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Holography and the Luxury Industry

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Abstract: The luxury goods industry and holography have a lengthy history together. In this article, we review the applications of holography to the industry and the relevant technical requirements, in particular when the hologram itself is the luxury item, when the hologram is used to promote luxury items, and when the hologram is used for authentication of luxury items. We then explore some possible scenarios for the evolution of this relationship.

Keywords: holography; 3D imaging; 3D display; optical authentication; retail applications of photonics

Citation: Bove, V.M., Jr.; Reader, N.A. Holography and the Luxury Industry. *Photonics* **2021**, *8*, 219. https://doi.org/10.3390/photonics8060219

Received: 16 May 2021
Accepted: 10 June 2021
Published: 13 June 2021

1. Introduction

Holography, which embodies a three-dimensional image in a thin surface, either acting as a window to a virtual volume behind the hologram plane or projecting a 3D image in space in front of the hologram, was a groundbreaking imaging technology as well as a cultural artifact influencing thought about the intersection of physical and virtual worlds long before the arrival of the modern conceptions of augmented reality or virtual reality. A number of authors, in particular Sean Johnston [1,2], have written at length about the simultaneous scientific and artistic impact of holograms. The commercial impact of holography as a general imaging medium—as opposed to specialized technical applications—has, however, been at best relatively modest.

The luxury industry, which prizes both craftsmanship and innovation, has on multiple occasions turned to holography for its unique visual experiences and/or for its technical affordances. While Johnston's books and authoritative references on holographic applications [3,4] mention a few examples of holograms in luxury, the present authors observe that despite the long history, there does not appear to have been a comprehensive study published focusing on this particular field of application. In this article, we will examine the history of the use of holography in this industry and the experiential and technical requirements, then look into how some current technological developments may lead to increasing use of display holography in luxury.

The authors prefer to reserve the use of the word "hologram" to refer to true holograms, which create a three-dimensional light field through the use of extremely fine diffraction patterns, but (like the general public) the industry has more often than not used the term to refer to other stereoscopic or multiscopic 3D display technologies, augmented or virtual reality headsets or mobile apps, or even ethereal 2D displays such as Pepper's Ghosts or projections onto fog screens. Indeed, a recent search of the archives of the publication Luxury Daily for articles mentioning "hologram" turned up 66 entries, none of which relates to a diffractive technology [5]. In addition to true holograms, we will also consider some notable examples of pseudo-holograms that were applied when a particular hologram-like experience was desired but true holograms were not practical.

2. Application Domains

The personal luxury goods industry is usually regarded as combining the sectors of designer clothing and footwear, luxury bags and accessories, luxury watches and jewelry, and luxury fragrances and cosmetics, and in fiscal 2019, had sales of US$281B [6].

There have been three main applications of holographic technology in the luxury business: where the hologram is the luxury item itself (or at least a component thereof), where the hologram is used in the promotion of luxury items, and where the hologram is used as part of anti-counterfeiting or traceability of luxury items. These will be discussed in separate subsections.

2.1. Holograms as Luxury Merchandise

Foil embossed with holographic diffraction patterns (to be discussed in more detail in a later section) has been applied to garments to create an iridescent effect, or three-dimensional rainbow images or patterns. While embossed holograms had been earlier used as appliques on garments [7], a company called Space Time was the first to develop a process for creating mass-produced holographic fabrics (including viscose and urethane) and then releasing in 1989 a line of garments based on the material [8,9]. This material drew wider attention when it appeared in designer Vivienne Westwood's Spring/Summer 1998 collection (Figure 1). A newer generation of diffractive fabrics has been embraced by fashion in recent years; particularly in the Fall 2018 season, when such fabrics appeared in the runway collections of numerous designers and brands including Tom Ford, Gucci, Lanvin, Maison Margiela, and Off-White [10].

Figure 1. Dress made from diffractive fabric in Vivienne Westwood's Spring/Summer 1998 collection (Photo ©FirstVIEW/IMAXtree.com, used with permission).

Volume reflection (Denisyuk) holograms (Figure 2) [11] have been made into earrings, pendants, watch faces, and other jewelry (Figure 3), often by holographers themselves rather than by jewelry companies [12]. While photopolymers or bleached silver halide can be used in this application, the preferred material is dichromated gelatin as it provides particularly bright images [13], although image quality from holographic jewelry can still be problematic because it requires direct illumination, which may not be the situation when holograms are being worn on the body. One well-known branded example of a holographic jewelry product is a series of hologram-faced watches that Fossil released in the early 1990s; a reissue limited to 654 watches came out in 2019 [14].

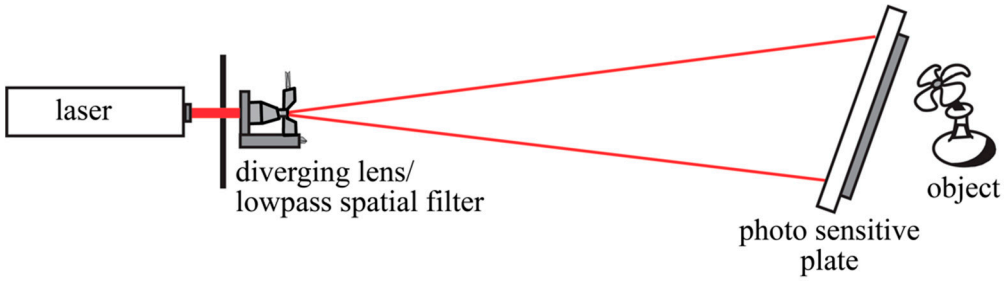

Figure 2. Creating a reflection volume hologram: laser illumination is brought to a photo-sensitive plate from the opposite side as the object; when the resulting hologram is illuminated with white light from the same side as the original laser, a 3D image of the object is reconstructed.

Figure 3. Couture 18K gold ring set with diamonds, opal, and a dichromated gelatin reflection hologram encapsulated in fused silica. Created by Mirasety, a collaboration of Francesco Mazzero, Michael Crawford, and August Muth (Courtesy Mirasety, photo by Francesco Mazzero).

2.2. Holograms in Luxury Merchandise Promotion

Credited as the first successful use of holography to promote luxury merchandise, a 50-by-60 cm pulsed-laser transmission hologram of the Leith and Upatnieks type (Figure 4) [15] was made for Cartier in 1972 by G. Robert Schinella at McDonnell Douglas Missouri, showing a woman's hand wearing a diamond ring and holding a diamond bracelet (Figure 5). This was mounted in the window of Cartier's Fifth Avenue location in New York City, and because of this sort of hologram's requirement for a monochromatic light source, was illuminated by a mercury arc lamp. The hand appeared 36 cm forward on the window [1] (pp. 352–353).

Another store-window appearance of holography in the luxury jewelry domain that is regarded as iconic by many holographers came in conjunction with the late-1986 opening of Tiffany's on Old Bond Street in London. The company Holovision was commissioned to produce a holographic homage to the well-known scene from the film Breakfast at Tiffany's. In the hologram, the woman at the table wears a necklace by Paloma Picasso and is surrounded by Tiffany's merchandise. Design work was by holographer Martin Richardson and the 50-by-60 cm image was captured in the pulsed-laser studio at the Royal College of Art and then transferred to a white-light-viewable transmission plate that was back-illuminated by a spotlight and placed in the shop window.

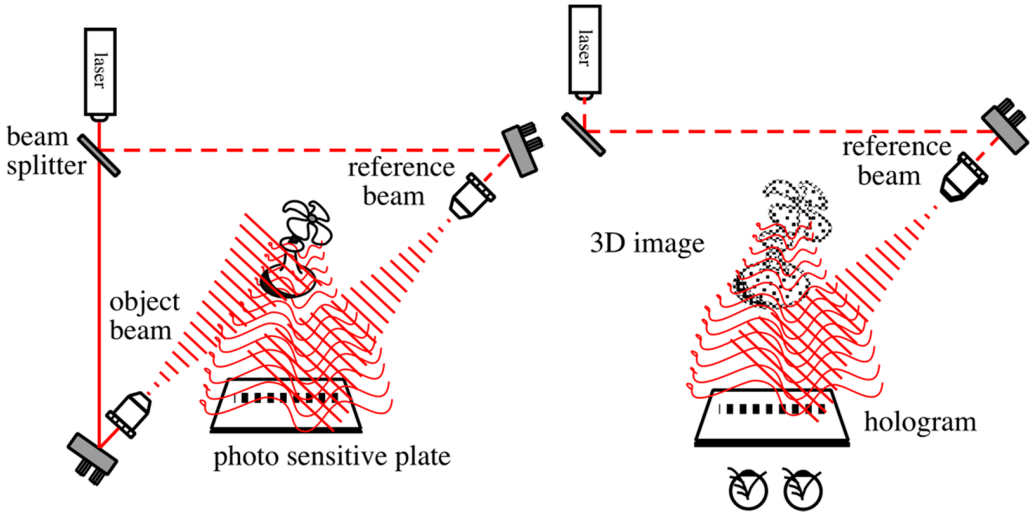

Figure 4. Creating and viewing an off-axis transmission hologram: photo-sensitive material receives an interference pattern between a reference beam and light reflected from an object. When the resulting hologram is illuminated with the same wavelength of monochromatic light at the same position as the reference beam, a 3D image of the object is reconstructed and visible through the plate.

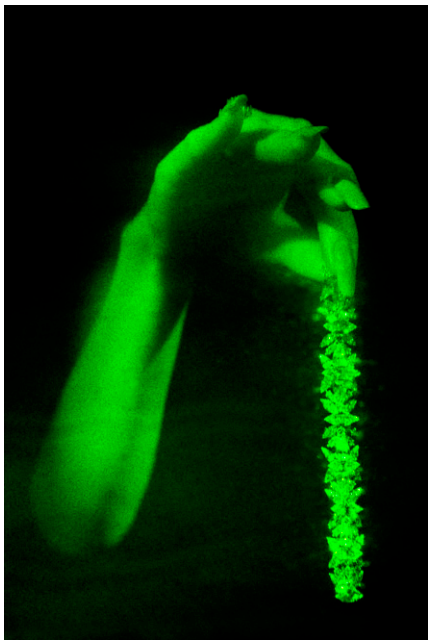

Figure 5. Pulsed-laser hologram made for Cartier window display, 1972 (Photo credit: MIT Museum, gift of Marian B. Javits, photo by Barry Heatherington).

Unlike the scene in the film, the hologram showed the woman from the back, and The British Journal of Photography reported at the time, "It is apparently driving the Tiffany staff gently mad because people keep coming into the shop wanting to see the other side—the girl's face. This of course is exactly what it was designed to do—get people in." [16].

In 1989, hosiery maker Hue commissioned Holographics North at an estimated cost of $10,000 to create a 76-by-102 cm transmission white-light rainbow hologram showing several angle-multiplexed images of a leg model in tights. This was installed as a point-of-sale display in Bloomingdale's in New York City [17].

Because of its cost, complexity, and rarity, holographic portraiture of the sort discussed above might itself be considered a luxury good. In recent years digital holograms (to

be discussed below) have been used for portraiture in addition to pulsed laser analog holograms [3] (pp. 306–312) [4] (pp. 512–515). Perhaps the best known example is a 2004 digital holographic portrait of Queen Elizabeth II captured by holographer Rob Munday as 205 parallax images, this also appeared as an embossed hologram (to be discussed in the following section) on a 2012 £10 postage stamp issued by Jersey Post [4] (p. 612).

The development of full-color digital holographic printing in the late 1990s and early 2000s, with its ability to create arbitrarily large white-light-viewable reflection holograms without the need of a holography studio—only requiring 3D computer graphics models or sets of 2D parallax views of scenes—greatly increased the potential availability of holography as a promotional medium [4] (pp. 507–511). However, so far, this process does not appear to have been much used in the luxury goods business, one example application in apparel/footwear being a series of large display holograms by XYZ Imaging in 2005. Three 1-by-1.2 m prints and one 1-by-1.5 m print were produced for Puma's campaign for their Ferrari branded footwear and placed in two Montreal Foot Locker stores during the Montreal Grand Prix in June 2005 (Figure 6). Imagery included close-ups of shoes with a racetrack in the background, and a car morphing into a shoe. In a similar promotional campaign for Nike, four large-format holograms were produced for the Niketown store on Oxford Street in London [18].

Figure 6. Digital holographic print of Ferrari shoes, 2005 (Courtesy Geola Digital UAB).

When holography is mentioned, fashion writers often recall supermodel Kate Moss' virtual, ethereal appearance at Alexander McQueen's autumn/winter 2006 "Windows of Culloden" collection show in Paris (Figure 7), though that was actually a pyramidal configuration of the 19th-century stage illusion called a Pepper's Ghost rather than an actual hologram [19]. McQueen had a continued interest in holographic-style experiences; for example the invitation to his spring/summer 2009 show was a lenticular portrait (incorrectly described in the press as a hologram) in which the designer's face morphs into a stylized skull [20].

There are several possible geometries for Pepper's Ghosts; when a virtual model is to share a stage with a live model, the setup in Figure 8 is commonly employed [21]. When based on 2D video projections, as in the examples discussed here, the images are flat rather than 3D, and work best for stationary viewers at distances where 3D visual cues do not operate strongly.

Figure 7. "Holographic" (actually Pepper's Ghost) model in 2006 Alexander McQueen show (Photo ©FirstVIEW/IMAXtree.com, used with permission).

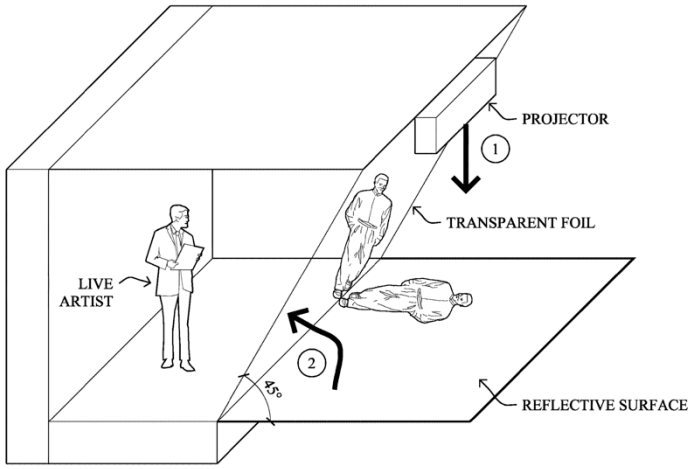

Figure 8. Pepper's Ghost illusion based on projector and tilted beamsplitting mirror, showing how a real and a virtual person can appear to share a stage. From [21].

It was not long before "hologram" fashion exhibitions went from luxury to mainstream. A year after the Alexander McQueen show, retailer Target staged an all-Pepper's-Ghost show in New York City's Grand Central Station [22]. However, Pepper's Ghosts have continued to feature in luxury goods exhibition; recent examples include a display at the 2017 Los Angeles premiere of the film The Last Jedi of Christian Louboutin shoe designs inspired by the heroines of the Star Wars films [23], and a 2018 Christian Dior show in Shanghai in which 68 models captured on video at the Musee d'Orsay in Paris were shown on a 30 m-long stage with 20 projectors [24]. When based on 2D video projections, as in the above examples, the images are not 3D, and work best for stationary viewers at distances where 3D visual cues do not operate strongly.

The term "hologram" has also been more recently and inaccurately applied to other non-holographic luxury experiences such as virtual or augmented reality applications that allow viewing merchandise from a variable viewpoint, visualizing it in the user's environment, or virtually trying it on (for example, shoes or eyewear) [25].

These non-diffractive approaches are worth discussing in this context as they point to some characteristics desired by the luxury goods industry: the imagery should be moving

and actual size (or larger), there should be no obvious display system but rather the imagery should appear in a physical environment, and the display should be deployable on a fashion show runway, in a retail setting, or (in the case of AR apps) in the user's environment. For holography to supplant displays like Pepper's Ghosts it will have to develop in these directions.

2.3. Holograms as Authentication Devices

Losses in the luxury goods market due to counterfeit merchandise were estimated at US$98B in 2017 [26]. An ideal authentication technology would be one that is inexpensive to manufacture but difficult and expensive to duplicate, that cannot be removed or altered without obvious damage, and whose validity can be quickly verified. Authentication technologies are commonly classified into overt and covert categories, the former of which can be authenticated without any specialized equipment or process and the latter requiring some external apparatus for verification. Currency, for example, typically has a combination of overt and covert features. Because of the fine detail and physical properties of diffraction patterns, holograms can provide both a quickly recognizable and colorful 3D visual appearance and any of a number of hidden properties including text at a scale of tens of microns, images that appear only when a laser is used for illumination, and machine-readable data patterns. Holograms with both covert and overt features have been used by the luxury goods industry at least since the early 2000s when Fendi, Gucci, and others began adding holographic labels to merchandise [27]. Chanel bags are individually numbered and since 2000, the label has incorporated a holographically-patterned film over the conventionally-printed serial number to increase the difficulty of counterfeiting; numerous websites explain how to authenticate these labels (e.g., [28]).

Because a diffraction pattern may be created by varying the thickness of a transparent material, it is possible to mass produce phase holograms inexpensively by a hot-stamping process. The first step is the creation of a surface-relief holographic pattern, typically in a photoresist material exposed with a deep-blue laser. Because photoresists are too soft to be used directly for stamping, nickel is electrically deposited on the original hologram and the resulting metal layer can be applied as a stamping die, or for high volume production further replicated many times to make a set of identical stamping dies. The stamper is heated and used to impress the holographic pattern onto a transparent or foil-backed thin plastic layer. More detail on the process is given in [29]. Readers will likely be familiar with the appearance of this sort of hologram as an anti-counterfeiting feature on credit cards.

Since for overt authentication the hologram must be viewable under white light, traditionally the source phase hologram is a "rainbow" hologram of the type first developed by Benton; the original process for making these involves first creating a standard off-axis transmission hologram of the subject matter and then making a second hologram of the first hologram illuminated through a slit aperture [30]. These holograms are bright but exhibit parallax in only the horizontal direction and the monochromatic image color changes with vertical viewing position; it is possible to create these holograms with multiple simultaneous hues though viewer-position-independent true-color imagery is not practical when this form of hologram is created optically.

Almost as soon as embossed holograms were commercialized, techniques for illicitly replicating them were developed, and an "arms race" between counterfeiters and the developers of authentication holograms has been underway since the late 1980s [31].

While some of the source holograms for authentication tags continue to be produced using traditional "analog" exposure methods and physical objects, typically the phase hologram used for the stamping die is now created by other means. Dot matrix hologram printers use interference to generate an array of microscopic diffractive patches whose orientations and spatial frequencies can be varied, allowing the creation of true-color patterns [32], while e-beam lithography can be used to write arbitrary computer-generated diffraction patterns directly, giving a maximum degree of flexibility of imagery [33].

All of the above mass-production techniques have the limitation that the holograms produced are identical; the company Optrace has developed a system that can print serialized security holograms for luxury goods and other products in photopolymer at the rate of 10,000 holograms/hour and has also demonstrated the incorporation of unique QR codes and covert features [34].

3. Discussion: Looking Forward

With respect to display holography, fashion and other luxury goods applications have aimed for unique, creative, and innovative visual experiences, using other technologies when true holography could not be employed. Ongoing development of digital holography and some parallel technological advances in other fields should permit a broader applicability of diffractive displays in coming years.

Even for still images, scene capture has always been a limiting factor for commercial holography. In the analog case, powerful lasers are needed to illuminate the scene and items in the scene cannot move during the exposure more than a small fraction of the wavelength of the light; this means that particularly for scenes with human models or even just fabrics, pulsed-laser exposure is required, and there have never been more than a few commercial pulsed-laser holographic studios in operation at any given time. Additionally, exposure and processing of very large photographic plates creates further complications. Digital holographic prints relax these limitations, as they can scale to large sizes (full-size prints of cars have been made, for example) and can be generated from a dense array of 2D parallax views (still a bit of a photo-studio challenge) or from 3D models of the scene [35]. At the time of the initial development and commercial push of holographic printing, though, computer graphics models of human figures and of luxury merchandise were not widely available and computational requirements made drape simulations of garments a challenge.

More recently, submillimeter-accurate body scanning has enabled the creation of extremely realistic poseable and animatable human body models (Figure 9) and advances in graphics processors have meant that ultra-realistic dynamic simulation of the mechanical and optical properties of garments and accessories has become possible even on PCs. Modern Mirror is able to capture textured 3D meshes of fashion models or of shoppers, dress them with digital versions of real merchandise, and render the results in real time [36]. Because of the underlying high-quality 3D data, this sort of process is suited for 3D displays such as digital holograms as well as 2D images.

Figure 9. Virtual fashion: stills from an animated video rendered from 3D body scan and 3D garment model (Courtesy Modern Mirror, Inc. New York, NY 10018, USA; garment design by Noe Bernacelli).

Though the rapidly growing amount of 3D imagery means that there will likely be more use of holographic prints in the luxury goods world in the near future, the ultimate goal remains a dynamic holographic display. Holographic video displays have existed for many years, and like holographic prints, they do not require scene capture with coherent light sources but rather can create diffraction patterns from 3D models or parallax image sets [37]. Because of the requirement for submicron-scale pixels in the display device, inexpensively scaling up the necessary electro-optic components (in particular, diffractive spatial light modulators) to the sizes of the still hologram and Pepper's Ghost examples described above continues to be a topic for research and development. In the meantime, luxury brands have begun exploring the use of non-holographic light field 3D displays [38]; the same data sources used for those displays can be used to generate digital holographic video as well when suitable displays reach the market.

Author Contributions: Conceptualization, V.M.B.J. and N.A.R.; investigation, V.M.B.J. and N.A.R.; writing—original draft preparation, V.M.B.J. and N.A.R.; writing—review and editing, V.M.B.J. and N.A.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors wish to thank the following individuals for their assistance with the preparation of this article: Patrick Boyd, Michael Crawford, David Brotherton-Ratcliffe, Joy Javits, Sean Johnston, Sam Moree, August Muth, Martin Richardson, Seth Riskin and colleagues at the MIT Museum, Jonathan Ross, and Richard Sharpe.

Conflicts of Interest: The authors declare no conflict of interest.

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