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Replica revolutions in rock art: from physical replicas to virtual reality libraries via contemporary art

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ABSTRACT

Rock-art replicas generally are judged as more or less faithful substitutes for inaccessible originals. While previous studies have demonstrated the value of replicas for individual archaeological experiments, we reconceive them as persistent interdisciplinary research infrastructure. Drawing on reflections from original sites, we compare physical copies with virtual environments, developing criteria for evaluating replicas. Physical replicas preserve material, spatial and atmospheric relationships but constrain enquiry through fixed routes and authoritative narratives; VR replicas increase freedom, manipulation and perceptual experimentation but sacrifice embodied materiality. Neither currently supports cumulative research: observations disappear when the encounter ends. Central to this contribution is a two-directional account of indexicality: replicas point backwards to the caves and their makers, but also outwards to the scanners, artists, software, institutions and interpretive decisions that produce them. We therefore propose the perma-library as an infrastructure through which replicas can become comparable, revisitable, annotatable and capable of accumulating research over time.

KEYWORDS

Rock art; cave art replicas; virtual reality; research environments; digital heritage; contemporary art; indexicality; post-digital libraries

Replicas of prehistoric cave art, understood presently as heritage and tourism experiences, can be reframed as interdisciplinary research environments – repositories and activators of new knowledge for contemporary interdisciplinary research. Cave art itself has been conceptualized as a repository of knowledge, akin to books or archives. Boyd (2016) describes sites such as the Trans-Pecos in Texas as visual texts, encoding sacred narratives meant to be revisited and reinterpreted over time. These texts are not written onto 'blank pages' though. Reading cave art requires an active engagement with embodied, spatial, and sensory dimensions of caves themselves (Achari 2007). The artworks' meanings arise through networks of material and spatial relationships, as well as symbolic ones (Robinson 2013). Three dimensional replicas of cave art – digital and physical – allow researchers to re-read the caves and the art in them in ways that are superior to photographic reproduction. They also allow for new avenues of enquiry – ways of interpreting the significant and meaning of ancient art practices through new circumstances, extending the networks of meaning they engage into the present day. Building on studies by Commins, Coppens, and Hidaka (2020) and Fontana and Pinotti (2022), we argue that replicas can allow for new kinds of fidelity to the spatial experiencability of the caves, while enabling experimentation with new kinds of research questions. In what follows, we combine field reflections from visits to a number of virtual and physical sites, to show how the

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replicas can be reconceived as contemporary cultural laboratories that can link the prehistoric to the posthuman present.

Plaster reproductions were first exhibited in museums in the 1800s (Foster and Curtis 2016; Hughes et al. 2021, 2). Substantial replicas of cave morphology and rock art at 1-to-1 scales started with Lascaux II and Altamira in the 1980s, the Angbangband project in New Delhi in the late 1990s, and have continued with Chauvet 2, Lascaux IV, and very recently with Cosquer 2. These large-scale projects require huge amounts of funding to complete: it is estimated that the Chauvet 2 replica cost 55 million euros to build. As well as being materially substantive, the physical replica is a technical virtuoso of modern technology such as laser scanning and printing combined with architectural modeling; and the images reproduced require artisan expertise also – they are typically hand painted by contemporary like Alain Dalis and Gilles Tosello who collaborated at Chauvet 2 and Cosquer Méditerranée and the artists from the Périgord Facsimile Workshop who painted Lascaux IV. Studies of rock art replicas have explored visitor experience and issues of authenticity, how replicas relate to their original sites (Bruyere 2022; Delluc and Delluc 1984; Dunn 2022; Duval et al. 2020; Hughes et al. 2021; Mayer and Poor 2024; Wallis 2021); how replicas provide inspiration for modern visitors (Dunn 2022); or how replicas work in socio-political contexts of modernity and the politics (Fernandez 2019; Leresche 2019). Other than Commins, Coppens, and Hidaka (2020) who used Laucaux IV as a proxy for the original cave when performing acoustical research, few researchers have explicitly considered physical replicas as vehicles in which new knowledge can be gained about the original cave, or indeed as a lens on contemporary conditions.

The making of a virtual model requires less expense and effort than the physical replicas, but it still entails considerable work including travel to the original site, laser and/or photogrammetry capture of the site and art, audio recording, post-processing, immersive design, and implementation of often bespoke coded elements. The inception of virtual reality replicas started in the early 1990s with Benjamin Britton's VR installation simply entitled Lascaux (Britton 1992). Since then, immersive models of rock art sites have likewise been studied from heritage perspectives, often including ideas of preserving the sites through limiting actual visitation while opening access digitally (Blanco-Pons, Carrión, and Luis Lerma 2016; Cassidy et al. 2019; Rivero et al. 2024) while some studies aim to 'restore' rock art using virtual techniques (Bea and Angás 2017). However, recently, work has begun to conduct research within the models to understand the rock art in its original setting. For instance, I. A. N. Wisher (2023) and Torres et al. (2024) have simulated fire/torch lighting inside virtual models to test hypotheses related to viewing and experiencing the effects of simulated light and Palaeolithic art. I. Wisher, Pettitt, and Kentridge (2023) have also used virtual reality simulation to test the potential role of pareidolia in deep cave environments.

These pioneering studies are illustrative of the potential value of replicas for research-oriented aims. Virtual replicas in particular have an un-tapped potential as *interdisciplinary* research venues: environments where, by virtue of their ease of access and the fluidity of the data they represent, experiments with archaeological, artistic, technological, sensory and environmental questions can be brought into sustained relation. Framing virtual replicas through historical reconstruction, preservation, visitor experience, or the testing of pre-existing archaeological hypotheses are vital uses, but they leave underdeveloped the possibility that replicas might generate new questions, methods and forms of collaboration in their own right. The possibility of using virtual models as research environments is activated further by the recent combinations of digital models with live-feed, real-time data, often described as 'digital twins' (Vuoto, Funari, and Lourenço 2023). Such technologies allow replicas to be dynamic and manipulable: revisitable spaces in which data, interpretation, user interaction and interdisciplinary enquiry can accumulate and change over time.

The contribution of this paper is to consolidate the impression from digital archaeological practices that replicas can support research, and to provide a comparative framework for understanding how they generate and proliferate knowledge. Physical and virtual replicas enable different forms of enquiry, yet both remain organised principally around self-contained visits. We therefore propose the perma-library as a model for converting replicas from individual heritage experiences and experimental tools into persistent, comparative and cumulative research infrastructure.

In the coming sections of this article, we show that notions of research and knowledge from contemporary art contain some illustrative theoretical lenses that prepare the ground for this set of considerations.

Contemporary art: indexicality and metaphorical space

The artist Robert Smithson's concepts of *site and nonsite* (1968) can be used to understand how cave art replicas work in relation to originals – and therefore how the practices of cave art resonate also with the kinds of knowledge-making inherent to art today. Smithson described the nonsite as a 'three-dimensional picture' referring back to an original location, creating 'a space of metaphoric significance' between the site and its displaced representation. Considered by Peter Osborne (2013) to be one of the key ideas in the formation of the genre of 'contemporary art', the conceptual gap between a site and its other allows for interpretive movements to take place – what Smithson calls 'travel in metaphor'. Smithson's *Spiral Jetty* (1970) – a monumental earthwork spiralling out into Utah's Great Salt Lake – is an illustrative example of this concept at work. While the jetty exists as a physical *site*, in Smithson's work its presence is extended through photographs, maps, drawings, and a short film, forming a *nonsite*. As Osborne (2013) observes of the jetty, the network of media documentation both records and transforms the jetty, displacing it into a system of representations that abstract concepts from the original site-work – an indexical relationship that allows for new understanding to emerge.

The nonsite becomes a space where meanings emerge *through* their displacement in the form of representations. This has a double, and even triple, valence to the cave art conversation: original cave artists were producing representations of their external environments, particularly animals and landscapes 'sites' from above ground, in the displaced context of cave galleries 'non sites'. Using contemporary art theory, we can understand this as a process of concept extraction, in which palaeolithic people were operating cognitively in the 'space of metaphorical significance' between the site and non-site of animals of the surface terrains. Now also caves and the concepts extracted into them by earlier art practices become 'sites', where the 'non site' publications: writings, graphs, statistics, drawings, and the 'three-dimensional picture' of the VR digital model of a cave, all refer back to the original caves in significant ways, 'extracting concepts' embedded their earlier by human and more than human activity, for academic and non-academic audiences. Rock art replicas *index* the original sites from which they are derived, but they co-create novel opportunities to realise and manifest the richer network of relationships at play in those caves, and inward to the kinds of technologies we are using to render them, offering new research potential. Osborne argues that contemporary art since Smithson has become 'post conceptual' – that is, it has moved beyond medium or concept specificity, embracing a practice defined less by discrete objects and more by networks of language-like relationships between concepts and materials and the kinds of multiple meanings that occur in the process of concept abstraction and accretion. Rock art studies recently mirror this understanding: Robinson (2013) considers Californian rock art as epistemological spaces

where artworks interrelate audience, artist, and myth, and as places to enact Indigenous ontologies, but these ontologies move beyond the site itself through differing assemblages that can create a new and novel entities (Robinson et al. 2021).

In work that has informed our present study, Jones (2019) seeks to take account of the critical and analytical possibilities that follow when contemporary artworks are understood as temporally and spatially distributed phenomena. Jones argues that contemporary art can operate as a 'research environment' in which artistic, scientific and technological modes of discovery are entangled and complementary knowledge emerges. Activities around Bruno Latour's *Critical Zones* art exhibition (Latour and Weibel 2020) exemplify this approach. Latour's concept of the 'critical zone' – Earth's fragile, reactive surface – becomes a metaphor for entangled systems of critical research available when artworks function as a reflexive and experimental spaces for understanding the planet. In a way that perhaps resonates with the motivations of the original cave artists, Latour describes the practices in *Critical Zones* as searching for 'ways to inhabit a land'. He is suggesting that the new circumstances of the entwined ecological, political and technological crises of our moment demand a refreshed perspective on the planet. The exhibition itself contains artists making 'non site' visualizations, acoustic environments, and experiences of particular localities 'sites' on the planet's surface. An accompanying publication for *Critical Zones* develops on the resulting extracted concepts: for example, Jonathan Gray's essay explores how digital data practices make visible the invisible networks through which the natural world communicates – rendering the ecological relations between trees, fungi, and their environments 'relatable through digital data' (Gray 2020, 1). Another example in *Critical Zones*, Sarah Sze's Timelapse (Sze 2012) provides a powerful artistic analogy from the experience of 'immersive art' – visualisations that embody space. Sze describes the impulse behind her work, which reassembles everyday objects and digital image projections, as an attempt to position audiences so that they are 'seeing from within the world'. Palaeolithic sites like Lascaux may do something structurally similar: Aujoulat (2004) interprets their imagery as encoding biological and cosmic rhythms, forging impossible perspectives that depict the earth's surface and its animals from within its crust. The prehistoric artists of Lascaux, working deep within the earth, were not only capturing animal movements across landscapes but may also have been 'looking up' through the rock, imagining cosmological patterns. As (Aujoulat 2004) suggests, '. . . the morphological characteristics of the cavity are to some extent a reminder of the architecture of the canopy of heaven' (quoted in Lima 2012, 57).

With Latour's vision of art as a planetary observatory, Lascaux's art, and its replica versions opened onto speculative connections between human and non-human worlds. Rather than functioning purely as symbolic representations, the Lascaux images may have operated as tools for embedding cycles of movement and environmental change within the visual language of the cave. Images of running bison and deer, repeated over time, evoke a collaborative, sustained exploration of the rhythms of migration, reproduction, and transformation in the enclosed environment of the cave. These compositions, rendered with materials such as charcoal and ochre sourced from the landscape – as Smithson said in 1968 (in Smithson 1996) would say, *non-site* abstractions from the sites in which they were found – additionally reflect an integration of artistic expression with an ecological, relational approach to observation and representation. Much like the artworks in *Critical Zones*, the cave's layered site-displacements evoke an idea of art as an observatory, perhaps even a lab, for exploring relationships between humans, animals, surroundings, and the technologies of representation.

The argument we are building here complicates straightforward binaries between originals and replicas, emphasizing instead a continuity of practices that foreground the concept of abstraction

occurring in reproductive practices. We observe that cave art and contemporary art may share a more expansive logic than has previously been noted: process, site-responsiveness, and the interplay of materiality and abstraction across times have key functions in both eras of art (which neither share, for example, with intervening eras of ancient, classical, modern or post-modern arts). The cave art replicas we read in this paper, therefore, are understood to create conceptual and literal spaces for understanding a leap across times. In the next section, we return to Boyd's notion of cave art as a kind of text, and replica-making therefore as an act of reading, or even librarianship – making a research space, archive, and networked environment for accretions of meaning to be re-read and re-written.

Evaluating replicas as libraries

The library metaphor is valuable because rather than thinking about caves replicas as tourism venues, it allows us to ask how they are organised to allow for knowledge to be retained, accessed and evolved. Again, contemporary art practice is a useful lens. The *BiblioTech* edited collection (Jones and Skinner 2025) documents art exhibitions in Cyprus and Liverpool UK, that reimagined libraries through the lens of the 'post digital' – a condition where digital and virtualising technologies have infused our physical infrastructures for living, requiring newer and revisited older conceptions of how information should be handled. In this section we build on the framework laid out by *BiblioTech* to argue that caves, rock art, and their replicas assemble, store, and activate meaning in ways that are require virtual and actual space to be understood together.

The framework provided by BiblioTech gains additional force when set against wider debates in Library and Information Science (LIS) and the Digital Humanities concerning what is gained and lost in the translation of material objects into data. Scholars including Sassoon (2004) have demonstrated how digitisation can 'dematerialise, dehistoricise, and decontextualise' objects, creating new representational systems that may suppress the meanings embedded in original materials. As Drucker (2025) and others in the Digital Humanities have shown, the organisation of knowledge is always a constructive, interpretive act, and the digitisation of collections makes sacrifices for all its claims to increased 'accessability' and affordability. For cave art – itself already perhaps an act of mediated abstraction as storage, as discussed in the previous section – the risks of a digital reproduction are acute: the loss of architectonic features such as texture, humidity and spatial depth may occlude the meaning of the original 'texts'.

The perma-library model described by Jones and Skinner in *BiblioTech* offers a way to understand durability without equating it with fixity. In post-digital collections, persistence depends on migration, versioning, annotation and continuing contribution rather than on preserving objects unchanged (Jones and Skinner 2025, 278). A VR Library would therefore keep its models available for re-search: return, comparison, manipulation, annotation and reuse through methods not anticipated by their original designers. It would preserve provenance while allowing interpretations and research layers to accumulate. This matters because existing VR experiences reset when the headset comes off. The perma-library converts an isolated encounter into a cumulative research act.

So the account of loss, while necessary, risks foreclosing a more ambitious and distinctive question: what forms of encounter become possible precisely because digital environments are not material caves? Fontana and Pinotti use the term 'environmental image' to describe both Palaeolithic cave art and contemporary VR: two historically distant but structurally related forms of image that engulf the viewer, unsettling the distinction between subject and object. In a companion article, we develop this conjunction as the 'paleocybernetic cave': a research

environment in which Palaeolithic and computational conditions of perception are brought into reciprocal investigation (Jones and Dragona 2025). VR replicas preserve something that photographs and descriptive data cannot: the environmental character of cave art. At the same time, their mutability and manipulability amplify the perceptual and interpretative instability of the cave itself. As a persistent research infrastructure, the VR Library could also support experimental, collaborative and revisitable forms of enquiry (Pawlicka-Deger 2020). Our own experience at Lascaux IV, where digital film allowed movement through cave walls as though they were flowing water, or PleitoVR's DStretch filters, which render visible painted surfaces no unaided human eye has seen, suggests that these technologies are not simply impoverished substitutes for embodied presence. They are modes of expanded consciousness, enabling the simultaneous perception of apparent opposites – inside and outside, deep past and present, human and geological time – in ways that resonate with the more-than-human ontologies that the original cave artists themselves may have inhabited (Viveiros de Castro 2004).

Criteria for analysis – evaluating replicas as research environments

If user engagement with spaces is fundamental to our concept of a virtual library of rock art replicas, then it is necessary to evaluate how existing original sites, physical replicas and virtual replicas organise encounter. Many existing studies of replicas focus on visitor experience, authenticity, preservation, conservation ethics, tourism, educational value and heritage management (Bruyere 2022; Hughes et al. 2021; Wallis 2021). These are important frameworks, but not the focus of our concern here. A replica may be highly successful as public heritage, as conservation strategy, as a tourist destination, or as an educational environment while remaining limited as a research space.

Rather than evaluating the VR Library's wider institutional infrastructure, our field reflections assess the qualities that would make each replica a useful, researchable contribution to it. From these strands, we propose two connected dimensions: **usability** and **indexicality**. Usability concerns whether a replica can actually be used as a research environment – whether users can move, pause, compare, manipulate, question and pursue lines of enquiry. It contains three criteria: freedom, narrative and interactivity. Indexicality is of a different order. It concerns the richness of the replica's possible relations: what it points to, what it carries forward, what it transforms, and what it makes available for thought. Together, the criteria ask how far a replica can become a library/lab – a read-write-research space that organises information, allows users to act upon it, and supports return, comparison, testing and the generation of new questions.

Freedom evaluates how far users can move through, around or within the replica, and whether they can pause, return, compare and form their own spatial questions. In this paper, we assess freedom through observable features: fixed routes, barriers, guided movement, ride systems, teleportation, free navigation, time limits and opportunities to inspect details from different positions. Freedom matters because research often depends on returning to a feature, changing position, testing a view, or pursuing a question not anticipated by the designer.

Narrative evaluates how interpretation is organised. We assess whether meaning is delivered through guides, recorded scripts, fixed sequences, interactive prompts or open-ended exploration. The key question is not whether a narrative is effective for public interpretation, but whether it allows interpretive plurality. A strong narrative may produce a coherent visitor experience while narrowing the user's ability to test alternative readings. For a library/lab, narrative should ideally support orientation without exhausting meaning.

Interactivity evaluates what users can do inside the replica. We assess whether users can manipulate lighting, change visual filters, handle virtual objects, choose paths, trigger information, compare images or alter the conditions of viewing. This criterion is limited to interaction available during the encounter itself. Long-term annotation, data capture, user-generated research layers and collaborative writing into the archive are discussed later as requirements for a future VR Library, rather than as current features of the replicas studied here.

Indexicality operates in two directions. Archaeologically, it concerns what the replica carries forward from the original site: morphology, scale, surface, image placement, spatial sequence, lighting, acoustics and environmental context. The fidelity required is question-dependent; different hypotheses require different forms and degrees of accuracy. At the same time, replicas index the circumstances of their own production – the scanning systems, software, interfaces, institutions, economies and interpretive decisions through which the cave is remade. This is why indexicality differs from the three usability criteria. Usability asks whether a replica can be used for research; indexicality asks what relations and fields of enquiry it can open.

To establish a baseline, we applied the four criteria to visits to Rouffignac, Pech Merle and L'Abri du Cap-Blanc (see https://data.lancashire.ac.uk/id/eprint/721). At all three sites, conservation requirements severely restricted movement, proximity and time, while interpretation depended heavily on guides. Interaction was principally embodied rather than manipulative: darkness, temperature, humidity, sound and descent shaped the encounter, but visitors could do little beyond looking and moving along prescribed routes. Their distinctive force was indexical. Image, surface and cave morphology remain part of the same material formation, which continues to register humidity, bacterial growth, geological change and human presence. Original sites therefore offer the closest material relation to Palaeolithic practice and the richest sensory encounter, while making repetition and comparison difficult. This establishes the conditions against which the replicas' losses and new possibilities can be assessed.

Field reflections: physical replicas of southern France

In this section we consider how the usability and indexicality of the large-scale cave art replicas of southern France. We visited the replica of Cosquer Cave, a remarkable cave only accessible under the water. However, the only way to experience Cosquer 2 is seated in an amusement park style pre-programmed ride through with recorded audio. While a fascinating experience, and certainly there are interesting connotations of indexicality, it had extremely limited value in terms of addressing the issue of usability and research (see Appendix). So instead, here, we focus on the largest replicas of Chauvet 2 and Lascaux IV.

Field reflections: Chauvet 2

The full-scale replica of Chauvet Cave, known as Chauvet 2, succeeds in preserving the visual and spatial impact of the original cave (see Jean-Jacques et al. 2014), but in doing so it also highlights the interpretive tensions inherent in translating Palaeolithic art for contemporary audiences. The museum is located, like the original cave, on a high promontory overlooking a river valley, and the replica itself is housed underground, accessible via a walkway of evocative polygonal concrete overhangs. Inside, the reproduction is achieved to a remarkable level of resolution – including, for instance, the small dusty craters left by bears as they turned and slept through winters. This physical fidelity sits alongside a broader visitor complex: exhibition halls, temporary displays, and outdoor

workshops in prehistoric javelin-throwing and weaving. During our visit, a temporary immersive experience about animals occupied one of the halls – engaging in its own terms, but jarring somewhat against the seriousness of the Chauvet brand. To pursue our analysis of narrative in particular, we took the cave tour twice: once with a male guide in his first year of service, and once with a more experienced female guide.

Freedom

Chauvet 2 preserves the scale of the original cave and maintains certain spatial relationships between artworks and wall formations – relationships that, as the surface-image readings of the main panels showed, carry genuine interpretive significance. However, the replica compresses the original cave layout into a coiled arrangement within a reduced footprint, generating vistas across and between panels that would not have existed in the original. This is an unintended research finding of sorts: the spatial distortion produces new juxtapositions, new lines of sight, that could prompt questions about the original placement and viewing conditions of the images – though only if visitors have the freedom to notice and pursue them. In practice, that freedom is limited. Movement is controlled by railings and designated walkways, and the pace of the tour is set by the guide. Our ability to take the tour twice was itself a form of expanded freedom – it allowed us to linger, to revisit, and at moments to drift briefly off-course – that ordinary visitors are unlikely to experience.

Narrative

The narrative dimension of Chauvet 2 proved the most analytically productive of the four criteria. A defining aspect of the experience is its reliance on guided interpretation, and the variability between guides revealed, with unusual clarity, how much interpretive authority rests on a single individual. During the first tour, our female guide cautioned visitors against the 'danger' of interpretation when they speculated that a series of spiralling patterns beside an owl sketch might depict a reclining woman (Figure 1). The remark – invoking the vast cultural and temporal distance between contemporary viewers and prehistoric artists – was striking: it raised, without resolving, the question of what interpretation is for, and who it belongs to. Shortly afterwards, and apparently



Figure 1. Chauvet cave images of an owl with a potential reclining woman to the viewer's left. Image from Chauvet 2 press pack.



Figure 2. A recess in Chauvet is interpreted as reminiscent of a vulva. Photograph by Patrick Aventurier.

without contradiction, the same guide offered a compelling account of the cave walls' vulva-like inlets as the reason the original artists chose those particular locations for their primary panels (Figure 2) – a reading that connected the imagery to the female body and framed the site as, at least in part, a meditation on birth and origin. Our second tour, with the male guide, contained none of this. His account focused on artistic technique and the fidelity of hunting scenes, treating the walls as a proto-canvas and the drawings as early precursors of cinema. He did not mention the mating scenes depicted; when asked, he suggested that children were present.

Interactivity

Inside the cave replica, interactivity is essentially limited to the act of looking, with lighting used to direct attention toward particular panels and features. There is no mechanism for visitors to alter conditions of viewing, handle objects, manipulate filters, or pursue details outside the guided sequence. The wider museum complex offers more – digital displays, workshops, temporary exhibitions – but these are physically and conceptually separate from the replica itself, and their relationship to the cave experience is largely curatorial rather than investigative. As with the original sites, the body is present in the space, but there is little it can do beyond receiving what is offered.

Indexicality

Chauvet 2 is not simply a copy of the original cave: it is a displaced site-form, in which the cave has been extracted, reorganised and made available for encounter in a new context. This displacement is the condition of its indexicality, and it operates in two directions at once.

In the direction of the original, Chauvet 2 carries forward a great deal. The spatial connection to the original is unusually strong: the replica sits in the same valley as the cave it reproduces, on the same promontory, orienting visitors to the same landscape. Inside, the morphological fidelity is high – wall textures, bear craters, the scale and sequence of the main panels, the relationship

between image placement and cave architecture are all reproduced with care. From an archaeological perspective, this gives the replica genuine research potential: it can support enquiry into viewing conditions, movement through the cave, the relation of specific images to surface and spatial context, and the likely experience of the original environment. The coiled compression of the layout introduces distortions, but these are themselves informative, sharpening questions about what the original spatial sequence would have felt like and what research depends on its accurate preservation.

In the direction of the present, Chauvet 2 indexes the full apparatus of its own production. It points to the labour of the contemporary artists who recreated each image by hand; to the architectural choices that compressed the cave into its new footprint; to the national heritage infrastructure that funded, designed, and continues to manage the site; and to the tourist economy of the Ardèche. It indexes, too, the interpretive frameworks embedded in the tour format itself – the assumptions about what visitors need to know, what they can be trusted to interpret, and what should be withheld. The temporary exhibition about animals, the javelin-throwing workshops, the concrete overhangs: all of these are part of Chauvet 2's indexical field, pointing outward to the contemporary cultural moment in which this version of Chauvet was made and continues to be experienced. Unlike the original cave, which indexes time through its own ongoing degradation, Chauvet 2 is fixed at the moment of its making. It does not accumulate. It records the interpretive priorities of a particular period in French heritage thinking and holds them there.

This push-pull indexicality – backward to the Palaeolithic, outward to the contemporary – is what gives Chauvet 2 its richness as a research object and also what complicates its use as a research environment. The replica can help us think about the original cave, but it can equally help us think about the systems through which the original cave is being remade, reframed, and delivered to contemporary audiences. Both directions of enquiry are legitimate; the question is whether the replica's current design allows either to be pursued with any depth.

Chauvet 2 as a research environment

Chauvet 2 offers more than the original sites in some respects and less in others. The high physical fidelity of the replica, and its spatial relationship to the original valley, sustain real research potential – particularly for questions about image placement, morphological context, and viewing conditions. What taking the tour twice revealed, however, was perhaps more unexpected: the variability between guides made visible something about the role of masculinity in museum interpretation contexts in France. The female guide's reading of the cave walls as gendered space – her account of the vulva-like inlets as determinants of image placement, her willingness to engage with what the imagery might say about birth, origin, and the female body – was entirely absent from the male guide's tour, replaced by a focus on technique, hunting, and artistic lineage. This was not simply a matter of individual style: it pointed to something structural about how gendered assumptions shape the mediation of prehistoric art in institutional contexts – what gets said, what gets withheld, and whose interpretive frameworks are treated as authoritative. That this finding emerged at all was a product of methodological freedom – the ability to return, to compare, to notice difference. It is precisely this kind of repeatability that a single visit, whether to the original sites or to Chauvet 2, cannot support. And it is what Chauvet 2, for all its fidelity, ultimately cannot provide: a mechanism for observations to accumulate, for enquiry to build on itself, for the replica to be returned to on the researcher's own terms. Like the original sites, it is organised around the visit. Unlike them, it is not even changing – it is fixed at the moment of its making, an interpretation of

Chauvet held in place while the original cave, and the questions we might ask of it, continue to evolve.

Field reflections: Lascaux IV

Lascaux IV is the second full-scale physical replica of the original Lascaux Cave, blending physical and digital elements in ways that make it the most formally complex of the physical replicas considered here. Robinson visited the facility twice before formal analysis by both authors was conducted. The replica is designed to mirror the scale, texture, and spatial layout of key sections of the original cave, immersing visitors in an environment that evokes the conditions in which the cave was found in the twentieth century. It is complemented by an adjoining gallery complex offering layered narratives through digital film and interactive display: a point-cloud render of the cave's geological formation by water; a projection-mapped theatre show dramatising the press and public reaction to the cave's discovery and the subsequent controversies about preservation; and an immersive CAVE installation demonstrating connections between the symbols at Lascaux and those found across European cave art sites (Figure 3). These multimedia elements expand the temporality of the experience, situating the cave as both prehistoric artefact and ongoing cultural phenomenon.

Freedom

As with the other physical replicas, movement through the cave replica at Lascaux IV is controlled by railings and designated walkways, and the pace of the visit is set by the guide. The adjoining workshop area offers a partial exception: here, sections of cave reproduction are suspended



Figure 3. A cave artificial virtual environment (CAVE) installation at Lascaux IV. The digital video depicted connections between the symbols on the caves in Lascaux and those found across the European continent. Photograph by permission of Clémence Djoudi Fauré.



Figure 4. Cave segments at the workshop area at Lascaux IV. Photograph by permission of Clémence Djoudi Fauré.

independently, allowing visitors to spend time with specific panels outside the guided sequence, though detached from the spatial context of the cave as a whole (Figure 4). Robinson's two visits provided the same methodological advantage as at Chauvet 2: the ability to return, to linger, to compare observations across visits, and to notice details that a single tour does not allow.

Narrative

The narrative at Lascaux IV makes a revealing choice: it centres not on the prehistoric makers of the cave but on its modern discoverers. The story of Marcel Ravidat, the boy whose dog fell into a hole in 1940 and led him to the cave entrance, is delivered by guides with evident care and dramatic investment. The emphasis on discovery rather than creation reflects a deliberate narrative strategy, one that positions Lascaux as a symbol of French cultural continuity – found, crucially, during the German occupation, and therefore bound up with questions of national identity, ownership, and survival. This framing is evocative and effective as heritage storytelling. As a research framework, however, it anchors the experience firmly in the twentieth century, leaving the Palaeolithic at a distance and offering visitors little interpretive space to move toward the prehistoric makers or their possible intentions. As at Chauvet 2, the narrative is structured to produce a coherent emotional arc rather than an open field of enquiry.

Interactivity

Lascaux IV offers considerably more interactivity than the other physical replicas, though most of it is located in the gallery complex rather than the cave replica itself. Digital tablets allow visitors to explore 3D visualisations of the art; press-button triggers activate audio and animation; blue-light viewing modes demonstrate how shadows and movement may have animated the original images; and AR handsets allow certain motifs to be examined in detail and across their degraded states over

time. These tools begin to approach, in modest form, some of the manipulability available in VR environments: they allow conditions of viewing to be altered, details to be isolated, and the cave to be encountered across different temporal and spectral registers. Their limitation is that they remain tightly embedded within the curatorial framing of the gallery, reinforcing rather than opening the interpretive structure of the visit. The cave replica itself, as distinct from the galleries, offers no equivalent interactivity.

Indexicality

In the direction of the original, the spatial connection is exceptionally strong: the replica sits in the same valley as the original cave, and its textured surfaces, controlled lighting, and attention to the scale and sequence of the main panels carry forward enough of the original's morphological logic to support serious archaeological enquiry. Questions about image placement, viewing position, movement through the cave, and the relationship between art and cave architecture can all be meaningfully pursued here.

The scientific monitoring laboratory on the hillside above adds a dimension unavailable at any other replica. Visitors who walk up to it encounter an active research infrastructure: instruments measuring humidity, bacterial growth, the effects of climate change on the cave walls, and the cumulative impact of human breath on the original paintings. The lab indexes the original cave's ongoing degradation in real time, making visible the entropic processes we identified as central to the indexicality of the original sites. It also introduces a quiet paradox: the replica exists in part to draw visitors away from the original, protecting it from the very human presence whose effects the lab is monitoring. The replica and the original are, in this sense, in active relation – not simply copy and source, but two elements of a single conservation system.

In the direction of the present, Lascaux IV indexes its own production with unusual explicitness. The Ravidat discovery narrative anchors the site in a specific moment of twentieth-century French cultural history, indexing it to the politics of occupation, national identity, and heritage ownership as much as to the Palaeolithic. The point-cloud geology film, the CAVE installation, the AR handsets, and the theatre show all point outward to contemporary scientific and media cultures – to the technologies of photogrammetry, digital projection, and immersive display through which this version of Lascaux has been constructed and is continuously maintained.

Lascaux IV as a research environment

Of the physical replicas, Lascaux IV comes closest to functioning as a research environment in the sense the framework describes. Its digital tools extend interactivity toward manipulability; its location in the original valley and its connection to the monitoring laboratory sustain unusually direct indexical links to the original cave; and the complexity of its multimedia programme opens the experience across multiple temporal and disciplinary registers. The Ravidat narrative, however, illustrates the cost of this richness: a strong, emotionally coherent curatorial vision that fills the interpretive space and leaves little room for the visitor to pose their own questions. The cave is presented as a found object, a national treasure, a twentieth-century story – and the Palaeolithic recedes accordingly. What Lascaux IV demonstrates, perhaps more clearly than any other physical replica, is the tension between the richness of a site's contemporary indexical field and its openness as a research environment. The more fully a replica is interpreted, the more it closes down the very plurality that research requires. Like Chauvet 2, it is organised around the single visit and fixed at the moment of its making. Unlike Chauvet 2, it gestures –

through its digital tools and its monitoring laboratory – toward the kind of dynamic, accumulative relationship with the original that a more fully realised research environment might sustain.

Virtual reality cave art experiences

The three VR cave art experiences considered here – *The Dawn of Art: A Journey Through Chauvet Cave*, *Memoria: Stories of La Garma*, and *PleitoVR* – represent a different order of replica-making from the physical sites examined above. VR environments are immaterial, portable, and – in principle at least – updatable. They were trialled by both authors for direct comparison with the Palaeolithic sites and physical replicas. Across the four criteria, they offer the widest range of variation of any replica type considered here: from the tightly structured narrative immersion of *The Dawn of Art* to the near-total interpretive openness of *PleitoVR*. That range is itself analytically significant.

Freedom

All three VR environments offer greater freedom of movement than any of the physical replicas. Users navigate at their own pace, inspect details from multiple angles, and are not subject to the time constraints, railings, or guided sequences that govern physical encounters. *PleitoVR* extends this furthest: users can teleport through the virtual cave, walk freely, approach the painted surfaces as closely as they choose, and even move into the rock itself – a perspective available to no visitor, prehistoric or modern, in any physical context. *The Dawn of Art* and *Memoria* offer more structured movement paths, guiding users through a sequence of spaces and panels, but even these allow greater autonomy than any guided tour. The freedom available in VR aligns these environments with the spatial openness of contemporary art installations, where the user's movement through space is itself a mode of meaning-making. The cost is real, however. The loss of uneven terrain, the darkness, the humidity and temperature shifts, the bodily sensation of descending into the earth, risks flattening something irreducibly dimensional into an experience that is primarily visual, however immersive its visual language.

Narrative

The three VR experiences occupy very different positions on the narrative spectrum. *The Dawn of Art* and *Memoria* both feature professionally produced, fixed narratives: high-quality audio storytelling combined with carefully designed visual sequences that guide users through an interpretation of the cave's cultural and symbolic significance. These narratives are accessible and often compelling, particularly for general audiences, and they demonstrate what VR can do with lighting, atmosphere, and cinematic pacing in ways no physical replica so far acheives. Their limitation, from a research perspective, is the same as that of the guided tour: the narrative is closed, and the user's ability to deviate from it, test alternative readings, or pursue questions not anticipated by the designers is minimal. *PleitoVR* takes the opposite approach, forgoing narrative altogether in favour of unstructured exploration. This opens the interpretive field considerably – users must bring their own questions and frameworks – but it also removes the contextual scaffolding that makes the encounter legible for those without specialist knowledge. Neither approach fully resolves the tension between orientation and openness that a research environment requires.

Interactivity

VR introduces a dimension of interactivity that no physical replica can match. In Dawn of Art, a torch can be brandished (Figure 5) while in both *Memoria* and *PleitoVR*, users can pick up and examine three-dimensional renderings of archaeological objects – handling a prehistoric blade (Figure 6), turning it in virtual hands, inspecting its surfaces. In *PleitoVR*, users can additionally view the cave art through DStretch filters (Figure 7), which render painted surfaces visible in spectral registers unavailable to the naked eye – revealing images that no human viewer, at any point in history, has been able to see directly. Ambient sound, recorded at the original sites, provides an auditory layer: the running stream, wind, local fauna. This level of interactivity genuinely begins to constitute an experimental space, one in which users can alter the conditions of their encounter and actively shape what they find. Its critical limitation is that nothing is recorded. Users leave no trace. The interactions do not accumulate, do not modify the environment for subsequent visitors, and do not contribute to any growing body of observations. The experimental space closes when the headset comes off.

Indexicality

In the direction of the original, VR replicas are built on laser scanning and photogrammetry – processes that are themselves indexical acts. The scan captures the cave at a specific moment, recording its surface with a precision no human observer could achieve, and that record becomes the substrate of everything the VR environment contains. The morphological fidelity this enables is high: image placement, surface texture, spatial sequence, and the relationship between art and cave architecture are all carried forward with enough force to support serious archaeological enquiry. *The Dawn of Art* reinforces this spatial grounding through its opening sequence, situating the user outside the cave, at the foot of the valley, before descent – indexing the experience to a specific geographic location in a way that several of the physical replicas, paradoxically, do less explicitly.

The DStretch filters in *PleitoVR* introduce a more complex indexical relationship. By making visible what no original viewer could see, they exceed the index in an interesting sense: they reveal aspects of the art that were always present but never perceptible. This is indexicality extended beyond human sensory limits.

In the direction of the present, the indexical field of VR environments is extensive and largely unmapped. Each experience indexes the scanning technology and photogrammetric methods used to capture the original; the game engine and interface design through which the data have been rendered and made navigable; the headset hardware through which it is experienced; and the institutional, funding, and design decisions that shaped each project. *PleitoVR*'s use of ambient sound recorded at the Pleito site, and of contemporary Native American singing, indexes living Indigenous cultural practice – a connection to the present that the French physical replicas, embedded in national heritage frameworks, struggle to make. This is a form of contemporary indexicality that opens research questions about the relationship between past imagery and descendant cultures that the other replicas do not raise.

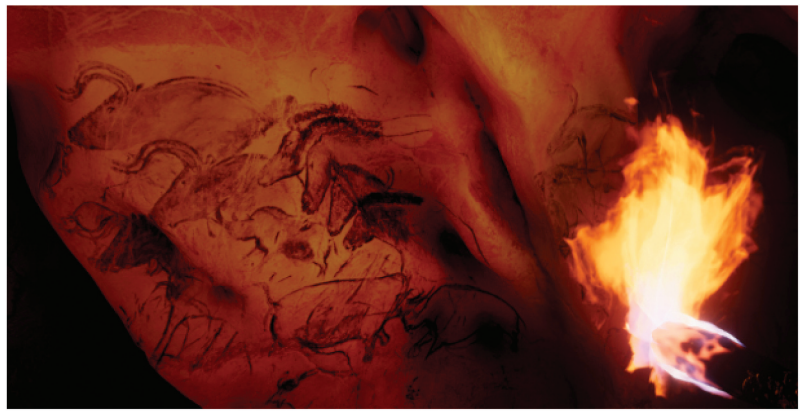


Figure 5. Screenshot from the dawn of art game, showing how torchlight is used in the VR experience, from Google Arts and Culture.

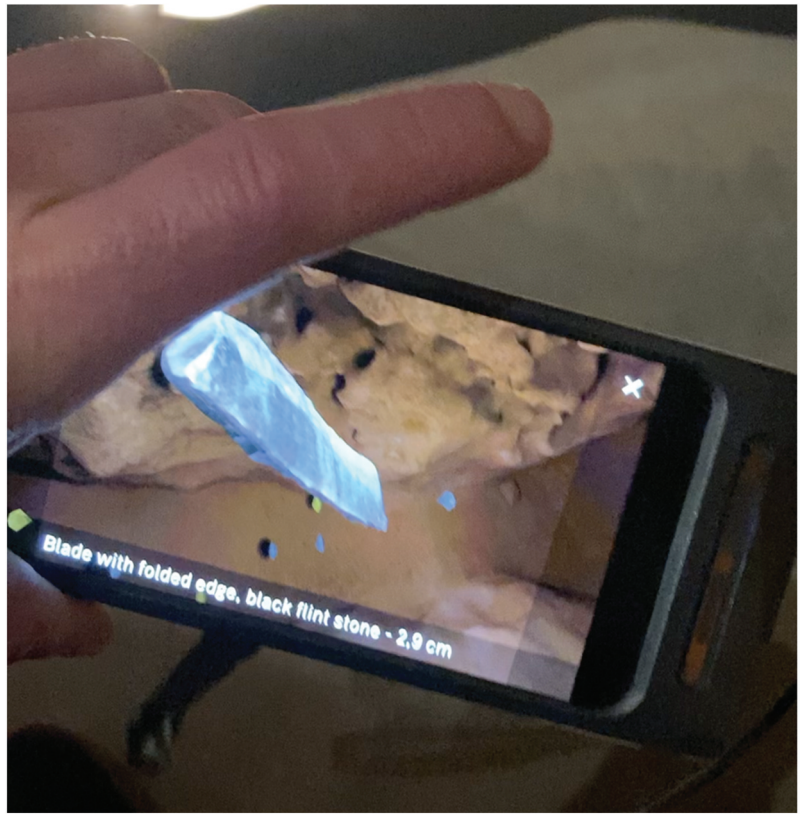


Figure 6. A prehistoric blade which can be handled in the virtual environment of *La Garma*. Photo by Adam Appleton.



Figure 7. Screenshot images of *PleitoVR showing how the drawings on the cave are made more visible through the use of Dstrech filters.*

VR environments as research environments

Across the four criteria, VR environments offer the greatest research potential of any replica type considered here – and *PleitoVR* in particular comes closest to functioning as a genuine research environment in the library/lab sense. *The Dawn of Art* and *Memoria* are more constrained by their narrative structures, but their production values and the depth of their spatial and auditory design sustain real research engagement, particularly for questions about the sensory and atmospheric dimensions of cave experience.

The shared limitation of all three is the absence of any mechanism for accumulation. Each encounter begins from the same state as the last. This is the fundamental gap between what these environments currently are and what a research environment would need to be. VR's dematerialisation – its sacrifice of haptic presence, atmosphere, and embodied depth – is a real cost. But the analysis suggests it is a cost that could be offset by what VR uniquely enables: spectral viewing, free spatial exploration, object interaction, and the potential, not yet realised, for observations to be captured, annotated, and built upon over time. It is precisely this potential that the physical replicas, for all their material richness, cannot approach.

Reflection: seeing from within the world

In each of the encounters described in this paper, something of what Sarah Sze (2012) calls 'seeing from within the world' was available, if unevenly. The digital film at Lascaux IV, which allowed movement through cave walls as though flowing water, made this most explicit: it provoked questions about whether the prehistoric artists of Lascaux, working deep within the earth, were not only capturing animal movements but imagining cosmological patterns from within the crust itself – compressing temporal rhythms and impossible perspectives into the surfaces of the cave. PleitoVR's DStretch filters enacted a different version of the same logic: enabling perception of images painted by the original artists that no human eye, prehistoric or modern, has ever directly seen since the overpainting events obscured them.

Physical replicas expand public access while broadly replicating the guided, expert-controlled narrative framework visiting actual sites; Lascaux IV partially addresses the interactivity gap through its digital tools. VR environments offer the greatest freedom and experimental potential – PleitoVR especially – but sacrifice materiality, haptic presence, and environmental depth. As data, all replicas

embody the interpretive choices, funding priorities, and heritage agendas of their makers: they are not neutral records but arguments about the past, and any research conducted within them must remain alert to the layer of mediation they introduce.

Physical replicas are designed chiefly as heritage experiences rather than research environments, but they need not remain so. Across all the replicas, the principal limitation is the absence of any mechanism for accumulation: visitors leave no trace. Replicas can already support acoustical analysis (Commins, Coppens, and Hidaka 2020), lighting and shadow simulation (I. A. N. Wisher 2023), pareidolia testing (I. Wisher, Pettitt, and Kentridge 2023), spectral imaging, and experiential hypotheses concerning cosmology and more-than-human ontology. What they cannot yet support is open-ended, cumulative and co-creative research. The educational case for extending that access is increasingly well evidenced: Keith et al. (2026) demonstrate that immersive VR significantly enhances learning in contexts, such as marine ecology, that mirror the access constraints facing cave art research.

Rock art sites function as archives of past visual communication whose meanings emerge through comparison across sites and landscapes (Boyd 2016; Mguni 2016; Montgomery and Fowles 2020). Because full-scale physical replicas cannot be produced for comparative research indefinitely, a VR Library designed for data capture, annotation and iterative enhancement could turn individual visits into cumulative research acts (Nair 2014). Such a library need not be limited to documentary fidelity. It could support synaesthetic, defamiliarising and more-than-human encounters, activating dimensions of cave art often suppressed by conventional heritage frameworks.

This perspective challenges binary distinctions between originals and copies, authenticity and simulation, past and present. The emerging replica revolution widens the interdisciplinary reach of rock art research, opening lines of enquiry that are only now in their nascent beginnings. Developing virtual libraries of rock art sites will enable investigation of deep time pasts and deep time futures from human and non-human perspectives alike – extending the work of the original artists of Lascaux and Chauvet into new territories of interpretation, alongside the contemporary artists, scientists, and digital makers who are their present-day interlocutors.

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