic substances a desired form. For instance, a plaster cast is taken from a face; the mask is the concave negative of the face's convex shape. This mould may be filled with wax, for example, creating a three-dimensional representation of the real face.
>
> Weibel, 2019, p.46

The *space scans* contrast with Weibel because the surfaces in the room act as a convex positive, and the scan produced is in the concave, flipping Weibel's description. The 3D scan is like a virtual plaster poured (or sprayed) into the interior.

While the original understanding of a digital casting is based on capturing positive forms, the scanner functions more as a mould-making device. The *space scans* act by casting the voids and gaps between walls and surfaces, reversing the definition of digital casting, and it is this inversion that provides a new negative definition. The *space scans* show previously unseen, solidified negative views of our

[43] Modelling was necessary to edit the space scans to create a paper model. The raw scans were transformed into a basic rectilinear 3D form; some surface detail was lost during this process, but the overall architectural geometry (negative) was preserved. The textures remained unchanged and were retained on the sides of the models.

spaces. This view contrasts with our own experience of interior space, but it represents Bachelard's ideas about houses as "lived" spaces and how these interior spaces reveal new perspectives of these environments.

The standard view of an interior of a room scan is also reversed. This interior viewpoint comes from all computer geometries being hollow. Typically, the practice is to place a virtual camera in the middle of a 3D scan of an interior space. This re-establishes a first-person view; the viewer is returned to the point of capture[44]. The internal first-person viewpoint aligns with ideas of photorealistic framing. For example, photographs of interiors or 3D architectural renders are typically visualised from the inside as if we were standing in the building. This perspective reinforces a realist expectation of how a room "should" appear and be navigated in three dimensions.

However, changing the camera position, whether inside or outside the scanned space, dramatically alters our perception, shifting the scan from positive to negative (Figure 70 and Figure 71). This raises an important question: why visualise the space scans negatively when they could be viewed from within? (Figure 72 and Figure 73) When opening a 3D scan file, I found that it initially loads from a third-person perspective, looking at the reconstructed space from outside (Figure 74 and Figure 75). In the digital 3D space, this external perspective is unfamiliar and unconventional. While the inclination may be to move the camera inside the scans, the third-person perspective allows us to conceptualise the scan as a negative digital cast. By choosing to render and present scans as they are first encountered, in their raw external form, we see them detach from the first-person photographic view of an

[44] The first-person flythrough view is typical of scans created for real estate walkthroughs. Third-person perspectives are a common viewpoint in video games. Players see the game from behind and above their character, rather than through the character's own eyes.

interior. This gives the scans a footprint-like quality that emphasises the absent architecture (Figure 76).

Figure 70. An interior scan is viewed externally in the third person.
Scan by the author.

Figure 71. An interior scan is viewed internally in the first person (detail).
Scan by the author.

Figure 72. A scan of a staircase viewed externally in the third person (close-up).

Figure 73. A scan of a house viewed internally in the first person (detail).

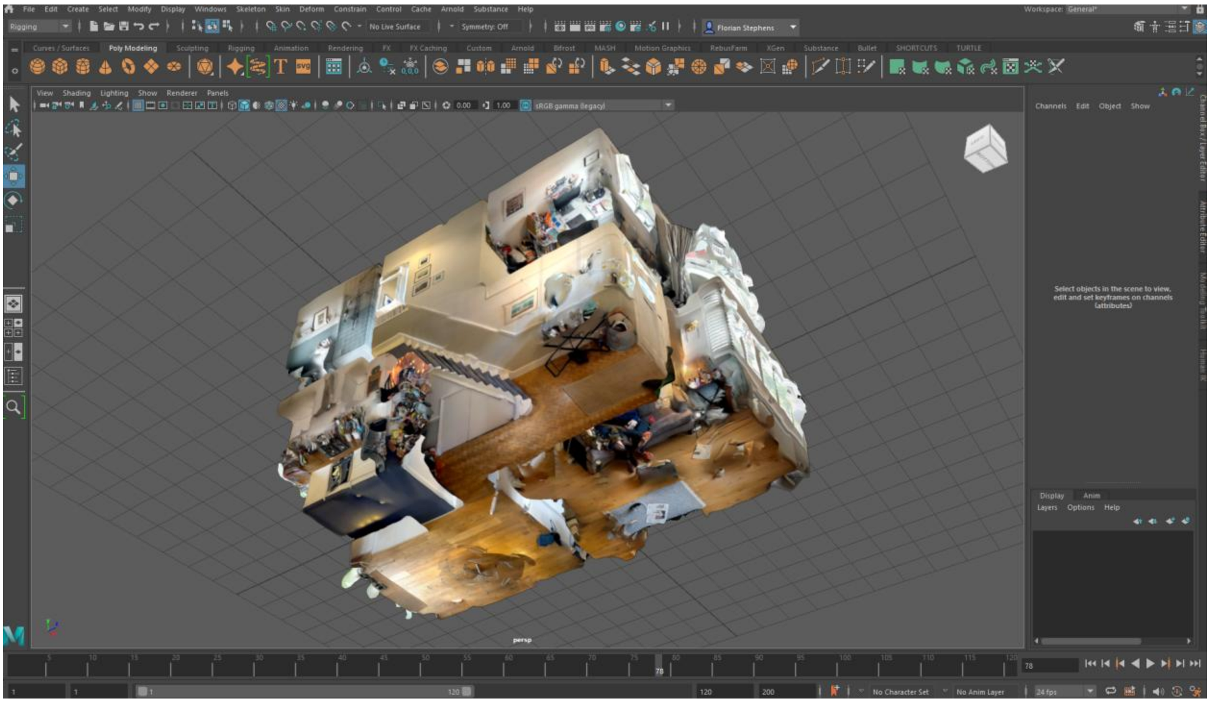

Figure 74. This is a house interior scan as it opens in 3D software. The software does not distinguish between the inside and the outside of the house model. Scan by the author.

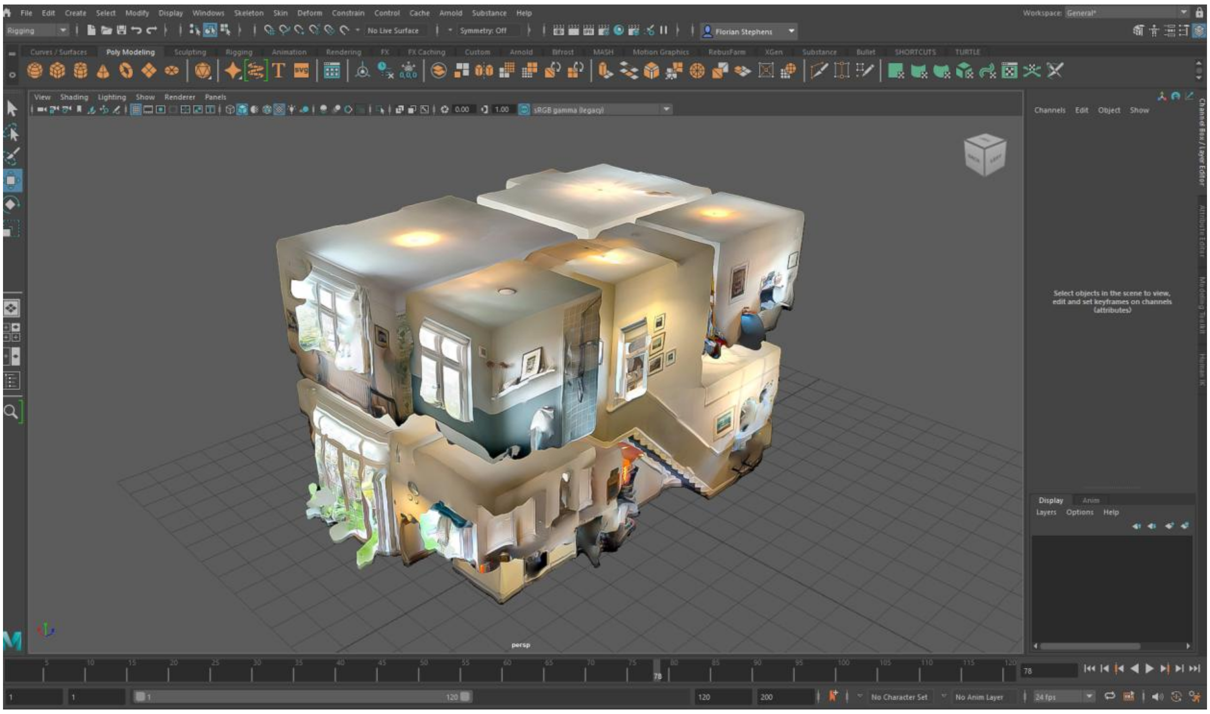

Figure 75. A house interior scan as it opens in a 3D software. Scan by the author.

Figure 76. A house scan with and without textures.

Comparing renders of *space scans* to architectural scans created by ScanLAB, we can see a difference between the positive viewpoint of ScanLAB's scans and the negative forms of the *space scans*. ScanLAB often presents semi-transparent point clouds set against a black background, giving their scans an X-ray-like appearance. This aesthetic allows animated flythroughs that traverse solid walls to reveal hidden spaces. This choice aligns with the transparent nature of LiDAR point clouds. However, the *space scans* are not point clouds, but shaded models with solid appearance. Perhaps a more suitable comparison can be made between the *space scans* and the physical casts of interiors by Sculptor Rachel Whiteread. Viewing the *space scans* through the lens of Whiteread's casts of architecture can help us better understand the relationship between the *space scans* and negative space.

While there are apparent technological differences between analogue methods of casting and digital reality capture methods, as well as between the multi-coloured captures of the space scans and the solid, minimal materials of Whiteread's work, Whiteread's mastery of negative as a medium offers a valuable perspective. Art critics and historians have extensively discussed Whiteread's casts. Artist-curator Peter Weibel (2019) describes them as:

> ..mediations on positive and negative, convex and concave, mould and casting, inside and outside. The casts she uses as positive forms unsettle our idea of space, for they turn the internal concave into the external convex.

Weibel, 2019, p.46

Similarly, the reversed nature of the space scans disturbs our perception of space. They represent the negative viewed as a positive, much like Whiteread's plaster and concrete, only in this case, digitally. In the scans, concave surfaces become convex when rendered in 3D or assembled into paper models.

Author Charlotte Mullins (2017) provides useful insights into Whiteread's sculpture; in her descriptions of the piece, we can find ways to understand and analyse the space scans. Mullins says of the piece HOUSE (1993), "the building became a mould." Just as Whiteread used buildings as moulds for her sculpture, the house and interiors in my scans act as moulds for the captures 2017, p.52). Reflecting on Whiteread's GHOST (1990), a concrete cast of a Victorian living room, Mullins notes, "everything appears in reverse," and the space scans are also disorientating reversals (2008, p.23). Mullins uses adjectives such as "recessed" "bulging" and "solidified" to describe qualities of Whiteread's cast forms. Again, these words help articulate the *space scans*' different shapes. However, there are differences between Whiteread's concrete surfaces; the space scans are not solid but hollow digital shells. The surfaces have breaks and gaps through which it's possible to peer and see the inside (Figure 77 and Figure 78). Another difference is how the interruptions caused by the objects and fittings in the scanned interiors lead to a more fragmented and less geometrical structure than Whiteread's clean, solid form casts.

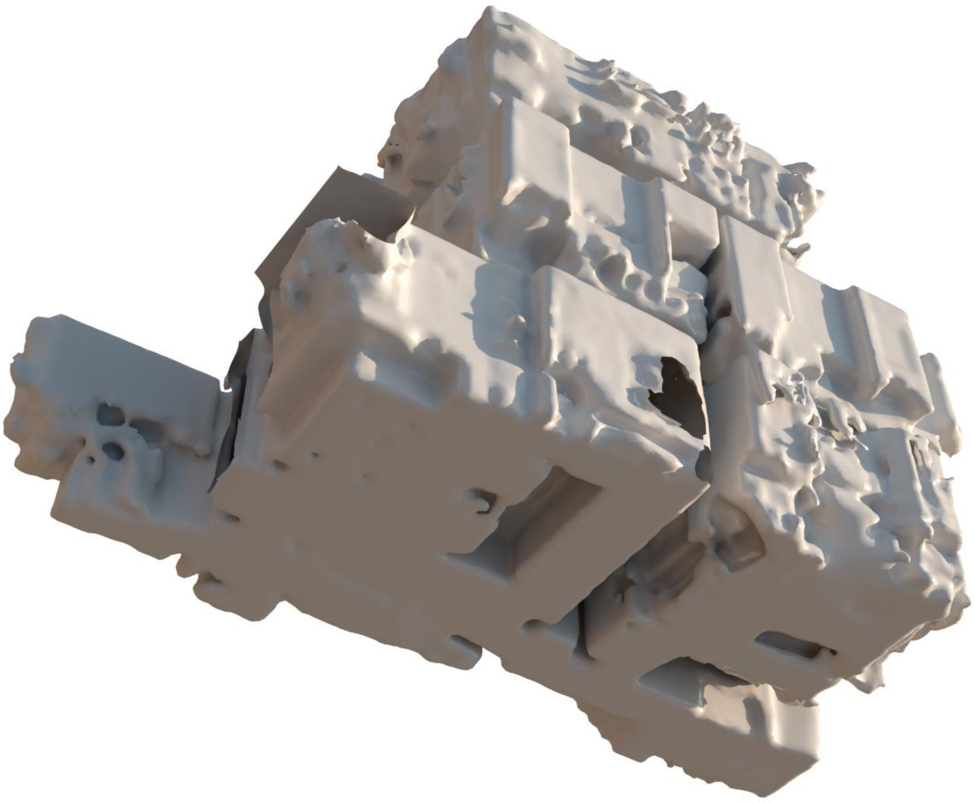

Figure 77. A London house scan rendered without textures. Scan by the author.

Figure 78. HOUSE (1993) Rachel Whiteread.

Mullins remarks that Whiteread's GHOST 'mummified the air in the room' and that Whiteread's sculptures resemble peeling away death masks (2017, p.23). This notion of casts and mummification evokes Bazin's description of the action of photographic film, which he suggests "mummifies" the changing world as it captures and preserves it indefinitely. Similarly, Mullins notes how GHOST encapsulates time and the air in the room. The *space scans* digitally preserve and solidify a moment in time; they record the light, shadows, colours, the arrangement of objects, and people caught in the scans. As Mullins says of GHOST:

> The cast just like the photograph, records a moment that can never occur again; the present has become the past and the future will not, cannot, alter this snapshot of time captured.
>
> Mullins, 2017, p.46

The scans immortalise surfaces at a point in time, a moment caught in three dimensions. However, the scans differ from Whiteread's casts because they are non-contact, non-destructive digital rather than physical capture. Whiteread's casts often result in the "destruction of the original object" whereas the scan of this project did not damage any of the interiors scanned (2017, p.135). In the *space scans,* surfaces remain and continue to change and are inhabited after the scan has been completed. Another difference is that the *space scans* eerily capture people in the room at the time, their blurry shapes recessed into the body of the scans (Figure 79 and Figure 80). Whiteread's sculptures are minimalist, deliberately marking the absence of past household objects and people. In *GHOST* and *HOUSE*, no people or objects are captured; only the fixtures and fittings remain.

Figure 79. People caught in a space scan of a suburban house. Scan by the author.

Figure 80. Details of people caught in the 3D scan. Scan by the author.

On the other hand, the *space scans* capture everything in the lived spaces. Nothing was removed from the houses and shed spaces before 3D scanning, making the *space scans* anything but minimal. They capture everything within an inhabited space. While Whiteread's sculptures capture hints of past fixtures, the *space scans* seem to carry the objects with them, embedded in the walls of the scan. Household objects become interred disruptions in the geometry of the spaces scanned. Where the scanner hits a bare wall, much like a physical cast, it picks out architectural references, "reveal[ling] the shape of the walls, fireplace, window, door, skirting and cornice" (2017, p.23). These architectural references ground the scans, offering iconic features we recognise as an indexical trace of their referent spaces.

However, jumbled objects get between the scanner and the wall in more chaotic areas, obscuring recognisable features. This results in blurred surfaces, gaps, folds, ridges, and a scrambled, irregular wireframe geometry. These chaotic elements contrast sharply with Whiteread's minimal suggested traces and monochrome works. Mullins attributes part of the power of Whiteread's work to the hints and material traces captured by the casting process. She notes the marks of soot from a fireplace, or bits of paint picked up by the plaster; these are "visual reminders of those lives remained" (2017, p.23). In the space scans, rather than trace-like reminders, we see dominant, conspicuous shapes and vivid colours that serve as reminders of what existed at the time of capture. The *space scans* are technicolour versions of Whiteread's conceptually considered deliberate one-to-one scale sculptures such as GHOST or HOUSE.

3.8 The space scans as indexical imprints

Another question that connects with one of the central themes of the thesis is: Are the negative digital casts of the space scans indexical? The literature on photographic indexical realism often draws parallels between photographs and physical impressions, such as moulds or casts. This concept of photographic indexicality suggests that photography captures a stencil or impression of reality akin to physical imprints such as casts or footprints (Sontag, 1977). To support my argument that the space scans function as indexical digital casts, this section further investigates notions of photographic indexicality as a stencil of the real. Indexical observations of Rachel Whiteread's artworks also help to demonstrate how digital 3D scans create indexical imprints, similar to the process of physical indexicality associated with plaster casts. The aim is to highlight indexical parallels between photographs, physical moulds and casts, and their digital scan counterparts, showing how, despite their inherent photorealistic limitations, space scans and other 3D scans serve as indexical imprints of places or objects.

Despite the apparent dimensional differences between photographs, moulds, and casts as physical and light-based recording processes, the association between photographs and physical impressions has often been referenced in academic writing to support the photographic concept of indexical realism. Can we not, therefore, extend this idea to digital 3D scans, which serve as actual digital imprints of the captured space? In the first chapter, I collected evidence that the digital realm can retain an index, providing examples such as motion capture and citing research for digital indexicality from scholars including Gunning (2007), Soderman (2007), and Wolf (2000). We can now apply this concept of the photographic index (as a mould or impression), created through light, to the digital *space scans*.

Bazin and Sontag both compared the photograph to a death mask, which, as Geimer (2007) notes, involves clay or plaster. Bazin says that the photograph is an “automatic process”, likening it to a moulding, where an impression is taken “by the manipulation of light” (1960, p.7). He suggests the photograph is like a fingerprint, which shares a commonality with its referent. Sontag characterises the photograph as “a trace, something directly stencilled off the real, like a footprint or a death mask” (1977, p.120). Krauss also notes that an index is like a footprint, or a mark left behind by something. She writes that the index can be a “type of sign which arises as the physical manifestation of a cause”, giving examples of traces, imprints, and clues (1977, p.59). The reference to the plaster death masks as a negative cast of a face has frequently appeared in support of photographic indexicality, leading us to think of the *space scans* as a digitally inverted index.

Further evidence for using physical imprint metaphors to explain photographic indexicality can be found in academic writings on the index. Geimer describes the index as a mark “lifted from” or peeled off a surface, physically transmitted by being pressed into something else (2007, p.10). In referencing Sontag on death masks, Geimer suggests that the index results from a bodily impression in a material that resembles its model and serves as a remnant. This Bazinian interpretation equates the photograph and its referent (the model), which can also be applied to the *space scans*. These scans function as moulded imprints of the original model, in this case, the scanned house, appearing as though they have been pressed into and peeled off the textures of the interiors. However, unlike physical peels or stencils, 3D scan texture maps are automatically generated from numerous photographic fragments. These fragments are divided and reassembled across the surface of the space scans like an intricate jigsaw puzzle (Figure 81 and Figure 82). This distinction between how the textures are captured and reconstructed in *space scans* versus traditional methods that use physical impressions or prints highlights a difference between analogue and digital casts.

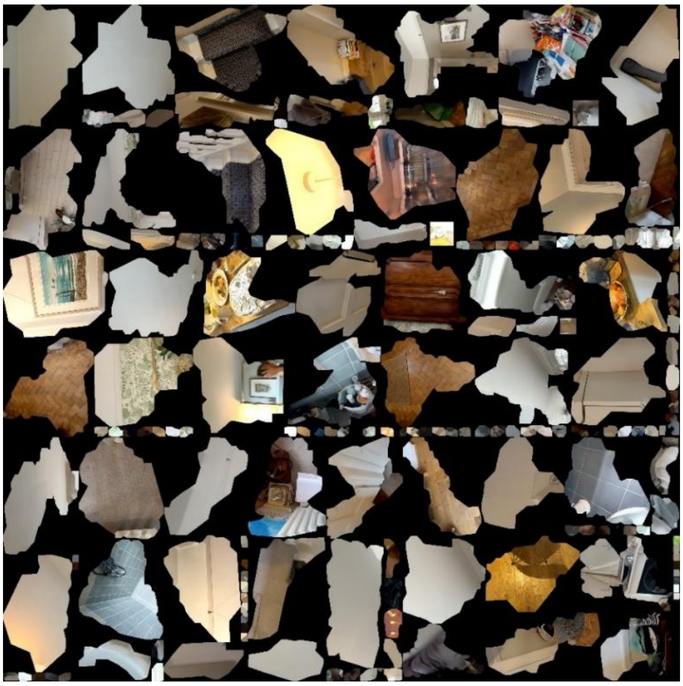

Figure 81. Polycam iPhone scanning application texture management.

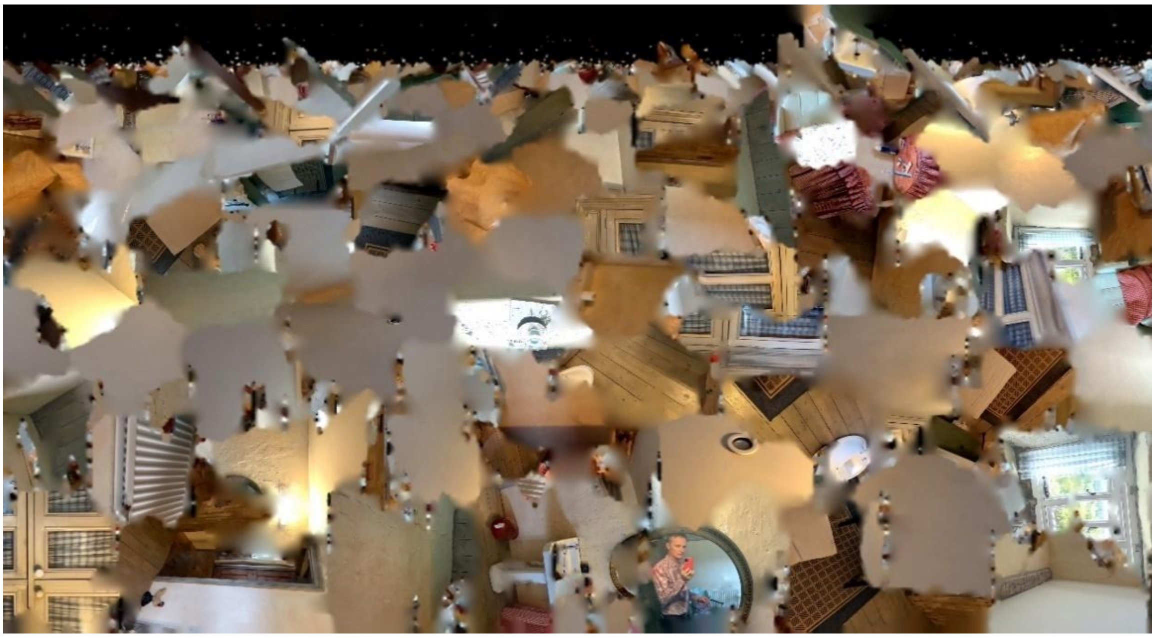

Figure 82. Scaniverse scanning application texture management.

Despite the differences between analogue and digital casting, space scans can still be considered digital impressions or mouldings. These scans appear to carry something over from the original, as seen in the moulding action of the referent interior architecture, resulting in negative-shaped surfaces. The shape of the scan is generated through laser measurements that assess depth and contour, with laser light playing a crucial role in connecting referent to sign, a key component for indexicality. This is supported by Doane (2007) and Geimer (2007), who emphasise the role of light in establishing indexical connections. Even in photogrammetry, which uses secondary light captured in photographic data sets to create 3D scans, natural light still plays a key role. Barthes describes this as “the luminous rays emitted by a variously lighted object [being] an emanation of the referent” (1980, pp. 180-181). These light rays make and link the image (or in our case, scan) to the referent, as Bazin says: “the photographic image is the object itself” (1960, p.8).

Comparing space scans to plaster casts or moulds illustrates how different analogue and digital techniques can achieve similar outcomes. 3D scans use both visible and non-visible light; they rely on transmitted light, including the “second-hand” light from photographs in photogrammetry. The analogy with photographs, death masks, or plaster casts helps explain the indexicality of the space scans, particularly when discussing their negative shape. Ultimately, the role of light may confirm their indexicality.

Bazin also used another analogy for photography that I have already mentioned: the process of mummification and preservation from death. He suggested that photographs fulfil a desire to escape death by freezing a moment in time. He likened photographs to relics, noting that both photographs and relics benefit from a transfer of reality. He used the example of the Holy Shroud of Turin, arguing it “combines the features alike of relic and photograph", being both a physical material form and a resemblance (1960, p.8). Just as plaster casts retain traces of material left behind on the surface, *space scans* resemble relics, as they suggest or incorporate physical form and a photographic after-presence in surface texture. Relics exhibit indexicality as part of the original, yet they also make us aware of the absence of the original. The *space scans* are also “a certificate of presence,” capturing a cluttered moment in time of the original place (Barthes, 1980, p.87). Sontag also noted that photographs embody both presence and absence, capturing what was there while, like a relic, emphasising what is no longer present.

The *space scans* capture the shape of a room, but their negative appearance does not resemble the room itself. Here, we can refer again to the sculpture of Whiteread, whose work has been described as indexical. Joan Gibbons (2007) says that through its indexicality, “memory” is present in Whiteread’s artwork. According to Gibbons, Whiteread’s casts are indexical because they disrupt traditional casting approaches by stopping at the negative stage, instead of replicating a positive object, Gibbons explains:

> Many of Whiteread’s works are not replicas of the originals, as would be the case when the mould is used to recast the object. They present the inverted surfaces of the first stage of the casting process in three dimensions so that a negative of the object is rendered that corresponds to the original detail for detail and mirrors the size and scale of the original but falls short of actually reproducing the original. This shortfall alters the presence of the object from the here and now to one of absence or of “the thing that has been there”, to invoke Roland Barthes’ characterisation of photographic indexicality.

Gibbons 2007, para. 6

Whiteread's pieces, as Gibbons notes, are inverted replicas from the first negative stage of casting, establishing a direct indexical link to the original surface. Similarly, the *space scans* also stop at the digital equivalent of an initial negative from a mould. Like Whiteread's casts, the scans do not produce a positive digital replica but evoke an absence of what was there. In her text, Gibbons discusses indexicality in other media. While recognising the clear indexical nature of physical casts and analogue photography, she is critical of the digital. She sees it as a threat to the index due to the "ability to produce pure simulacrums" (2007, p.30). While I believe digital indexicality exists in these scans, as I mention elsewhere in the thesis, simplifying or manipulating scans in post moves them closer to simulacra. For example, creating a positive version of the *space scans* may dilute its indexical connection to the original surface by taking it beyond a straight copy of the original.

Gibbons is concerned about the degeneration of the index in digital contexts, and she notes that Peirce pointed out the index was vulnerable and "rarely existed in a pure form" (2007, p.30). Gibbons explains that Whiteread casts are not first-order indices like a shadow but are close to it, as they are separated from their referent by a release agent, a fine non-stick liquid, on the surface before casting. This barrier allows the mould to easily detach once set. On the other hand, the *space scans* are non-contact digital casts that require no release agent barrier, potentially bringing their indexicality closer to the referent surface than a physical cast is capable of.

In her discussion on the indexical nature of Whiteread's sculptures, Gibbons refers to Peirce's original semiotic definitions. Peirce said that photographs are a special case, functioning as icons and indices; photographs are unlike most indices, which have "no significant resemblance to their objects" (1931, p.172). Gibbons notes how plaster moulds, through lacking colour, possess an iconic quality due to their inverted resemblance, and she says that they are naturally indexical. The *space scans* resemble the room surfaces but as reversed representations. Unlike traditional moulds, digital scans can capture the colour and light in the room. Yet their indexical precision as a true negative complicates these mimetic qualities. Their external negative form diminishes the iconicity of the space scans, and the lack of internal viewpoint is disorienting, disrupting first-person photoreal perspectives.

The *space scans* disrupt photorealistic resemblance with their negative forms. As inverted representations, they contain numerous holes, irregularities, and overlaps. Rather than detracting from their indexicality, these imperfections highlight the limitations of the scanning process; they are like incomplete plaster casts where the material fails to fill the cast. These disruptions are indexical because they reveal the scanning medium at work and how it digitally interacts with surface details in a tight space. We observe the scanning medium grappling with the intricacies of jumbled objects, attempting to navigate behind objects in the interior space. These imperfections and artefacts are a direct result of both technology and surfaces. Digital scan artefacts caused by this interaction can be regarded similarly to photographic distortions, film grain, or optical lens distortion found in photography. Blur in photography has often been viewed as indexical by photographic theorists, and scan artefacts such as inverted shapes or imprinted objects on the sides of the scan are unique to the medium as digital traces authentic to the scanning space.

Peirce wrote that indices are “modified” and “affected by the Object; [the index] necessarily has some Quality with in common with the Object” (1931, p.143). The scans share a quality with the room's shape; they prompt us to think about that shape beyond simply our direct experience of it. The indexical attributes of the space scans can be summed up with a quote from Peirce who tells us about photographs as signs:

> ..are very instructive, because we know that they are in certain respects exactly like the objects they represent. But this resemblance is due to photographs having been produced under such circumstances that they were physically forced to correspond point by point to nature. In that aspect, then, they belong to the second class of signs, those by physical connection.
>
> Peirce, 1931, p.159

Similarly, the *space scans* maintain a direct laser connection to the objects they represent. Technologies like LiDAR capture reality in a “point by point to nature” manner, where a laser reflects off a surface to create an exact point in a 3D point cloud. The space scans reflect the shapes of the architecture and are produced through short-range laser reflection. Like Whiteread’s casts, these scans are generated by technology that physically compels them to correspond point by point to their referents. Furthermore, as Gibbons observes of Whiteread’s artworks, their cast-like resemblance underscores their indexicality. Yet, their inversion challenges photorealistic perceptions of the scans as digital computer models and our typical perception of a room as a familiar internal space filled with convex surfaces. With their disrupted negative shapes, the *space scans* become uncanny icons, digitally demonstrating Peirce’s concept of the index in action.

3.9 Conclusion

The chapter began by examining how LiDAR technology can be considered a modern evolution of earlier perspective drawing and measuring machines that also “scanned” to create accurate three-dimensional representations. I argued that the LiDAR scanner could be seen as an indexical measuring machine, conceptually aligning with Peirce’s semiotic idea of point-to-point correspondence, where a wire-like description of a laser point on an object connects to a point in a photographic image or, in this case, a digital LiDAR scan. Although the space scans were found to be imperfect digital replicas created in complex, sometimes unscannable conditions, they remain indexical because they prompt us to think about the referent interiors that were scanned. At the same time, the scans embody the medium's specificity, how it behaves like digital plaster casting, seeing different surfaces as a continuous whole rather than as discrete objects. The comparison to Whiteread’s work provided a lens through which to understand this process, where space scans functioned much like an indiscriminate casting material that enveloped the interior spaces. However, unlike Whiteread’s minimal sculptures, the clutter of everyday environments presented challenges to the digital medium, creating gaps, holes, distortions, and other imperfections. This prompted discussions about how we interact with domestic space and the discrepancy between how we view or (photographically) frame a space compared to its physical construction. The contrast between the positive interior space and the negative shaped scan unsettles conventional ideas about digital 3D models. Instead of distinct, neatly formed geometries, the negative scan produces a new model where individual meshes are replaced by a continuous surface, an almost incomprehensible form where all objects merge into one whole. However, this negative digital cast result underscores the indexical nature of the space scans.

4 Chapter 4: Mirror and glass

4.1 Introduction

Reflections are natural phenomena almost as ubiquitous as shadows.

Hockney and Gayford, 2020, p.108

What happens when you attempt to 3D scan a mirror or glass? This presents an interesting problem for reality capture technologies. While commercial scanning practices typically avoid or mitigate the effects of reflectivity and transparency, this chapter thoroughly examines how shiny, reflective, metallic, and transparent glass materials impact photogrammetry-based digital 3D scans. As part of the scanning research practice, I focus on 3D scanning extensive collections of scanned glass, mirrored, and metal objects created for and integrated into this chapter. The *mirror and glass scans* aim to push the scanner to its representational limits by attempting to scan challenging to capture transparent and mirror surfaces. In addition to my own 3D scans, the chapter reviews examples of others scanning similar materials and surfaces; it explores industry debates on the scan disruptions caused by reflections and transparency and how these surfaces affect reality capture photorealism. ScanLAB Projects, the primary industry case study of the thesis, features again in the chapter for their LiDAR experiments with reflections and transparencies. Their LiDAR scans of mirrors reveal a through-the-looking-glass effect, capturing an additional spatial reality that photographs cannot.

Mirrors and glass cause some of the most well-known scan disruptions. These surfaces lead to multiple distortions in photogrammetry models or misaligned LiDAR point clouds. Disruptions by reflective and transparent materials raise questions: Are these faults in the scanning process or unique kinds of scan readings that reveal previously unseen aspects of captured reality? As we saw with the negative space captures of the *space scans*, disruptions may be new types of previously unseen 3D scans. This chapter illustrates how scans of mirrors and glass reveal novel views of optical phenomena that significantly differ from traditional photographs of the same surfaces. It illustrates how a scan of a polished metallic, mirror-like surface reveals multiple reflections as overlapping viewpoints distorting the scan geometry. Transparent glass seems to soften rigid shapes into molten-looking forms, capturing and fixing fleeting refracted light in the digital textures of the 3D scan file.

Throughout the chapter, the practice demonstrates how the *mirror and glass scans* resist conventional photorealistic framings applied to photogrammetry scans. As 3D digital models and geometries, these scans do not fit the photorealistic standards of similar computer models. In 3d software, digital representations of reflective and transparent surfaces are simulated to appear as they would in a photograph or to our own eyes. Scans of reflections and transparency can therefore be unsettling because they challenge accepted notions of photographic realism and significantly differ from our visual experience of optical phenomena. The *mirror and glass scans* produced for this chapter challenge scanning technology to capture these materials at a scale not previously attempted before.

The scans systematically investigate what occurs when scanning different reflective and transparent surfaces. The setups scanned during exhibit numerous reflective and refractive optical effects, and images produced from the scans of mirrors and glass are discussed concerning debates on computer-generated photorealism and digital indexicality, including 3D scanning. I present evidence of indexicality in the mirror and glass scans, particularly when scanning transparent objects. While scanning, transparent surfaces evade LiDAR yet leave a visible trace of their shape, resembling a photogram of a shadow or silhouette and serving as an indexical marker.

Towards the end of the chapter, I explore the relationship between photogrammetry and computer photorealism, which can struggle with capturing mirrors and glass. Lastly, I review emerging reality capture technologies that utilise machine learning and artificial intelligence for their ability to accurately capture, represent, and predict the behaviour of mirror reflections, transparent surfaces, and other optical effects.

4.2 Scanning reflections and refractions

Reflective and transparent glass surfaces create complex optical effects, including fleeting reflections and refractions that have traditionally posed significant challenges for reality capture technologies. At the beginning of this chapter is a quote by David Hockney, in which he discusses the difficulties of painting constantly changing reflections and the movement of light on the surface of water. Reality capture encounters a similar challenge when scanning glass or metal surfaces. These materials disrupt conventional photogrammetry, requiring images of still objects with static features and unmoving surfaces. However, optical effects naturally occur when the camera moves around a shiny glass or metal surface to photograph it for photogrammetry. The ever-changing reflections and light refractions in mirrors and glass lack distinctive unmoving features and points that photogrammetry needs to assess parallax differences and triangulate 3D points to reconstruct the 3D scan as a model[45].

The Apple LiDAR scans of windows in the *space scans* showed areas such as windows where the scanner registered glass not as a surface but as a space that bows out, extending beyond the physical plane of the window. It was as if the 3D scanner was trying to reach through the window into the outside space (Figure 83 and Figure 84)[46]. Photogrammetry struggles to “see” a mirror glass surface that it thinks is not quite there; the scanning algorithm was not specifically designed for reflections and transparency. However, I have found that it is possible to make scans of mirrors and glass, which contradicts the prevailing thought in the field that advocates avoiding or mitigating these subjects. The mirror and glass scans reveal that photogrammetry can capture aspects of these optical effects. However, it achieves this in strange and unexpected ways that we may not anticipate, resulting in scans that challenge the photographic understanding of the behaviour of reflections and refractions. Photography and video capture reflection and refraction of light in a familiar way, shaped by our common experience of seeing shiny surfaces and glass. A photograph freezes any reflections or refractions visible before the camera at the time of exposure, while video, due to its temporal nature, can keep up with and record a moving reflection. In contrast, photogrammetry captures reflections

[45] Photogrammetry is a slower capture process than photography or video. It involves walking around a subject to scan it and capture all its parts, often using hundreds of photographs. This process requires time; light conditions may vary, objects can move, and this can result in blurring of edges or even duplicate objects in the scan.

[46] 3D-scanned windows and mirrors do not always behave consistently. Mostly, they appear to distort and balloon out beyond the mirror or window plane, but sometimes, they simply fix a view from outside or a single reflection on the mirror.

and transparency as a range of distortions to the scanned models' geometry and textures.

Figure 83. An example of window scans "spilling" over into the outside environment.

Figure 84. Sometimes, scanned windows.

Reflections disrupt photogrammetry scans, affecting their resemblance to the original and undermining perceived photorealism. In a commercial context, for example, when used for screen-based computer animation or 3D printing, a scan is valued for its accuracy in shape and texture compared to the subject. Commercial photogrammetry results that show disruptions from reflections and transparency are considered errors and are generally avoided. However, artists may be more inclined to explore these reflective and transparent artefacts of reality capture. Researchers and artists have recognised mirror disruption as an opportunity for a deeper understanding of the scanning medium, which may, in these cases, cause the technology to perceive the world quite differently.

Film-based scanning companies and fine art facilitators, such as Lidar Lounge, Factum Arte, ScanLAB, and Sample and Hold, all utilise reality capture to create digital replicas. In published articles on scanning and company webpages, they emphasise the issues presented by metallic, mirror, and glass materials. They note how these materials contrast with the relative ease of capturing non-shiny, matte, and highly textured objects. Textured surfaces scan predictably and without error, becoming a standard for photogrammetry performance. Textured models are viewed on computer screens and fulfil many computer photorealism ideals for 3D models. In contrast, mirrors and glass markedly differ from the predictable scanning behaviour of textured surfaces. Instead, the scans of mirrors and glass reveal a collection of bent and distorted metal and glass models. These scans are unsuitable for most industrial computer animation or 3D printing applications. However, they represent authentic scan readings operating within the technology's parameters. The scans provide novel results that may bring new knowledge about the medium to the field.

Industry approaches for scanning reflective and transparent materials generally involve some form of mitigation of the surface itself. Understanding standard practices and accepted ways of scanning mirrors and glass will provide context for scans created for the chapter. Most sources on scanning mirrors and glass are anecdotal, originating from blogs, forums, and individual or company websites. However, these sources can offer valuable insights for achieving fidelity when capturing these challenging surfaces. In this field, avoiding mirror and glass surfaces is the primary suggestion; beyond that, others propose workarounds and techniques to achieve a photorealistic resemblance. For example, sketchfab.com co-founder Alban Denoyel has observed that 3D scanning “doesn’t work great with shiny/reflective things” (2021, para.10). Meanwhile, James Bushy of the 3D Scan Store comments that “a highly polished transparent glass bowl” is a “photogrammetry nightmare if ever there was one” (2016, para 1). Trino (2021), creators of the Trino 3D scanning app, explain that “light that reflects off of a shiny object will move, obstructing the photo matching process that creates your 3D model” (2021, para.1). Additionally, Factum Arte describes a reflection as a “limiting surface” that typically poses challenges for their 3D scanners (i.e., shiny, highly contrasted, gold, or metallic surfaces) (2022, para 23). Factum Arte also includes featureless surfaces, specifically coloured or dark objects, in this list.

Bushy, Denoyel, and Trnio, in their respective blog posts on improving reality capture workflows, provide detailed “how-to” guidance for addressing technical challenges, particularly with reflective and transparent surfaces. These texts function as problem-solving manuals, aligned with Factum Arte’s assertion that the primary goal of 3D scanning is the complete and accurate capture of an object in all its three-dimensional detail. Within these workflows, partial or flawed scans are treated as inadequate, reinforcing an industry standard prioritising photorealistic fidelity. Reflective and transparent materials like mirrors and glass are typically seen as surfaces that must be subdued through surface treatments like matte sprays or dusted coatings (Figure 85)[47]. These interventions make it much easier to capture the object's shape accurately. However, they reveal an underlying assumption that scanning aims to produce a seamless, lifelike representation. This methodology, which I term a "preservation of resemblance", reflects the dominant ethos in commercial scanning contexts such as visual effects, animation and advertising. Altering the surface to ensure "scannability" is acceptable if it results in a more photorealistic digital model.

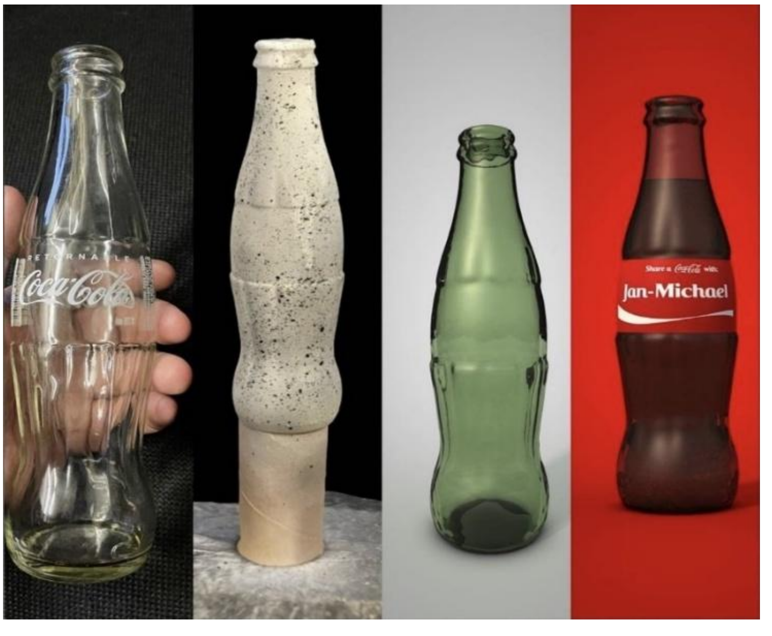

Figure 85. Mediation procedure to 3D *scan a glass bottle, recommended by scanning pioneer Trnio*3D*.*

[47] A white matting powder can be applied as a spray-painted covering, and substances such as talcum powder or specialist 3D scanning paints may be used. Additional splatters of black paint can be added to create tonal or colour variation, further assisting the 3D scanner in capturing the object's shape (Busby 2016; Universität Rostock 2024; Clark and Mitchell 2021).

However, mitigating problematic reflections and transparency with a covering is not always feasible. For example, Factum Arte has published 3D scanning guides that state they prefer not to conceal the surface of an important art historical object that needs to be scanned. They do not alter surfaces for scanning because, as they say, the surface is part of an art object's aesthetic and meaning. For Factum Arte, the focus is often on capturing surface detail; they operate at the cutting edge of reality capture to digitise even the challenging surfaces. Lowe of Factum Arte has said that, in many ways, the surface is more important than the overall form, making any surface disruption undesirable.

Factum Arte has developed many specialised 3D scanners for challenging surfaces. Like other specialists, Factum Arte uses polarising lens filters to minimise reflections and bright spots on scanned models. This technique, known as cross-polarisation, employs filters on both the light source and the camera lens to suppress specular reflections, thereby preserving the object's diffuse colour. Set at 90 degrees to the reflected light, the filters effectively eliminate light waves from a specific direction, such as bounced and reflected light, allowing the colours and details of the surface to emerge, enhancing clarity and improving contrast. This is another common form of mitigation based on optics. However, it is often insufficient with highly reflective surfaces and complex surrounding environments, which can introduce numerous reflections. Factum Arte uses such filters, but they have not yet developed a system specifically designed to address the issue of reflections and transparency in scanning.

Altering the material properties of a surface before scanning from glass to an opaque material will cause the 3D scans to conform to the shape of their reference object; however, they will lose the original qualities of glass or mirrors. Many other natural attributes will be altered or changed. Colours, reflections from the scene, transparency, and the behaviour of light and shadow are also modified. While this practical approach benefits the 3D modelling workflow, it may lead to losing some of the scans' indexicality. The matte covering method sacrifices surface features, such as transparency and reflections, in favour of shape and form. This method goes further by digitally recreating the absent mirror or glass material in post-production 3D software, simulating the missing glass or mirror materials disconnected from the original surface.

When scanning 3D glass or metal shapes for computer animation, creative license is taken in the post-production phases to remodel the scan and address deformation-related issues caused by reflection and transparency effects. This remodelling often involves several stages that gradually diverge from the original scan. Remodelling and adding computer-generated materials move the scan from a straightforward copy to a simulation and a copy. This scenario reminds us of Jean Baudrillard’s (1981) stages of simulacra. In this digital interpretation of the ‘Precession of Simulacra’, the original material is digitally replaced with something that resembles, presents itself as, or mimics the original (glass) or a first-order copy of it; it is still read as a scan rather than an original 3D model. As software processes a digital 3D scan, the connection between the 3D scan file and the physical object diminishes. Illustrated in (Figure 86 and Figure 87), this process moves the 3D scan (as a digital model) away from being a precise digital twin of its referent object. An example is digitally simulating glass or mirror materials that resist capture. Still, there is a wider resonance with Baudrillard’s notion of simulation: I have already mentioned how 3D scans, destined to be used as assets in computer animation or game environments, are usually reconstructed or “retopologised” by creating a new simplified digital wireframe that is modelled over the original scan. This is done for efficiency and to correct polygon model errors; we can see examples of this procedure in (Figure 88 and Figure 89). During retopologisation, the digital scan's texture is transferred onto the new simplified version; its material is digitally transported and regenerated onto a copy of a copy, increasing the distance from the original capture[48].

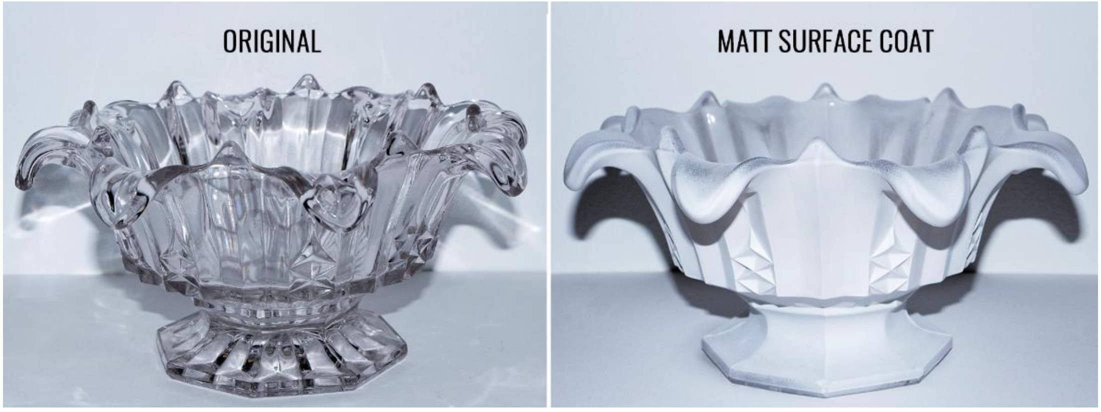

Figure 86. Screenshot from a tutorial on how to 3D *scan reflective objects with Photogrammetry.*

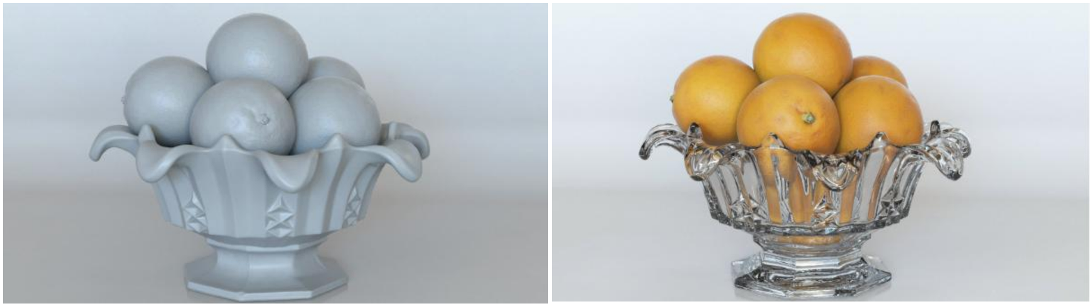

Figure 87. In these images, the glass is constructed "in post" as a simulated material; the oranges are added digitally.

[48] The process of reconstructing the topology of a 3D model to create a cleaner, more efficient mesh often involves reducing the number of polygons while maintaining the model's shape and detail, thus making it easier to work with in various applications such as computer animation or gaming.

Figure 88. Dartmoor location used for photogrammetry.

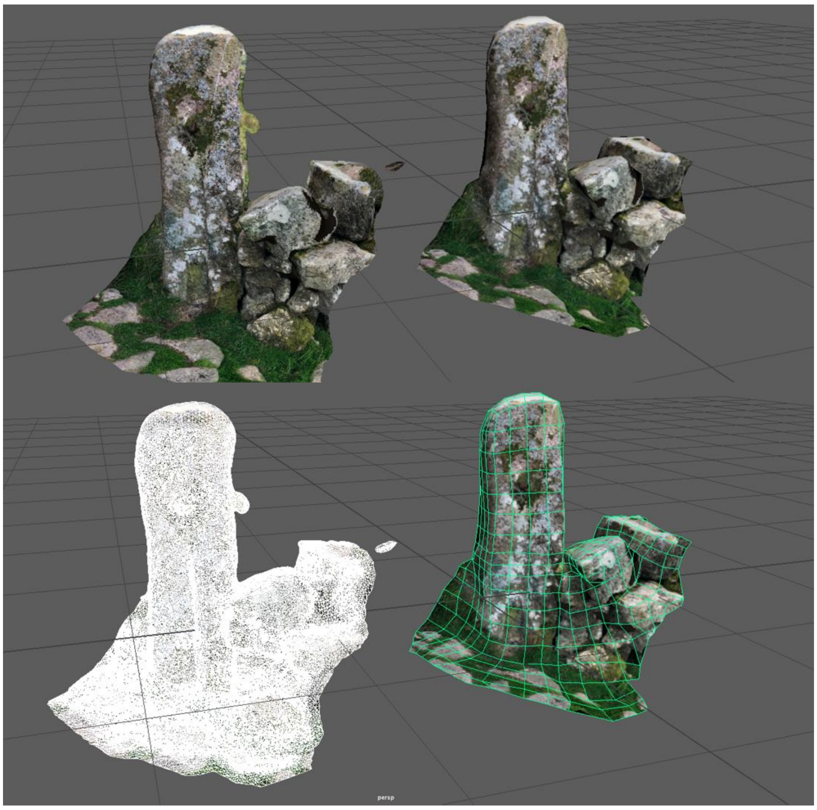

Figure 89. Photogrammetry of Dartmoor wall: Raw scans (left) and retopologised versions (right).

In retopologisation, a 3D modelled simulacrum has effectively replaced the original 3D scan with an altered copy, often manipulated to achieve photoreal results. This aligns with Baudrillard's "second order of simulation", and it moves the scan closer to a "hyperreality", which bears less relation to the original's physical reality but is crucially still presented or marketed as a direct copy of the referent. It becomes a sign that refers to other symbols and signs, thereby blurring the notion of a 3D scan as a truthful, objective representation. This is not to say that anything is inherently deceptive about the remodelling process or digitally manipulating a 3D scan for commercial purposes. However, it does show how imperfect scans are adapted for photoreal outcomes and how the digital 3D scan can evolve as a representation: it transforms into an iconic sign, and it is increasingly removed from its indexical origins. The addition of a physical barrier to improve shape recognition, however slim, may also interfere with the claims of an indexical connection between the scan and the object.[49] This barrier may disrupt the semiotic link, but this is not necessarily a concern for commercial 3D scanning procedures that essentially imitate the reflections and transparency.

We have observed that in commercial processes, reflective and transparent surfaces are mediated so that photogrammetry can accurately scan their shapes. This results in glass or mirror materials being digitally recreated later in post-production. In these cases, does creating a barrier layer disrupt the 3D scan's connection to its referent object? Often, surface modifications to prepare for

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[49] The previous chapter examined the indexicality of the *space scans*, explored in part through indexical interpretations of Whiteread's work. Mullins highlights the presence of a release agent used by Whiteread in plaster casting, a greasy substance painted onto the surface to facilitate the cast's release from the mould, or room, in Whiteread's case. Applying a matte covering on glass or mirror in 3D scanning is analogous; it allows the digital cast to accurately replicate a shape when there is a disruptive material. However, it also creates a gap that may diminish the indexical connection, even though it may enhance the resemblance to the object's shape.

scanning or alterations later in post-production are a hidden part of the scanning process, yet the final result is true and accurate. Similar mitigations and manipulations occur with other media, such as photography, where fakes have been presented as a truthful record (Gunning, 2004). Reality capture has been associated with accuracy, and a reputation has been gained in engineering and surveying. Still, like other forms of digital media, it is open to extensive post-production manipulation, particularly when dealing with disruptive surfaces like mirrors and glass.

However, the perception of reality capture as a truthful recording technology persists because it is viewed as a technology of indexical accuracy at the point of use. Steyerl, Manaugh, Parikka, Shaw, and Trossel of ScanLAB all note the prevailing view of how scanning is deployed as "a new technology of truth, " for example, in contexts such as crime scene evidence collection (Steyerl 2017, p. 192). Yet, these authors all caution against the ideals of accuracy and truth associated with the technology. Parikka argues that the "apparent technological accuracy" of these tools is merely perceived, while ScanLAB, which uses LiDAR —considered one of the most accurate types of 3D scanning— describes the technology as an "illusion of perfection" (Parikka, 2021, p.198; Shaw and Trossel, 2014, p. 25). They all acknowledge that the technology is vulnerable to misdirection at the scanning stage and manipulations in software during post-production and clean-up. Surfaces like glass can produce readings that offer a different view than what we see with our eyes. The technology may capture more than we can see, such as when scans reflect mirror images as new kinds of spaces. Still, our perception of a truthful or accurate record is susceptible to photorealistic understandings of how things look.

As a technology, reality capture is, as Barthes said of the photograph, the acquisition of a "necessarily real thing" before the scanner, and "without which there would be” no scan (1980, p.76). The concept of the 3D scan as an objective record underpins its authenticity, which, combined with resemblance, delivers photorealism. We see this with photogrammetry, which in most cases produces a perfect like-for-like replica, and it is highly valued for the detail it can capture. It visually resembles its object, and we accept its accuracy. Yet when reflections and transparency disrupt reality capture, they are blamed for creating inaccuracies and losing photorealism. As Shaw has noted, reality capture produces the intended result when used under ideal conditions. However, taking it out of those “perfect” operating conditions and a new, unseen or previously dismissed type of scan emerges, which may go against accepted ideas about the technology but ultimately contribute to new knowledge in the field.

The notion of a 3d scan as a truthful, perfect replica is framed partly through an association with photographic mimesis (Milnes, 2021; Ainsworth, 2020). Ideas about scientifically acquired data are logical and underpin an indexical connection. However, we can see how disruptive mirror and glass surfaces are to the geometrical accuracy of reality capture processes, and this is counterintuitive to getting mimetic scans. But what happens if reflections and transparency are allowed to “run free” in photogrammetry and LiDAR?

We have seen that ScanLAB’s scans catch anomalies caused by reflections and other optical phenomena that create phantom signals that they call “noise” in their LiDAR scans. They recognise how this noise can show us different kinds of previously unseen space. They have experimented with scanning various phenomena, such as smoke, creating stealth shapes, and capturing mirror spaces that evade LiDAR scans. They even hosted a playful workshop on using sheets of reflective plastic with LiDAR scanners, which first sparked my interest in disrupting scans in unorthodox ways.

Willkens wrote about how mirrors caught the attention of ScanLAB when making scans of the Sir John Soane’s Museum. She commented on how the mirror in the museum created a kind of “4-D” space offering new possibilities for studying the perceptual experiences of light, space, and time” (2019, p.215). The scans showed how LiDAR could inadvertently capture a reflection; it recorded both the glass surface of the mirror and the depth of its reflection, creating a strange visual disparity (Figure 90). Willkens observed how Lidar is significantly bent by mirrors and refracted through glass; it records these optical phenomena and behaviour as data. This data was only later revealed in the 3D file. This project showed LiDAR’s ability to record more than a mapping of a physical space but also capture reflections as an additional reality. Through scanning, Sir John Soane’s Museum mirrors provoke an experiential understanding of the museum’s architecture. I have also found effects in my experiments with short-range Apple LiDAR scans (Figure 91). In some scans of mirrors, I recreated a comparable behaviour to Willkens' description of high-end LiDAR. When the scanner encounters a mirror, it follows the reflection route by stretching and ballooning it into a perceptual space. The scanning rays effectively travel past the mirrors, possibly to capture an entire mirror copy of the room. Two types of space are recorded: the physical and reflected, both treated equally by the scanner. Again, these space extensions, as Shaw and Trossel, as well as Willkens discuss, would generally be treated as errors and edited out, but they note how with increased use of glass in modern buildings, these “scanning errors will exponentially increase” (2019, p.217)

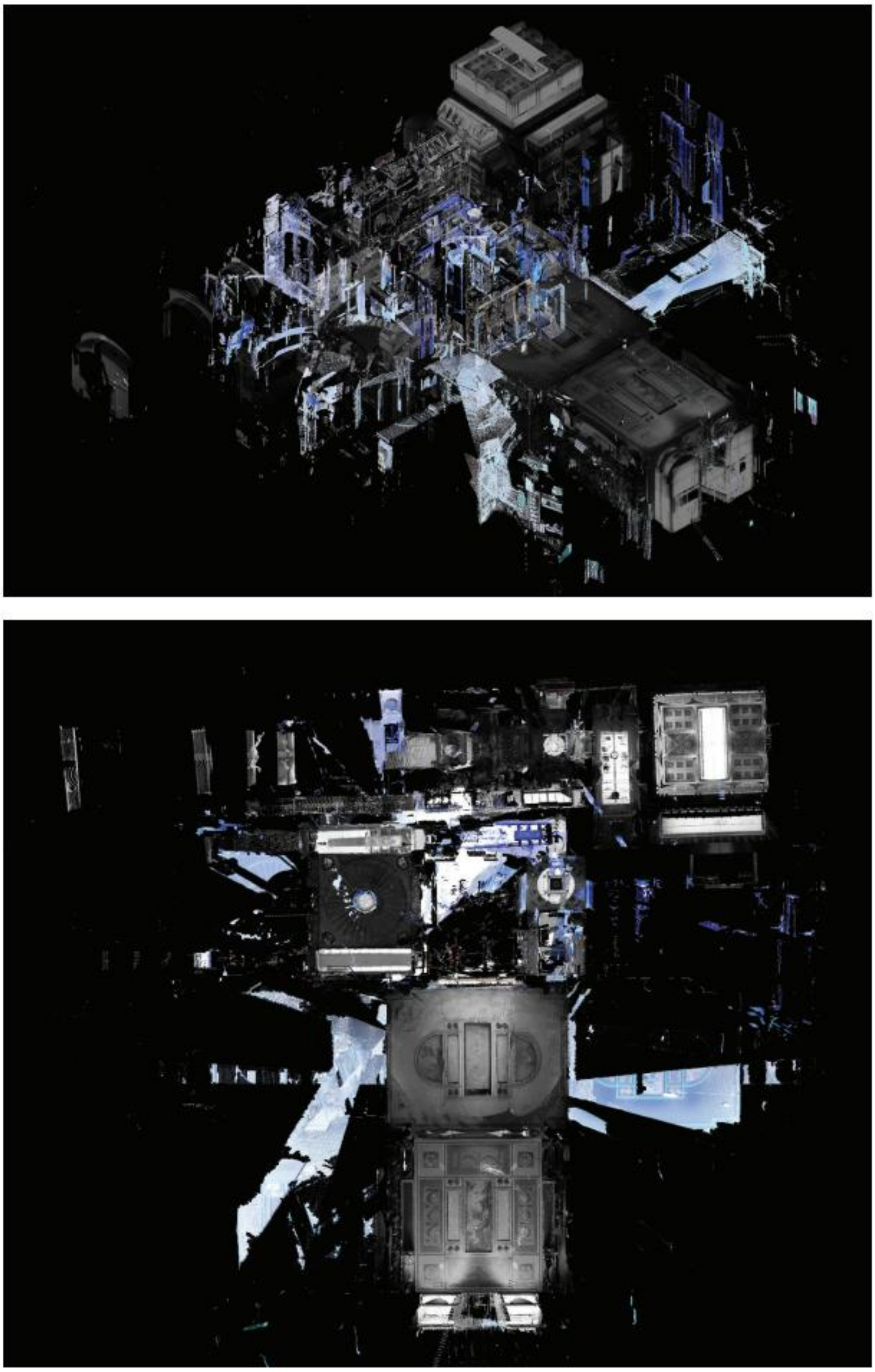

Figure 90. ScanLAB Projects LiDAR images revealing reflective surface effects in the scans of John Soane's Museum (blue), with reflections manifesting as image noise extending into the mirror.

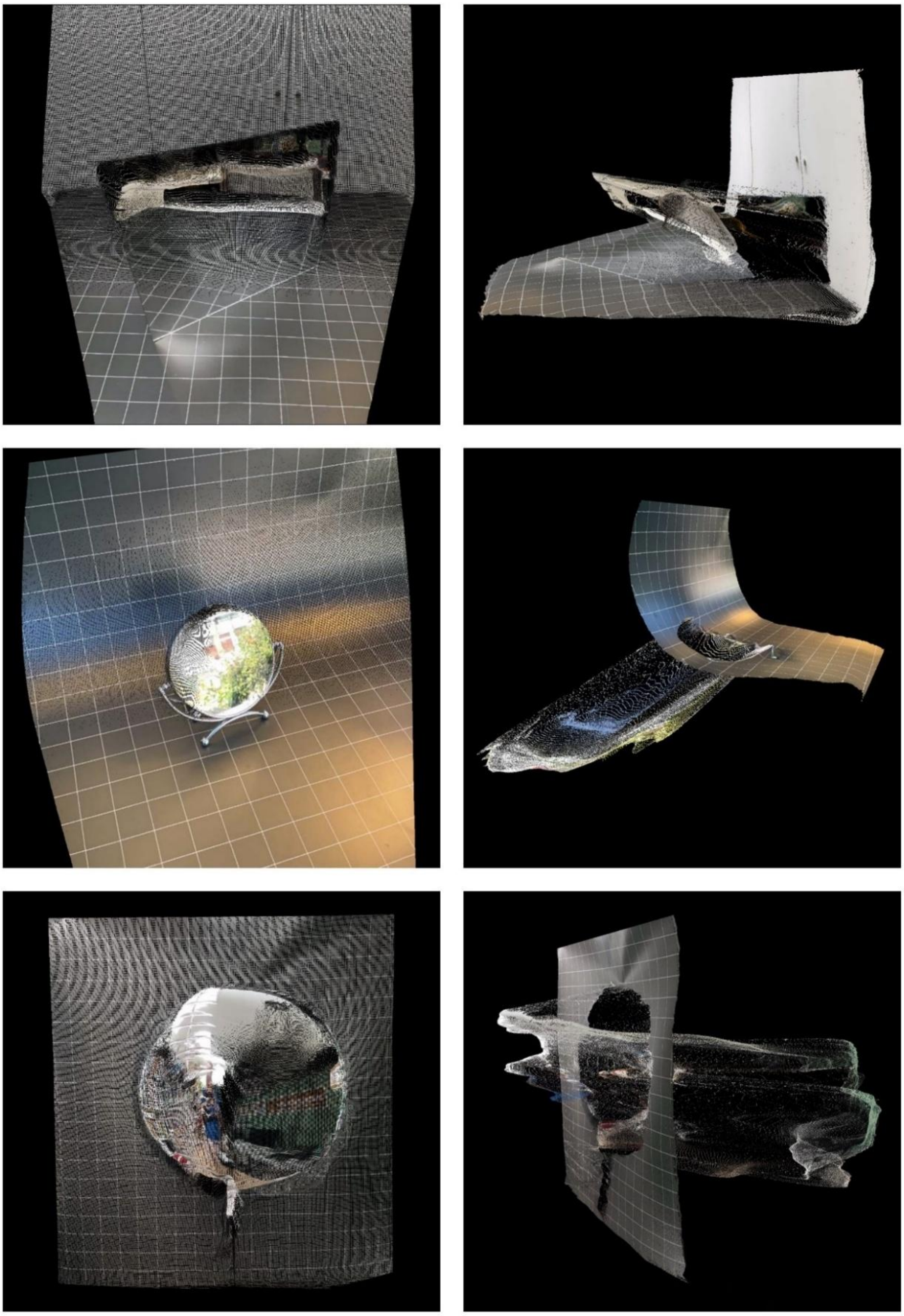

Figure 91. Scans of mirrors on a grid illustrate how the scanner interprets reflections as actual physical space. Captured using the Record 3D app, these scans demonstrate that mirrors produce similar optical effects in smaller handheld scanners, and they are kno

Accidental capture of reflection space by ScanLAB with LiDAR is not necessarily an error, as the scanner is simply following the path of the light into the reflection. However, Scanlab ScanLAB points out that these are “optical reflections we take for granted in our everyday lives, but to a machine’s eyes, they fuse, offset, reflect, refract and obstruct the spatial measurement (Trossel 2014, quoted in Winston, 2014). This highlights a disparity between how we expect the 3D scanner to interpret reflections and refractions —likely based on our association between human vision, cameras, and photographs— and how scanners see reflections differently.

The inadvertent LIDAR capture of reflections in other projects is of value to my research as I attempt to build upon these existing results. My practice-led scanning research deliberately targets multiple reflections using photogrammetry, a method not yet extensively applied to scan mirrors and glass objects. My approach aims to build upon existing discoveries. There are meaningful connections between some of the ideas and projects of ScanLAB and this research. Both inadvertently or directly question the perception of reality capture as purely a photoreal tool. While ScanLAB’s high-end LiDAR reality-capture work has touched upon reflective surfaces as an incidental discovery, my research practice intentionally examines these disruptions in depth[50]. The *mirror and glass scans* take the marginal but observed errors in ScanLAB’s work and expand them into a deeper investigation of these scanning phenomena using other forms of reality capture technology. The next part of the chapter focuses on the effects of these materials on photogrammetry and

[50] Scanning unsuitable and difficult-to-capture subjects is not the sole focus of ScanLAB’s practice. However, they have experimented with the fringe behaviour of LiDAR scanners with ephemeral phenomena (such as smoke), human movement, and the passage of time (the growth of plants and tidal shifts).

more accessible scanning tools, such as Apple's short-range LiDAR. In contrast, ScanLAB's scans of reflections and shiny surfaces were partly a by-product of larger projects.

4.3 The mirror and glass scans

The *mirror and glass scans* take the marginal error or artefact in ScanLAB's work and expand it into a deeper investigation of scanning phenomena concerning reflective and transparent surfaces. Conducted using photogrammetry and short-range LiDAR, they maintain a sustained focus solely on reflective and transparent surfaces. The resulting scans illustrate how, when left unmitigated, the technology interacts with various metallic and glass surfaces in new ways to reveal a set of twisted, distorted, and molten forms. Silver and metal-plated items, clear and ornate glass, glass spheres, chrome balls, coloured glass, and other reflective everyday objects were all scanned and produced many strange-looking forms. The important point to note here is that, instead of scanning flat mirrors as ScanLAB did, which produce somewhat predictable results, the *mirror and glass scans* aimed to capture three-dimensional reflective and transparent surfaces in their entirety, emphasising their silhouettes. This contrasts with Scanlab's approach.

J.M.W. Turner's 1810 drawings of glass and polished metal globes inspired early practice-led mirror and glass scan tests. Turner used the globes to study the interplay between light, reflections, and refractions (Kemp,1990; Tate, 2012) (Figure 92 and Figure 93). I attempted to 3D scan similar globes and metal spheres to observe how the light reflections and refractions would behave (Figure 94, Figure 95, Figure 96, and Figure 97). The results revealed intriguing geometric deformations and overlapping reflections captured in the textures of the digital 3D model.

However, due to their uniformity, these spheres provided limited opportunities to test the effects of mirrors or glass on photogrammetry. Objects featuring more intricate designs and complex shapes, beyond simple geometric forms, were necessary to explore the scanning of reflections and transparencies fully. Intricacy of form led to a much more complicated set of scan distortions that unravels the relationship between photogrammetry and photorealism at a deeper level than previously undertaken.

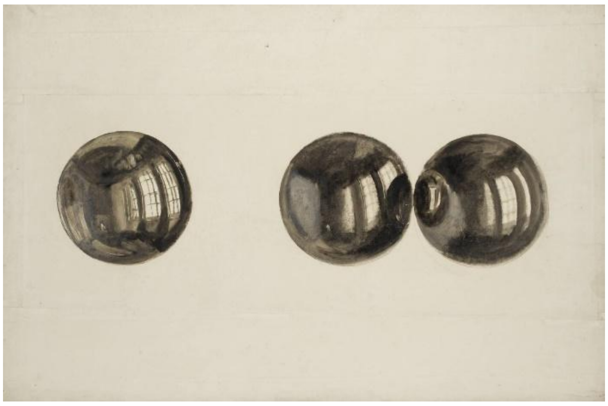

Figure 92. Watercolour: Reflections in polished metal globe(s), Turner (1810).

Figure 93. Watercolour: Reflections and refractions in the water-filled globe, Turner (1810).

Figure 94. Photogrammetry of a mirrored

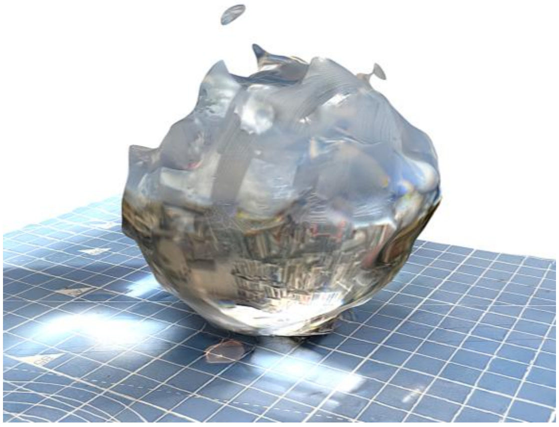

Figure 95. Photogrammetry of a glass sphere. Scan by the author.

sphere with overlapping reflections. Scan by the author.

Figure 96. Photogrammetry of a chrome sphere on a wooden tabletop. Scan by the author.

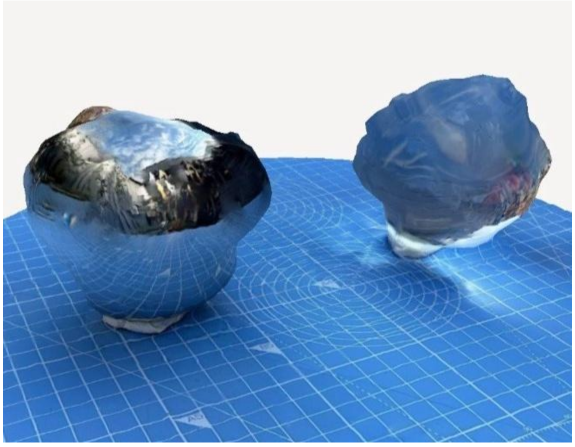

Figure 97. Photogrammetry of chrome and glass spheres. Scan by the author.

Old pieces of silver-plated and glass tableware were scanned to create the *mirror and glass scans*. These items are notable for their varied shapes and are optically challenging to capture, reflecting and refracting surface qualities. These items were also chosen because, since the Renaissance, artists have depicted still-life objects like these, fascinated by the challenges of the optical effects of representing reflected and refracted light (Metmuseum, 2024). Subjecting these objects to 3D scanning posed optical obstacles to the technology that once tested painters and early photographers (Figure 98 and Figure 99)[51]. Photographs from the 19th century included glass objects to test the capabilities of the new medium. William Henry Fox Talbot, for instance, featured glass and metal surfaces in *Articles of Glass* (1844) and *Articles of silver or pewter on three shelves* (1839)[52]. Unlike

[51] There is also a precedent involving artists like Cornelia Parker and Rob and Nick Carter, who revisit, reinvent, and pay homage to this early period of photography.
[52] Talbot consistently photographed the same objects while refining his photographic techniques. Images of glass and metal forms showcased the capacity of his new photographic process to capture optical effects, rivalling those previously only depicted by skilled painters.

traditional painted still life compositions, Talbot arranged glass, silverware, and porcelain on shelves for scientific purposes. Talbot's photographic work of glass and silver inspired how the *mirror and glass scans* were often arranged and captured in rows on grids.

Figure 98. Scanning tests for polished silver and gold-plated teapots. Scans by the author.

Figure 99. Scanning tests of polished silver teapots. Scans by the author.

The development of the *mirror and glass scans* was also linked to the complex photorealism studies of reflection and transparency in computer graphics and the work of photorealist painters of the 1970s. Photorealist paintings and computer renderings of glass and mirror subjects are accomplishments within their respective media. Photorealist painters depicted kitchenware as groups of optically challenging, highly reflective glass objects. Similarly, computer graphics developments from the 1990s and even 3D rendering tutorials today emphasise the ability of computer systems to depict the optical properties of everyday glass and metal objects. Both areas influence the selection of objects scanned and their arrangements, like the choice of scanning glass jars. I discovered that collections of scanned metal and glass objects significantly amplified results by bouncing reflections and refractions between surfaces.

Repeatedly scanning similar objects in different arrangements revealed new insights. A single glass item often resulted in a failed or unremarkable scan. Still, a collection of closely arranged glass appeared to force reality capture to register and capture what was present. Items such as teapots, vases, bowls, wine glasses, jam jars, candlesticks, and glass bottles were all chosen for their optical properties and tabletop size. Using photogrammetry techniques and smartphone scanning apps, the objects were scanned as mixed glass and mirror items, as well as individual material and object types. Numerous tests, experiments, and failures created distortions in the scan data that had not been seen before, where the sheer quantity of reflections and refractions, such as glass and metallic surfaces, was a factor. The most notable result was a “molten” appearance to the objects captured; it was as if they had partially melted, merged and resolidified. Many scans displayed holes, gaps, detached rims, bent and buckled sides, and missing parts. Suspended edges floated alongside indistinguishable blobs of geometry that indicated where a structure once existed (Figure 100, Figure 102, Figure 102 and Figure 103).

Figure 100. Photogrammetry scan of assorted glass objects. Scan by the author.

Figure 101. Photogrammetry scan of assorted metal and silver objects. Scan by the author.

Figure 102. Photogrammetry scan of assorted crystal glass objects. Scan by the author.

Figure 103. Photogrammetry scan of assorted metal and silver objects. Scan by the author.

Despite deformations due to their surfaces, the scanned objects remained largely recognisable, their shapes mostly intact. While a notable effect occurred within the hollow interiors of jam jars and silver teapots, which, when scanned, appeared as if filled with machine-imagined glass and metal that did not exist. We can see this liquid-filled effect in the gold teacups and glass jars (Figure 104, Figure 105, Figure 106 and Figure 107). Almost all the scanned surfaces displayed some distortion, varying degrees of liquid or mercury-like deformations. The more reflective the object, the more extreme the molten distortion effect, while introducing coloured glass into the scans further amplified the molten distortion, shown in (Figure 108 and Figure 109). The jumbled coloured glass exaggerated these effects to the extent that, in some instances, the objects completely lost their shape. Collections of clear and coloured glass illustrated how molten distortion spread from areas of colour to the nearby clear glass (Figure 110 and Figure 111).

Figure 104. Photogrammetry of a gold pots and saucers. Here the scans filled the pots with the gold material. Scan by the author.

Figure 105. Photogrammetry scans of a group of glass jars. Scan by the author.

Figure 106. Photogrammetry of glass jars shows molten distortion. Scan by the author.

Figure 107. Photogrammetry of glass jars show filled interiors. Scan by the author.

Figure 108. Photogrammetry of coloured glass showing increased liquid-like disruptions. Scan by the author.

Figure 109. Detail of photogrammetry of stacked coloured glass objects. Scan by the author.

Figure 110. Photogrammetry of mixed coloured and clear glass. Scan by the author.

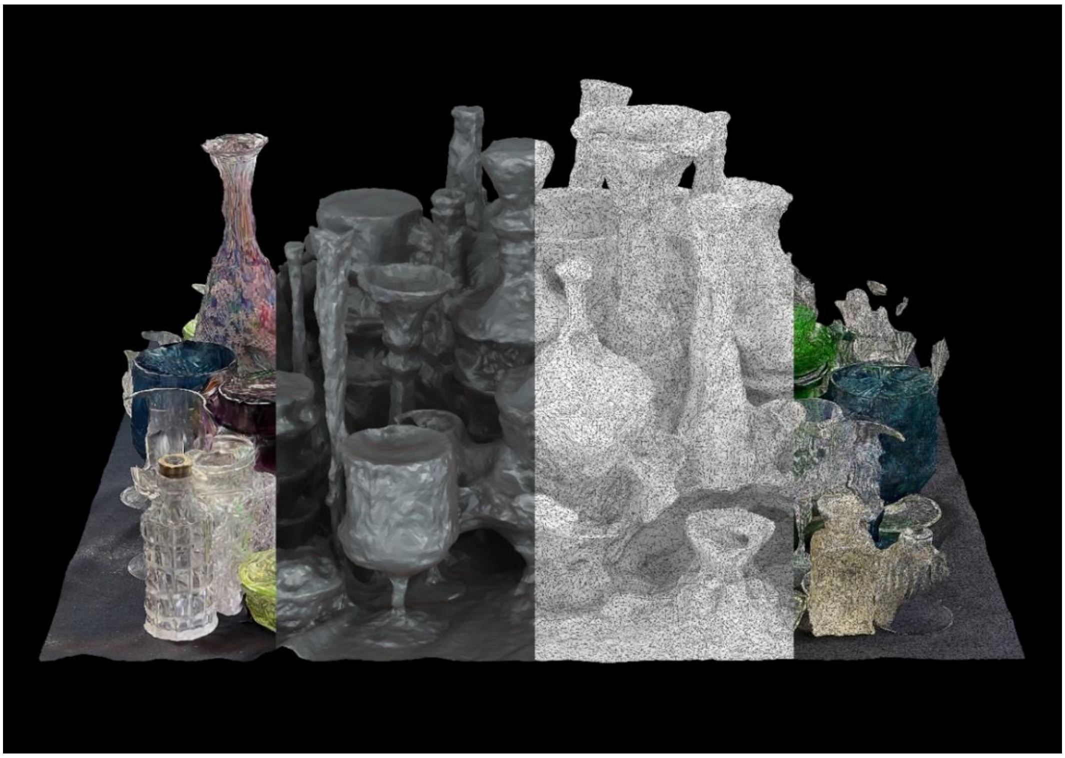

Figure 111. Breakdown image showing geometric structure. Scan by the author.

The *mirror and glass scans* are digital copies of physical objects, and we (along with the general reaction I received from others) expect them to resemble the originals. Photographic images, if lighting, exposure, and focus are correct, of reflective and transparent surfaces align with our visual experience. However, these scans deviate noticeably from what we recognise, challenging our mimetic expectations. Unlike standard photogrammetry, which produces familiar objective results, these scans led to unexpected distortions. These deviations reveal a new and distinct aesthetic that emerges when photorealism breaks down. The *mirror and glass scans* go beyond what has been captured before using the same technologies and similar surfaces.

While our instinct to these distorted images might be to ask if there is something at fault with the scans. A close look reveals optical effects such as reflections and refractions being captured and "fixed" into the twisted surfaces of the models (Figure 112 and Figure 113). The expected behaviour of light can be spotted along with the distortions in the scans. Embedding transparency and fleeting reflections are captured in the scan textures, the process effectively digitises the mirror and glass surfaces in a novel way. Capturing optical effects challenges the common industry belief that reflections and transparent surfaces cannot be scanned using photogrammetry.

Figure 112. Indistinct reflections captured on the sides of silver teapots. Scan by the author.

Figure 113. Optically transparent effects are fixed onto the models by photogrammetry. Scan by the author.

Although these results might appear strange to us, the scans show how photogrammetry is, in a sense, capturing something beyond human perception —the culmination of dynamic, overlapping, and constantly changing reflections and transparencies that occur as the scanner orbits around the objects in 360 degrees. The layers of repeated reflections and refractive optical light effects that distort the shapes of the mirror and glass scans are also captured in the textures of the scanned models. Although these textures are derived from photographs taken for the photogrammetry, the textures they generate do not necessarily look photographic in a conventional sense, appearing blurred and mixed to the point where it is hard to pick out anything recognisable in the reflections. The digital scan images evoke parallels with recent developments in generative AI, which can imagine reflections and hallucinate strange pictures in the reflections. Here, snippets of resemblance, parts of objects and reflected surfaces from the surrounding environment, and bounced reflections across multiple glass surfaces represent the scanner's interpretation of what a reflection looks like.

In addition to scanning mirror and glass surfaces without the recommended mitigation of a powder covering, I took the inadvisable setup further. Bright studio lighting was used to further enhance reflections and refractions, pushing the limits of what the scanning technology can capture. The setup is completely inadvisable by industry standards, but it unleashed a multitude of visual phenomena (Figure 114). Large quantities of glass and silverware in proximity intensified the effect. Scanned individually, a glass jar might disappear altogether, but interestingly, grouping the scanned objects appeared to help rather than hinder the photogrammetry scanning of these typically evasive surfaces.

Figure 114. Studio setups of the mirror and glass photogrammetry show varying degrees of closeness between the objects. Photographs by the author.

The proximity of glass or metal objects seemed to help prevent failed scans, but also caused geometric inference between adjacent surfaces. In some instances, the boundaries of objects merged, and experiments with stacked glass tableware resulted in a total breakdown of object delineation into a single amalgamated surface (Figure 115 and Figure 116). In the process of setting up photogrammetry, I utilised the technology in very unorthodox ways; the technological provocations of the research setup aligned with what Manaugh (2015) and Parikka (2021) refer to as "wrong-footing" the 3D scanner. This approach freed the mirror and glass scans from associations with photorealism, causing the objects geometrically to morph away from something familiar into a distorted, alternate view of the surface's captures.

Figure 115. Photogrammetry of many glass objects that became merged in the scan. Scan by the author.

Figure 116. Photogrammetry of metal and glass objects shows molten and merged results. (detail). Scan by the author.

Incorrectly applying photogrammetry to scan unscannable surfaces reveals a unique aesthetic infrastructure of reality capture that, instead of rigid, solid shapes, is characterised by soft and melted forms. These softened geometries challenge conventional understandings of polygon models as tidy wireframe structures. The mirror and glass scans contradict the typical perception of 3d polygon model structures. They comprise a collection of entangled, interconnected wireframes, where sharp-edged shapes are significantly softened. The geometric wireframes of 3d scans can showcase many gnarly details, but the intertwined and scrambled wireframes of the mirror and glass scans represent a new digital structure. Again, they would likely be rejected by the scanning industry. Still, they are a discovery in that they illustrate how polygons can be unevenly disrupted in a significantly intersected, overlapping, disorderly way and remain a digital scan representation.

They do not adhere to modelling conventions like continuous edge loops or consistent sets of polygons pointing in the same direction. They demonstrate the disruptions caused by reflections and transparency, breaking down ideas of mimesis and revealing the digital structure of the files that is usually hidden.

The metallic and glass objects enhance the molten effect in the scans and polygon disruption to the limits of representational accuracy. The soft, sometimes liquid or molten impact observed in the scans has appeared in other instances of photogrammetry, but here it is more extreme and consistent. The *mirror and glass scans* reveal scan behaviour previously captured in this way, and they would be considered failures in an industrial or commercial context. The idea of what constitutes a “good” 3D scan depends on the photorealism requirements and standards applied to reality capture functions and uses. In this context, what some may consider a visual failure was a valuable research outcome. As Will Gompertz states, “failure is subjective,” and he argues that “mistakes and making errors” in artworks are crucial for creativity to uncover visually important aspects (2015, p. 40). The *mirror and glass scans* do not capture a lifelike replica. Still, they provide an opportunity to understand how the scanner interacts with a complex mix of light and matter. They are a new kind of polygon model, a novel collection of models that demonstrate how photogrammetry models are not always a neat and orderly representation. That, in fact, the technology can be chaotic and somewhat unpredictable when interacting with optical light effects, a subject not previously documented in detail.

A criticism of the scan results is that they may come from an incorrect workflow involving low-fi equipment (such as smartphone photogrammetry apps), inappropriate lighting, and insufficient mitigation of reflections and refractions.

However, the argument is that these results authentically represent what the scanner machine is "seeing". This is supported because the photogrammetry scans were produced using a setup and methods mainly reflecting standard photogrammetry practices. While bright lighting was used to increase reflections highlight, the photogrammetry involved hundreds of 4K high-resolution photographs, which are typically associated with high-quality scan results.[53] Given that the photogrammetry data was collected objectively and scientifically following a standard photogrammetry workflow, we can argue that these results are genuine.

In 3D scanning, there is often a counterargument that higher-quality images, larger image sensors, better lenses and cameras, or higher-resolution laser scanners will produce a more accurate, cleaner mimetic outcome.[54]. Factum Arte emphasises the importance of resolution, particularly for photogrammetry, which requires high-resolution photographs. However, they also note:

> Photogrammetry is a fundamentally democratic technology: it can be done by anyone with a phone camera and access to free photogrammetry software.

Factum Arte, 2023, para.2

This democratisation is part of what made the mirror and glass scanning research possible. Smartphone cameras paired with 3D scanning apps can provide fast, high-quality results. Comparable in quality to DSLR photographs and expensive

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[53] It was not the case that we completely ignored the procedure; the photogrammetry workflow, which involves the use of hundreds of overlapping photographic views from different angles, was respected to ensure that a scan could be produced.

[54] Handheld 3D scanners, such as the Artec Eva, can achieve a 0.1mm object-based scan accuracy for incredible surface detail.

desktop photogrammetry software. A similar comparison has been made between Lidar scanners and Apple Lidar in iPhones. Some scanning forums criticise Apple LiDAR as not being “true” LiDA, a cheap, inaccurate technology version. But both Apple LiDAR and photogrammetry apps like Polycam.com can produce impressive results[55]. Polycom was used for the *mirror and glass scans* due to its speed and capability, for rapid scan data collection that would have taken much longer with established software and “higher-end” scanning methods. The ease of use and accuracy of modern 3D scanning apps challenge conventional arguments about resolution and equipment (Polycam 2024)[56]. This rapid democratisation has transformed 3D scanning from something rigid and formulaic into a creative tool for exploring the fringes of the medium. This shift made the *mirror and glass scans* possible, enabling research to occur at the borderline of what 3D scanning could capture.

This research has extended the borderline of what reality capture technologies can capture to include scanning reflection. One of the ways this was possible was to use grid patterns on paper, which helped ground the scans by providing a stable surface that could be easily captured. The grid improved the ability of photogrammetry scans to handle normally challenging glass and metal surfaces. Using a grid was initially inspired by research into photographic pioneers, and the work of Eadweard Muybridge, Étienne-Jules Marey, Frank and Lillian Gilberth, who used grid backdrops as reference for their early photographic studies of motion and efficiency. Additionally, the use of the grid paper was influenced by computer graphic

[55] Polycam Photogrammetry utilises raw photographic data suitable for the professional physically based rendering workflows (PBR) now commonplace in 3D computer graphics. Polycam competes effectively with other high-end scanning setups.
[56] Smartphones can now function as scanning computers in our pockets, enabling the rapid creation of high-quality 3D scans processed in the cloud.

workflows, specifically computer-generated grids commonly found in 3D modelling software[57].

The grid provided a reference point in both physical and digital spaces. Scanned objects occupy the same digital 3d space as other types of 3d models. In the software, they are placed on a virtual grid. A printed version of this grid beneath the mirror and glass objects created a connection between these two realms- one actual and the other virtual- a link or bridge between them. The grid assisted in fixing difficult-to-scan surfaces and acted as a tracking marker, keeping the scans around the bottom of the objects intact and stable. It effectively compelled the photogrammetry software to capture the mirror and glass objects that typically resisted capture. These surfaces, when isolated, might otherwise have been rejected but were captured when placed on a grid. For instance, scanning suspended glass items on wires against a plain background often results in failures. However, the glass and metal objects also disrupted the grid lines, pulling at the surface on which they rested (Figure 117), but overall, the grid had a stabilising effect comparable to the labels and lids on the scanned jam jars.

[57] The 3D grid supports the construction, dimensions, and layout of digital 3D models in virtual perspective space; it establishes the concept of a floor to construct upon where none exists.

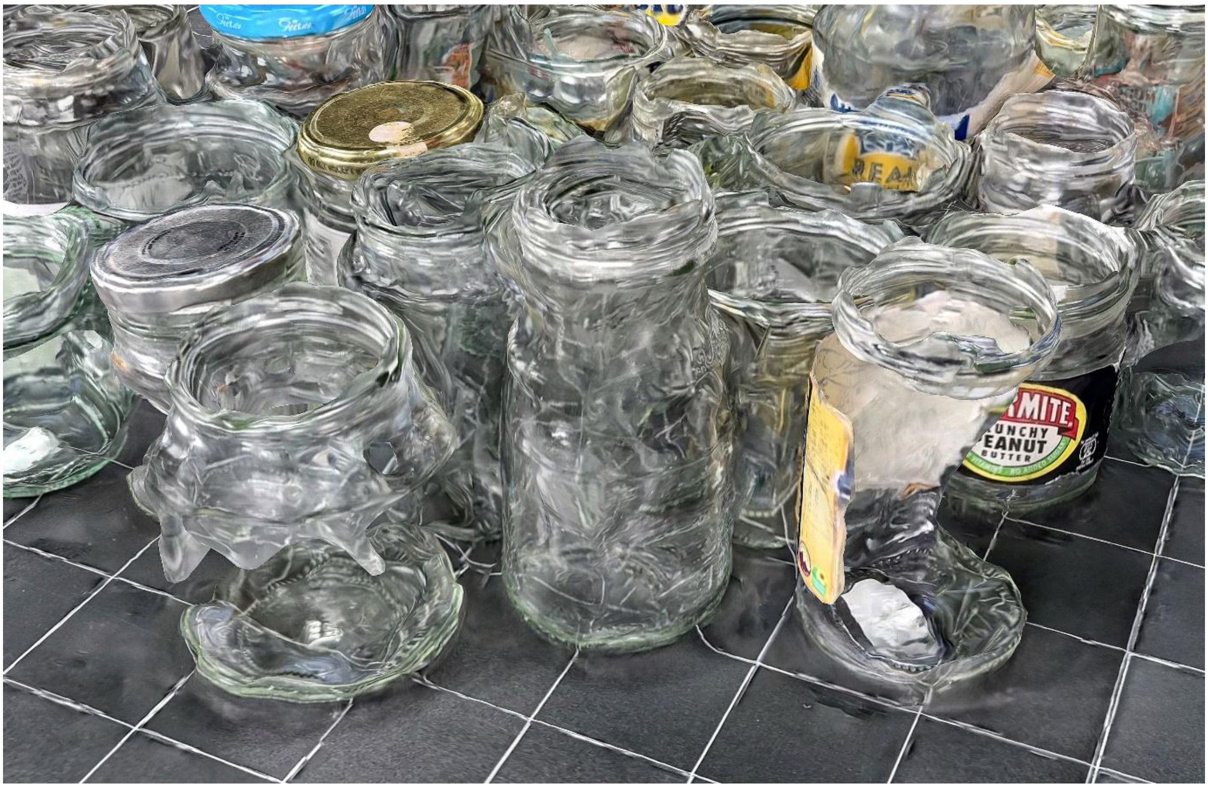

Figure 117. Photogrammetry of glass jars shows distortion of the gridlines at the base of the jars. Scan by the author.

These features helped maintain the shape of the glass objects. The labels on the jars wrapped around the glass and appeared to assist in preserving their cylindrical nature (Figure 118). Textured areas, such as the grid, labels, lids, engraving on the glass, or patina on metal surfaces, compelled the technology to capture the glass or metal near those areas. Here, it captured more readily compared to the top of the objects, where pure glass or silver surfaces tended to become fragmented, with some parts separating completely from the object and leaving behind floating blobs and rims. The point to emphasise is that without visual aids, clear glass or mirrors are very difficult to capture, and valuable insights can be gained at the edge of failure

Figure 118. Photogrammetry of glass jars shows how labels on the jars helped to maintain the cylindrical forms. Scan by the author.

The labels and grids provided sufficient anchors to scan the glass and metal, enhancing photorealism in those areas. However, the overall aesthetic of the *mirror and glass scans* remained a chaotic mix of transparent shapes and reflections —a liquid-like assembly of deformed shapes and colours that hovered between the recognisable and the abstractly distorted, sometimes unidentifiable. These distorted scans offered insights into a previously unseen behaviour of photogrammetry and how it perceives complex optical phenomena, such as large amounts of glass and reflective metal. These scanning experiments emphasise the importance of combining unorthodox setups and creative methods with conventional scanning workflows to push the limits of reality capture. They also show how technological failure can drive artistic research. The exploration of 3D scanning with reflective and transparent surfaces continues in the next section, which investigates what happens when Apple LiDAR is used on the same mirror and glass subjects.

4.4 Scanograms

The reflective and transparent surfaces captured using photogrammetry were also scanned with short-range (Apple) Lidar. They were created using smartphone scanning apps like Polycam, Scaniverse, and 3DScannerApp, all of which support Apple Lidar. While photogrammetry was the primary focus, comparisons with Apple LiDAR setups yielded very different results. In these scans, photogrammetry's distorted and melted geometry characteristic was replaced by a LiDAR interpretation, in which reflective and transparent surfaces were rendered absent, causing objects to disappear altogether from the scans.

Captured against the grid surface, the scanned objects disappeared, leaving a flattened image of the absent three-dimensional glass object projected onto the grid surface (Figure 119). Several images from various angles were projected through the glass items (Figure 120). While photogrammetry scans reconstruct objects as solid three-dimensional (albeit deformed) meshes, Apple Lidar scans produced a new type of scanned photogram. These photogram-like projections were prevalent among glass objects, often displaying angled views captured and rendered into 2D textures. The scans resembled crude versions of photograms, and they reminded me of the first photograms by Fox Talbot. The Apple LiDAR scans appeared, as Talbot wrote of his photograms, to be “inscribing the shape of the object onto the paper in an inverted silhouette” (Campany, Parker, Shaw, 2018, p.14). Interestingly, shadows of the missing objects and other optical light patterns were conventionally captured on the same grid surface. This indicated an indexical effect that rendered the presence of absent objects, such as shadows, where the scan-photograms pointed to the mirror and glass surfaces without representing the objects[58].

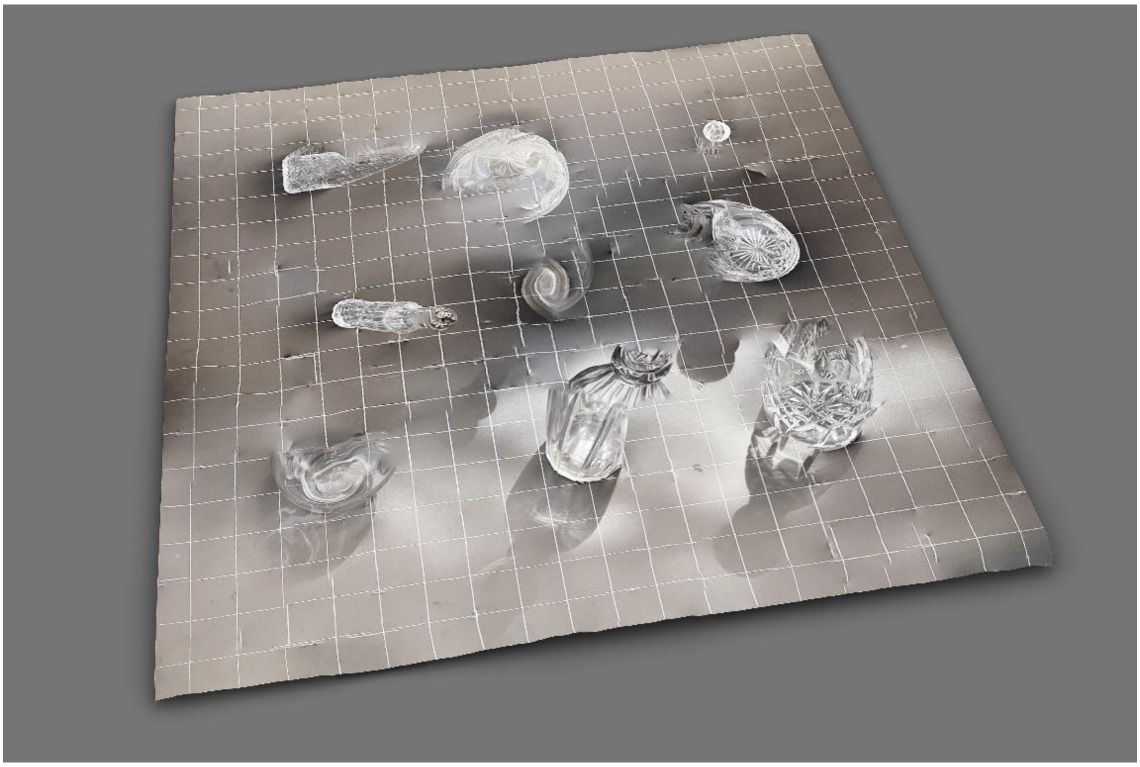

Figure 119. Short-range LiDAR “Scanogram” shows projected images of absent glass objects. Scan by the author.

[58] The scan-photogram effect was most pronounced with the Apple LiDAR. Nonetheless, slender or transparent objects were imprinted in image textures on larger objects throughout the project scans. The space scans captured delicate objects as imprinted images on walls, ceilings, and floors.

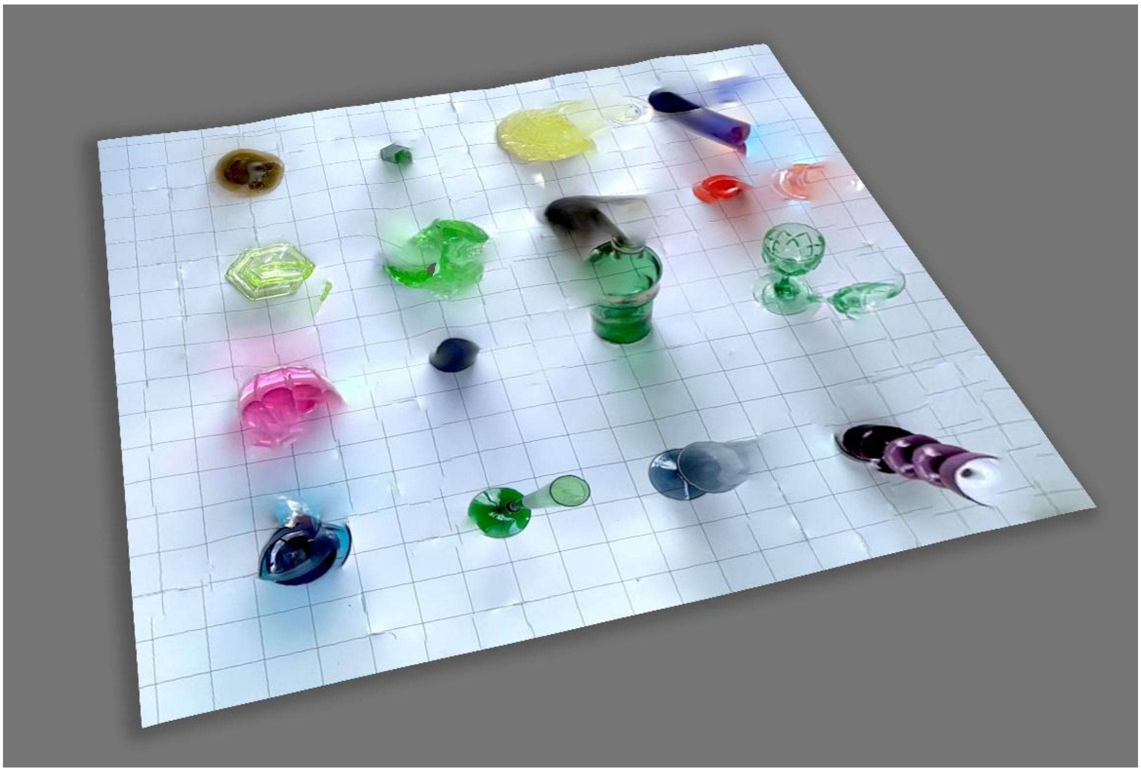

Figure 120. “Scanogram” shows coloured projections. Scan by the author.

The Apple Lidar scans resembled photograms, shadowgrams, or even multiple exposures. However, they were created entirely differently from the darkroom practice of exposing physical objects on light-sensitive paper. Several key differences set these scans apart from traditional photograms, beyond how the image was made. For instance, the partial remnants of some three-dimensional objects and the random, multi-directional projections of surfaces differ from the singular, fixed view in a photogram[59]. Unlike chemical photography photograms, the scans resembled digital photograms created in 3D software. Photographer Thomas Ruff has simulated photograms using virtual lights and cameras in 3D rendering software, where he digitally renders “the play of light and shadow on objects” (Baker,

[59] Unlike a photogram, glass scans register projections of surfaces as image imprints and are sometimes accompanied by geometry bumps and blobs where the scanner captured elements of the solidity of the glass item.

L'Ecotais and Mavilian 2018, p 215). We can position the scan-photogram somewhere between the mechanical chemical photogram and a simulated photogram, referring to these LiDAR photograms as "scanograms" [60]. This phenomenon has not been documented before in 3d Scanning, and to fully comprehend how they form, we need to explore what the scanner sees, and does not see, when it encounters transparent surfaces.

In the scanograms, the glass surfaces are absent from the scans but are indicated by projected light patterns on the grid surfaces. This suggests that the Apple LiDAR sensor failed to recognise the glass surfaces. However, the onboard iPhone or iPad camera has captured images of the glass that have become embedded in the scan's digital texture. This in-scan technological phenomenon projects images of the transparent object onto another surface. The camera recorded multiple projections of glass objects; the angle between the scanner and the object dictates how the projected image is stretched across the surface. This action recalls Paikka's distinction between wifi-seeing (sensor vision) and visible light photography. The LiDAR sensor can see through glass or reflect off metal surfaces, but the linked iPhone camera captures projected images of these surfaces from various angles. The scanner also captured shadows and other light patterns, such as caustics. While a 3D scan observes these optical effects, it strangely does not see the object. The scanograms are oddities within the field of 3D scanning; certain surfaces are left as traces in the scans. Again, these would be viewed as errors by the 3D scanning industry.

[60] There is a tradition among photographic artists working with variants of the photogram to assign them designations that differentiate processes or artistic styles and methods (perhaps the most well-known example of this is Man Ray's Rayograph) (Baker, L'Elotais and Mavlian, 2018, p.215).

To both conceptually and technically help us interpret the *scanograms* of glass, we can look at the work of Cornelia Parker. According to Robert Malbert of the Hayward Gallery, much of Parker's artwork is "the translation of three-dimensional objects into two dimensions" (Campany, Parker, Shaw, 2018, p.6). Malbert gives the example of Parker's *Thirty Pieces of Silver* (1998), an installation where she physically flattened objects with a steamroller, transforming them into squashed, image-like versions of their former three-dimensional shape. In the *scanograms* we see three-dimensional objects imaged and flattened to two-dimensional versions within a three-dimensional space. Parker's photogravures explore this transition from three to two dimensions, a photogram process in which objects are exposed against a photographic plate using ultraviolet light (Figure 121). She describes glass items used in photogravures as the negative, with the photographic plate upon which they are exposed as the positive (Cristea Roberts Gallery 2020). We can think of the scanograms similarly, where glass surfaces act as a kind of transparency or lens, projecting an image of themselves within the 3D scan. It functions as a negative, fixing a projected image onto the (positive) surface on which the glass rests. In Parker's photogravures, the glass creates an image that extends into the pictorial plane, while the *scanograms* generate fragmented images that recede from the surface. These are two-dimensional versions of three-dimensional objects (Figure 122).

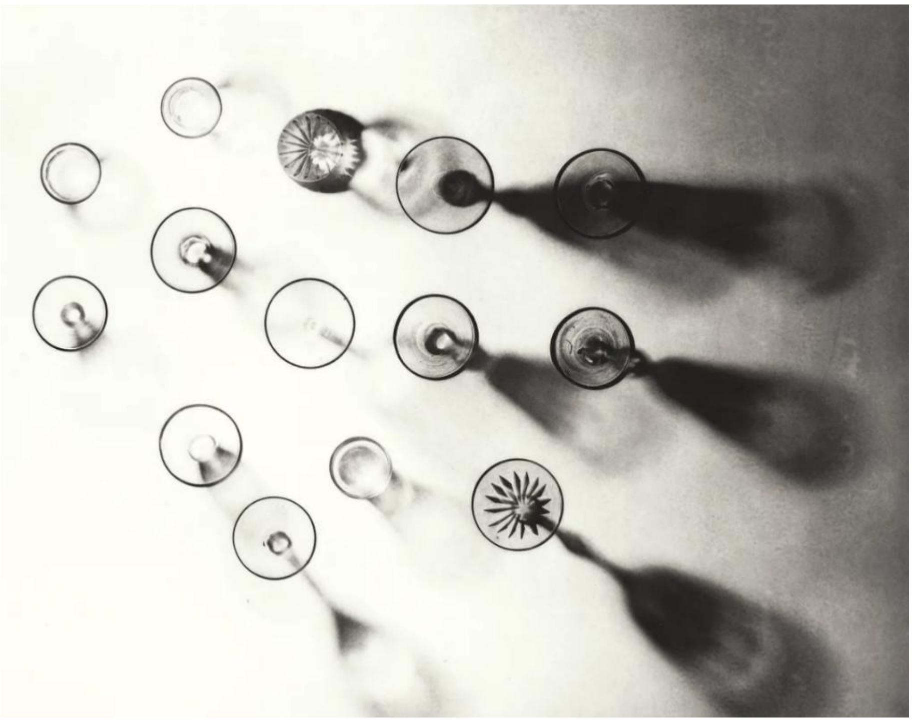

Figure 121. A Sideways Glance (2020) Cornelia Parker.

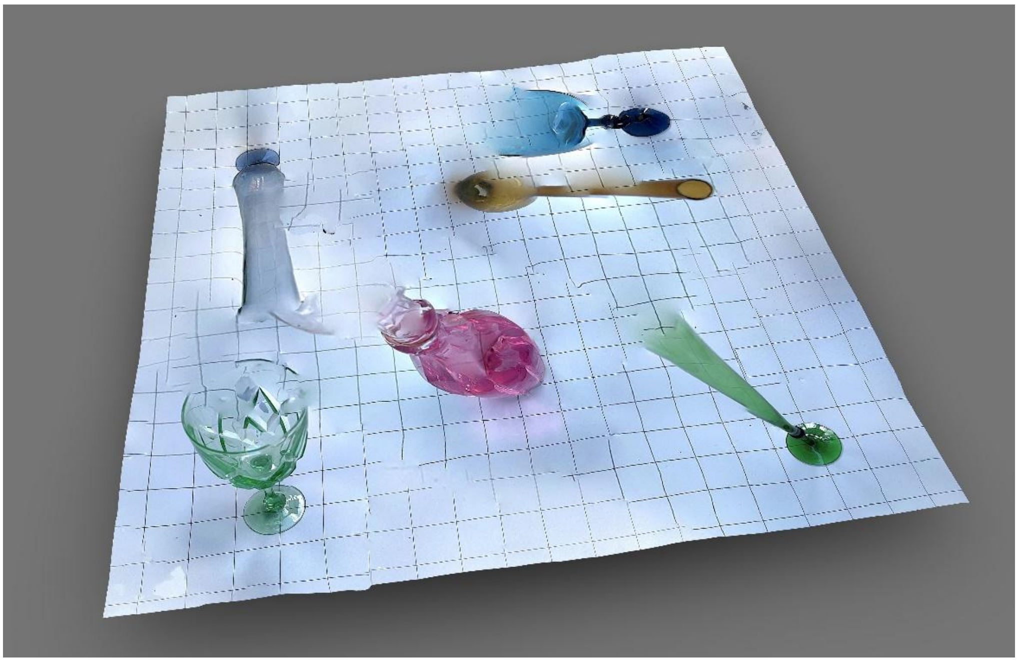

Figure 122. "Scanogram" shows the scanner catching different views of the absent objects. Scan by the author.

The *mirror and glass scans*, like most 3D scans, are ultimately flattened into a two-dimensional image on the screen. However, other forms of flattening occur when these objects are scanned. For example, a photogrammetry scan of silver items on a tray becomes a collection of flattened, mixed-up reflections (Figure 123 and Figure 124). Here, the silver objects (a teapot, sugar bowl and a milk jug) appear to have collapsed onto the tray's surface. What remains are skeletal outlines, as if the solid bodies have disappeared, leaving only their bones. The reflections cause the scans to break apart and reassemble the objects in a disordered manner. The scan of a silver tray also reminds us of Parker's flattened silver objects, but in the metal tray scan, the objects are less distinguishable than Parker's steamrollered silhouettes.

Figure 123. A group of reflective metal teapots and jug.
Photograph by the author.

Figure 124. Photogrammetry of a tray of metal teapots and jugs. Scan by the author.

The *scanograms* turn familiar glass objects into flattened projections. Baker, L'Ecotais and Mavilian (2018) write about photograms in *The Shape of Light*, a text on abstract photography. In this book they describe a photogram as a " technique that relied closely on real physical objects, was then paradoxically used to create abstract artworks" (Baker, L'Ecotais and Mavilian, 2018, p. 215). This is true of the *scanograms* where 3D scanning, as a tool for accurately copying reality, begins to behave abstractly. The multi-view perspectives captured in the *scanogram* images lead us to think of artworks that reject singular photographic viewpoints in favour of many different views. For example, David Hockney's variable-viewpoint photo montages or the shifting perspectives of George Braque's cubist paintings. Occasionally, in a *scanogram*, a glass object will be drawn as a recognisable shape with a single vanishing point, much like a Parker print. Still, the *scanogram* images are often fragmented views from different perspectives and vanishing points. Like Parker's photogravures, they show how the scans capture from many "oblique angles over and through the objects, transforming the once familiar item into something very unfamiliar" (Cristea Roberts Gallery, 2020, para. 2). The *scanograms* present familiar glass objects from, oblique angles, seemingly at random during the scanning process.

These fragmented views act as traces of objects seen by the scanner from different angles. Like Parker's photogravures, they can be understood as indexical signs of absent objects. Antonia Shaw, a curator at the Hayward Gallery, describes Parker's photogravures as "a trace, or indexical reference" (Campany, Parker, Shaw, 2018, p.17). Photograms and photogravures have traditionally been considered indexical processes. The *scanograms* function similarly to a photogram (within the scan's system), showing projections of missing forms, like a footprint. Interestingly, the *scanograms* not only resemble digital photograms, but they act like digital reliefs, combining both two and three-dimensional features. Within the image, there may be a raised area where a glass object stood, like the partial remnants left by melting ice.

In conclusion, the *scanograms* differ from other mirror and glass scans. Unlike the distorted, melted geometries seen in photogrammetry scans, the Apple Lidar technology interprets reflective and transparent surfaces as physically absent. However, it records evidence of their presence by projecting flattened images of the missing objects onto the surface where the glass once rested; a trace remains visible. The *scanograms* resemble photograms but are closer to digital simulations of photograms than to traditional chemical ones. Like Parker's photogravures, they symbolise absence and function as indexical signs. With this understanding of the index, the next part of the chapter will further explore a key theme of identifying indexical traits in the mirror and glass scans.

4.5 Resemblance and index

> Assumptions about realism in the cinema are frequently tied to concepts of indexicality prevailing between the photographic image and its referent.
>
> Prince, 1996, p. 28

The quote above by Prince addresses how photographic realism traditionally relies on the indexical link between a photograph and its referent. Prince and others have extended this exploration of indexicality to digital capture and computer-generated images. Similarly, this thesis investigates indexicality in 3D scanning and examines its role in what is often perceived as scan detail and representational accuracy. It achieves this by analysing the scans produced for the research practice, situating them within broader perspectives on indexicality in digital media, and supporting photographic theory. To explore how indexicality shapes the perceived realism in scans, even when visual resemblance deteriorates, this section incorporates literature and the views of authors and artists identified in the first chapter; it also brings in some new sources concerned with semiotics, visual realism, and digital indexability.

I argue that photorealistic standards applied to reality capture are underpinned by assumptions about the technology's resolution, quality, detail, overall visual accuracy and indexical link to the referent surface. As Gunning points out in his discussion of photography, “visual accuracy and recognizability” are how “indexicality intertwines with iconicity in our common assessment of photographs” (2004, p.40). A similar logic seems to apply to evaluating indexical realism in 3D scanning, where indexicality and photorealistic standards are intertwined in both how scans are produced and interpreted. Like photography, in 3d scanning, indexicality appears to be conflated with visual fidelity, reinforcing the assumption that photorealistic detail is a measure of objective representation.

However, just as Gunning was sceptical about this notion, saying that it is possible to “produce an indexical image of something or someone that remained unrecognisable,” many of the scans in this research exhibit a similar ambiguity due to unscannable surfaces (Gunning, 2004, p.41). The *mirror and glass scans* are a mixture of recognisable and unrecognisable elements. Still, the capture process appears unchanged; the software does not list the scans as failures or flag up warnings about the viability of the scans. Does this mean that indexicality persists in scans that lack visual resemblance to their source objects? More broadly, here I continue to examine whether digital reality capture can be considered indexical.

It can be challenging to detach from the perception that a successful 3D scan is determined by how closely it resembles the object. In the 3D scanning industry, the visual fidelity is the degree to which a scan visually and geometrically matches its referent. This remains a dominant factor when assessing the accuracy and overall “realness” of the capture. Factum Arte, for example, describes scan resolution as the amount of physical detail digitised in the 3d file, and, as with photography, detail is crucial for indexical connection. In scanning, higher resolution tends to result in a closer resemblance. The success of a scan is often measured by direct visual comparison with the original: if the scan looks the same, it has, according to Factum Arte, passed the “mimesis test” (2022)[61].

The concept of mimesis to which Factum Arte refers can be understood through Lister et al.’s definition. Writing in the context of digital media, Lister et al. describe mimesis as an ancient theory of representation in which meaning is thought to lie in real things themselves, and where the work of representation is to faithfully copy the appearance of that thing, “rather in the way that a mirror reflects reality” (2009, p.129).

Reality capture can be seen as a practice of three-dimensional mimesis: a digital mirror of the physical world. In 3d scanning, mimesis is traditionally achieved through resemblance, based on appearance, resolution, and assumptions of indexicality. Technological updates to reality capture methods, particularly photogrammetry, incrementally increase the potential for higher resolution and greater visual similarity. Higher scan detail translates into millions of polygons that describe the surface's topography in photogrammetry. In this way, resolution and indexicality appear interlinked: the more detailed the scan, the stronger its perceived connection to reality.

Indexicality in 3D scanning can be most clearly understood through Peirce’s idea that an index involves “a pair of particles, either of which may serve as an index of the other” (1931, p.169). In LiDAR scanning, this relationship can be interpreted as the lasers travelling between the scanner and the object. LiDAR scans generate point clouds, millions of points in virtual space, each corresponding to a physical point in the world. These points could

[61] In 3D scanning, photorealism relates to the objective understanding of the scan's resolution and the subjective validation of mimesis through visual comparison between the scan and the original object.

be seen as a digital manifestation of indexicality in action, where each point in the cloud traces a real-world location.

Peirce also described photography as a special type of sign that combines a physical connection to the referent with a visual resemblance. 3D scanning operates similarly as it resembles its referent and maintains a physical connection through the scanning process. In scanning, as in photography, the icon (resemblance) and index (physical trace) are deeply interwoven. As a sign, the scan is compelling because it appears to deliver a photorealistic representation that stems from life. We have seen how this is particularly true of photogrammetry. To understand why photogrammetry is so powerful in this respect, we can turn again to Bazin's writing on photographic realism. As Bazin said of photographic images:

> Only a photographic lens can give us the kind of image of the object that is capable of satisfying the deep need man has to substitute for it something more than a mere approximation, a kind of decal or transfer. The photographic image is the object itself, the object freed from the conditions of time and space that govern it.
>
> Bazin, 1960, p.8

Photogrammetry seems to extend this logic, offering detailed three-dimensional form, colour and texture; it is, in a sense, a fuller embodiment of the object than a photograph. Bazin further told us that photography and cinema as mediums satisfy "once and for all and in its very essence, our obsession with realism" (1960, p.7). Reality capture pushes this further; its three-dimensional nature appears to satisfy a desire for a lifelike three-dimensional realism in both form and image. It transcends the two-dimensional aspect of older media. Bazin referred to this desire as the "mummy complex", a need to embalm time somehow, to "snatch it from the flow of time, to stow it away neatly, so to speak, in the hold of life, and preserve it in an image” (1960, p.4). 3D scanning can also express this mummy complex as a technical means of embalming objects inside digital scans. An objective and measurable mechanical process satisfies our “appetite for illusion by a mechanical reproduction” (1960, p.7).

Yet, as we know, not all indexical signs look like their referents. As the *mirror and glass scans* demonstrate, visual resemblance can be disrupted or broken in 3D scanning, especially when materials such as reflections push reality capture to its representational limits. Visual resemblance and indexical connection do not always align perfectly. When scans diverge from visual resemblance, they are often seen as at fault because they fail to meet the photorealistic ideals and standards applied to reality capture. The *mirror and glass scans* hover on the edge of this photoreal iconicity, partially resembling the objects they represent. This creates a sense of dissatisfaction because, as Bazin noted regarding photography’s collective psychological need to replicate reality, we instinctively desire the scans to mirror our perception of the object or function like a photograph; any deviation disorients us. Nevertheless, the scans are revealing in other ways; as artworks, they represent a creative journey through the aesthetic character of the scanning medium at the fringes of what it can capture. They explore the accidental discoveries of unscannable materials, pushing them to the point where perceived photorealism unwinds just enough to reveal its internal structure. They achieve this without a complete collapse in resemblance, allowing the images to embody how the scans are constructed and what the scanning process perceives.

Parikka wrote about how reflective surfaces and complex architectural structures “throw sensors off, leaving [scanning] to perceive the cityscape in surprising, accidental ways” (2021, p. 199). Parikka described this phenomenon as the “over-seeing of light,” which he refers to as new “ways to understand the functions of this form of [scan] imaging.” He continues that this provides “an experimental framework for a scanning device that also records its own existence” (2021, p. 199). This “framework” aligns with the creative technical method of the research practice involving 3D scans produced for this thesis.

The mirror and glass scans illustrate how photogrammetry interprets reflection and refraction as surface textures, inscribing light and shadow as representations. As the camera moves around the scanned objects, transient optical effects caused by mirror and glass materials behave like surfaces in motion. Photogrammetry reconstructs these surfaces as distorted, molten geometries that shift, change shape, and reform during the scanning process. Reflections are captured as a series of fixed, overlapping views, contrasting sharply with how we perceive reflections in real life. The disruptions caused by reflective and transparent surfaces result in diminished resemblances of the scanned objects, unravelling the connection between mimesis and index. Is the disrupted resemblance of the mirror and glass scans indexical? Are we left with an index, an error, or an artefact?

To explore the nature of indexicality in photogrammetry, we can compare reality capture with another form of computer-generated imaging: a 3D ray-traced render of glass (Figure 125 and Figure 126). These two examples illustrate different optical interactions- one simulated, the other captured. The computer-generated glass is a mathematically precise, ray-traced simulation of light behaviour, whereas the distorted glass scan is derived from real-world photographic data. A computer render is a type of simulated photography that behaves like a camera but lacks a direct physical referent. In contrast, reality capture produces digital models that maintain a physical index, even if the result is imperfect or distorted. This distinction highlights various kinds of indexicality in digital capture.

Figure 125. Photogrammetry of crystal glass objects.

Figure 126. 3D *render of a pitcher, ashtray, and dice. Gilles Tran (2003).*

Wolf (2000) and later Soderman (2007) described how simulated images function as conceptual indices within software systems. They lack the classic definition of indexicality, as it depends on a physical referent. However, following Soderman's definition, a scanned index can serve as a perceptual index, a digital visualisation of physical data, like motion capture or LiDAR scanning. The key point here is that a digital index can be based on a data referent, and as Soderman wrote, it may not, or can not, resemble the referent. Following Soderman's idea on the perceptual index, the mirror and glass scans diverge from resemblance. They break from computer photorealism because they do not always resemble the referent object.

Distortions and disruptions caused by reflections and transparency may be viewed as creating flawed scans. However, these results align more closely with Peirce's broader theory of non-photographic indices that do not necessarily resemble or directly represent their referent. Indexicality in the disrupted mirror and glass may seem complicated to identify, but photography has other parallels. Bazin was convinced that distorted or blurred photographs were just as important as those in focus; they were still a transfer of reality into the image. He said:

> No matter how fuzzy, distorted, or discoloured, no matter how lacking, in documentary value the image may be, it shares, by virtue of the very process of its becoming, the being of the model of which it is the reproduction; it *is* the model.
>
> Bazin, 1960, p.8

We could consider the *mirror and glass scans* fuzzy captures that lack sharpness and documentary value, but as Bazin says, by reproducing the model, they share in its creation process.

Parikka's writing on sensors and non-visible light capture provides further evidence for the authenticity of 3D scans that do not resemble their referent surfaces. Parikka noted how Benjamin Bratton's (2017) writing on sensors and scanning tells us that scanning is not like photographic capture but a collection of overlapping types of visible and non-visible light systems utilising cameras, lasers, radar, and other sensing technologies. These various imaging systems can be complicated to distinguish. Similar to some scans from this project, they result in 3D models or point clouds constructed from collaborating capture technologies. Parikka calls this "multiple kinds of [data] knowledge", which leads to a "transformed notion of photography, they become emphasised as connective images" (2021, pp. 205-207). Parrikka states that this questions the rhetorical tropes of photography and how they apply to 3D scanning. Images produced by certain sensors and non-visible light scanning can be anything but photorealistic. They may appear blurred, indistinct, and translucent, as seen with point clouds. However, this data can still be photographically framed because reality capture is linked to older media forms, particularly photography and computer-generated models and images. Although 3D computer graphics serve as a companion medium to reality capture, they maintain a symbiotic relationship.

Reflective and glass materials may degrade the resemblance value of visible light scanning technologies like photogrammetry. However, as Peter Geimer (2007) notes (writing on the index and the photograph), resemblance is based on "a series of codes, conventions and varying ascriptions" that create photographic realism 2007, P.8). Geimer comments that this has little to do with indexical traces. This can be seen in the mirror and glass scans; even though these scans do not closely resemble their referents, they still maintain an indexical trace. The scans may not resemble the glass surface, but they share a fundamental quality. In this case, that quality is how the scans interact with and are distorted into molten shapes by reflection and transparency. This behaviour is similar to the warped reflections in a hall of mirrors. While we do not mistake these reflections for an exact truth, we still recognise that they originate from the original object and follow optical principles and laws. We have already seen Scanlab's accidental LiDAR mirror scans, which showed the bending and twisting of mirrors and glass but accurately represented how lasers interact with mirror surfaces; they produced truthful but unexpected results.

The mirror and glass scans disrupt ideas about resemblance and photorealism, yet they may still remain objective. Beyond the disruptive surfaces, there are other indexical markers in the scans that are clear to interpret, such as light patterns on the grid and shadows, which testify to the presence of objects. Shadows in the mirror and glass scans demonstrate how the object blocked or interacted with a light source. In his writing on computer-rendered shadows, William Mitchell pointed out that shadows bring solidity and visual realism to a computer-generated scene. Shadows convey several certainties; they anchor objects to their resting surface and tell us about the object's shape and opaqueness:

> shadows play such an important role in the interpretation of three-dimensional scenes: they provide a "second view" of shapes, from a different vantage point. Sometimes this second view becomes the only source of information about the third dimension, as when peaks and craters of the moon are revealed by the shadows that they cast.

Mitchell, 1998, p.150

Like photography, both photogrammetry and LiDAR capture the optical effect of visible shadows. However, the scanning systems produce another type of shadows specific to scanning. Surfaces blocking LiDAR lasers cast shadows as distinct black shapes, which represent holes (data gaps) in the scans. Despite appearing empty, the boundaries of these shadows are silhouettes that reveal information about the objects in the scene (Figure 127).

Figure 127. ScanLAB Projects (2010) LiDAR scan shows indistinct moving figures, with clear shadows.

In addition to the scanning equipment generating infrared shadows, visible light shadows are present in the scans. According to Pitor Sadowski (2019), who wrote about the shadow as an indexical sign, “shadows inform us about the solid objects that produce them, even if we do not see the objects themselves” (2019, p.13). While mirror and glass objects disrupt how reality capture represents these surfaces, the shadows cast by the scanned objects remain undistorted around the base objects and missing surfaces. (Figure 128, Figure 129 and Figure 130). As Sadowski states, shadows prove that something exists:

> Shadows testify to the existence of spatially displaced objects, just as footprints or photographs testify to the existence of objects that are displaced in both space and time. A sign physically caused by an object and referring to that object, now spatially and/or temporally removed, is what semiotics, the science of signs, describes as the index.
>
> Sadowski 2019, p.13

Sadowski suggests that we make “inferences” from indices such as shadows, arguing that shadows hold more meaning on their own than when seen alongside their referents. He likens this effect to chiaroscuro, which, while used to convey modelling through contrasts of light and dark, excites the imagination through darker areas or missing imagery more than a brightly or evenly lit scene, revealing everything to the viewer. In the same way, shadows serve as indexical markers that tell us about objects.

Figure 128. Photogrammetry shows the distorted glass with clear shadows of the object's original shape. Scan by the author.

Figure 129. Intact shadows are cast by disrupted coloured glass. Scan by the author.

Figure 130. Shadows around disrupted coloured glass. Scan by the author.

In the physical world, you cannot disassociate shadows from their objects, but with reality capture, sometimes a shadow is more identifiable than the form that causes it. Distant or moving objects in LiDAR scans leave shadows, but the objects may appear less defined or absent. The disrupted glass objects in photogrammetry scans cast sharp and defined shadows compared to the object casting the shadow, which is captured as a deformed molten shape. E.H. Gombrich (1995), writing about shadows in art, observed that while a shadow is intangible and fleeting, it helps describe shape and the presence of form. He wrote that “there are situations when the appearance of a shadow testifies to the solidity of an object, for what casts a shadow must be real” (1995, p.6). Gombrich’s thinking about the shadow is similar to Peirce’s writing on how shadows are proof of the referent object. While Cornelia Parker notes the significance of shadows in her artwork, where “shadows are as much part of the piece as the physical objects”, they represent the “compression of three-dimensional objects” (Cristea Roberts 2022, para 8).

Writers on the index noted in a list of categories that “cast shadows could also serve as the indexical signs of objects” (Krauss, 1977, p.70). Kraus elaborated on the shadow, stating that actual shadows occurring in the world and shadows permanently “fixed” from objects were indexical markers. Shadows captured in mirrors and glass scans result from both 3D scanning equipment (as data gaps) and, more noticeably, the objects interacting with visible light in the scene. Shadows provide insight into an object's shape, dimensions, and distance from the light source (Kaufmann 1975). If the mirror and glass scans only partially resemble the objects, we can identify the category of an object based on its shadow captured in the scan. Stoichita calls this “the index’s likeness,” where the representation of the shadow must form a recognisable profile (1997, p.113). Stoichita states that “the index has the same characteristics as both shadow and photograph in so far as it refers back to its object" and that while shadows are spatially connected with particular objects, they also evoke meaning through our own experiences and memory. A shadow, therefore, is a sign which, due to the shadow's profile, is both "mimesis and index (likeness and physical connection)" (1997, p.113). Even if the level of resemblance in the scan is diminished by reflections and transparency, or in some cases results in the complete loss of the object, the shadow persists; it signifies indexicality in the scanned scene.

Several authors have written about the indexical nature of shadows; however, reflections as indexical signs appear to receive less attention. Just as a shadow is considered an index, it seems logical that, because light behaves predictably and according to the laws of physics, reflections can be regarded as indexical signs. Photogrammetry fixes reflections onto the surfaces of scanned objects, and reflections captured in the mirror and glass scans may also serve as indices, imprinting the reflected environment into the textures of the scan. Photogrammetry captures 360-degree multi-viewpoint reflections, which can become quite blurred, but traces of the reflected environment are evident in the scan. Earlier scans of mirror and glass spheres clearly show overlapping reflections relating to objects from numerous viewpoints. However, these blurred reflections also appear to be the primary reason for the distortions of the spheres, jam jars, and other glass items. The result of the mirror and glass scans is an aesthetic that contrasts with the static single view of a camera or computer render, while remaining true to how photogrammetry works from many angles.

The distortions and molten effects observed in the *mirror and glass scans* separate resemblance from indexicality. While assumptions about the photorealism of 3D scans often remain unchallenged in commercial or technical contexts, they typically equate visual resemblance with accuracy and resolution. An indexical connection to physical surfaces underpins the realism of 3D scans. However, the *mirror and glass scans* demonstrate that indexicality remains evident in these scans through other traces when visual resemblance deteriorates. Geometric distortions, overlapping reflections, and shadows serve as indexical markers, offering a more nuanced understanding of how these digital models function as traces of reality.

The following section explores the evolving relationship between photogrammetry and photorealism. Concepts related to photorealism and its connection to photogrammetry aid in understanding the inconsistencies observed in photorealism in mirror and glass scans.

4.6 Photogrammetry and photorealism

Photogrammetry extracts 3D data from sets of photographs to reconstruct geometric models with detailed photographic texture mapping. Among the various reality capture techniques available for 3D scanning, photogrammetry stands out as its textured 3D models look the most photorealistic, and they are visually close to how we see things with our own eyes. Companies like Quixel claim that their photogrammetry-based scans are photorealistic. However, despite industry claims and the evident photographic framing of reality capture data, the idea that photorealism can be digitised through reality capture is difficult to quantify. This is because photorealism is not a quality or aspect of the world around us; it is a cultural mediation, a visual cultural construction through media (in painting and computer-generated imagery). Despite this, mimesis is used to judge realism when evaluating photogrammetry scans. Resemblance in scanning becomes intertwined with photorealism assessments. Is a scan photorealistic because it looks like the original, or is a photorealistic ideal or standard applied? Photorealism in scanning is most evident in how commercial 3D scanning extensively markets photogrammetry scans as photoreal assets (Unreal Engine, 2019). This section examines the connections between photorealism and photogrammetry scans conducted for the research. It asks whether photorealism is misinterpreted when comparing a scan to the original. In addition, this section concludes with a look at Artificial Intelligence (AI) in 3D scanning and how it is used to capture and represent unscannable surfaces such as mirrors and glass.

The *mirror and glass* scans deliberately explore non-photoreal, unscannable surfaces. Photorealism effectively unravels in these scans when photogrammetry encounters optical effects generated by polished metal surfaces and glass surfaces. Reflections turn into geometric distortions fixed within the shapes of the scanned models, scans of coloured glass merge into a single surface like mixing paints, while transparency is permanently captured and represented as texture maps of the models. These scanning phenomena challenge the capture technology and industry notions of photorealism in 3D scanning. The unscannable mirror glass surfaces disrupt our understanding of how reflections and transparencies behave with scanning technology, which is quite different to how we and the camera perceive them, and how computer rendering simulates them. In these scans, reality capture perceives reflection and refraction very differently from the human eye or the camera.

The scans are created from hundreds of scene photographs. The photogrammetry software processes the photographs (as it would for any other surface type), reconstructing the 3D scan as a geometric model. Photogrammetry, like different types of scanning, can fail; the software might reject photographs of reflective or glass surfaces, and when processed, scans may be only partially formed or unsuccessful. There are stages in the scanning process that can go wrong in the software if there is insufficient information (points of similarity) in the photographs to reconstruct a photogrammetry model. However, with *mirror and glass scans*, there was a high success rate, with few failed scans, even though the results did not resemble the original; technically, the scans were a success for the software.

This section establishes a broader theoretical backdrop for understanding photorealism in photogrammetry before addressing the specific challenges it faces when encountering reflections and transparent surfaces. I incorporate sources on photorealism to better grasp its relationship with 3D scanning and the disruptions to photorealism observed in mirror and glass scans. The first chapter identified definitions of computer graphic photorealism in the literature. Authors, including Bolter and Grusin (2000), Mitchell (1994), Manovich (2002), and others, broadly define computer photorealism as based on the photograph as a model, creating a computer image that resembles a photograph rather than a representation of reality based on our perspective. Computer photorealism is a digital rendering that imitates the visual qualities of photographs. In this section, I reference academic writing on photorealism and the work of specialist photoreal artists when analysing the results of the scans.

Bolter and Grusin define computer photorealism thus:

> Computer graphic photorealism needs at all costs to avoid inconsistencies or breaks in the illusion. It constructs the real as a plenitude, which is one reason that the photograph is used as a model.

Bolter and Grusin (2000) P.119

The concept of “the real as a plenitude" aligns with Quixel's philosophy of harvesting thousands of scans from the world to create photoreal computer-generated environments, and for the 3D scanning industry, scanning shortcuts the hand-modelling process necessary to develop a photorealistic 3D model. Photogrammetry provides a pathway to creating a level of previously unseen digital photorealism that is challenging to achieve with traditional methods of constructing 3D models by hand. In many practical cases, photogrammetry will perform better than the modeller, particularly when capturing natural patinaed structures or human form. This is an evolving form of photorealism in 3D scanning that I call “scan-photorealism”. Scan-photorealism focuses on object digitisation using photogrammetry and is shifting the understanding of digital photorealism from a photograph's visual appearance to the scanned model's perceptual credibility.

High levels of surface accuracy (scanned or modelled) in individual digital assets provide photoreal credibility to both the model and the overall scene. I have discussed how assessing a 3D scan involves comparing the original and digital replica, examining surface shape, material, and accuracy, effectively judging mimesis. This type of realism assessment aligns with Prince’s (1996) concept of “perceptual realism”, seen in computer-generated images for film. The distinction here is that when working with 3D scans as three-dimensional objects, any realism assessment focuses on the experience of the referent object or environment. Perceptual realism in computer-generated environments or characters is when these elements “structurally correspond to the viewer’s audiovisual experience of three-dimensional space", and we can think of photogrammetry scans being scrutinised in similar terms (1996, p.32)[62].

Prince expands on how perceptually realistic surfaces work by "employing realistic lighting (shadows, highlights, reflections) and surface detail" (1996, p.32). Prince refers to computer-generated images in film and how the audience is likely thinking more about how something computer-generated would look if they saw it with their own eyes rather than through a camera. Perceptual judgements about levels of photorealism in photogrammetry scans might shift the focus from photographic framing to the visual accuracy and credibility of the model.

The film theorist Berys Gaut (2010) discusses how photorealism in computer animation is changing, describing it as a highly technical process involving 3D modelling which goes beyond simulating lens effects or film grain. Gaut highlights how levels of 3D modelled anatomical structure and detailed textures in animated fantasy creatures help contribute to a photoreal ideal (2010, p.66). While Gaut subscribes to digital photorealism as proposed by Manovich, we get a sense that digital photorealism in computer animation is more complex and evolved today than its previous definition as a photographic simulation. Gaut emphasises structural anatomical accuracy in digital creatures, builds on Prince's concept of perceptual realism, and both move beyond photographic likeness and simulation to the plausibility of the 3D model.

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[62] Over several years of teaching 3D computer modelling and animation to undergraduate visual effects students, I have observed that they tend to respond to digital 3D models according to Prince's model of perceptual realism. Despite learning about photography, cameras, and lenses in visual effects, students often use the terms "real" and "realistic" to describe their 3D models or those of their peers, rather than photorealism. Perceptual realism offers a framework for non-critical outcomes analysis in the modelling and texturing processes, as well as when processing 3D scans. However, industry sources frequently assess 3D scans based on the levels of photorealism achieved. In visual effects workflows, photorealism serves as a benchmark for the final result of a visual effects shot.

Photorealism has long been used as a benchmark or standard when assessing the realism of computer-generated images. However, I believe photorealism has evolved through scanning to incorporate perceptual judgments. With its capacity for extremely high levels of captured detail, photogrammetry changes concepts of photorealism in scanning from photographic simulation to object fidelity. I call this “scan-photorealism”, a form of realism not based upon recreating lens effects or the look of a photograph but the objects' believability. This perceptual understanding of 3d digitally scanned models builds on Prince's definition of perceptual realism to incorporate scanning technologies' ability to capture rather than simulate surfaces and material detail.

Scan-photorealism is evident when companies like Quixel refer to their scans as photoreal or imply that photorealism can be captured. They emphasise the high visual and spatial accuracy levels in their photogrammetry models as their version of digital photorealism. They market these models as superior to previous hand-built versions or methods of creating 3D digital assets to produce photoreal computer-generated environments. Today, the practice of using photogrammetry to construct environments for video games, computer animation, or as part of a visual effects shot shows how scanning is used in photoreal construction. Incorporating photogrammetry models into digitally generated environments helps maintain what Gunning calls the “truth claim” in photography, where we are subconsciously aware that there is an index, a referent somewhere in the image (2004, p.41). In this case, it is a 3D scanned model.

While digital photorealism might be an obvious application for photogrammetry, as I have demonstrated, not all scanning outcomes are photorealistic in appearance or maintain a close resemblance to their referents. This was the case with the *mirror and glass scans*, where photogrammetry faces specific challenges of reflections and transparency. As with other unscannable surfaces and spaces in this project, scanning interprets these surfaces in its way, but this disrupts and undermines the illusion of photorealism. To understand how *mirror and glass scans* challenge or alter our understanding of computer-generated or computer-scanned photorealism, we can examine how the scanning aesthetic reveals itself in these scans.

In a photorealist painting or computer rendering, the visual trick is that the viewer is initially unaware of the medium due to the sophistication of the representation. Computer graphic photorealism needs to preserve a photographic illusion; its artifice only succeeds when it is invisible to the viewer and has erased (with the help of software or modelling techniques) any evidence of the medium. Bolter and Grusin call this photoreal illusion “immediacy”, where the medium is transparent to the viewer, and they believe in the image before them. In contrast, “hypermediacy” occurs when the substance of the medium (in this case, the geometry of photogrammetry) becomes evident to the viewer. When photogrammetry disruptions happen in the *mirror and glass scans*, the medium experiences hypermediacy. We, as viewers, become aware of disruptions occurring in the scanning medium because they are visible in the model.

A further concept from Bolter and Grusin useful when looking at scanning and photorealism is “remediation”. This is when a “new medium is justified because it fills a lack or repairs a fault in its predecessor, it fulfils the unkept promise of an older medium” 2000, p.60). Remediation is apparent in photoreal uses of photogrammetry, which fulfil deficits in the representational roles of the 3D modeller. With the photoreal use of photogrammetry models, the modeller or computer artist wants to maintain immediacy. The *mirror and glass scans* disrupt remediation in various ways. One issue is that they reflect the captured environment, yet the modeller or computer artist often requires a reflective 3D model to represent the computer-generated scene, which the scans fail to provide. Computer-generated reflections and transparency are procedurally straightforward to simulate with digital shaders. In contrast, scanning reflections and transparent surface capture are much more complex, at least with photogrammetry. Again, the *mirror and glass scans* do not fit the 3D model format. A scan of a glass object is usually remediated, with a computer-generated glass replacing the material to achieve a photorealistic ideal.

Photogrammetry is remediating 3D modelling and texturing; it addresses many aspects where 3D modelling and texturing have failed in representing organic, natural forms. However, it encounters difficulties with artificial surfaces such as glass and metal. Faults in the *mirror and glass scans* make us aware of the medium and the materiality of reality capture. In computer photorealism, there are faults and problems too. Bolter and Grusin note photoreal failures as “imperfect (not convincingly photographic)” elements (2000, p.123). The authors analyse the failures and successes of photorealism in painting and digital rendering, comparing treatments of material representation. They find that photorealistic painters better portray certain elements, such as rough textures, while computer photorealists struggle in this regard but excel in other areas of material representation.

> In computer graphics, too, shiny, artificial surfaces dominate. The plastic and chrome are often flawless, whereas skin, cloth, and unpolished wood are not, as if to confirm the traditionalist’s bias that the computer cannot render any human or natural textures.
>
> Bolter and Grusin, 2000, p.125

While the authors' assessment of the effectiveness of computer photorealism is over 20 years old, it remains relevant in many areas. It can serve as a helpful benchmark for analysing photorealism in reality capture. The challenges of creating natural-looking textures using computer graphics are overcome by photogrammetry, which effectively captures skin, cloth, stone, and all rough-textured surfaces, scanning them with relative ease and clarity. For photogrammetry, texture is essential, textures with ample colour variation scan well and without disruption. In *mirror and glass scans*, the absence of texture leads to issues with photogrammetry, which perceives metals and glass quite differently from the sleek computer-generated versions described by Bolter and Grusin. They wrote that the material look of computer photorealism was prone to failures in areas of natural texture. Still, today, photorealistic texturing is easier to achieve with specialist digital texture painting 3D software and the added use of photogrammetry, which invariably gives mimetic texture results. But the disruption of photorealism by the *mirror and glass scans* is where, as Bolter and Grusin say, "the shading and textures, not the perspective [that] fail" (2000, p.126). With the *mirror and glass scans*, the perspective construct of the 3D space remains, but the material disruption results in both mishapen geometry and non-photorealistic shading and textures. Although in fact, the *mirror and glass scans* are a mixture of intact photoreal textures and areas of decreased representation, distortion, and simplification.

I have been comparing the mirror and glass scans to photorealistic 3D renders of glass and metal; however, another comparison can be made to painted photorealism of similar surfaces. Photogrammetry treats reflections and transparency similarly to how some photorealistic painters represent highlights, transparency, and reflection as tonal areas. There are such large amounts of reflections and transparency in some photoreal paintings that their complexity results in hyper-realistic depictions. Optically complex scenes of glass or silverware by photorealist painter Don Eddy are on the verge of losing the object's shape and becoming a depiction of pure reflection and refraction (Figure 131 and Figure 132). The mirror and glass scans perform a similar function; they blend reflections and highlights to such an extent that they appear to be manually painted (Figure 136). The scans move beyond accurate technical depiction. They have an impressionistic aesthetic, where conjoined distorted shapes appear as a sea of metal and glass. There are glimpses of identifiable elements, but these molten-looking forms are a collection of swirling highlights and reflections that appear painted on (Figure 133 and Figure 134.

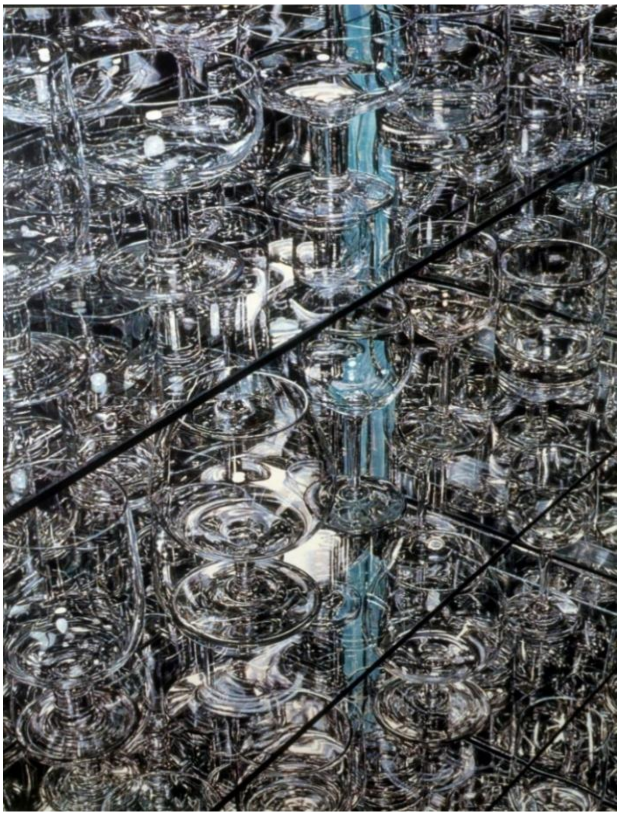

Figure 131. G/I, glassware, Don Eddy (1978)

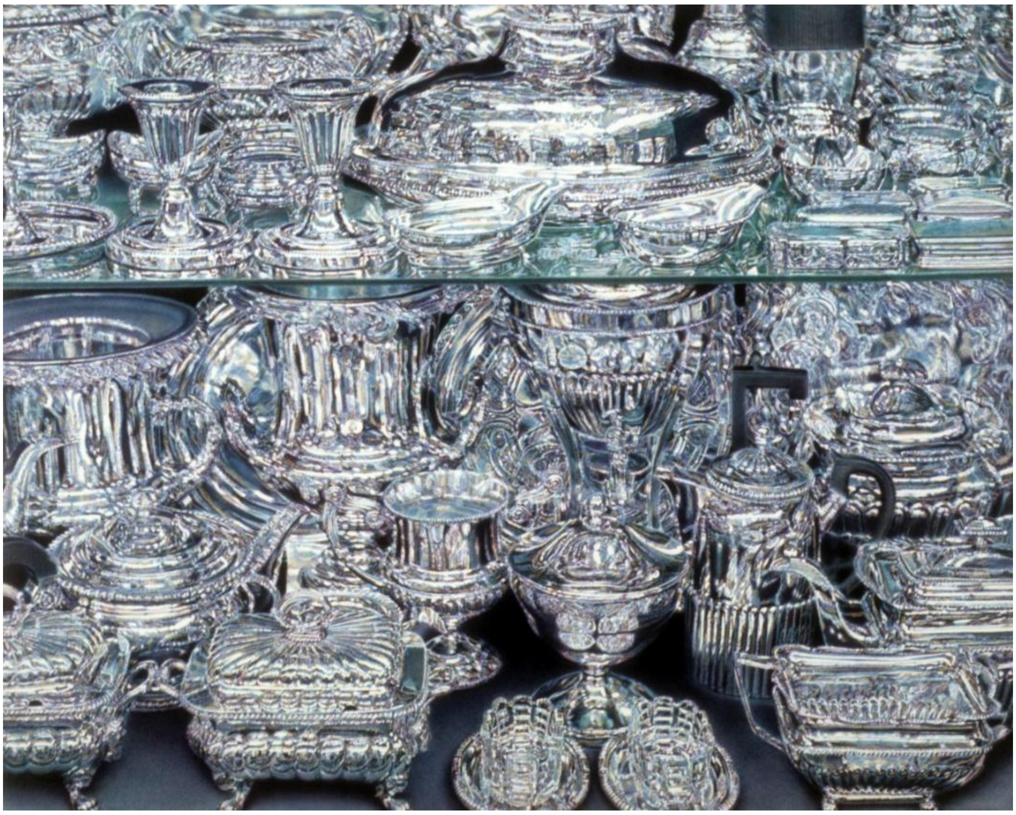

Figure 132. Silverware V (detail) Don Eddy (1977)

Figure 133. Photogrammetry scan of jars (detail).
Scan by the author

Figure 134. Photogrammetry scan of metal and glass items (detail).
Scan by the author.

Depicting photorealistic reflection was a challenge embraced by the photorealist painter for its difficulty. A photorealist painter cannot paint a very reflective scene in situ. Movement or change of light could radically disrupt the position of reflections in the scene. This was why the photograph was used as a reference for painted photorealism, a photograph freezes all reflections and optical effects of transparency into a single image. Don Meisel writes that “only a photograph can do that” (1989, p.13). Meisel gives as an example the problem facing Don Eddy, encountering many mirror reflections:

> Don Eddy’s series of show windows displaying silverware. Silver and chrome exist as instantaneously changing reflective surfaces. No eye sees the same image from one blink to the next, and the attempt to paint a silver or chrome object from life would produce an Impressionistic work. In fact, all realism prior to Photo-Realism is to some degree Impressionistic, or at least an impression.
>
> Meisel, 1989, p.13

This quote helps us understand why photorealism collapses in the *mirror and glass scans*. When the 3D scanner moves around the metal and glass objects, the appearance of the reflections and transparencies naturally changes, which is what causes disruption and distortion in the photogrammetry process. The scans capture the result of many different reflections, refractions of light, and moving highlights and freeze all these optical effects into one state. The optical effects impact photogrammetry’s ability to judge where a surface begins and ends, affecting object separation. This causes the molten result we see so prominently in these scans.

Like Meisel’s observations about the eye never seeing the same image twice, this is true of the *mirror and glass scans,* where each photograph of the photogrammetry data set is of a different viewpoint, capturing different reflections or transparent optical effects. Similarly, as our eyes constantly look at objects from many different angles, 3d scanning is dynamic and requires seeing objects from all angles. Most 3D scanned surfaces are static, usually resulting in an undisrupted result that better fits ideas about photorealism. The disrupted surfaces in the *mirror and glass scans* remind us that the scans are created from many viewpoints. They show us that photorealism is a concept built upon a fixed photographic view and a fixed idea about how certain types of surfaces look and behave. As Meisel indicates the need for photography to serve as a reference for photoreal painting, the various perspectives on photogrammetry, combined with the moving reflections and transparencies, produce an impressionistic scan, resulting in a naturalistic, nonfigurative outcome. By deliberately scanning mirror and glass surfaces, I have shown how realism in photogrammetry is not a pre-defined mimetic medium. The much-advertised photorealism of photogrammetry and the scan work of Quixel breaks down when they encounter an ordinary, everyday glass surface.

Despite the disruption caused by reflections and transparency, photogrammetry captures the appearance of scanned glass in the texture map. These texture maps are fragments of photographs taken to build the scan from. They are processed by the photogrammetry algorithm and split into hundreds of parts, like rips or tears, placed across the model's surface. It is almost as if the scanning system has taken apart reality and reassembled it according to how it sees the behaviour of reflective metal glass surfaces. Instead, due to association with 3D computer rendering, one might expect a technological process like photogrammetry to reconstruct mirror and glass surfaces optically, but it does not. Rather than a sharp, in-focus image of a reflection, this machine-created texture appears almost as if it has been painted by hand. Close-ups are like the complex patterns of light seen in Eddy’s details of similar objects.

Photogrammetry visually represents glass (or any other material in the scene), digital texture maps, and image files mapped across the model's surface. However, it does not create digital glass as a shader; there are no specific attributes of material beyond the simple properties of JPEG textures that look somewhat like glass. One might expect photogrammetry to produce a digital shader due to its close relation to 3D digital models and systems. In a photoreal 3D computer graphics workflow, glass or mirrors are accurately simulated by recreating physically based attributes like specularity and transmission. The *mirror and glass scans* go against this workflow and are counterintuitive to the modeller focused on photorealism: their surface textures are the machine equivalent of painted glass and mirrors. Photogrammetry interprets the fleeting and shifting nature of reflections and transparency as a computer-painted or imagined reflection that changes with every camera angle.

I want to consider further the role of reflections in photogrammetry, photorealism, and in the *mirror and glass scans*. A reflection can help describe a three-dimensional form. This is explained by Jonathan Miller (1998) in the catalogue for the exhibition Reflections, held at the National Gallery, London. Miller says a bent reflection and highlights around a curved mirror surface can describe form without shading. Even without the certainty of a mirror, which provides a detailed reflection as a solid image, reflective highlights can reveal three-dimensional shape. We observe this across the surfaces of the *mirror and glass scans*. Glass objects without the backing of other things (like the mirror foil), or glass in a dark environment or plane background, can be hard to discern as a form. When scanning transparent or reflective objects, dark environments or plain backgrounds create similar problems. Placing glass or metal objects in a white or black empty studio space and lacking an environment to reflect can lead to a partial scan. I found that scanning mirror and glass surfaces in a room full of objects provided additional reflective surface information that aids the 3D scanning process.[63]

Miller writes that reflections do “not depend exclusively on recognisable imagery. A non-figurative highlight can be just as informative” (1998, P.54). Non-figurative highlights on the surface of the mirror and glass scans look like a painted interpretation of a reflection rather than the sharp ray-traced reflection of computer photorealism. Such reflections are a “kind of rippling, moving mirror.” Here again, I return to the words of David Hockney, who was observing the problem of painting changing reflections on the surfaces of pools, but we can borrow this description for photogrammetry: the shifts and changes in reflection in photogrammetry scanning (Hockney and Gayford, 2020, p.128). In a way, the 3D scanner has a similar problem to Hockney or any painter: that of how to represent something that is always changing depending on how you look at it.

Hockney’s discussion on painting water helps us understand the challenge reflections pose to photogrammetry. Photogrammetry of the *mirror and glass scans* comprised 100 to 350 overlapping photographs for each scan; no single view of a reflection or highlight could be dictated to the device. The multiple views of reflections lead the texture maps to contain images combined from different viewpoints, which means there is probably some approximation going on, even in what is thought to be a precise medium. However, we could argue that the 3D scanner perceives a true representation of reflections and transparent surfaces

[63] In 3D computer modelling, dark environments or plain backgrounds create problems when rendering reflective or transparent materials on digital 3D models, making them appear plain and featureless. For this reason, adding a modelled environment or using high dynamic range (HDRI) panorama photographs on a “skydome” globe provides the models with something to reflect and also affects the CG lighting in the scene.

before it, and that this is what hundreds of reflections look like when they are all overlapped. Bolter and Grusin noted, when discussing the notion that photographic truth was “not unassailable,” how the impressionists believed “their paintings captured the truth of light better than photographs could” (2000, p. 109). The interaction of light with transparent glass and shiny, polished, highly reflective objects creates shimmering surfaces with various optical effects; photographing such surfaces can, in some ways, lessen the impact of representing these transitory effects in a single image. The *mirror and glass scans* may depict optical effects and light interaction more accurately than photographs of the same scene. As Bolter and Grusin wrote about developments in computer graphics, “the failure to achieve photorealistic light and colour can itself become part of the meaning of the image” (2000, p.126).

The *mirror and glass scans* are a novel record of how photogrammetry perceives multiple reflections and transparent, transient optical effects. These images differ significantly from photographs of the same surfaces or computer renders of similar models. Such results would likely be viewed as realism errors in a commercial scanning pipeline. To use Rosalind Krauss’s words on photography in the context of photogrammetry: “the pervasiveness of the photograph as a means of representation [is] obvious in the case of photo-realism” (Krauss 1977, p.78). This pervasiveness has extended to contemporary interpretations and uses of reality capture as an evolving form of three-dimensional computer photorealism. The difference is that photogrammetry is not computer-generated but captured from the physical world, like a photograph. Furthermore, photogrammetry and scanning variants that reconstruct geometric models depend on object-based perceptual judgements about scan mimesis and resemblance, as well as image-based photoreal standards. This opens a new form of scan-photorealism within these scans. While the *mirror and glass scans* liberate photogrammetry from the photoreal ideal, they demonstrate that photorealism is not always guaranteed in 3D scan models. They enable the scans to be aesthetically unique compared to other commercial scan collections like Quixel.

A final concluding thought on photogrammetry: If, as ScanLAB has observed of LiDAR scanning, photogrammetry is a form of machine vision, then the results of the *mirror and glass scans* compel the scanning machine to reveal what it sees. They react to the photoreal mediation of 3D scanning, which is based on the photographic idea of the world. Through the *mirror and glass scans*, photogrammetry generates impressionistic 3D digital imagery from solid physical objects. In addition to blurring, stretching, and sweeping reflections across surfaces, it softens and melts hard forms and sharp edges; it appears somewhat surreal (scans of hard objects become soft like Dali's melted clocks). Can we consider reality capture behaving here like other forms of machine art? Like the Ai-Da robot built by Oxford University and Rob and Nick Carter's robot arm paintings, both of which, undirected, create abstract versions of what they see. Is the 3D scanner doing something similar?

Artificial Intelligence is undoubtedly being incorporated into 3D scanning. As I near the end of my PhD project, developments in Neural Radiance Field (NeRF) scanning technology and Gaussian Splattering are gathering pace. These new forms of scanning are like the aspects of their predecessors in photogrammetry and LiDAR, a technology seemingly pursuing an increasingly photographic representation in 3D scans. Reality capture developments in AI use machine learning to create unique views of scanned scenes, where a reflection, for example, may be calculated and predicted from any position (Kerbel, et al. 2023). NeRF can create novel 3D views of a subject from a few images, using AI to predict occluded parts without the need for large photographic data sets. NeRF can also capture moving objects, visualising them like long exposure photographs in three dimensions. Gaussian Splattering is like NeRF, but it processes on the fly for real-time rendering, using a form of neural network in can produce highly photorealistic results. It is a rasterization technique, instead of using points or polygon meshes for 3D scan reconstruction, Gaussian Splattering uses “splats” which are digital particles of a similar kind to those in point clouds but with ellipsoid shapes. Gaussian Splats are very efficient at rendering high-quality results; they can overcome many of the reflection and transparency challenges photogrammetry faces.

Gaussian Splats possess what I would describe as a photographic appearance and texture. Their particle-based rendering creates areas of softness and sharpness, which, in certain parts, resemble depth of field. However, Gaussian Splats are not without their issues, particularly at the edge of the capture area where they unfurl into a nebula-like mass of colour and noise. The lifelike results, photographic style, and machine learning assistance in representing reflections and transparency make Gaussian splats a formidable contender for the photoreal standards that are often expected in all areas of 3D scanning. Nevertheless, Gaussian Splats prove challenging to work with when it comes to manipulation or modelling in many 3D software applications. When converted to geometry, Gaussian Splats degrade and resemble the disrupted scans of mirrors and glass produced here. While visually impressive as “splats,” these technologies are volumetric renders, meaning that converting them into usable 3D geometry results in deformation, distortion, and holes, akin to what occurs in the *mirror and glass scans*. Thus, a post-production workflow for this new scanning technique has yet to be established.

4.7 Conclusion

This chapter investigated the results of 3D scanning reflective and transparent, metallic, mirror and glass surfaces. It has explored how these scanned surfaces are disrupting perceptions of resemblance and photorealism. It has looked at why scanning reflections and transparency are seen as problematic; how formulas are used to promote established models of realism based on photorealism in capture workflow, and how these methods deny the material of the object in favour of a computer-generated alternative. However, we have seen that not all work in 3D scanning pursues a photorealist agenda. Projects by ScanLAB have sometimes inadvertently explored the phenomena of reflection and refraction as noise in 3D scans at the fringes of what a 3D scanner can do and see. These are spaces that we can only perceive as reflections, but that the scanner was fooled into seeing as real spaces. The capture of mirrors represents the ability of the 3D scanner to record more than a three-dimensional mapping of physical space, implying that the scans can “see” reflections as an additional through-the-looking-glass reality. This chapter has departed from and extended ScanLAB’s scans by using photogrammetry (rather than LiDAR) to capture mirrors and glass. It has then pushed the medium of reality capture to a point where it can, through digital flaws and struggles, tell us about what it is seeing as a medium, similarly to how the early photographs of Fox Talbot described the photographic process.

The research-by-practice linked to this chapter was aimed at (in the words of Linda Chase writing on photography and photorealism) creating “a climate inhospitable to realism” (Meisel, 2002, p.13). The *mirror and glass scans* show photogrammetry’s successes and failures, as it attempts to interpret what it sees.

Photogrammetry of mirror and glass exists between the recognisable and unrecognisable; familiar elements remained, such as labels, metal lids, patterns, dull or scratched areas, and shapes cut into glass. These can help the image to be decipherable, but rather than delineate (object masking is an integral part of reality capture), we see objects amalgamate in these scans. Indexicality can be found in absent objects, shadows and scanograms projected through the glass. When resemblance breaks down, indexicality may remain to testify to the existence of spatially displaced objects.

Differences and alignments between the realism of photogrammetry and other types of photorealism show where computer photorealism succeeds – in representing virtual mirror and glass materials – and where the scanning technology "fails". My photogrammetry artworks capture a previously unseen view of reflections and transparency, the process depicting these optical effects is similar in a way to how a painter might perceive and represent such phenomena. The *mirror and glass scans* have moved towards hypermediacy, they make us aware of its medium rather than their representational content. Resemblance in photogrammetry was found to be a judgment of visual likeness (mimesis) between scan and object, but this is dependent on high levels of indexical resolution – the number of points scanned, and detail collected. However, the resemblance started to unravel when it was disrupted by the *mirror and glass scans*. Flaws and errors caused by the reflective and transparent surfaces will likely be edited out as part of the realism-pursued workflows built around capturing models with a close resemblance to their referent object. However, working with the *mirror and glass scans* has raised many questions about existing conceptions of realism and its root in photorealism. It has provoked us to think about how something as common as reflection is perceived by reality capture.

5 Chapter 5: Conclusion

My PhD research is a comprehensive study of disruptions in digital 3D scanning. The project integrates practical experimentation with theoretical inquiry to challenge scanning practices and the concepts of realism within the field. It critiques the terminology of photorealism, which has become associated with digital 3D scans. It questions the idea of photorealism as the predominant aesthetic mode of representation in 3D scanning, proposes new insights into digital indexicality, and contextualises 3D scanning technologies within contemporary media theory, art history, and philosophical frameworks. An original art-practice methodology that focuses on both novel and existing categories of scan disruption enhances our understanding of how these unscannable surfaces and materials can be digitally captured and represented.

The project is distinguished from other research in the field as a new investigation by the following:

1. I introduce *new* and previously *underexplored* categories of 3D scan *disruption*, *solid colour* scans, *negative space,* and *mirror and glass* scans. I argue that these disruptions are *authentic* representations of the scanned environments rather than errors.
2. Innovative fine-art, research-by-practice method involving digital 3D scanning, *targeted*, *systematic* and *extensive* creative exploration and digital cataloguing of 3D scan disruptions.

3. *Accompanied* critical-contextual framing, focusing on photorealist aesthetics and questions of digital indexicality through the concept and practice of digital casting in new reality capture technologies.

This research presents an extensive portfolio of completely new types of 3D scan disruption. It offers a comprehensive study of how certain materials, surfaces, and structures provoke digital 3D scans to reveal something different; they uncover alternate perspectives that move away from photorealistic interpretations of scanning. These novel views of reality captured in my scans showcase several previously unseen 3D scan effects and phenomena. I argue that these scanning phenomena are neither errors nor mistaken readings but actual, objective, indexical digital scan results. Therefore, these raw, unaltered scans are not subject to the photoreal ideals, standards, or framings prevalent in reality capture. The exhibition and practical portfolio of scans accompanying this thesis demonstrate that the effects of colour, glass, mirrors, and interior spaces consistently produce the same scan phenomena. For instance, scans of solid areas of colour merge and bleed into adjacent colours like paints on a palette. Photogrammetry of transparent glass and reflective metal objects appears as liquefied or molten distorted versions of these surfaces captured by the scans. LiDAR scans of glass remind us of photogram-like traces rather than a solidly captured, rounded version of the glass surface. In contrast, scans of cluttered interior spaces result in inside-out representations of negative space that resemble digitally cast fossilised versions of the objects and surfaces captured. These results, consistent across each set of scans, dispel the industrialised myth that scanning must consistently achieve a photographic or computer graphic-oriented photoreal resemblance to the captured objects.

My artworks and images, created from mirrors, glass, color, and space scans, challenge traditional photographic framings and photoreal concepts surrounding how 3D scanning technologies capture reality. The accompanying exhibition showcased these discoveries by presenting a series of unique scanned interpretations of reality. The artworks illustrate how my PhD research responds to prevailing photorealistic scanning methodologies based on traditional photographic models. The scans and artworks produced responded to how scans in industry have been framed, similarly to photographs. The research showed how 3D scans on screen, particularly renders of LiDAR point clouds, are digitally framed from a specific viewpoint, imitating photography's inherent ability to capture and represent receding forms in space. Photogrammetry’s connection to photorealism stems from its capacity to capture surface form, detail, and texture with high fidelity. These attributes are also found in computer-generated 3D models and renders, which often mirror photographic aesthetics. Consequently, I discovered that screen-based reality capture is influenced by photorealism as a standard or aesthetic ideal, especially in commercial and non-critical reality capture applications.

Even the 3D scan images and animations created for the thesis are framed and rendered using virtual in-software cameras due to the constraints of the technology. As a result, it is challenging to completely separate scanning from a photographic perspective, as the scans must ultimately be viewed as images on a screen. However, the digital geometries of the scans illustrate the disruption to photorealism demonstrated by the phenomena uncovered in the research. This phenomenon, arising from surface material and its optical behaviour and altered by negative shapes, represents the actual outcome of the practical research. The types of scan disruption centred on the surface and texture deformations captured in the scans, rather than their presentation as digital images, which, in a sense, could not be avoided. Although the sculptures I created as part of the scan artworks, as physical pieces, enable the scans to transcend being digital renders, as we can walk around and observe them.

I believe the categories of scanned disruption are original for a PhD thesis. These categories originated from the colour scans case study in practice. The *colour scan* category revealed initial evidence of scan phenomena that deviated from standard practice. The case study aimed to evaluate the method's effectiveness and detail how colour disrupted fragmented and blended scan geometries. Consequently, it was valuable to investigate how scanning technology captures and interprets colour. In these scans, distorted colour forms contrasted sharply with the accurately captured gravel and brick-textured background environments. This difference highlights how scanners rely on texture and irregularities to accurately lock onto and reproduce surfaces. More importantly, observing colour disruption at work within these scans, and how it contrasts with areas of mimesis, embodies the ideas and themes of the thesis within the scan as a digital artefact.

As the research progressed through the *space scans* of interiors and the *mirror and glass* scan categories, it became clear that scanning disruptions were much more prevalent and stable than previously believed. Consistent results indicated that disruptions affect how reality capture technologies perceive certain surfaces differently than the human eye or camera. The industry's dismissal of these suggested errors can be attributed to photographic framing or understanding of capture. However, conducting large-scale scans of this behaviour had not been undertaken in academic research before, or indeed explored at this scale by artists and pioneers using 3D scanning. This resulted in insights that could not be obtained from a single disrupted 3D scan. Furthermore, this demonstrates how the methodology of performing multiple scans of disruptions reveals them as constant and predictable results. This contrasts with other research that has noted potential disruptions in individual scans but has not explored beyond that.

For example, a molten or liquid-like aesthetic frequently appeared when scanning glass. This was because the glass and metal captured had highly reflective, transparent, shiny surfaces, which the 3D scanner perceived not as physically solid static surfaces, but rather as a collection of fleeting, shifting optical effects –a sort of moving, transient surface. Molten-looking scans of merged adjacent geometries and scans filled with pooled metallic reflections exhibited significant distortions in the wireframes of the models. Alongside this came multiple overlapping reflected views from hundreds of angles, embedded as if by a cubist painter, yet captured consistently across multiple scans. This indicated that they were a reliable feature of the data rather than technological random artefacts. What might be seen as a shortcoming in the scanning process, a resolution issue, or a lack of static image requirements for the photogrammetry process, emerged as a prominent scanning outcome.

Contextual research revealed the extended optical reality of mirror spaces, where laser scanning follows an optical light trajectory, as a recognised phenomenon captured in LiDAR scans. I observed that the depth-scanning of mirrors behaved similarly to their LiDAR counterparts, enhancing existing knowledge in the field. Photogrammetry scans of reflective and transparent surfaces consistently displayed molten merged aesthetics, where swirling textures contained light patterns, such as captured caustic optical effects and overlapping reflections. What might have been considered anomalies illustrated that, rather than merely failing to capture these surfaces, photogrammetry records them in distinctive ways, uncovering different, previously unseen visual layers. In addition to directly questioning the belief that such reflective and transparent surfaces cannot be captured, the *mirror and glass scans* (and to some extent the *colour scans*) showed new, alternative kinds of digitisation where reality capture perceives reflective and transparent surfaces in a manner that might resemble the approach of a painter rather than a camera. It constructs surfaces in a fragmented, impressionistic, or flowing manner, combining multiple angles and viewpoints into a single model. The *mirror and glass scans* were part of a pattern of non-photorealistic behaviour that contradicts established thinking in the field.

The project's other main category of disruptive 3D scans was the *space scans*. These resembled the spaces they captured; their textures mirrored the materials of floors and walls, but the shapes were depicted in the negative. The inside-out nature of the space scans contrasts with how we typically expect an interior to appear or be represented in other media, such as photography or architectural computer modelling. These scans are original types of negative digital capture, digital casts of the space between room surfaces. The inverted captures were shaped by the walls, floors, and objects within the household interior. While the concept of 3D scans as digital casts had been previously proposed by Di Bello (2018), this practice expanded that definition, demonstrating that a new version of negative space in digital casting is possible. The existing definition was grounded in the traditional notion of the digital 3D scan as a positive replica. My research indicates that this concept is reversed, with the room's walls becoming the mould for the scan, which contradicts Di Bello’s definition. The space scans offer a visualisation of negative space that traditional artistic and commercial 3D scanning has yet to create or explore. These scans break away from conventional photorealistic understandings of 3D scans and computer models as positive shapes. By presenting inside-out perspectives and capturing the space between surfaces rather than the surfaces themselves, they invert both the accepted view of interior space with which we are familiar and the computer graphic understanding of a model as something that logically reflects what it aims to represent. They challenge our understanding of interior spaces depicted or framed in photorealistic terms.

The research illustrated valuable parallels between the digital negative process in the *space scans* and the physical plaster casts created by Rachel Whiteread, who produced artworks from these casts of houses and interior spaces. Comparisons to Whiteread's analogue casting processes and the scanning of architectural interiors highlighted similarities in the reproduction processes, which resulted in a negative representation. Like casting methods used by Whiteread, the scans treat all elements in an interior, the walls, floors and furniture as a single continuous surface. Differences between the digital scans and Whiteread's analogue casting processes were evident, such as the non-invasive nature of scanning and the ability of the digital medium to capture colour. However, the *space scans* were a somewhat chaotic reconstruction of disparate elements amalgamated into single surfaces. This went against conventional understandings and methodologies in 3D computer modelling, which keeps delineation between things. Furthermore, scanning *space* prompted reflection on our interactions with domestic space, highlighting the complexities of lived-in environments and our perception of their physical construction. The *space scans* disrupted perceptions of traditional first-person or photographic perspectives of architectural environments. The scanning software treated the captures as single objects, and the separation between surfaces was gone. In a sense, the *space scans* were a new digital 3D model representation of negative space and the architecture surrounding it.

Another aspect of my research that contributed to knowledge in research methodologies was developing an original art practice method that embraced the often-intuitive, practice-led approach artists use to conduct academic research. This method includes a targeted system for conducting research, collating, storing, and organising digital scan data. The methodology is supported by a theoretical framework informed by studies on artists' work as creative researchers, drawing from publications on art practice research methods that emphasise iterative artistic experimentation within a reflective practice cycle (Bell, 2021; Gompertz, 2015; Frayling, 1993). This is a developing area of doctoral research that values both written and creative outcomes equally. As an artist, I was interested in how the intuitive creative process of discovery through making, reflecting, and later conceptualising could be structured into a methodology suitable for PhD research. Therefore, the research employed a fine-art experimentation technique utilising cutting-edge reality capture technologies, where artistic methods of investigation were applied to objective research, data collection, and testing.

To address the research questions, the philosophical approach explored how 3D scanning, much like the abstraction of other technological recording mediums such as camera-less photography, can move beyond merely reproducing and documenting. I aimed to build upon some of the exploratory practices of ScanLAB Projects. They argued that if you use a machine (the 3D scanner) under ideal conditions, it will produce a predictable result. However, if you challenge it or exceed its limits, you can provoke accidents and unexpected outcomes that stimulate aesthetic intrigue. Therefore, I developed a method that triggered scan disruptions using fine-art approaches to investigate new media.

Extending and formalising the accidental discoveries of previous pioneers, such as ScanLAB, was essential to understanding the artefacts or anomalies present in 3D scans as objective readings. The scan error served as a lens through which to investigate and comprehend the function of 3D scanning technologies and the results of the scans themselves. 3D scan disruptions might represent photorealism errors in the context of the computer graphics industry, but importantly, the research indicated that these disruptions stemmed from the surfaces or spaces themselves, rather than a fault in the operation of the 3D scanner. The method also involved a comparative analysis utilising contemporary and art historical references to better understand what would typically be perceived as errors and to interpret the scan results. In particular, the works of Cornelia Parker and Rachel Whiteread contributed to theorising the materiality and spatial representation of the 3d scans, culminating in an exhibition as the primary research outcome. (Appendix 3).

One key research theme in this project was digital indexicality in reality capture technologies. In the mid-1990s, advancements in digital photorealism prompted media scholars and theorists to explore the concept of digital indexicality. However, since the mid-2000s, research on this topic in digital contexts has been limited. While some digital capture technologies, like motion capture, have been theorised as potentially indexical, the presence of indexicality in reality capture technologies has not been thoroughly examined. Drawing on photographic theory and philosophy, which view photographic indexicality similarly to a physical impression, like a cast or footprint, I examined how space scans could be regarded as digital indices equivalent to physical casts. The digital imprint made from the mould of the space indicated their indexicality. This imprint concept aligns with Bazin's and Sontag's comparison of photographs to death masks, implying that the photograph is created by the imprint of light and thus serves as a sign pointing to its referent, much like a footprint or plaster cast, both of which have been considered physically indexical. I analysed writers such as Geimer, who discussed how indices can result from physical impressions that potentially resemble their models, and Krauss, who describes the index as a trace of a physical connection. The index concept was evident in Whiteread's work, where the indexical link between the negative cast and the surface it is moulded from is clearly observable. This research helped support my claim that a digital index concept exists in reality capture technologies and that *space scans* are an example.

In the *space scans*, we observe evidence of a digital index through the jigsaw-like relationship between the scan and the surface. The recesses and protrusions of the scan's topography illustrate how it was moulded by the captured interior surfaces. This action aligns with Peirce's definition of the index as a sign physically connected to and altered by its object. Peirce described indices as signs that must physically correspond to their referent, being influenced by it, and potentially sharing some qualities with it. He noted that the index might possess a degree of iconicity and resemblance, but it could be an unusual icon, not precisely resembling its referent. I have discussed how the space scans were shaped by the captured environments, with their forms and textures appearing as inside-out versions of the scanned spaces. I propose that they align with Peirce's original descriptions of indices that retain some of the iconicity of the original.

Compared to the space scans, the mirror and glass scans were disrupted to the extent that they became unrecognisable, with their shapes distorted almost beyond resemblance. However, indexical markers were found within these blended and merged geometries. The *scanograms*, as part of the mirror and glass scans, produced results that included projected, flattened images of glass objects onto surfaces. I found the *scanograms* to be similar to digital photograms, projecting images of absent objects onto surfaces within the scans. While these images visually resemble other types of photograms, they signify a discovery in the behaviour of reality capture, driven by visible light in the scene and the Apple LiDAR sensor's apparent inability to detect glass surfaces. I compared *scanograms* to photograms as indexical signs and drew parallels with Cornelia Parker's (indexical) artwork, where photogravures flatten three-dimensional objects into two-dimensional representations. The *scanograms* uniquely represent both absence and presence; they exhibit the same flattening effect as a photogram or a shadow and can be considered indexical. In scans, we can also observe shadows, transparency, and reflections across the surfaces of the objects, the optical effects of light that have previously been regarded as indexical.

The *mirror and glass* scans show a diminished resemblance; it seems that in these scans, the referent creates distortions and a molten effect. If this effect is indexical, it represents an unusual kind of sign, perhaps an index without an icon or partial resemblance. I surmised that if the molten effect was indexical, this was the 3D equivalent of a photographic blur, which, as Bazin suggests, still serves as evidence of something present before the camera or, in this case, the 3D scanner. These effects highlight a distinction between resemblance and indexicality in digital captures. Ultimately, the degree of distortion makes digital indexicality in these scans less apparent or logical. A further issue for research into potential claims of digital indexicality in 3D scanning was the evident digital malleability of 3D scans as models. Preserving the scans produced for the research in their raw, unaltered form was essential. However, in the 3D scanning industry, I discovered that scans were often remodelled or copied in software, undermining the authenticity of the original. While this is a significant concern, it is part of a broader, older argument about the differences in ease of manipulation between analogue and digital media that has persisted since the advent of digital media. Digital tools enable the ability to fake images (with them indices) to a photoreal level. However, perhaps the more pressing question is whether scan indexicality can exist in digitality? I turned to authors such as Gunning, Soderman, and Wolf, who made compelling arguments in support of digital indexicality. In brief, reality capture, similar to digital photography or motion capture, can be regarded as a form of capture that is digitally indexical.

Another area of theorisation I explored during the project was the development of the concept of reality capture and LiDAR as a perspective machine, evoking art-historical research by Kemp on perspective machines. I proposed that 3D scanners can be seen as modern-day versions of these Renaissance drawing devices that represent three-dimensional surfaces. I connected laser scanners, used for spatial measurement and layout, to historical surveying methods involving plotlines and measurements taken by hand. In my assessment of LiDAR scanners, I included the evolution from linear perspective to 3D computer rendering systems, where both hand-drawn and digital perspectives have been utilised to visualise collected spatial data along with the layout and dimensions of objects. Despite the technological differences between LiDAR, photogrammetry, and older perspective machines, I argue that 3D scanning fulfils a cultural desire for increasingly accurate representations of reality. This desire traces back to historical methods capable of capturing and visualising space.

Another well-known theory explored in this project is Baudrillard’s stages of simulacra, examined here in the context of digital duplication and manipulation, and through the lens of 3D digital scan alteration, retopologisation, and remodelling. Baudrillard’s theory assists in investigating how efficiency-driven photoreal modelling processes and standards influence the manipulation of 3D scans as digital models. In this context, computer graphics workflows simplify and remodel scans in a way that Baudrillard described in his writings as a large map representing a territory that comes to replace the actual place. 3D scans are copied and digitally reskinned, with textures transferred onto new skins or models, producing digital “copies of copies. " These new models become simulacra, and each stage of the 3D scan retopologisation workflow signifies a further disconnect from physical reality. This simplification and photoreal workflow transition the scan from a direct index that points back to its referent to an icon built upon another sign. This shift leads the scan toward hyperreality, as defined by Baudrillard, a common practice among those working with 3D scanning and modelling.

We might argue that digital copies are nothing new, and digital data does not degrade like an analogue copy would with each duplication. From a semiotic perspective, an unaltered digital file copy may be just as indexical as another when the data is duplicated. However, the critical difference here is that the scans are significantly altered to achieve a certain appearance and are simplified, resulting in a loss of detail while still being presented to the viewer as an exact facsimile. The retopologisation process goes beyond merely cleaning up a 3D scan; it represents an evolution of the scan, showcasing how scans are adapted for photorealistic purposes and ultimately become icons rather than accurate representations of the original objects. While this and other side investigations were relatively brief, I felt including them in the thesis as a springboard for future research was necessary. These investigations engage with broader questions about capturing physical reality, art-historical technical recording processes, and philosophical and cultural debates regarding fakes and simulations.

As the practical part of the project neared completion, it was shared through an exhibition that showcased the disruptive 3D scans as artworks. This exhibition featured digital 3D scan images, animations, sculptures, and portfolios (Appendix 1). As an outcome of the research, the exhibition occurred at an artist studio community gallery, enabling the findings to reach a broader artistic audience. By visually communicating the research findings, the exhibition transformed what had previously been regarded as flaws or errors in 3D scanning into intentional aesthetic pieces. Although the scanned artworks were presented through somewhat traditional image formats, such as renders and animations, these formats allowed for scrutiny of areas where detailed disruptions affected model resemblance, challenging the viewer's expectations of photorealism in the digitally scanned images. The contrast between areas of mimesis and disordered aesthetics directly illustrated the work's response to and deviation from photorealistic ideals. This divide between resemblance and disruption struck the viewer, prompting engagement with the images to contemplate the nature and reasons for these disruptions.

The project's data, which includes over 400 disrupted 3D scan models, is stored permanently online as an inventory for artists, researchers, and digital media scholars interested in the behaviour, aesthetic composition, and history of reality capture. I mention history here because, as discussed throughout the project, whether the results of the 3D scan disruptions are viewed as errors or authentic readings, prevailing scanning practices and uncritical approaches in the field tend to prioritise a photographic or photorealistic perspective in 3D scans. Already, we can see these disruptions edited out through manual processes, software algorithms, and programmed “realism” updates through AI advancements. Scan software updates are designed to align with how our eyes or cameras generally perceive the world. The categories of solid colour, negative space, mirror, and glass disruptions are thus significant now, as rapid technological developments in reality capture mean we may not be able to recreate results in the future.

During the project's duration, reality capture technology advanced rapidly in accuracy and accessibility. The miniaturisation of 3D scanners, now integrated into smartphones, significantly impacted this project. Photogrammetry has evolved from bulky DSLR camera setups to effective smartphone scanning apps like Polycam, which played a crucial role in *space scans* and *mirror and glass captures*. The transformative effect of smartphone scanning apps is a modern-day equivalent to the Box Brownie in reality capture. Although not as iconic as that classic camera, scanning apps represent a significant democratisation of reality capture technologies, where low-fi, user-friendly apps no longer yield inaccurate results. This likely cultural shift, like the impact of early mass-produced cameras, has made the high-end limitations of expensive LiDAR accessible to novice users and creatives. Initially, scanning apps felt like toys, but they are now serious competitors in reality capture.

3D scanning algorithms today are much more tolerant of out-of-focus photographs and varying exposures. Perfecting photorealism from poor scan data is a clear goal for reality capture programmers. We have seen how the advent of AI will likely play an increasing role in reality capture, and this is a rapidly evolving area of technology. Ultimately, AI enhancements focus on scan realism. AI-driven scanning methods continue to pursue a photographic or photoreal ideal of what a 3D scan should be and how it should look. Focusing on verisimilitude in Neural Radiance Field scanning and machine learning requires less scan data (fewer views of an object). It can compute novel views from limited or poor-quality scan data. AI introduces a kind of disruption to scanning by imagining missing parts that the scanner has not captured, such as how the back of a chair may look or how a mirror reflection will behave from a certain angle. Google's Luma AI is an example of this. AI fills in the gaps that the scanner misses or predicts how a reflection will behave according to our photographic understanding.

Finally, this thesis has been a somewhat experimental creative journey researching 3D scanning interactions with unscannable surfaces. However, the data was collected systematically and organised into a detailed survey of scan phenomena and disruptions. The method demonstrated how creative practice engages with digital media, showing that artists are curious about new technologies and how they develop new ideas by disrupting them, moving beyond their original scientific purposes. As such, the scans provide insight into the aesthetic infrastructure of contemporary reality as captured at a point in time. The research also extensively reviews contemporary scanning practices, workflows, and attitudes toward photorealism in 3D scanning. The thesis advocates ideas about how digital photorealism has developed to include 3D scanning as a new form of scan-photorealism. The research advances and updates concepts of digital photorealism and digital indexicality to include 3D digital scan media. The project advocates for the potential of 3D scans as a digital index. It presents unique examples of scan indices from novel categories of scans, such as the negative representations in space scans. A final point is that the project focused on three categories of unscannable surfaces, focusing on two. However, there are other unscannable surfaces and materials in the world that we can see or photograph but are challenging to 3D scan, such as moving people and objects or ephemeral effects such as smoke, which warrant further future research.

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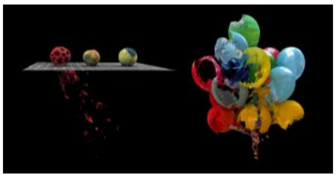
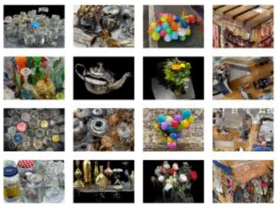
8 Appendix 1: Unsuitable Objects exhibition Artworks (2023)

Large Format Prints

	*Shed with breakdown* (2021)	Digital space scan: Short-range LiDAR, photogrammetry. Fine Art inkjet print on Hahnemühle Baryta 325	120 x 150 cm
	*Jam Jars on black with breakdown* (2023)	Digital object scan: Photogrammetry. Fine Art inkjet print on Hahnemühle Baryta 325	120 x 150 cm
	*Elevation and plan views of a London House* (2022)	Digital space scan: Short-range LiDAR, photogrammetry. Fine Art inkjet print on Hahnemühle Baryta 325	90 x 150 cm
	*London House and Cumbrian Farmhouse* (2022)	Digital space scans: Short-range LiDAR, photogrammetry. Fine Art inkjet print on Hahnemühle Baryta 325	290 x 150 cm
	*Cumbrian Farmhouse tumbled views* (2022)	Digital space scan: Short-range LiDAR, photogrammetry. Fine Art inkjet print on Hahnemühle Baryta 325	90 x 150 cm

	*Four sets of crystal glass objects on grids* (2020 and 2023)	Digital object scans: Photogrammetry. Hahnemühle Fine Art inkjet print on Baryta 325	90 x 150 cm
	*Two sets of assorted silver and glass objects* (2021 and 2023)	Digital object scans: Photogrammetry. Fine Art inkjet print on Hahnemühle Baryta 325	290 x 150 cm
	*Four sets of assorted silver, gold, and glass objects* (2019, 2021 and 2023)	Digital object scans: Structured-light depth scan, photogrammetry. Hahnemühle Fine Art inkjet print on Baryta 325	90 x 150 cm
	*Four sets of coloured objects* (2019, 2021 and 2023)	Digital object scans: Structured-light depth scan, photogrammetry. Hahnemühle Fine Art inkjet print on Baryta 325	90 x 150 cm
	*Three coloured spheres and coloured Balloon group with Helium* (2019 and 2020)	Digital object scans: Structured-light depth scan. Hahnemühle Fine Art inkjet print on Baryta 325	290 x 150 cm
	*Six coloured balloon groups with Helium* (2019)	Digital object scans: Structured-light depth scan. Hahnemühle Fine Art inkjet print on Baryta 325	120 x 90 cm

	*Mixed clear and coloured glass with breakdown* (2023)	Digital object scan: Photogrammetry. Hahnemühle Fine Art inkjet print on Baryta 325	120 x 150 cm
	Selection of 3D scan images, details. (2019 – 2023)	Digital object and space scans: Short-range LiDAR, structured-light depth scan, photogrammetry. Hahnemühle Fine Art inkjet print on Baryta 325	200 x 150 cm

Sculptures

	*Cumbrian Farmhouse* (2022)	Digital space scan, re-projected simplified model. Fine Art Baryta Photographic II 310, foam board	80 x 25 x 35 cm
	*London House* (2022)	Digital space scan, re-projected simplified model. Fine Art Baryta Photographic II 310, foam board	70 x 48 x 35 cm
	*Allotment Shed* (2022)	Digital space scan, re-projected simplified model. Fine Art Baryta Photographic II 310, foam board	50 x 50 x 35 cm
	*Store* (2022)	Digital space scan, re-projected simplified model. Fine Art Baryta Photographic II 310, foam board	55 x 28 x 23 cm

	*Barnes Workshop* (2022)	Digital space scan, re-projected simplified model. Fine Art Baryta Photographic II 310, foam board	22 x 13 x 12 cm
	*Dorset Chalet* (2022)	Digital space scan, re-projected simplified model. Fine Art Baryta Photographic II 310, foam board	24 x 12 x 11 cm
	*Fisherman's Shed* (2022)	Digital space scan, re-projected simplified model. Fine Art Baryta Photographic II 310, foam board	50 x 36 x 40 cm

Print Editions - Image A3, paper A3+

	*Coloured balloon groups with Helium* (2019)	Digital object scan: Structured-light depth scan. Fine Art Baryta Photographic II 310	£50
	*Coloured balloon group with helium* (2019)	Digital object scan: Structured-light depth scan. Fine Art Baryta Photographic II 310	£50
	*Jam Jars on black paper* (2023)	Digital object scan: photogrammetry. Fine Art Baryta Photographic II 310	£50

	*Coloured glass vessels on black* (2021)	Digital object scan: photogrammetry. Fine Art Baryta Photographic II 310	£50

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9 Appendix 2: Exhibition invitations (2023)

Unsuitable Objects

An exhibition of 3d scans

2nd – 6th May. 2023

Kindred Studios. 13 Market lane. London. W12 8EZ

Private View: 4th May 6 - 8:30pm

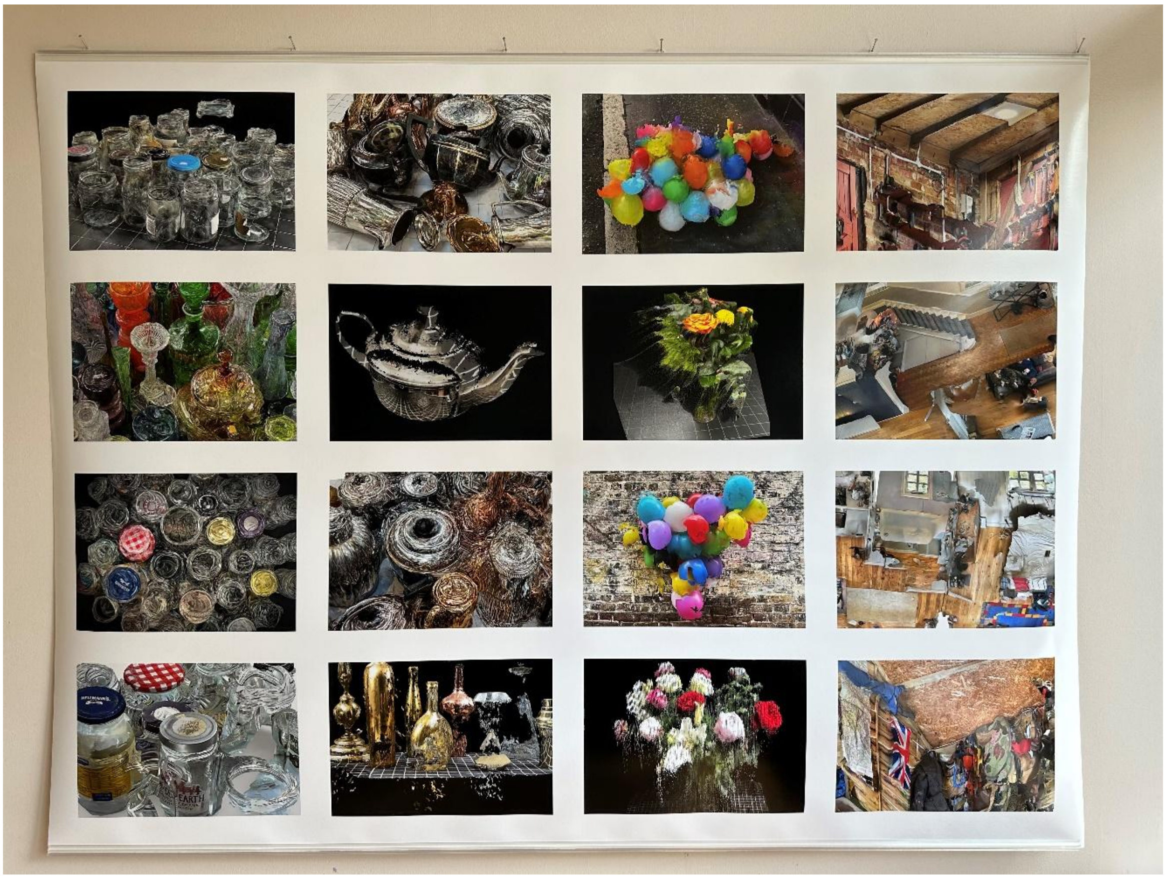
Disrupting photorealism in the digital 3d scan through Art Practice

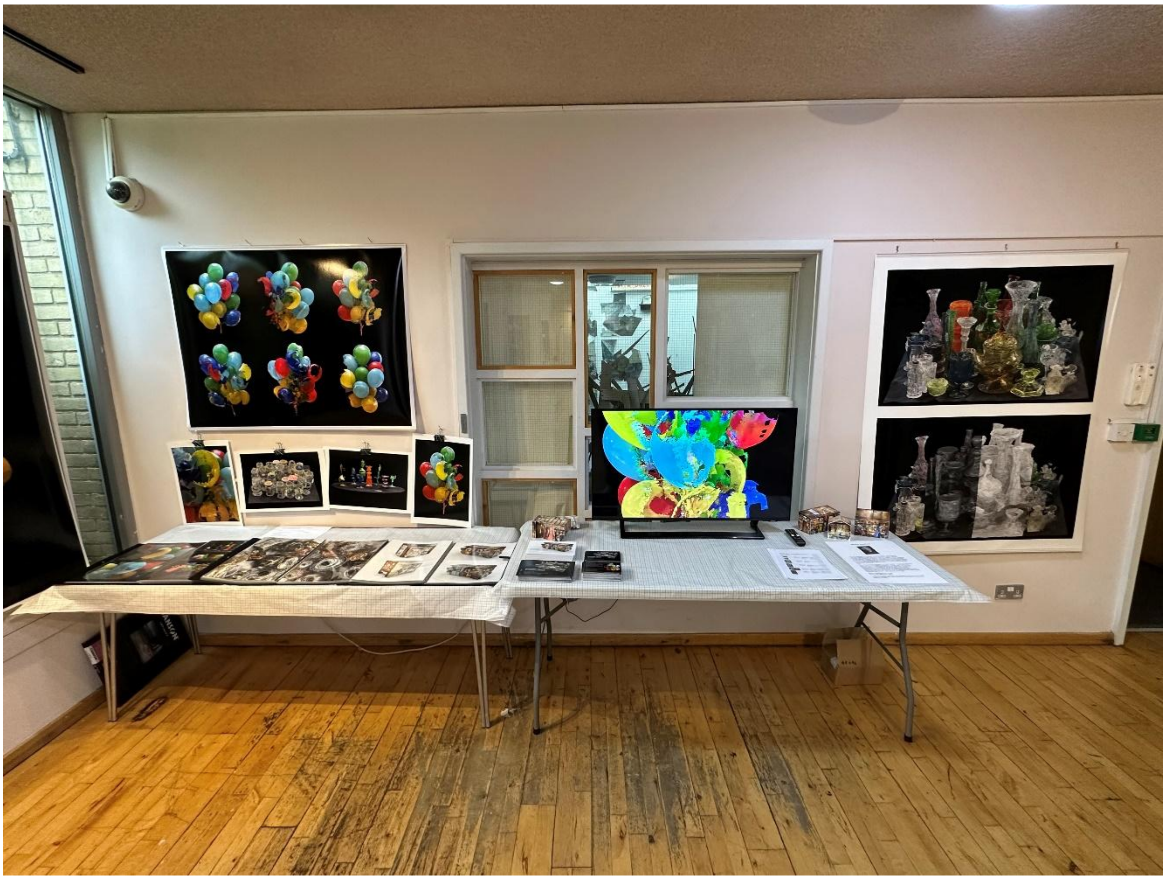
This exhibition of digital 3d scan images shows the findings of my PhD by Practice.
3d scanned collections of still life objects and interior spaces reveal material-led disruptions and irregularly shaped digital casts of negative space.
The artwork interrogates the scans' relationship to photography and photorealistic computer-generated image.

During the 2nd – 6th May 2023 the exhibition can be viewed between the hours of 10am and 5pm.

Viewings should be made by appointment.
To arrange a viewing, please contact :
Florian Stephens - florian.stephens@uwl.ac.uk
Instagram: @florians_3d_phd

10 Appendix 3: Exhibition photographs





Private view