ChatGPT

Real-Time Holographic Torus Display: Technologies & Viability

Introduction

A **real-time, dynamic optical hologram system** capable of projecting a free-floating 3D donut (torus) promises a striking blend of art, education, and technology. The goal is to create a torus-shaped hologram visible from multiple angles, interactive (potentially responsive to gestures or even brainwaves), for use in art installations and future devices. Achieving this requires surveying **all viable holographic display technologies**, from laser-based holography to volumetric and light-field systems. Each approach comes with distinct strengths, weaknesses, required components, and levels of commercial readiness. Notably, the torus is more than just a 3D shape – in *sacred geometry* it symbolizes dynamic energy flow, balance of opposites, and the interconnectedness of all things [1]. This makes an interactive torus hologram a fitting "Universe Map/Time Map" interface, where technology meets symbolic significance. Below, we examine the key holographic display technologies, evaluate their feasibility for rendering a floating donut, and discuss integrating brain–computer interfaces (BCI) for mind-responsive holograms.

Laser-Based Holography (CGH and Interferometric)

Laser holography offers perhaps the most literal 3D imaging by reconstructing light wavefronts. Traditional analog holography (using holographic interferometry) can record a static 3D scene (e.g. a physical torus) on a photosensitive plate and replay it with a laser, yielding a life-like 3D image viewable from many angles. However, for a *dynamic* donut hologram that can change in real-time, we turn to **computer-generated holography (CGH)**. In CGH, a spatial light modulator (SLM) – such as a liquid crystal on silicon (LCoS) panel or a digital micromirror device (DMD) – is used to display computed interference patterns (holograms) of the desired 3D object. When illuminated by a coherent laser, the SLM diffracts light into a volumetric reconstruction of the scene. This method theoretically reproduces all depth cues and perspectives correctly, making it the "ultimate" 3D display technology [2]. Recent advances have produced high-resolution holographic **prototypes** and even demonstrated full-color holographic video in lab settings [2]. A holographic torus generated this way would appear truly floating and 3D to the naked eye, without any glasses.

Strengths: Laser CGH can create extremely realistic 3D images with *continuous depth*, true binocular disparity, and focus/accommodation cues (your eyes can actually focus on the virtual donut as if it's a real object). Because the image is formed by light interference in space, multiple viewers can see the hologram from different angles simultaneously, each seeing the torus with correct perspective. In principle, this approach achieves what other 3D displays simulate – it's a "true hologram." It's also inherently **non-mechanical** (aside from electronic components), meaning no moving parts in the display itself. As such, once the computation challenge is solved, CGH could enable compact holographic projectors. Researchers note that holographic displays *"promise to be the ultimate 3D display… able to account for all visual cues,"* with prototypes indicating they *"may become widely available in the near future."* The major hurdle is computational complexity [2] – generating hologram patterns for complex 3D scenes at interactive frame rates is *highly* demanding, often requiring dedicated GPUs/FPGAs or novel algorithms.

Weaknesses: The biggest challenges for real-time CGH are **computational load and hardware limitations** [2]. Computing a high-resolution interference pattern for a 3D object (especially one as detailed as a textured donut) in real-time (e.g. 30–60 fps) is an intensive task. Even with modern algorithms and hardware acceleration, achieving video-rate, photorealistic holograms remains at the cutting edge of research. Additionally, current spatial light modulators have finite resolution and refresh rate. High-end phase-modulating LCoS panels might be 1080p to 4K resolution at ~60–120 Hz; this limits the angular field of view of the hologram (wider view requires finer pixel pitch to satisfy Nyquist criteria of holography). In practice, many dynamic CGH demos have a limited viewing zone (the hologram might only be visible within, say, a ±20° window) or suffer from lower image quality (speckle noise, limited depth range). Another issue is *laser power and safety*: to project a bright hologram, powerful lasers are needed, and one must ensure eye safety (diffuse holographic light is generally eye-safe, but any strong undiffracted beam or higher-order beam can be dangerous). **Alignment and optical complexity** are also non-trivial – a typical setup involves lasers, beam expanders, the SLM, and lenses to position the hologram in space (e.g. focusing the hologram so the 3D image appears at a certain distance in front of or behind the SLM). All these add to system complexity.

Components & Cost: A CGH system requires at minimum: one or more lasers (for monochrome or RGB), an SLM (either LCoS or DMD), driving electronics/computer, and optics (lenses, mirrors). High-quality phase SLMs (LCoS) can cost several thousands of dollars apiece. DMDs (micro-mirror chips) are mass-produced for projectors and can be cheaper, but using them for holography often means binary or phase-limited holograms. Lasers have become much cheaper (diode lasers in the tens to hundreds of mW range are a few hundred dollars), but for large, bright holograms you might need watts of laser power (solid-state or gas lasers can cost thousands). All together, a custom holographic projector could easily run into the tens of thousands of dollars for a research-grade setup. Commercially, companies are exploring laser holographic displays (for example, some augmented reality headsets internally use holographic projections onto waveguides, see later section), but **no mass-market "hologram projector" exists yet**. We are, however, seeing steps toward that – for instance, in 2023 Samsung demonstrated a holographic display prototype, and academic labs (MIT Media Lab and others) have built dynamic holographic video displays. These remain mostly lab demos.

Viability for a 3D Donut: In theory, CGH is capable of rendering a perfect 3D torus with full 360° viewing. In practice, current tech could perhaps project a small donut floating a few cm wide, viewable within a restricted angle. Achieving a large (say 0.5 m wide) donut viewable from all around would require a **huge** SLM resolution or some novel tiled-SLM setup, and immense computation. Thus, for an *immediate art installation*, laser CGH is likely *too immature or costly*. However, it's a promising route long-term – as algorithms improve (e.g. using deep learning to speed up CGH computations [3]) and as SLM tech advances (higher pixel counts, faster refresh, maybe even optical *phased arrays* on chips), real-time holographic projectors could become reality. In summary, **laser-based CGH offers the highest fidelity and "truest" hologram, but is currently the hardest to implement in a robust, large-scale real-time system**. It might be a longer-term path toward a genuine holographic donut display.

(Note: **Holographic interferometry**, per se, refers to using holograms to measure small differences in objects (like deformation, vibration) by interference of wavefronts. It's less about display, more about metrology. In this context, the term was likely included to cover laser holography methods in general. The primary relevant method for a *dynamic display* is digital/CGH as described above.)

Volumetric Display Systems (Swept-Volume & Plasma Voxels)

Volumetric display using rotating LED panels (James Brown's DIY 3D display). Multiple LED arrays spin at high speed, tracing out a volume where 3D images (like a donut) appear [4] [5].
Volumetric displays create **3D images by physically filling a volume with light points (voxels)**. Unlike holography, which encodes depth in light wave phases, volumetric displays generate 3D visuals by *sweeping or addressing points in space*. This category includes **rotating LED arrays, swept screens, and plasma emission displays**. The principle is often persistence of vision: if you can rapidly plot many 2D slices of an object in different spatial positions, the human eye will integrate these into a continuous 3D image floating in mid-air [6]. For a torus hologram, a volumetric display would actually illuminate the volume of the donut's shape, allowing one to literally see a "solid" donut from any direction.

Rotating LED Arrays & Swept-Volume Displays

One proven approach uses a high-speed **rotating display surface** to sweep out a volume. For example, the Voxon VX2 is a commercial volumetric display that spins a dual-sided LED matrix panel at 30 rotations per second (900 RPM) inside a volume [7] [8]. As it spins, each "slice" of the panel shows a different horizontal cross-section of a 3D scene, synchronized to its angle. Thanks to persistence of vision, the viewer perceives a full 3D image in a cylindrical volume [6]. In effect, the display is *printing* the 3D object in mid-air repeatedly. Such a system can indeed render a torus: the device would draw many circles (slices of the torus) as the panel moves, and the combination appears as a donut shape. A major strength here is **true 360° visibility** – volumetric images can be viewed from any angle around the device (and even from above to some extent), just like a real object [6]. Multiple people can walk around and simultaneously see the floating donut without any eyewear. The image is also genuinely in space (not behind glass), so one could potentially reach in and gesture around it (though touching the image itself may intersect the moving panel, which is a safety consideration unless enclosed).

Modern implementations have achieved decent resolution and color. The Voxon VX2, for instance, offers a **256 mm diameter × 256 mm tall cylindrical display volume** with about **8 million voxels** (volume pixels) lit at **30 volumes per second** (30 Hz volumetric refresh) [9] [10]. In practice this corresponds to a voxel density akin to a few hundred pixels per slice and ~198 slices vertically (since 8e6 ≈ 200×200×198). It produces full RGB color. The result is a small but fully volumetric image – think of a roughly 10 inch wide sphere in which the hologram appears. The donut would thus be up to ~25 cm across if it nearly fills the volume. An image in such a display truly "floats" in a glass dome and can be seen from all sides.

Strengths: Volumetric LED displays provide *real* 3D with *no viewing zones or special viewing optics*. The visual is intuitive and physical – often described as a "3D printout made of light". There's no vergence-accommodation conflict (your eyes focus at the actual point in space where light is emitted). This makes viewing comfortable and natural, without eye strain or nausea issues that some 3D illusions cause. They are also interactive-friendly: since the image is in a fixed volume, one can add sensors to detect hands or tools intersecting that space for direct interaction. For example, one could imagine pointing at parts of the floating torus to trigger responses, or using a stylus to "draw" on the hologram. The technology is also **commercially available now** – as of 2025, Voxon's display (VX2) is marketed as *"the only commercially available volumetric display… true 360 degree experience"* [11], and it has been used in museum exhibits, gaming demos, and medical visualization. Costs are high but not prohibitive for prototypes: the VX2 is listed at **US$6,800** for the core device [12] (not including a host PC), which is actually on par or cheaper than some high-end 2D hologram or light field displays. Simpler "homemade" versions, like the Raspberry Pi-powered spinning LED project by maker James Brown, demonstrate that with off-the-shelf parts one can build a volumetric display (albeit lower resolution) relatively inexpensively [4] [5].

Weaknesses: The current limitations include **image resolution and size**. Millions of voxels sound like a lot, but spread across a volume they translate to fairly coarse detail compared to HD or 4K flat displays. The floating donut will appear, but it might look a bit "voxelly" or low-polynomial surfaces might show aliasing. Also, volumetric displays tend to be *small* – the spinning panel approach becomes mechanically challenging to scale up. A larger volume means a bigger, faster spinning surface, which introduces noise, vibration, and safety issues. (Some large experimental units have been built – e.g. a big volumetric display shown by Voxon had multiple panels and was primarily a tech demo – but these are not products.) The need for moving parts brings **mechanical complexity and maintenance** concerns: motors can wear out, calibration is needed to avoid wobble, and the device usually must be enclosed (a clear case or dome) to protect users from the high-speed spinning panel. That enclosure can slightly dim or reflect the image as well. The rotating blade also means you cannot have solid objects intersecting the volume (no putting your hand fully inside unless the rotation is stopped), which can limit direct touch interactivity to the periphery of the image. Another issue is **content computation and format** – one must render a 3D model into many slices for each frame, which is a manageable but specific pipeline (the Voxon SDK, for example, handles this, but not all 3D engines output volumetric slices easily). In terms of **color and brightness**, these displays are generally less bright than flat screens; the light from LEDs is spread in 3D, and the display may not fare well under strong ambient lighting (for an art installation, you might need controlled lighting or a darker environment to clearly see the hologram). Finally, there's a "pole" or blank spot potentially – note the VX2 spec mentions an *axial occlusion of 12mm diameter* [9], meaning the very center of the volume (around the spinning axis) doesn't display content (since that's where the motor/spindle is). This might create a slight artifact if your donut's exact center is at the axis (though a torus could be positioned offset to avoid a hole at the center of the image).

Despite these, **volumetric displays are one of the most viable near-term options** for a floating torus hologram. For an initial art installation, a device like the Voxon VX2 could be used almost immediately to showcase a dynamic torus, perhaps rotating it or changing its patterns. The cost (~$7k plus a PC) and setup is comparable to other high-end AV equipment. The trade-off is the modest size of the hologram and resolution. If a larger scale is needed, multiple units or a custom bigger volumetric display would exponentially increase complexity and cost.

Note: A related class are *"holographic fan" displays often seen in retail – spinning LED propellers that project an image that appears floating. Those are effectively 2D POV displays; one or two blades spin to form a flat image plane (like a floating screen). They can show a 3D-looking animation (even a rotating 3D model) but not* a true volumetric view – if you go around the back, you see a mirror image or nothing. They are inexpensive (hundreds of dollars) and good for signage, but would not give a true multi-angle donut experience. True volumetric (multiple slices through the volume) requires the 2D panel (or multiple LED blades) to cover the whole volume, not just a single plane.

Plasma Voxel Displays (Laser-Induced Air Plasma)

Another fascinating volumetric technique creates glowing points *directly in mid-air*, using **focused laser pulses to ionize air molecules**. Essentially, intense laser beams intersecting at a focal point can excite air into a plasma, emitting a tiny flash of light at that point. By rapidly steering the focal point through a 3D region, a sequence of such sparks can form a 3D image made of "plasma voxels." This is often referred to as a *laser plasma display* or aerial hologram (though it's not a hologram in the interference sense). Several Japanese groups have pioneered this: for example, Burton Inc. showed as early as 2011 a system that could form simple shapes (like a 3D spiral or the word "LOVE") floating in air using a green laser focused by a lens system [13] [14]. That system produced about **50,000 dots per second at ~10 fps** (aiming for 24+ fps) [15]. More recently, the Utsunomiya University "Fairy Lights" display used **femtosecond pulsed lasers** to generate touchable, safe plasma points [16] [17], even demonstrating interactive mid-air floating animations.

For a torus hologram, a plasma display would trace out the donut shape with glowing points. Imagine thousands of tiny sparkling dots outlining the surface or interior of a torus. Because these are actual light emitters in space, the donut would be visible from any angle (everyone sees the same points floating in the air). And notably, there's *no screen or enclosure at all* – it's the closest thing to the science fiction idea of a Princess Leia hologram projected into thin air.

Strengths: This approach produces **free-floating voxels with no physical medium except air**. The result is truly 3D in open space – you can literally pass your hand around/behind the image without any obstruction (aside from the light being very faint). There are *no glasses, no rotating machinery*. The only moving part is the light focus point, which is steered by mirrors or phased arrays of lasers. Modern implementations using femtosecond lasers have made the effect safer and even **interactive to touch**. Because the plasma burst is so brief and small, touching it won't burn you if done correctly; in fact, touching can make the light momentarily brighter and also creates a tiny shockwave that gives a tactile sensation [18] [19]. This means one can literally *feel* holographic points – a primitive but intriguing form of haptic feedback. In an interactive installation, a user could poke the mid-air torus and, say, see it ripple or hear a sound. Plasma voxels also have very fast inherent response – the limiting factor is how fast you can steer the laser. Researchers have achieved on the order of **hundreds of thousands of voxels per second** with galvo mirrors or acousto-optic deflectors, which means high frame rates for simple shapes. One report demonstrated a display at **≈10 kHz voxel firing rate** to draw persistent images, and even claimed an effective frame rate of ~30 fps for small objects by rapid scanning [20]. The **"wow factor"** of this technology is extremely high – it looks like genuine magic to see points of light materialize in thin air. For a thematic art piece involving sacred geometry, an ethereal glowing torus floating above a pedestal would be very impactful.

Weaknesses: Despite its promise, this technology is currently *very limited and experimental*. The primary issue is **voxels count and scalability**. Tens of thousands of points per second sounds good, but to make a solid-looking 3D object (even a simple torus), you might need millions of voxels per frame to fill its surface with light. With 50,000 points at 10 fps, you're effectively drawing extremely sparse wireframes. The images are usually just outlines or sparse dot clouds – a "dot-matrix" hologram. Increasing voxel count means more powerful lasers or faster scanning, both of which are hard. There's also a trade-off between area and point density; early systems had a tiny interaction volume (a few cubic centimeters) to get decent point density. Achieving a large volume (say several cubic feet) is an active research challenge. Another huge factor is **laser power and safety**. To create plasma in air, especially with nanosecond lasers, you need high peak power – earlier versions could actually cause burns if touched [17]. The newer femtosecond lasers mitigate this by using ultra-short pulses (lower energy per pulse needed for breakdown, and minimal heat transfer), but the lasers themselves are very expensive and bulky (femtosecond laser sources can cost tens of thousands of dollars alone). The whole apparatus (lasers, beam expanders, 3-axis scanners) is not trivial to package; most demos are tabletop apparatus with optics on an optical bench. For an installation, alignment and maintenance of such a system would be challenging. Additionally, the **brightness** of plasma voxels is limited – in a lit room, the tiny spark points are hard to see; they work best in dark conditions. The color is usually fixed (the plasma tends to emit bluish-white light by default, though using multiple lasers at different focal points could produce RGB points). Some work has been done on color mid-air plasma by using multi-wavelength lasers, but it's not yet full color at each voxel. Noise is another consideration: the plasma pops can make audible clicking sounds (like static crackle), especially if many points are generated continuously. This could either be a feature (could form part of the sensory experience) or a distraction.

Components & Cost: A laser-plasma display system for a torus would require: one or more **ultrafast pulsed lasers** (likely high repetition-rate femtosecond lasers), a beam steering mechanism (fast galvo mirrors or acousto-optic scanners to direct the focus in X, Y, Z), a focusing lens (or dynamic focusing via perhaps a spatial light modulator lens or moving lens to achieve different Z depths), plus control electronics/computer to synchronize and position the pulses. This is cutting-edge hardware. The cost is substantial – even a low-power femtosecond laser oscillator can cost in the tens of thousands of USD. There are some startups and labs developing this (e.g., see Aerial Burton in Japan, or the Digital Nature Group's work), but it's not something one can easily buy. If an art project had a very high budget and strong technical team, it could attempt a one-off build. But there's currently **no turnkey plasma hologram product** on the market. It's mostly research, with perhaps a few companies doing demo installations at tech expos.

Viability for Donut and Future: As of now, a plasma-volumetric torus would likely be small and composed of twinkling dots – more like a wireframe or pointillist sculpture of a donut. It could be captivating in a dark room, especially if interactive (touch-responsive), but it won't look like a solid, bright object. For near-term practical deployment, this approach is *the furthest from commercialization*. However, it represents a truly "free-floating" 3D image, which is the holy grail of display. If the technology matures (more powerful compact lasers, faster scanning, perhaps eventually using phased laser arrays to address many points in parallel), we could imagine future devices projecting large, solid 3D objects in mid-air. In that future scenario, rendering a sacred-geometry torus in the air that changes with your thoughts would be straight out of science fiction. In summary, **laser-plasma displays have unmatched visual purity (true mid-air points) but are currently limited to small, sparse images and require expensive, complex equipment**.

Light Field & Multi-View Displays

A 27-inch light-field display (Looking Glass 3D) showing a 3D object to multiple viewers. Such displays use many view angles so each eye sees a different image, creating a stereoscopic and motion-parallax 3D effect [21] [22] *.*

Light field displays take a different approach: instead of physically forming points in space, they emit a carefully arranged set of 2D images such that observers get the illusion of 3D. These are basically advanced **auto-stereoscopic or multi-view systems**. A common design is a **lenticular or barrier screen** or a **projector array** that projects dozens of views of a 3D scene simultaneously. Each view is seen from a different direction, so as you move your head, the perspective shifts correctly (horizontal parallax, and in some systems vertical parallax as well). To each eye, the display provides a slightly different image, creating stereoscopic depth. The result is a 3D scene that appears to float *inside or just behind the display glass*, visible to multiple people at once without glasses. The torus in this scenario would appear as if inside a box or coming out of the screen, with true depth, but it is not literally in the air in front of the device – it's within a fixed viewing cone.

Notable examples include **Looking Glass Factory's displays** (like the Looking Glass 16″, 27″, and their 8K 32″ and even 65″ prototypes). These use a combination of a high-resolution LCD and complex optics to project ~45 to 100 distinct views of a 3D scene within a ~50° viewing cone [22] . For instance, the Looking

Glass 27″ generates up to **100 simultaneous perspectives** of the content within a **53° cone**, so a group of people can gather and each eye pair catches appropriate left/right images for 3D [22]. Another example is **Holografika's HoloVizio**, which used an array of microprojectors behind a screen to produce a true 3D scene with continuous parallax across a wide area. There are also smaller-scale light-field displays like the Sony Spatial Reality Display (which is more for single-user, using eye-tracking to show two correct views), or the Leia Inc. lightfield tablet screens (which use a diffractive backlight to show a few views for a handheld device). For an interactive art installation, one could imagine a larger light-field panel or "holographic screen" that people stand in front of and see a 3D donut hovering behind the screen glass, potentially moving or responding to them.

Strengths: Light-field and multi-view displays are *already commercially available* and fairly mature for what they are. They can produce **high-resolution, full-color 3D images** with much more detail than current volumetric displays. For example, the Looking Glass 27″ has a base panel of 5K resolution (5120×2880) and uses that to render multiple views, achieving a quite sharp image in 3D [23] [24]. These systems can display photorealistic content (e.g., 3D photographs, models with complex textures) that volumetric or holographic displays might struggle with due to voxel/phase resolution. The content creation pipeline can be as simple as rendering from multiple camera angles – many 3D software and game engines can be adapted to output multi-view images. So for showing a torus, one could use a 3D model and the provided SDK to visualize it with correct depth, potentially even with interactive changes. **Multiple viewers** can share the experience (on the 27″, it's advertised that 5–10 people can see the 3D effect together comfortably). Because these displays don't require glasses, it's easy to include in a public space – people can just walk up and see a 3D donut "inside" the screen. There is also **no moving part** in these (aside from maybe eye-tracking cameras in some designs), which makes them robust for long exhibitions. Interaction can be done via external trackers (gesture sensors like Leap Motion can track hands and let people "grab" the virtual donut through mid-air gestures, which the software then reflects in the display – e.g., rotating the 3D model). In terms of *comfort*, these displays avoid VR/AR headsets, so no wearing equipment, and they mitigate some of the eye strain issues of earlier 3D TVs by using more views and better optics (though some people still experience slight discomfort after long viewing, depending on implementation). They also support **full color and relatively high brightness**, making them suitable for reasonably lit environments.

Weaknesses: The main limitation is that the 3D image is confined to the *volume within/behind the display*. It's not a free-floating hologram you can walk around 360° – rather, it's like a window into a 3D world. You typically get about 50° of viewing angle total; beyond that, the image either disappears or you start seeing repeated view cycles. So if someone tries to walk fully around, they cannot – it's fundamentally a front-view experience (some systems provide a wider horizontal range by sacrificing vertical parallax, but still, you can't go behind it). In the context of a torus, you could see the front and a bit of the sides/top of the donut as you move, but you couldn't go behind the screen to see its far side (the far side would be rendered, but only visible when you're on the correct side of the screen). Another issue is **view resolution**: because many views are produced from a single high-res panel, the effective resolution per view is much lower. For example, with 100 views from a 5K panel, each view might be equivalent to 512×288 pixels or so reaching a given eye position. The manufacturers mitigate this with clever optics (so it doesn't look as simple as 512×288 pixel image; they overlap in space smoothly), but the perceived resolution of the 3D image is typically lower than a normal 2D display of the same panel. Fine details can appear a bit soft. Also, these displays suffer from *limited depth of field* – the 3D scene can only project within a certain depth range (for Looking Glass it might be a few inches in front of and behind the glass). If you push content too far out, it breaks the view or gets blurry. So the donut hologram would appear either right at the screen surface or just behind it, rather than strongly projecting out into the room toward the user. **Cost and size** are non-trivial: the 27″ Looking Glass was launched at around **$10,000 (discounted to $8k on pre-order) for businesses** [25] . Larger models (like the 65″ 8K display) are even more expensive and rare. They are targeted at enterprise/museum use. Additionally, the displays are heavy and not easy to move frequently (the big ones especially). For an art installation, one must ensure viewers stand at the right range – usually a few feet away – to get the best effect. Crowds have to be managed so they all stay within the viewing cone.

Components: Typically a **high-resolution LCD or OLED panel**, an **optical layer** (either a lenticular lens sheet or a guided wave optics array) precisely bonded to it, and significant **computational rendering hardware** (often a powerful PC with a high-end GPU is needed to render all views in real-time). Some products integrate a PC (the Looking Glass 65″ had an integrated computer; the 27″ can offload rendering to an attached iPad Pro or PC [26]). The content needs to be rendered from many vantage points; software like Unity3D or Unreal can do this with plugins, but it means the content pipeline is more complex than standard 2D.

Viability for Donut and Interaction: Light field displays are **very viable** for demonstrating a dynamic 3D torus *visually*, as long as we accept it being inside a display case. For example, one could mount a 27″ light field display on a pedestal and have the torus rotating or pulsing in it, and viewers will see a nice 3D donut with depth. If interactive, the screen could respond to gestures – e.g., a Leap Motion sensor can detect a user miming a grab or rotation, and then the torus in the display could rotate accordingly. There are already instances of such interactive museum exhibits using these displays because they are relatively *plug-and-play*. The drawbacks are that it won't have the "reach out and touch" illusion as strongly as a true volumetric or mid-air display – you are still looking at a glass panel (albeit a magical one). Also, only front-side interaction is possible (since you can't go behind it). **Commercial viability is high**: companies are actively selling these, with support and improvements. Over time, costs might come down, though at the moment it's a specialized product. For a manufacturable device in the near term, this tech is one of the frontrunners (for instance, for 3D dashboards or collaborative design displays). So, in summary, **light field displays offer multi-view 3D with high detail and are available now, but they provide a "window-like" hologram rather than a free-floating one, and at substantial cost for larger sizes**.

Metasurface Optics and Diffractive Waveguides

In recent years, **metasurfaces** – nanostructured optical surfaces – and **diffractive waveguides** have emerged as cutting-edge solutions for manipulating light. In the context of holographic displays, they represent a miniaturized, potentially wearable or integrated approach.

A **metasurface hologram** is a flat panel etched with microscopic features that can impart spatially varying phase shifts to light. Essentially, it's like having millions of tiny antennas on a surface that can steer and shape wavefronts. Researchers have created static holographic images using metasurfaces (for example, a single metasurface that, when illuminated by a laser, projects a fixed 3D image). The challenge has been making them *dynamic*. One avenue is to combine metasurfaces with tunable materials – e.g., overlaying a liquid crystal layer that can be electrically switched to modulate which parts of the metasurface are active, or using phase-change materials that can toggle optical states. There have been demonstrations of **"dynamic meta-holograms"** with limited frames or patterns. For instance, one research achieved a meta-holography display that could switch among 28 distinct hologram frames at an ultra-high rate (~9523 frames per second) by using a coded metasurface together with a high-speed DMD laser modulation system [27] . This hints that metasurfaces could someday enable very fast holographic video, but in that case the frames were pre-defined (not freely computed on the fly). Another approach uses **cascaded**

metasurfaces or a stack of a metasurface with a spatial light modulator to achieve dynamic 3D images [28] – e.g., a Nature paper in 2020 demonstrated a cascaded device with a polymer dispersed liquid crystal layer to select different holographic projections from a metasurface, achieving multiple depth planes.

Diffractive waveguides are a bit different: these are typically used in **augmented reality (AR) headsets** like Microsoft HoloLens or Magic Leap. They involve a transparent slab (glass or plastic) with embedded diffraction gratings that in-couple and out-couple light, effectively piping a display image from a small projector into the user's field of view. For example, an LCoS microdisplay or micro-LED projector creates an image of a 3D object, which is injected into the waveguide via a grating; the light travels through the waveguide by total internal reflection and then another grating in front of the eye extracts the light, forming a virtual image at some focal distance. This allows a wearer to see a virtual 3D object overlaid on the real world. In our context, using waveguides would imply **AR glasses or a headset** that make the user see a holographic torus floating in space. That is a valid approach – it's how many AR applications work – but it requires each viewer to wear a device. The user's prompt, however, seems to prefer a free-space solution for multiple viewers, so waveguide AR would turn it into a *personal* hologram rather than a shared one. Still, it's worth noting because waveguide optics are a practical holographic-ish display tech today, just in near-eye form.

Strengths (Metasurfaces): Metasurface optics can be extremely **compact and thin**. A metasurface hologram could be the size of a postage stamp yet project a complex hologram. They could allow holographic projectors to be built into slim devices (even possibly future AR glasses without bulky optics). Because they manipulate light at sub-wavelength scales, the precision of images could be very high – in theory, a well-designed metasurface could produce a high-resolution hologram with wide field of view if illuminated properly. They also can be mass-manufactured using semiconductor fabrication techniques (like printing nanostructures over wafers), so in the long run, if dynamic metasurface displays can be perfected, they might be relatively low-cost per unit. Some metasurface devices also can operate over a broad spectrum (there are designs for RGB meta-holograms, though often metasurfaces are narrowband by nature of their resonances). The high switching speed demonstrated in certain experiments (thousands of frames per second when coupled with a fast projector) indicates that ultra-fast refreshing holograms (far beyond typical 60 Hz) could be possible, which might reduce flicker or enable multiple images to be multiplexed in time for different depths.

Weaknesses (Metasurfaces): Right now, truly **dynamic metasurface displays are mostly experimental**. The ones that exist have very limited degrees of freedom – for example, only toggling between a set of predetermined holographic images (not generating arbitrary new content on the fly). A fully programmable metasurface SLM is an active research area (imagine an array of nanoelements each tunable by electrical signal – essentially a microscale phase modulator array). There are challenges in material science to achieve that (liquid crystal or MEMS-tunable metasurfaces suffer from limited resolution or small phase range). Another issue is **efficiency**: metasurfaces often waste a lot of light into unwanted diffraction orders or absorption; a dynamic one might be even less efficient. For a bright hologram, efficiency is key. If using them as an output coupler (like perhaps a meta-optic that directs light into specific angles), one might still need a powerful source. The fabrication of large-area metasurfaces is also non-trivial – making a big panel with nanostructures is possible with techniques like nanoimprint, but yields and uniformity can be concerns. So scaling to a billboard-sized holographic screen, for instance, would be challenging currently. In short, metasurface holography holds *long-term promise* for compact holographic projectors or glasses, but in 2025 it's not something one can use for a robust, reprogrammable donut display. It's more likely to see use in *assisting* other systems (like meta-lenses to improve SLM performance, or combiners for AR, or static hologram art pieces that don't move).

Strengths (Waveguides for AR): Diffractive waveguides are a **proven technology in AR headsets**, enabling a decent field of view and transparent display. For an interactive torus application, giving the user an AR headset with EEG sensors (some research prototypes do combine AR glasses with EEG or other biometrics) could create a very personal "holographic donut" that only they see, floating in their environment and responding to their brainwaves. The advantage here is you leverage existing devices like HoloLens 2 or Magic Leap 2, which can display 3D objects at maybe arm's length with relatively good fidelity (though not as solid as a light field display). The user can move around the donut (within the tracking limits) and see it from different sides, since the device tracks head position and renders appropriately. It's a **one-user-at-a-time** solution typically, but multiple people each with a headset could share an experience if networked (each sees a synced donut in the same real location). Also, since AR systems already integrate interactivity (hand tracking, voice commands) and you can attach EEG, it's a very flexible platform for the *interactive symbolic tool* aspect of the project.

Weaknesses (Waveguides/AR): The necessity of wearing a headset is a big drawback for public installations – it adds friction and cost per user. AR headsets are still expensive (thousands of dollars each) and not really designed for large audiences to use casually. They also have limited field of view (typically 40-50° FOV, so the hologram can disappear if you look too far to the side). Brightness and opacity of virtual objects are also limited; in AR, you often get semi-transparent holograms rather than fully solid-looking ones, especially under bright ambient light. For a glowing torus meant as an educational art piece, AR might make it appear too ghostly or could break immersion if environment lighting isn't ideal. Also, integrating EEG into a headset is another challenge (though companies like OpenBCI have a product called Galea, which mounts EEG sensors onto a VR/AR headset, so it's feasible). In summary, AR waveguides can definitely produce a 3D torus and are commercially available, but they shift the experience from a shared external hologram to a personal, headset-mediated one.

Viability: For near-term manufacturing, metasurface tech is *emerging* – we might see first products in specific niches (like optical encryption devices, or small augmented reality HUDs using metasurfaces) soon. They won't directly give us a large dynamic hologram within a year or two. Waveguide AR is already in limited production (HoloLens, etc.), and could be leveraged if the project is okay with head-worn devices. If the goal is a *free-standing display piece*, metasurface/waveguide isn't the immediate answer. But they could become important as the project evolves into "device manufacturing" – e.g., imagine a **future generation holographic device** that uses a metasurface as the projector to create the donut in air, or a wearable personal "hologram generator" in glasses form for education. So, **metasurface and waveguide technologies are forward-looking options**: metasurfaces could eventually allow compact hologram projectors with no moving parts, and waveguides (with AR) allow interactive 3D visuals now but via headsets. They both emphasize *miniaturization and integration* over large-scale 3D visuals.

Spatial Light Modulators: DMD vs LCoS (Enabling Tech)

Because the user specifically inquired about **Digital Micromirror Devices (DMD)** and **Liquid Crystal on Silicon (LCoS)** panels, we will discuss these as the *key components* in many holographic and projection systems, and how they compare for creating a holographic torus.

Both DMDs and LCoS are types of **spatial light modulators (SLMs)** – they modulate an incoming light beam on a pixel-by-pixel basis. The difference lies in how: a **DMD** is a micro-electro-mechanical array of tiny mirrors that tilt to modulate light (each mirror corresponds to a pixel and can tilt typically ±12° to direct light either into a lens or away). An **LCoS panel** is a reflective liquid crystal display on a silicon backplane; by applying voltage per pixel, it changes the phase or polarization of reflected light for that pixel.

DMD (Digital Micromirror Device): These are produced at scale by Texas Instruments for projectors. A common DMD might be 1920×1080 mirrors, each ~7-10 microns in size, mounted on a chip. DMDs are **binary light modulators** in the sense that each mirror is either tilted "on" or "off" (though intermediate intensities can be achieved by time dithering at high speeds). The big advantage of DMDs is speed: they can switch states extremely fast, on the order of tens of microseconds. High-performance DMDs can reach frame rates of up to 10 kHz or more for binary patterns [29]. This speed opens up possibilities for *time-multiplexing* in 3D displays. For example, one can rapidly display a series of sliced images or holographic patterns at different depths. Our earlier mention of using a DMD for volumetric CGH is a prime example: researchers modulated a laser with a DMD at ~10 kHz to sequentially project multiple depth "slices" of a 3D object within one 1/60 second frame, effectively stacking a 3D image [30] [31]. Each slice is shown so briefly that the eye blends them into a continuous volume (similar to the spinning LED volume concept, but here the "slices" are in time rather than physical space). DMDs can also be used for *computer-generated holography*: even though they are binary amplitude devices, there are techniques like binary phase or kinoform approximation where the rapid toggling creates an effective phase pattern. In fact, some research has demonstrated high-speed holographic displays by using DMDs to display hologram patterns and synchronizing with shifting focus planes or angled illumination to cover depth.

For a holographic torus, a DMD could be used in one of two ways: (1) **Volumetric projection** – e.g., project 2D cross-sections of the torus at successive depths rapidly. This would need either a focus-tunable lens or some optical system to shift the image plane of the projector in sync with the frames. If done fast enough, the torus's slices would appear as a volume. (2) **Holographic wavefront** – use the DMD as a hologram generator (with a laser and lens) to directly form the torus image via diffraction. The binary nature reduces efficiency (most light goes into unwanted orders), but what remains can form the image. One cited work (Gao et al.) used a DMD in combination with a metasurface to achieve 9523 fps holograms (they essentially precomputed 28 holograms and used the DMD to rapidly switch which pattern illuminated the metasurface) [27]. This points to the synergy: DMD's speed can leverage other optics to get dynamic results.

LCoS (Liquid Crystal on Silicon): These devices are essentially mini LCD panels, but reflective and often designed to modulate phase. They have the advantage of being able to represent grayscale or phase levels per pixel (typically 8-bit or more), which is ideal for displaying a holographic interference pattern. A phase-only LCoS SLM can achieve, say, 0–2π phase modulation continuously for each pixel, which allows much higher diffraction efficiency and better control of the hologram than a binary SLM. LCoS panels are widely used in holographic research and in some commercial AR displays (for example, the HoloLens 1 used LCoS to project its images). The disadvantage is **speed**: most LCoS SLMs switch at 60–240 Hz (a few kHz in special cases but usually with reduced resolution or using analog resonant methods). That's orders of magnitude slower than DMD. So LCoS can't time-multiplex many slices per frame; you usually get one hologram frame at video rate. That means if you want a volume, you might need multiple LCoS panels each fixed at a different depth (which is impractical), or accept a smaller depth of field. Also, liquid crystals inherently have slower response and you have to balance phase stability with switching speed (some advanced ferroelectric LC or digital LC can be faster but still not close to DMD speeds).

Strengths and Weaknesses Summary: DMDs excel in **speed and binary modulation**, making them great for projection and multi-plane tricks. LCoS excels in **phase accuracy and resolution**, making them great for high-fidelity holograms (static or moderate speed) and fine intensity control. For example, if one wanted to display a high-quality still hologram of a torus, an LCoS SLM with a computed phase hologram could create a beautiful diffraction image. If one wanted to display a fast-changing, perhaps lower-resolution volumetric torus, a DMD might achieve that with time slicing. There's also the matter of **light source**: both need an external light source. DMD often paired with LEDs or lamps for normal projectors, but for holography you'd pair it with lasers. LCoS typically works with lasers in holography setups too (you need coherence for interference images).

Cost & Practicality: DMD developer boards (like the TI LightCrafter series) can cost a few thousand dollars, but the DMD chip itself in volume is cheaper. LCoS SLMs (research grade) cost $5k-$20k depending on resolution and features, since they're niche. However, mass-produced LCoS (like for micro-projectors or AR) can be a few hundred dollars at most, but those might be optimized for intensity modulation (color field-sequential) rather than pure phase. Depending on the path, a holographic torus project might use one or both: e.g., a DMD could project onto a rotating diffuser to make a pseudo-volume (another possible method: a hybrid of DMD and mechanical sweep), whereas an LCoS could generate a static hologram of a torus but struggle with interactive updates.

In summary, DMDs and LCoS are enabling technologies rather than complete displays by themselves. **DMDs** bring high frame-rate slicing ability – one could achieve a form of volumetric hologram by rapid projection of slices or patterns [29] [32], which is promising for real-time rendering of a donut if combined with appropriate optics (some experimental systems have shown multi-plane 3D reconstructions using a single high-speed DMD and a focus-tunable lens). **LCoS** brings high quality phase modulation – ideal for precise holographic imagery; a torus hologram generated on an LCoS could have good fidelity but the system would refresh slower (maybe 30 Hz for full color if using time-multiplexed color, or up to ~60–120 Hz mono).

A practical approach might even combine them: use LCoS for fine phase hologram and a DMD for another function like multiplexing multiple depths (there are advanced research setups that use two SLMs in series to improve image quality or depth range).

For our consideration of manufacturable product paths: currently, **LCoS is used in products (AR displays, some HUDs)**, while **DMD is used in projectors and some experimental 3D displays**. If one were to build a "holographic donut device", using a DMD plus laser could leverage the massive MEMS industry and existing supply chain. For example, one could imagine a small box containing a laser and DMD that projects a mid-air donut (perhaps onto a diffusive volume or with aerial imaging tricks). Meanwhile, if one aimed for ultimate quality, one might pick LCoS but then struggle with frame rate. So, the choice can be tuned to what aspect is prioritized: *speed/volume (DMD)* vs *fidelity/phase control (LCoS)*.

Brain-Computer Interface Integration (EEG-Responsive Hologram)

To make the holographic torus **interactive to brainwaves**, we integrate an **EEG-based Brain-Computer Interface (BCI)**. The vision is that the floating torus could respond in real time to the mental or emotional state of the viewer/participant, effectively linking human consciousness with the holographic display. This is an ambitious but intriguing aspect – turning the hologram into a "mind-driven" object.

Current BCI technology: Noninvasive BCIs typically use EEG (electroencephalography) sensors placed on the scalp to measure brainwave patterns. These signals are then processed to detect certain states or intentional commands. For instance, one can detect changes in alpha wave amplitude (associated with relaxation), or use specific evoked responses (like focusing on a flashing target yields a detectable frequency called SSVEP, or sudden surprises yield P300 signals) to derive simple control inputs. There are commercial EEG headsets like the Muse, Emotiv, OpenBCI's Ultracortex, or research devices that can provide a user's brain activity data to a computer in real time.

Integration Approach: The basic loop is: EEG device on user's head -> EEG signals filtered and interpreted -> mapping to hologram control -> hologram output updates. There have been experiments in using brainwaves to interact with 3D displays. For example, a 2016 SPIE News article discussed *"hologram interaction based on brain wave measurement"* (Park et al.), demonstrating a system where visual stimuli and EEG measurements were combined to let a user influence 3D content. Another more recent example is a system announced by MicroCloud Hologram in 2023 which *"combines BCI with holographic technology, enabling the two to complement each other"*. In their words, *"Holographic technology can be used as an information feedback tool for BCI systems, providing more realistic…stimulating contextual feedback… BCI can be used as an input device for the holographic system, providing more direct and faster input."* [33] . This nicely summarizes the synergy: the hologram gives the user a vivid visual feedback, and the EEG provides a direct channel of user input (thoughts, attention, etc.) to control that visual.

Practical implementation for the torus: We could choose a few EEG-responsive features. For example: - **Meditative state control:** If the user becomes more relaxed (higher alpha waves), the torus could glow brighter or change color. If they become tense or focused (more beta waves), it could shrink or rotate faster. This creates a biofeedback loop – teaching the user to control their mental state to influence the hologram. This fits the "sacred geometry as a meditation interface" idea. - **Intentional commands:** If the system uses a paradigm like motor imagery (imagine moving left hand vs right hand), we could assign those to actions (e.g., think "left" to spin the donut left, "right" to spin right). Or use steady-state visually evoked potentials (SSVEP): parts of the torus or UI blink at certain frequencies; when the user focuses on one, the EEG picks up that frequency and triggers a corresponding action (like changing the torus into another shape or opening a "time map" menu). This is more complex but doable with known BCI techniques. - **Emotional mirroring:** Using machine learning on EEG, one might classify excitement vs calm, and have the torus pattern reflect that (spikes, pulsations for excitement, smooth flow for calm).

BCI Frameworks and Components: We would need an **EEG headset** (with at least a few electrodes covering regions of interest, ideally around the forehead if we want portability, or a cap for more signals if higher accuracy needed). Then a software pipeline – perhaps using an open-source BCI platform like **OpenBCI** or MATLAB/BCI2000 or OpenViBE – to process and classify the EEG in real time. This software runs on the PC that is also driving the display content. Many toolkits exist that can output computed metrics (like "attention level 0–100" or detect specific events) which can be fed into Unity3D or custom visualization code. For instance, if using Unity to show the torus on a Looking Glass display, one could have a thread reading EEG bandpower and update the Unity scene parameters accordingly.

Challenges: EEG signals are **noisy and have low bandwidth**. They are influenced by muscle movement, eye blinks, etc. So we'd likely use robust, low-information-rate control schemes. It's not like "think of a complex change and it instantly happens" – it's more like detecting general states or simple choices. There's also a calibration/training period often needed for a new user (machine learning models might need a baseline of the person's brain pattern). In a public installation context, you'd either have one dedicated operator/user or you'd allow multiple people to try sequentially with some quick calibration each. This is a logistic consideration – perhaps the installation is facilitated by someone who helps the participant don the EEG device and guides them.

Another consideration is **latency**: EEG processing typically might add a second or two if averaging signals (like to detect relaxation, you might average a few seconds of data). But for some interactions like SSVEP selection, you can get results in sub-second. The hologram should ideally respond within a timeframe that the user can associate with their mental action – otherwise the feedback loop breaks. So careful optimization is needed.

Symbolic/Educational Aspect: By connecting the torus to brainwaves, we reinforce the *"Universe Map / Sacred Geometry interface"* idea – essentially the torus becomes a mirror of the mind. In many esoteric traditions, the torus (or aura, or energy field) is thought to reflect our consciousness. Here, technology is literally doing that, by making the torus visualization change with brain state. This could provide a profound educational demonstration: e.g., showing how **focus** can create order in the torus (perhaps the shape becomes more coherent), whereas **distraction** makes it flicker or distort. It could also tie into biofeedback training or artistic expression – the user's mind creates ever-evolving patterns on the torus surface.

Prior work: Aside from the mentioned SPIE article and MicroCloud press, there have been art projects and research prototypes connecting EEG to visuals and even VR/AR. It's not far-fetched – the main challenge is doing it reliably and meaningfully. Given the multi-sensory nature, one could also incorporate sound (e.g., an ambient soundscape that changes with brain rhythms along with the torus visuals).

Technical Feasibility: On the technical side, it's quite feasible to implement the basics with existing hardware. For example, an **OpenBCI 8-channel EEG headset** (~$1000 with headband and electrodes) could connect via Bluetooth or USB to the controlling PC. One could use an open-source Python library MNE or OpenBCI's GUI to measure alpha waves in real time. If the user closes eyes or relaxes, you'd see an alpha spike and could then code "if alpha > threshold for 2 seconds, trigger torus color shift to blue". Similarly one can detect if they are mentally task-engaging (alpha goes down, maybe beta/gamma increases slightly) and do another effect. There are also simpler EEG devices (like Muse headband ~$250) which output a "calm vs active" score; some developers have used those to drive visuals (like calming an animation when the user is calm). Those are easier but a bit more of a black box.

Safety and Comfort: EEG is noninvasive and safe. Just need to ensure the user is seated and not moving too much (movement generates artifact). The hologram display's presence (flickering lights) could potentially induce some brainwave response itself (for instance, flashing lights can cause SSVEP or in rare cases seizures in photosensitive individuals). We should keep flashing in moderate ranges and always err on side of caution (since it's an installation, we'd probably avoid rapid intense flashing patterns).

Conclusion for BCI: Making the donut hologram BCI-responsive is a cutting-edge feature that will add significant depth to the experience. It moves the project from a static display to an *interactive cybernetic system* – the user's mind affects the hologram and the hologram in turn provides feedback to the user. As one source described, it *"expands the holographic display of the brain's interaction with the outside world"*, opening new output channels and enriching neurofeedback experiences [34]. While still in early stages, such integration has been demonstrated in prototypes. So, it's quite aligned with the experimental nature of this project. It would require interdisciplinary expertise (neuroscience + programming + the hologram tech), but the pieces exist to be assembled.

Comparison of Approaches & Commercial Outlook

Bringing it all together, we compare these technologies in the context of creating a **floating, real-time holographic torus** and consider which path is most practical for a real prototype and eventual product:

- **Laser CGH (Dynamic Holography):** *Ultimate image realism*, full depth cues, but currently requires expensive SLMs and immense computation. Closest products are in R&D or very specialized (no off-the-shelf dynamic hologram display for open air exists yet). Good long-term potential for device manufacturing (if SLM and compute tech improve, one could imagine a "hologram projector" that you point and it shows a 3D object in space). In near term, likely not the first choice for a tangible prototype due to complexity. But research should continue in parallel (e.g., exploring algorithms to efficiently compute a torus hologram, maybe using neural networks as some recent works do).

- **Volumetric (Rotating panel LED – e.g., Voxon):** *Ready now* – one can purchase and implement immediately. Provides genuine 3D viewable by all around. The donut will indeed float in a volume (enclosed in a case). Interaction can be facilitated (e.g., Leap Motion outside the case to sense hand motions, or a wand inserted from top if careful, or just use gamepad/PC to manipulate it). The drawback is size and moderate resolution. As an art installation, a small glowing donut might suffice; for a larger visual impact, you'd want a bigger display which could be far more costly or custom-built. Reliability is reasonably good (these have been used in exhibits), just have to account for the hum of the motor and dimming in bright light. **Commercial viability:** Voxon is selling these, indicating a level of support and maintainability. For "later device manufacturing," volumetric displays could be scaled or combined (maybe arrays of them, or larger versions). But they are mechanical, so scaling up to say a 1-meter diameter torus display would be a major engineering project (and possibly dangerous with large spinning parts).

- **Volumetric (Laser Plasma):** *Futuristic, high wow-factor*, but not productized. Great for small-scale demos under controlled conditions. Not practical for continuous use or for a wide audience yet. A possible niche in the near term could be special art performances (some artists have used laser plasma to create fleeting images in dark rooms). For manufacturing a device, this is the far horizon – if ever made practical, it could revolutionize displays (true free-floating holograms). But right now, it's more a lab curiosity. That said, continued research could yield incremental improvements, maybe in 5-10 years we'll see limited commercial systems (perhaps for advertising or theme park effects) where a simple mid-air image appears for a few seconds.

- **Light Field/Multi-view:** *High maturity for what it delivers.* It's a strong candidate for an installation if one doesn't mind the "window" format. It provides the best **image quality** of all listed – the torus can be richly shaded, high-res, and even animated with complex textures or data (imagine overlaying a "time map" on the torus surface, etc.). Commercial viability is proven by companies like Looking Glass Factory and others actually shipping units (and improving them). For manufacturing a future product, light field displays could feasibly be made into larger panels or integrated into devices (for example, an arcade machine style exhibit with a big light field screen showing interactive 3D content). The cost is high but if budgets allow, it's turnkey. On the flip side, it doesn't give the *free-floating in mid-air* effect that some might expect from the word "hologram" – the audience might perceive it more like a very realistic 3D TV.

- **Metasurface/Waveguide:** *Emerging and specialized.* For a near-term project, these wouldn't be the main display method, but they could augment others. For instance, one could incorporate **metasurface art** by having etched holographic patterns on the installation that diffract light artistically (as a supplement to the main dynamic display). Or one could have an *AR mode* where someone with a HoloLens sees extra holographic layers on top of the physical volumetric display – blending real volumetric and virtual AR holograms. In terms of making a real product, waveguide AR is already commercial (just not mass-adopted), and metasurfaces might be used inside those to improve them. A speculative but interesting path: in the future, one could have **metasurface projectors** that sit around a room and create a hologram by interference in mid-air. That's an active research (optical phased arrays). Not available yet, but perhaps relevant to "device manufacturing" down the line.

- **DMD vs LCoS (SLMs):** We view these as building blocks. **DMDs** could be used in a custom-built volumetric projector (if one wants to experiment, one could combine a high-speed DMD with a motorized focus or moving screen to create a unique volumetric display – some DIYers and labs have attempted such). **LCoS** could be used if someone wanted to attempt a direct-viewing holographic video (one could try to build a holographic display by taking a phase SLM and using it in an optical setup – a complex project, but some prototypes like MIT's holographic video display used multiple LCoS panels). If we consider a path to product: DMDs are robust (they're used in millions of projectors), so a product that uses a DMD plus fancy optics is not far-fetched from a manufacturing standpoint. LCoS is also in many products (projectors, AR glasses), so similarly feasible if the product is more along AR or a stationary holographic table.

Closest to floating, real-time donut now: *The rotating volumetric display is arguably the closest available solution for a true floating donut.* It literally can do it, with the trade-offs noted. The light-field display is a close second if "floating" is loosely interpreted (the donut will appear floating *within* the device). If the requirement is that one can walk around it, then light-field fails that, and volumetric wins.

Cost estimates: - Volumetric LED: $7k (small), maybe tens of thousands for larger custom. - Light field: $10k for 27″, up to who-knows for 65″ (likely $50k+). - Laser holography setup: If attempted DIY, maybe $20k+ (SLM $5-10k, lasers $5k, optics $5k, plus labor). Not really off-the-shelf. - AR waveguide: HoloLens 2 around $3.5k per headset. - EEG setup: couple hundred to a couple thousand depending on quality. - Development effort: All approaches require significant software development to integrate the interaction and content.

Sacred Geometry & Symbolic Implications: The torus as an interactive hologram ties technology with spiritual symbolism. The torus has been called a shape that *"embodies complex energy dynamics… a symbol of wholeness, unity, and flow"* [35]. Using it in this project isn't just aesthetic; it's meant to evoke that universal form. In a way, the technology choice itself can carry symbolism. For example, a *volumetric torus* – composed of many points of light swirling in space – visually conveys energy flow and could remind viewers of a "galactic donut" or magnetic field. A *laser plasma torus*, flickering with tiny star-like points, could symbolize the raw energy of consciousness. A *light-field torus*, with its glass window, might symbolize the portal or gateway to understanding (peering into another dimension). Integrating brainwaves – the user's mind literally causing changes in this torus – underscores the idea of interconnectedness (mind and matter interacting). This is essentially high-tech psychophysics art.

From an educational perspective, one could use the holographic torus to explain concepts like magnetic fields (the Earth's magnetic field is toroidal), donuts in mathematics (torus topology), or metaphors of time (a looping flow). If multiple modes are allowed, the torus could morph into other sacred geometry forms (cube, flower of life spheres, etc.) based on user input, creating a “Universe Map” of shapes. The BCI could even choose which shape to display depending on the user’s thought patterns (a creative but challenging idea: e.g., calm mind shows a stable torus, chaotic mind shows a complex flower-of-life pattern – tying personal state to universal geometry).

Conclusion: Each technology has its role and timeline. For an immediate **prototype**, a *mechanical volumetric display* or *light-field display* would be the top picks due to availability and true 3D effect (volumetric for 360° viewing, light-field for high detail 3D in front view). Coupling with EEG is feasible with either (especially since both can connect to a PC that can run EEG processing). If the user experience prioritizes group viewing and physical presence, go volumetric. If prioritizing visual fidelity and perhaps easier integration (no moving parts), go light-field.

For a longer-term **product roadmap**, one might start with those, then as holographic SLM technology matures, migrate to a laser holography solution (which could eventually offer a larger, glasses-free 3D display without moving components). And keep an eye on metasurfaces and AR waveguides – they could either miniaturize the experience (taking it personal) or serve as components in the holographic projector of the future.

In summary, **to create a floating holographic donut today, a volumetric display is the most practical solution, with light-field displays as an alternative.** Both are relatively close to commercial viability (indeed being sold). **Laser holography and plasma displays**, while alluring, are more distant but should be monitored for breakthroughs. **Metasurfaces and waveguides** point toward future holographic devices, especially wearables or compact projectors. And integrating **EEG/BCI** is an achievable enhancement that can transform the hologram into a truly interactive “mind-mirror,” aligning perfectly with the symbolic and educational aspirations of the project.

Sources: The analysis above draws on a variety of sources: technical descriptions of volumetric displays [6] [36], reports of plasma 3D display capabilities [15] [18], product information on light-field displays [22] [25], cutting-edge research on metasurface holography [27], and statements on the synergy of BCI with holographic feedback [33], as well as contextual information on the sacred geometry of the torus [1]. These illustrate the current state and possibilities of each approach discussed.

---

[1] [35] Exploring the Torus: A Gateway to Sacred Geometry and the Nature of Flow | Nature of Flowers
https://natureofflowers.com/blogs/news/exploring-the-torus-a-gateway-to-sacred-geometry-and-the-nature-of-flow?srsltid=AfmBOopejjNK-ypF_JY4WJFBzvHGMH0C4G1h4IfsiiOWjUDUjDJLkGcs

[2] [3] The state-of-the-art in computer generated holography for 3D display
https://www.light-am.com/article/doi/10.37188/lam.2022.035

[4] [5] This Raspberry Pi volumetric display is a new spin on LED 3D animations | Tom's Hardware
https://www.tomshardware.com/raspberry-pi/this-raspberry-pi-volumetric-display-is-a-new-spin-on-led-3d-animations

[6] [11] Voxon | Revolutionary 3D Volumetric Hologram
https://www.voxon.co/

[7] [8] [9] [10] [12] [36] Voxon Products | Advanced 3D Volumetric Hologram Solutions
https://www.voxon.co/product-page/voxon-vx2

13 14 15 20 Burton rolls out True 3D laser plasma display
https://newatlas.com/burton-true-3d-laser-plasma-display/20499/

16 17 18 19 Femtosecond Lasers Create 3-D Midair Plasma Displays You Can Touch - IEEE Spectrum
https://spectrum.ieee.org/femtosecond-lasers-create-3d-midair-plasma-displays-you-can-touch

21 22 23 24 25 26 Looking Glass Releases 27 Inch 5K Light Field Display
https://newatlas.com/technology/looking-glass-27-light-field-display/

27 Highly-efficient full-color holographic movie based on silicon nitride ...
https://www.degruyterbrill.com/document/doi/10.1515/nanoph-2023-0756/html?lang=en&srsltid=AfmBOorAOw6AUMyIL1NWXbz730qdhKGAw6usTxwwvLDGZ7n4g7x2YcDP

28 Dynamic 3D metasurface holography via cascaded polymer ... - Nature
https://www.nature.com/articles/s41378-024-00855-6

29 30 31 32 High-density three-dimensional holography using rapid modulation of light
https://arxiv.org/html/2506.08253v1

33 34 MicroCloud Hologram Launches Holographic Brain-Computer
https://geospatialworld.net/news/microcloud-hologram-holographic-brain-computer/