Graspable Memories: A Sustainable Approach to Holding Personal Memories Through Occlusion-Aware Projected Interaction

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***Abstract*—As personal digital media accumulate across devices and cloud services, they become abundant yet intangible, weakening the rituals that once supported remembering. Graspable Memories is an AI-based XR system built on Embodied Projected Mixed Reality (EPMR) that explores how projected interaction and bodily occlusion can restore tangibility to digital memories while advancing United Nations Sustainable Development Goal 12 on responsible consumption and production. Using a fixed projector–camera setup with AI-based hand tracking, the system projects personal media onto a tabletop, where they can be selected by occluding them with an open palm, moved through a volumetric interaction space, and transferred with a grasp gesture to a wearable pendant with a reconfigurable display. This dematerialized workflow offers an alternative to physical photo printing and disposable keepsakes, directly engaging SDG 12 targets on waste reduction and more sustainable consumption. An exploratory study with twelve participants, using the User Experience Questionnaire and semi-structured interviews, examines usability, emotional engagement, and the symbolism of hand-to-pendant transitions. Findings highlight strong perceived novelty and personal resonance, along with current tracking limitations, and point to design implications for human-centered, sustainable Industry 5.0 XR experiences that treat the body and occlusion as primary elements of the interface.**

***Index Terms*—Embodied Interaction, Projected Mixed Reality, Tangible Interfaces, Memory Technologies, Sustainable HCI**

I. Introduction

In the transition from analog to digital, our personal media, such as photos, audio, and videos, have become increasingly abundant yet physically untethered [1]. Tangible keepsakes such as photo albums, lockets, and heirlooms once invited intentional encounters and emotional rituals. By contrast, digital content is convenient and scalable yet dispersed across devices and cloud accounts, hidden behind obscure interfaces, and lacking the material presence that helps memories surface meaningfully [2], [3].

This pilot study investigates whether projection-based interaction and bodily occlusion can reintroduce physicality, intimacy, and ritual into engagements with digital memories, while avoiding the resource expenditure required to generate physical representations (e.g., paper prints). We ask how the body, specifically the hand, can become not a passive occluder of a projected interface but an active participant in memory interaction. How might we hold digital content, not metaphorically, but physically and visibly, through light, gesture, and movement?

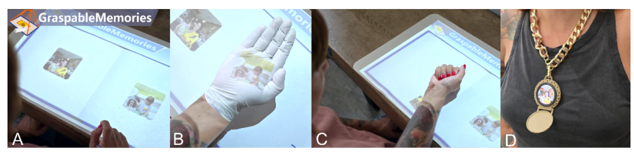

Fig. 1. **Graspable Memories interaction.** (A) The user browses projected personal photos. (B) Raising the palm anchors a selected image. (C, D) Closing the hand transfers the photo to a wearable pendant, evoking a sense of personal connection and ownership. Optional use of gloves improves image sharpness under varied lighting conditions and helps create a more equitable visual experience.

Beyond experiential goals, this work relies on employing advanced AI-based hand-gesture tracking and furthers the UN SDG 12: Responsible Consumption and Production, particularly Target 12.5 on waste reduction [4]. Physical photograph production involves paper manufacturing, chemical processing, and waste, while many maintain dual digital-physical collections. Our system aims to approximate tactile qualities through projection and grasping, and employs a reusable digital pendant that can be reconfigured indefinitely, eliminating recurring material costs and waste. By blending a reusable physical interactor (the pendant) with multiple forms of virtual mediation—namely, the projection and the pendant's own reconfigurable display—our work aligns with the concept of "cyberphysical interfaces," systems explicitly designed to operate across a spectrum of physical (tangible) and virtual (soft) interactors [5]. Our design choice is not

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merely technical but strategic; it engages with tangible/virtual tradeoffs from an environmental responsibility perspective, offering a path to reduce material waste without sacrificing meaningful interaction.

To this end, we introduce *Graspable Memories*, a system in which users explore projected media on a tabletop and "grasp" a selected virtual item by covering it with their hands (See Fig. 1). This act of occlusion transforms the hand from a disruptive surface into a dynamic projection site. The projected image of a selected memory locks onto the hand and follows it through the 3D space, extending the interaction space from a flat interface to an interaction volume. In addition, in our proof-of-concept prototype, when the hand is closed, the memory is transferred to a custom-built pendant containing a digital display, allowing the media to be physically carried and worn.

This design is based on *Embodied Projected Mixed Reality* (EPMR), a paradigm in which projected interfaces extend beyond the flat plane of a display to the volume of the user's immediate physical space. EPMR differs from spatial augmented reality (SAR) in treating the user's body as the primary interface rather than an external actor within augmented space. While SAR projects onto environmental surfaces and may treat bodily occlusion as interference [6], EPMR uses occlusion and gesture as primary input. The body becomes both an input mechanism and a display surface, extending interaction volumetrically around the user's reach. In this model, bodily occlusion is not treated as an error to be corrected, but as an opportunity to anchor content to the user's hand in motion. The hand becomes a temporary canvas that activates and transports the selected content. Interaction transforms from touching a point into a movement-based ritual of selection, transfer, and display. This way, we explore new ways of making digital content personally and physically present.

This paper contributes:

- The conceptualization of EPMR as a framework that reimagines occlusion as an embodied interface.
- A system that enables users to hold and carry digital content through occlusion-aware projection of the hands.
- A proof-of-concept prototype for interaction with personal memories that consists of a tabletop projection, real-time hand tracking, and a custom wearable pendant.

Our prototype is not intended as a productivity or collaborative tool; it follows the tradition of systems that foster personal, reflective engagement with digital content through projected, embodied interaction [7]–[11].

II. Related Works

A. Tangible Interaction with Digital Memories

The transition from analog to digital media has fundamentally reshaped how individuals store and revisit personal memories. Digital formats offer convenience and ubiquity but often lack the physical presence that fosters emotional resonance and ritual [2], [11]. This disconnect is further emphasized by digital photo collections accumulating across generic devices that provide no visual cues about the meaningful memories stored within [1].

Researchers have explored how tangible interaction can reintroduce materiality and meaning to the experience of digital content [12]. Kirk et al. [13], for example, emphasized the importance of physical mementos in supporting memory practices and emotional attachment. Also, managing physical mementos—accessing, revisiting, and sorting them—becomes an enjoyable activity, particularly for smaller, more manageable collections [2].

Within the Human-Computer Interaction (HCI) and Tangible, Embedded and Embodied Interaction (TEI) communities, tangible interaction has long focused on embedding digital information in physical forms [14]. With the Tangible Bits framework, Ishii and Ullmer [15] articulated the potential of coupling bits and atoms to make digital information manipulable. Building on this, although our platform does not support interaction with strictly physical tangibles, it embraces the concept of "soft tangibles" introduced by de Siqueira et al. [16]. In our system, projected images act as graspable representations of memory.

More recent work highlights the role of the body and emotion in interaction design. Spiel [17] critiques normative assumptions in embodied interaction and calls for emotionally resonant, inclusive systems that reflect diverse experiences. Our work contributes to this lineage by treating the hand not only as an input surface but also as a canvas and container for memory. By allowing projected media to be "grasped" and transferred to a wearable display, we bridge ephemeral digital content with the embodied rituals of remembrance.

Our work builds on these foundations by exploring how projection-based systems can support interaction. Prior work on tangible memory artifacts has explored how physical objects support remembering through materiality and presence. Systems like digital photo frames, memory boxes, and interactive keepsakes have shown that physical form can enhance emotional connection to digital content. Our system extends this research by demonstrating how projection can deliver tangible qualities—ritual, presence, emotional resonance—without requiring dedicated physical substrates. This approach addresses both experiential goals of meaningful interaction and sustainability considerations by eliminating material consumption while preserving the embodied qualities that make memory artifacts valuable.

B. Projected Interfaces and Occlusion as Opportunity

Projection-based augmented reality (AR) interfaces have traditionally focused on flat surfaces such as walls, tables, or static objects [18]. Systems like MirageTable enabled perspective-correct interaction with 3D projections, allowing users to interact naturally across a shared virtual space [19]. Adaptive projection techniques have extended this by dynamically conforming visuals to non-rigid or deformable surfaces [10], [20].

Earlier spatial AR systems often treated the user's body as a visual obstruction to be minimized. Shader Lamps introduced by Raskar et al. [21] pioneered techniques for animating real

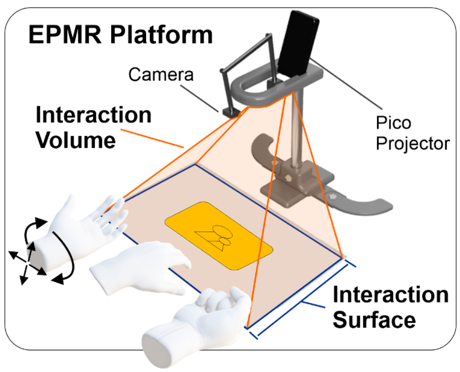


Fig. 2. **Embodied Projected Mixed Reality platform.** The EPMR platform extends the interaction area from a projected surface to the projected volume. Body occlusion is treated as an interaction mechanism allowing content to be projected on and respond to hand gestures.

objects via projector-based image-based illumination, compensating for occlusion and shadows in the scene. Later, Projection-Aided Occlusion Compensation methods by Bimber and Raskar [18] dynamically adjusted projected imagery to minimize self-shadowing and user-caused visual interference. In contrast, more recent systems explored projecting directly onto the human body. For instance, Skinput [22] and OmniTouch [23] used sensing and projection to enable touch input on skin and nearby surfaces. LumiWatch [24] further demonstrated an on-arm interface using a wearable pico-projector and touch tracking.

Yet even in these systems, occlusion was treated as a constraint. Occlusion Shadows [25] changed this perspective by treating shadows as an aid to enhance the visual realism of projection-based AR, rendering synthetic shadows that simulated physical occlusion. However, user-cast shadows themselves were not treated as input or part of the interaction model. GrabAR [26] modeled occlusion to improve AR realism, but did not repurpose it as a generative gesture. In contrast, *Embodied Projected Mixed Reality* (EPMR) repositions occlusion as an intentional, interface-level event. In our approach, the hand enters the projection field not to block it, but to transform it to become both surface and signal, capable of summoning, carrying, or transforming digital content.

C. Wearable Displays and Memory Carriage

Wearable devices have long served as repositories of identity and memory, offering people a way to carry emotional artifacts close to the body. In HCI, this idea has evolved through the study of personal objects augmented with digital content that support remembering and reflection. Elsden et al. [27] introduced the concept of "quantified pasts," showing how wearables that capture personal informatics data can shape reflective memory practices. Their work highlights how personal data becomes more meaningful when revisited and reinterpreted through design. Similarly, Odom et al. [3] described the loss of attachment to digital possessions when stored in distant, invisible cloud systems, urging designers to consider how to re-materialize digital content.

Unlike fitness trackers or ambient biofeedback displays, our system uses projection and gesture to externalize memory in motion. The pendant becomes a transitional vessel that is not just a passive container of digital traces, but an active participant in their value and meaning. This approach extends the legacy of physical keepsakes [2], embedding personal meaning into dynamic, embodied interactions that link projection, gesture, and memory.

III. Conceptualizing EPMR: From Flat Projection to Volumetric Interface

At the heart of the *Embodied Projected Mixed Reality* (EPMR) paradigm is a conceptual shift: from a **flat, fixed projection plane** to a **volumetric interaction field**, where light, gesture, and body intersect (See Fig. 2). The projected interface is no longer limited to a desk or wall; it includes the airspace above it and the surfaces of the hands that move through that space. A user's palm can catch and carry digital content (images, video, or audio), the back of the hand can become a projection site, and the act of grasping can initiate a transition in the interface. This reconfiguration treats the body not as peripheral to the system but as a primary surface of expression and control.

The EPMR interaction logic is driven by four core occlusion-based cues:

- `Hand Region`: Different parts of the hand, such as the palm, back, and fingertips, are recognized as distinct interaction surfaces, each affording unique actions or symbolic meanings.
- `Postural Configuration`: Hand poses (e.g., open, closed, rotated) convey interaction intent. For instance, an open palm may invite content placement, while a closed fist can signal commitment or transition.
- `Spatial Depth`: The vertical position of the hand relative to the projection surface can modulate system behavior. While hovering may indicate interest or preview, elevation may enable different content states.
- `Intentional Occlusion`: The deliberate intersection of the hand with projected content is interpreted as a meaningful gesture, transforming occlusion from a tracking challenge into an input mechanism that anchors or releases interface elements.

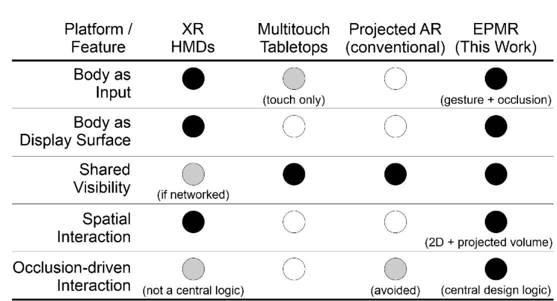


Fig. 3. **Comparison of Platform Capabilities.** Present capabilities are indicated by black circles, and absent capabilities by white ones. Grey circles indicate that a capability may not always be present in the platform.

Fig. 4. **Vintage-style Locket Pendant.** The Graspable Memories prototype includes a 3D printed pendant that houses an ESP32 microcontroller and an AMOLED round screen.

To operationalize the EPMR concept, we developed a functional prototype using a fixed tabletop projection setup, informed by previous projection-based interaction research [28]. Unlike wearable AR or optical see-through systems that track interaction in 3D while projecting into head-mounted fields, EPMR is grounded in external projection and relies on the user physically entering the visual field. This leads to a tangible, shared, and embodied experience, where **interaction is both visible and spatially situated**, accessible to onlookers and grounded in real-world space.

Compared to existing spatial interaction paradigms, such as XR head-mounted displays (HMDs), multitouch tabletops, and conventional projected interfaces, EPMR offers a distinctive set of capabilities. HMDs and AR glasses support spatial interaction but often isolate the user or obscure embodied visibility from others [29]. Multitouch tables afford collaborative input but confine interaction to a fixed flat surface [30]. Standard projected AR treats the body as an obstacle or limits interaction to environmental surfaces [31]. In contrast, EPMR blends projection with embodied occlusion to **create a shared, spatially grounded interface** that transforms the user's hand into both input and display. This allows for intuitive, co-located interaction without wearing equipment, combining the social visibility of tabletops with the spatial richness of wearable and immersive systems (see Fig. 3).

EPMR builds on a tradition of embodied interaction and projection-based systems but diverges by integrating occlusion, spatial gesture, and body-as-display into a single framework. It proposes that the meaning of interface elements emerges not from their static position but from their **relation to the body in motion**, and the transformations triggered when digital light intersects with human presence.

IV. Prototype: Graspable Memories

The *Graspable Memories* prototype was developed not only to validate the EPMR paradigm but to explore how bodily action, especially through the hand, can recover the intimacy and ritual once afforded by physical keepsakes. Our goal was to re-materialize digital memories through projection and occlusion, transforming otherwise fleeting content into personally held, visibly carried moments of significance.

In contrast to typical digital archives that hide media behind layers of abstraction, this system positions memory content in open spatial dialogue with the user. By allowing users to reach out, grasp, and wear media objects, the prototype supports a choreography of selection and remembrance that invites gesture as meaning, reminiscent of opening a locket or flipping a page in a photo album. It embodies a design philosophy in which memories are handled, not merely accessed.

A. Hardware Setup

To embody this vision, we reproduced a desk-mounted projection and sensing system [28] and a pendant-display comprising:

- **Pico projector** (1920×1080 resolution) angled vertically to illuminate a horizontal surface (60×40 cm projection area).
- **RGB camera** mounted above the projection area, calibrated with the projector to maintain alignment between tracked gestures and projected elements.
- **Wearable display** housed by a locket pendant. The pendant was 3D printed and built using the Waveshare ESP32-S3 1.43" AMOLED round screen module (466×466 resolution), with onboard Wi-Fi and a compact form factor (see Fig. 4).
- **Lightweight white latex gloves** (optional) to enhance the visibility and contrast of projected content on the hand. These gloves can improve image sharpness under varied lighting conditions and help standardize projection quality, supporting more equitable visual experiences.

This hardware configuration was chosen to emphasize accessibility, low cost, and reliability without sacrificing real-time responsiveness.

B. Software and Interaction Logic

At the system's core is a Unity-based interaction engine [32] augmented with MediaPipe Hands [33], a state-of-the-art hand tracking library capable of detecting 21 anatomical landmarks in real time. These landmarks correspond to precise anatomical features such as fingertips, joints, and the wrist, enabling fine-grained gesture classification and spatially anchored interaction.

To support reliable and expressive input, we implemented a landmark processing pipeline grounded in hand biomechanics (See Fig. 5). The wrist landmark (Landmark 0) serves as the global origin for coordinate transformations, while the metacarpophalangeal (MCP) joints of the index, middle, ring, and pinky fingers (Landmarks 5, 9, 13, 17) are used to calculate the palm center. This is computed through a weighted average to reflect typical grasp mechanics:

$$\text{palm\_center} = \frac{1}{4} \sum_{i \in \{5,9,13,17\}} \text{landmark}_i$$

To account for the functional center of manual interaction, which often lies distal to the geometric palm center, a 60% interpolation toward the wrist is applied:

$$\text{functional\_center} = \text{lerp}(\text{landmark}_0, \text{palm\_center}, 0.6)$$

This adjustment provides a stable interaction anchor for projected images, especially during dynamic hand movement.

Finger gestures are classified using distance-based analysis between fingertips (Landmarks 4, 8, 12, 16, 20) and intermediate joints (Landmarks 3, 6, 10, 14, 18) to detect curl, extension, or grasp states. Joint points (Landmarks 1, 2, 7, 11, 15, 19) contribute to orientation and hand rotation detection.

The interface supports three primary stages of interaction:

1) `Selection via Palm Occlusion`: When the user places their open palm above a projected image, the image locks to the palm, transforming the hand into a moving display surface (see Fig. 6a).
2) `Deselection via Hand Rotation`: Rotating the hand to show the back breaks the selection, returning the image to the table (see Fig. 6b).
3) `Transfer via Grasp Gesture`: Closing the hand while the image is locked transfers it from the projection to the pendant, where it remains displayed until replaced. Transfer happens over Wi-Fi to the wearable display using the Open Sound Control (OSC) communication protocols [34]. (see Fig. 6c).

The integration of gesture-based projection and wearable display establishes a continuous, embodied loop: from seeing, to holding, to carrying. The user does not simply view a photo. They take it with them.

V. User Study and Evaluation

To examine how users engaged with the prototype that embodies the *Embodied Projected Mixed Reality* (EPMR) principles, we conducted an exploratory user study (IRB Protocol ET0047427) combining think-aloud protocols [35], semi-structured interviews [35], and quantitative feedback using the User Experience Questionnaire (UEQ) [36]. The study aimed to evaluate how users interpreted occlusion-based projection as input, how they perceived embodiment and spatial feedback, and how well the system supported expressive or affective interaction.

A. Participants

Twelve participants (4 female, 8 male; ages 19–40, $M = 30.8$, $SD = 5.5$) were recruited via flyers and emails. The sample included eight general users, three human-computer

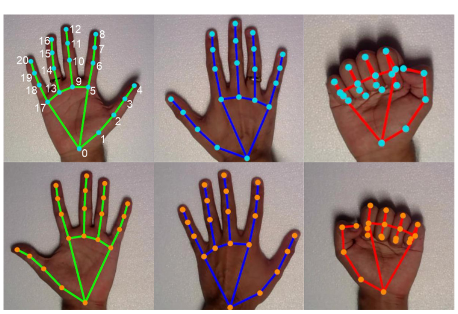


Fig. 5. **Hand tracking.** Green lines (palm facing up, selection gesture), blue lines (palm facing down, deselection gesture), red lines (fist closed, transfer gesture). Light blue landmarks represent the right hand, and orange ones represent the left hand. Numbers represent landmark labels.

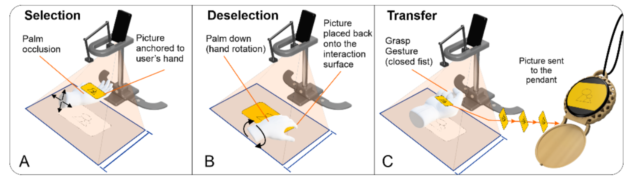


Fig. 6. **Graspable Memories: interaction logic.** (A) The user can select a picture via palm occlusion, by hovering an open palm on top of the target image. Once selected, the picture is anchored onto the user's hand. Interaction can happen within the boundaries of the projected volume of the interface. Crossing those boundaries triggers the image to return to its original position. (B) The user can deselect the picture by rotating their hand such that the palm faces down. (C) The user can perform a grasp gesture by closing their fists to send the picture to a pendant.

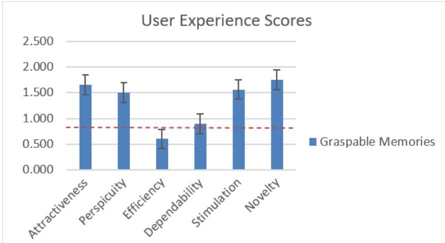
interaction researchers, and one psychologist. All participants were right-handed and reported normal or corrected-to-normal vision. None had prior experience with projection-based AR systems involving the body as an interface.

All participants reported browsing personal photos or videos using their Smartphones at least once per week, indicating that this is a regular activity in their lives. Notably, 58% engaged with this content multiple times per week, with one-third (33%) doing so daily. This suggests that navigating personal media is not only common but is often integrated into participants' daily or weekly routines. Additionally, most participants saw value in having physical versions of their pictures. All participants expressed some degree of agreement, with 75% responding 'Definitely yes' and 25% 'Probably yes'. Only one participant expressed uncertainty ("Might or might not"). These findings suggest a strong appreciation for tangible representations of personal media.

B. Procedure

Each participant completed a 45-minute session in a controlled lab environment using the *Graspable Memories* prototype. Participants were verbally informed about the study procedures and signed an informed consent form. A researcher then demonstrated the three core interaction tasks (selection, deselection, and transfer) using projected images to familiarize the participant with the system's functionality. Following the demonstration, participants were asked to perform these tasks themselves using each of the presented images. These guided interactions involved grasping digital photos from the tabletop (selection), moving them in mid-air, returning them to the desk surface (deselection), and sending them to a wearable pendant display by closing the hand (transfer). After completing the structured portion, participants were invited to explore the system freely at their own pace. Throughout the session, they were encouraged to verbalize their thoughts aloud following a think-aloud protocol [37].

Following the interaction, participants completed a structured post-test survey designed to capture their experiential, emotional, and reflective responses. The survey included the User Experience Questionnaire (UEQ) [36], which measured six core dimensions of user experience through 7-point bipolar adjective scales. To assess emotional and embodied responses,



Scale	Graspable Memories	
	Mean	STD
Attractiveness	1.65	0.86
Perspicuity	1.50	1.36
Efficiency	0.60	1.03
Dependability	0.90	0.83
Stimulation	1.56	0.92
Novelty	1.75	0.95

Fig. 7. **User Experience scores.** Mean scores and standard deviations for the six UEQ scales. Values above +0.8 (represented by the red dashed line) are considered positive. Between -0.8 and +0.8 neutral. All scales received positive evaluations except Efficiency, which fell within the neutral range.

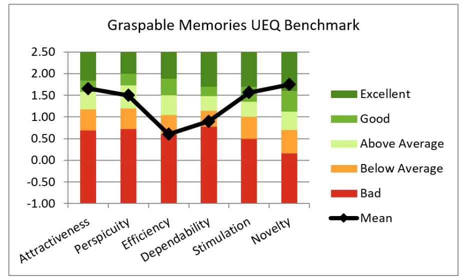


Fig. 8. **User Experience Benchmark scores** Mean UEQ scores across six user experience dimensions. Novelty was rated Excellent, Stimulation and Attractiveness as Good, Perspicuity as Above Average, while Efficiency and Dependability received Below Average scores.

an affective state inventory adapted from PANAS [38] was used; this version extended the original emotional descriptors by incorporating physiological markers such as sweaty palms and dry mouth. Participants also responded to custom Likert-scale items that evaluated the intuitiveness of gestures, the sense of personal connection, and the perceived ownership of the images they manipulated. Finally, demographic questions and open-ended prompts encouraged participants to reflect on memorable moments, challenges encountered, and possible real-world applications for the system. No identifiable data was recorded during the experiment.

C. Data Analysis

Survey data were analyzed using a mixed-methods approach. Quantitative responses were summarized with descriptive statistics, and UEQ scores were processed using the official analysis tool. The affective inventory was examined for patterns in emotional and physiological responses, while Likert-scale items on gesture and ownership were averaged to assess user perception.

D. Results

1) User Experience Scores: The UEQ results suggest a generally positive user experience with the *Graspable Memories* prototype (See Fig. 7). Most dimensions exceeded the +0.8 threshold for favorable evaluation, with *Novelty* receiving the highest mean score (M = 1.75, SD = 0.95), followed by *Attractiveness* (M = 1.65, SD = 0.86), *Stimulation* (M = 1.56, SD = 0.92), and *Perspicuity* (M = 1.50, SD = 1.36). *Dependability* also scored positively (M = 0.90, SD = 0.83), while *Efficiency* was the only dimension to fall within the neutral range (M = 0.60, SD = 1.03), suggesting some friction in task performance.

When compared to the UEQ benchmark dataset, which contains responses from over 21,000 users across 468 product evaluations [35], a similar trend is observed (See Fig. 8). *Novelty* was rated **Excellent**, *Stimulation* and *Attractiveness* as **Good**, and *Perspicuity* as **Above Average**. *Efficiency* and *Dependability* received **Below Average** ratings, highlighting potential areas for refinement. Taken together, the results emphasize the system's strengths in engagement, originality, and aesthetic appeal, while also indicating opportunities to improve reliability and ease of execution.

2) Affective Inventory: Participants reported overwhelmingly positive affective responses to the *Graspable Memories* prototype. Ratings for *"happy," "relaxed," "comfortable,"* and *"content"* were consistently high, with over 85% of participants selecting "a lot" or "a great deal" for these positive items. In contrast, physiological symptoms such as *"sweaty palms," "dry mouth,"* and *"heart palpitations"* were endorsed as "none at all" by more than 90% of respondents, suggesting low levels of anxiety or physical discomfort during the session. Similarly, negative emotional states like feeling *"uneasy," "insecure,"* or *"threatened"* received "none at all" from over 95% of participants. These findings indicate that, despite its unconventional interaction model, the system successfully fostered an affective climate characterized by emotional safety, comfort, and embodied enjoyment.

3) Interaction Experience and Feedback: A majority of participants reported positive impressions of the interaction. Specifically, 82% agreed or strongly agreed that the gesture of grasping felt intuitive, and 73% felt the projection onto the hand made the interaction more personal. Similarly, 73% agreed that the act of moving an image fostered a sense of ownership. As one participant noted, *"Grabbing the pictures felt very special,"* while another shared, *"It felt intuitive and satisfying."* Several respondents described the moment of transferring an image to the pendant as memorable and meaningful, with one writing, *"The gesture to send the image to the pendant was really cool."*

Participants' views on the wearable pendant were mixed but leaned positive. Roughly 55% felt it reinforced the metaphor of "carrying" a memory, as reflected in one comment: *"It helped reinforce the idea of carrying a digital memory."* Another described the device as "futuristic in the way that you could grab a picture and have it on the pendant." However, a few participants suggested refinements, such as making the pendant smaller or enhancing its clarity.

While overall impressions were favorable, some users noted areas for improvement. One participant remarked that although

TABLE I
PARTICIPANT REFLECTIONS ON THE GRASPABLE MEMORIES PROTOTYPE

Theme	**Representative Quote**
Grasping Symbolism	"Grabbing the pictures felt very special."
Personal Connection	"The projection onto my hand made it feel personal."
Emotional Resonance	"Sending a picture to the pendant helped reinforce the idea of carrying a digital memory."
Gesture Clarity Gap	"It's not truly comparable to a real-world grasp."
Limited Efficiency	"The interaction sometimes felt slow, especially when grasping didn't work immediately."

the grasping gesture worked, *"it's not fully intuitive or truly comparable to a real-world grasp,"* pointing to a mismatch between the system's metaphor and embodied expectations.

Table I shows participant reflections on the *Graspable Memories* prototype, organized by themes.

VI. DISCUSSION

Our evaluation underscores the potential of *Embodied Projected Mixed Reality* (EPMR) as a design paradigm that reshapes how projected interfaces can interact with the human body. Unlike traditional projection systems that treat bodily presence as a disruption, EPMR frames the body, particularly the hand, as a layered, expressive, and context-aware interface element. Participants in our study embraced this reinterpretation, perceiving their hands not as obstacles but as enablers of meaningful, embodied interaction. This shift opens new design avenues in projected interfaces that actively engage spatial and corporeal dimensions.

In our evaluation, users reported a generally positive experience across all UEQ dimensions, particularly for *Attractiveness*, *Stimulation*, and *Novelty*, which received *"Good"* to *"Excellent"* benchmark ratings. These responses suggest that the system successfully fostered curiosity, personal engagement, and emotional resonance. At the same time, the *Efficiency* scale fell into the neutral range, which may reflect both technical limitations, such as occasional imprecision in hand tracking, and the nature of the interaction itself.

Graspable Memories was not designed as a productivity tool but as an expressive medium for reflection, ritual, and symbolic meaning. In this context, slower pacing may have supported the contemplative goals of the interaction. Still, these results point to a broader tension: while individual EPMR applications like *Graspable Memories* may prioritize emotional depth over speed, the underlying paradigm is not inherently limited to introspective scenarios.

This approach extends the expressive range of projected interfaces, supporting emotionally grounded and socially meaningful interaction rituals, while also offering a flexible foundation for task-oriented and performance-driven scenarios.

A. Occlusion as Constructive Input

In traditional projection-based systems, occlusion is typically treated as a technical constraint to be minimized or avoided [6]. In contrast, EPMR reframes occlusion as a meaningful and intentional gesture.

This design shift echoes the broader movement in HCI and TEI toward leveraging the body as an active and expressive medium. For instance, Grubert et al. [39] explored how user gestures and body-based occlusion could be integrated into spatial AR environments, showing that spatial hand movement can be used to trigger reliable interaction events.

In our study, participants interpreted occlusion not as accidental interference but as an empowering gesture. The act of "grasping" projected items felt intuitive and symbolically potent. Rather than flattening the interaction space, EPMR reconfigures it as a volumetric zone where the interplay of gesture, spatial depth, and projection creates opportunities for embodied control and presence.

B. The Hand as Interface

EPMR reframes the human hand as a dynamic, multivalent interface surface, with distinct regions, such as the palm, fingertips, and back of the hand, each supporting different affordances. This spatial decomposition enables a richer interaction grammar, where pose, orientation, and region work together to signal intent and structure interaction.

In *Graspable Memories*, users enacted transitions by moving images onto their palms, holding them in motion, and turning the hand to release them. These gestures were not only functional but symbolically meaningful. The palm served as a container or vessel for memory, while the turning of the hand enacted letting go. Participants described these actions as "clear," "intuitive," and "satisfying," underscoring how spatial configuration and body metaphor can reinforce the interaction logic of an interface.

These findings support previous research showing that different body regions can act as expressive interaction zones [40], [41]. But unlike prior work focused on tactile feedback or wearable input, EPMR uses projected light and body pose alone to encode—making the interface visible, externalized, and socially legible.

By treating the hand not just as a controller but as a symbolically loaded site of interaction, EPMR enables interfaces that are both physically grounded and emotionally resonant. This highlights the potential of projected systems to build interaction languages that are intuitive, embodied, and metaphorically expressive.

C. From Hand to Pendant: Elevating the Symbolic Meaning of Digital Content

Participants described the act of transferring an image from the hand to the pendant display as emotionally meaningful, less of a technical interaction, and more of a symbolic act of carrying, offering, or sealing a memory. One participant remarked that the gesture *"felt intuitive and satisfying,"* while another said it *"helped reinforce the idea of carrying a digital memory."*

This framing aligns with prior research that explores how tangible artifacts can support emotionally resonant transitions, particularly in contexts of personal significance or relational change [42]. Mementos that integrate physical and digital elements have the potential to make the process of exploring and selecting digital media as enjoyable as creating physical albums or scrapbooks [2]. In our system, bodily gesture, especially closing the hand to send an image to the pendant, serves not only as input but as a metaphorical boundary between private reflection and public display. Moreover, the transfer of the digital memory to the pendant is distinguished from other technologies like smartphones and cloud storage that target mass storage and efficient retrieval.

By projecting directly onto the body and embedding transitions in meaningful spatial movement, EPMR repositions interaction as something socially visible and affectively charged. Unlike wearable systems or private screens, this approach supports co-present, shared experiences. Other memory systems have explored prioritizing social visibility, resulting in notably diverse experiences when compared with private digital collections. Projects like Cueb and 4Photos demonstrate that when remembering becomes a shared, observable activity, it facilitates storytelling, strengthens relational bonds, and creates intimate spaces for meaningful conversation about personal histories [1]. Similarly, in EPMR the act of memory transfer became performative, inviting others to witness or even participate in the interaction, while also moving the interaction to the personal realm.

Rather than expanding technical control alone, these findings point to the potential of projected gesture-based tangible systems and associated wearables in shaping moments of reflection, communication, and emotional presence.

VII. Limitations and Future Work

The current implementation of EPMR introduces novel interaction capabilities but reveals technical constraints. Sensitivity to ambient light and tracking results from the single RGB camera setup. Although MediaPipe provides robust pose estimation, performance degrades with fast motion. Unlike prior body-as-display research that treats the skin as a 2D surface, EPMR uses volumetric occlusion as an intentional gesture. Future iterations will incorporate depth cameras or infrared sensing to improve robustness [43] and explore vertical hand position as an interaction cue.

EPMR assumes planar projection surfaces, limiting deployment in spaces where irregular surfaces are common. Geometry-aware or adaptive projection techniques could support more flexible use [44]. Low-light requirements are a constraint, yet align with the envisioned ritualistic interactions.

The pendant represents a design element drawing on lockets as intimate, carried objects. As a tangible destination for memories, it motivates the ritual while offering sustainability benefits over prints through its reconfigurable display. This positions the pendant as a "cyberphysical" interactor [5]. Future work should examine how users share stored memories and assess long-term sustainability benefits compared to prints.

The interaction model also does not yet adapt automatically to variations in hand morphology. While the system does not depend on skin-color detection, its vision-based methods may still show performance gaps across diverse user populations. Prior work on somatic interaction highlights the importance of inclusive sensing strategies and calibration to accommodate bodily diversity [45]. Future work should investigate bare-hand interaction and specialized equipment (for example, gloves) to enhance tracking and image visibility on the hands, as well as adaptive and co-design approaches to improve accessibility.

Ultimately, this paper focused on memory interaction; however, EPMR principles may also be applicable to collaborative sketching, shared storytelling, and embodied annotation. Longitudinal field studies could reveal patterns of adoption, user fatigue, and the social acceptability of projected interaction in everyday settings. Given that external memory cues are shaped by individual significance, environment, and activity [46], future research should also examine how to design tangible objects that serve as effective, personalized memory cues.

VIII. Conclusion

This work introduces *Embodied Projected Mixed Reality* (EPMR) as a new paradigm that reimagines projected interfaces as volumetric, embodied spaces for interaction. Instead of treating the hand as an obstruction, EPMR turns it into an expressive and intentional surface where touch, gesture, and light converge to form dynamic interfaces shaped by the body.

At the core of the prototype is grasping a memory without relying on physical media, transforming a simple gesture into a meaningful encounter while generating no material waste. When the palm covers a projected photo, the image anchors onto the hand, follows it through space, and is transferred to a wearable display. This interaction is not only functional but symbolic. It reintroduces presence, care, and ritual to a domain where digital media is fleeting and disembodied.

Much like how e-books have made literature more accessible but less tangible, digital media has made personal content abundant but more difficult to connect with [2], [11]. *Graspable Memories* proposes a reversal by restoring material and spatial intimacy to digital information without the environmental costs of physical production. This work demonstrates how projection-based systems can reduce material consumption while maintaining meaningful, tangible interaction—eliminating the need for printed photographs while preserving the ritualistic, embodied engagement that makes memory artifacts valuable. It invites us to imagine holding a memory not as a metaphor but as a physical experience enabled by gesture, projection, and embodied presence.

Our evaluation showed that users were drawn to this interaction model not only because it was intuitive but because it felt emotionally meaningful. In a world where digital experiences are increasingly confined to flat screens and abstract taps, EPMR offers a grounded alternative.

Looking ahead, this approach holds promise for personal storytelling and shared embodied experiences. It invites creating not only for functionality but also for meaning. It allows users to touch what they value, carry what matters, and bring digital memories into the space of lived experience.

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