heritage

MDPI

Article

Virtual Museums as Meaning-Modeling Systems in Digital Heritage

Huining Guan [1,†], Pengbo Chen [2,*,†] and Cheeyun Lilian Kwon [1]

[1] Department of Arts and Cultural Management, Graduate School, Hongik University, Seoul 04066, Republic of Korea
[2] Department of Digital Culture and Contents, Graduate School, Konkuk University, Seoul 05029, Republic of Korea
* Correspondence: chpebo@konkuk.ac.kr
† These authors contributed equally to this work.

Abstract

This article frames the virtual museum as a meaning-modeling system within digital heritage and proposes an operational semiotic method for analysis. Grounded in Modeling Systems Theory and informed by Adorno's non-identity, we construct a twelve-category coding matrix that combines three modeling levels with four organizational forms. Applying this matrix to five heterogeneous cases (web, VR, and 3D environments), we derive three quantitative ratios that summarize each system's profile: the Abstraction Ratio (degree of conceptual mediation), the Connectivity Ratio (degree of interlinking and systematic organization), and the Object Primacy Score (degree of object-centered representation). Exploratory clustering on these ratios reveals three recurrent patterns of virtual-heritage mediation: Network-Symbolic, Concept-Dominant, and Object-Preserving. The results articulate how different curatorial and technical choices redistribute attention between objects, contexts, and concepts, and how these redistributions affect the subject–object balance in digital settings. The contribution is twofold: a transparent, reproducible coding protocol that enables cross-case comparison, and an interpretive lens that relates quantitative patterns to critical concerns in heritage, including authenticity, legibility, and over-standardization. We conclude with implications for curators and designers seeking to align immersive interfaces with heritage values while preserving the irreducible remainder of the object.

Keywords: digital heritage; virtual museum; modeling systems theory; semiotics; subject–object relation; quantitative content analysis; non-identity

Academic Editor: Andreas Aristidou

Received: 15 October 2025
Revised: 5 November 2025
Accepted: 17 November 2025
Published: 18 November 2025

Citation: Guan, H.; Chen, P.; Kwon, C.L. Virtual Museums as Meaning-Modeling Systems in Digital Heritage. *Heritage* **2025**, *8*, 484. https://doi.org/10.3390/heritage8110484

1. Introduction

The virtual museum, as a specialized area of study, has persistently grappled with several contentious and ambiguous issues. Chief among these is the question of the subject–object relationship within the virtual museum [1–6]. While the distinction between thought and its object has always been significant in museum discourse, this issue was less apparent in traditional, physical museums where visitors directly encountered authentic artifacts. In physical galleries, subject (viewer) and object (artifact) met in tangible co-presence. However, the dynamics become significantly more complex in the virtual museum [7], where what is displayed often comprises reproductions or entirely digital artifacts. This shift raises critical questions about the "aura" of original objects, the unique authenticity that, as Walter Benjamin famously argued, is tied to an artwork's presence in time and

space [8]. As materiality gives way to informational representation, objects are increasingly reduced to providers of data [9–12], underscoring the substitution of information for physical substance. Within digital heritage, this raises not only epistemic questions but also practical concerns about how immersive interfaces, data structures, and curatorial choices re-mediate authenticity and legibility for diverse publics.

In traditional museums, the subject–object relationship is typically centered on the object (the exhibit), emphasizing its educational value and the passive role of the audience as recipients [13–16]. Within this framework, the construction of meaning in the museum relies on the audience's perceptual capacity, as only the audience can engage in interpretive, meaningful activity. Hetherington, for instance, has argued that museums, as spaces, shape the subjective interpretations of their audiences and serve as spatial frameworks for the evolution of subject–object dynamics [17]. However, Hetherington also notes that museums are primarily "spaces of the object", relegating the subject to a secondary position [18]. This perspective remains applicable to virtual museums, provided they are considered museum spaces in their own right. Subsequent research, such as that by Bayne, Ross, and Williamson, highlights a shift from object-centeredness to user-centeredness, leading to the decentering of traditional museum frameworks [19]. In this new paradigm, users emerge as co-creators of knowledge. Indeed, studies reveal that traditional views of entangled subject–object relationships face challenges when examined through the lens of material relationality in museums [20]. Certain research, while acknowledging epistemological potential to address object-related issues, critiques its limitations and emphasizes the dependence of artifacts on subjective consciousness [21]. Within these conventional frameworks, visitors are often positioned as "the other", revealing the limitations of Cartesian dichotomies that tend to describe complex relational entities using restricted terminology.

Compared to traditional museums, virtual museums introduce more dynamic interactions between subjects (viewers) and objects (displayed artifacts). Digital interfaces add new layers to the interaction of meaning. Nevertheless, the conceptual limitations of the subject–object relationship persist. For example, describing virtual museums as the "Bodies-On" version of physical museums emphasizes how they alter the experiential dimensions of subjectivity [22]. Such interpretations often involve phenomenological traditions to explain the interplay of embodiment, learning, and technology. However, the very difference between the existence and non-existence of the object being thought about indicates that a completely different concept of relationship is at play here. Furthermore, beyond the interplay of technology and audience, there exist agents (curators, designers, technologists) who construct these systems using technology to discipline and reconfigure the meaning of objects. Such activities do not primarily serve communicative or dialogical purposes but instead reflect a form of hegemony aimed at asserting specific agendas.

The subject–object relationship, deeply rooted in philosophical inquiry for centuries, remains a fundamental problem in philosophical discourse. Virtual museums inject new dimensions into this age-old debate. Their technological nature and interactivity offer opportunities to revisit and explore novel research pathways. The term "virtual museum" itself has been widely applied across numerous projects, yet its conceptualization and definition remain in a state of flux [6,23,24]. Frequently, the term fails to differentiate itself clearly from related concepts such as online archives, digital museums, and cyber museums, all of which imply various forms of "digital" or "online" museum-like entities. Unlike traditional museums, the virtual museum lacks physical collections or exhibition spaces resembling architectural structures [25]. Instead, it represents a digital technology-based service that remains under curatorial control [26], with information technology significantly expanding the curator's capabilities [27]. However, this openness also risks the virtual museum devolving into a series of unending commercialized projects, where

the artistic "aura" is continually mediated and diluted by technological frameworks. In such cases, opportunities for critically engaging with original artifacts are diminished, as the mediating technologies obscure, rather than illuminate, the informational content. The virtual museum thus often functions not as a direct encounter with "things-in-themselves" but as re-constructed external representations, a "mediator of mediators".

To address these challenges, this research adopts a combined framework of semiotics and dialectics. Specifically, the study draws on Thomas Sebeok's Modeling Systems Theory (MST) [28] and Theodor Adorno's dialectical philosophy [29] to explore the theoretical underpinnings of virtual museums. This dual approach is grounded in several key premises. First, the museum itself is a vast semiotic system, and virtual museums are no exception. As described in MST, the virtual museum operates as a complex modeling system. Semiotics provides a foundational lens to examine the intricate sign processes that underpin human cultural systems. MST elucidates how human cognition and social activity are mediated through forms of meaning [28], a principle directly aligned with the objectives of this research, to determine how the virtual museum system functions as a human representation. Before it can facilitate meaning-making, the virtual museum must first establish itself as a constructed, observable entity within the human perceptual framework.

Second, the subject–object relationship remains a central epistemological issue. The critique and reconfiguration of this duality can be addressed through Adorno's materialist dialectics. Adorno's reinterpretation of Hegelian dialectics offers a way to resolve the inherent tensions in the subject–object binary [30]. His approach not only counters Husserl's negation of the process of meaning generation but also compensates for MST's implicit downplaying of the role of the object.

Third, while MST provides a detailed framework for analyzing the internal generation and external representation of meaning, it does not dismiss the significance of external reality [31]. Instead, it embodies a recognition of the fundamental uncertainty of knowledge [32]. MST conceptualizes semiosis (meaning activity) as inherently subject-driven, where the "other" is often constructed within the semiotic system as an entity to be perceived and understood. This systemic classification aligns with Adorno's skepticism toward standardization, a foundational principle in MST that becomes, paradoxically, its meta-concept. The tendency toward standardization in modeling can weaken the specificity of both the artifacts and the virtual museum itself, echoing Adorno's warnings about the cultural homogenization wrought by instrumental reason [33].

Within this combined perspective, our research focuses on resolving the first problem identified earlier: the delineation of the subject–object relationship within the virtual museum. We approach the virtual museum not as a neutral tool but as an active, meaning-generating environment. Regarding the ambiguous term "virtual museum", whether framed as a "collection complex virtually represented" [34] or by other nomenclature, most definitions merely modify existing paradigms without offering substantive replacements. Rather than become mired in definitional debates, we proceed by contextually describing the virtual museum phenomena under study, thereby clarifying our use of the term (cf. Saussure's view [35] that meaning depends on contextual distinctions). With this clarified understanding, we move on to articulate the theoretical framework and methodology by which we analyze how virtual museums model meaning and how non-identity manifests in digital cultural spaces.

We use virtual museum experience as an umbrella term for curated digital experiences with museological intent, including web interactives, 360 tours, VR/AR applications, and 3D simulations. The term virtual museum remains in use for brevity when we refer to the genre as a whole; our analysis concerns meaning-making patterns in these experiences

rather than institutional status. This usage aligns with recent reviews that treat virtual museums as a broad family spanning VR, XR interfaces and web-based mediations [6,10,36–39].

Guided by this framing, we address three questions. RQ1: How do virtual museum experiences distribute modeling instances across MST levels, and what does this distribution reveal about conceptual abstraction? RQ2: How do organizational forms aggregate into connectivity, and how does connectivity relate to abstraction and object primacy across cases? RQ3: When triangulating Abstraction Ratio, Connectivity Ratio, and Object Primacy Score, which meaning-making patterns emerge, and how do they mediate the subject–object relation under Adorno's non-identity? Throughout, virtual museum refers to virtual museum experiences as defined above; where helpful for precision in Sections 3 and 4, we use "virtual experiences" for specific interface instantiations.

2. Theoretical Framework

2.1. Forms of Meaning in the Virtual Museum

The concept of "forms of meaning" discussed in this study is primarily derived from the Modeling Systems Theory (MST) proposed by Thomas Sebeok and Marcel Danesi in their 2000 work, *The Forms of Meaning: Modeling Systems Theory and Semiotic Analysis*. MST extends beyond the Peircean framework of semiosis, which emphasizes the triadic relationship between representamen, interpretant, and object [40]. By employing the notion of modeling, MST addresses the terminological ambiguities inherent in classical semiotics [31], offering a structured explanation of meaning as a flowing, mediated phenomenon. According to MST, semiosis can be redefined as "the capacity of a species to produce and comprehend the specific types of models it requires for processing and codifying perceptual input in its own way" [28]. In this context, a form becomes a model once it is endowed with meaning [31]. This principle is highlighted in the opening of *The Forms of Meaning*:

> "...they are mediated by the innumerable forms of meaning created and conveyed by the words, drawings, artifacts and other models of the world that people make and use routinely. The world of human beings is a de facto world of meaning-bearing forms." [28]

MST posits that models can be both imagined constructs and externally created forms. Modeling, therefore, is an intrinsic cognitive capability [28], enabling humans to produce forms not only through external representational acts but also through internal processes of generating meaning. MST addresses both the external world of artificially created forms, such as artistic expressions or designed artifacts and the internal psychological behavior of modeling, which seeks to generate significance. In other words, MST treats cultural artifacts and mental schemas alike as models employed by humans to interpret reality.

Crucially, MST categorizes the artificial forms specific to human activity into four general types: singularized forms, composite forms, cohesive forms, and connective forms (see Table A1) [28,41]. These forms represent not only external manifestations but also internal strategies of modeling. Sebeok emphasizes that more complex or abstract models evolve from simpler ones, a process he terms the "extensionality principle" [28]. By classifying external modeling behaviors, MST reveals the internal processes of meaning construction that these behaviors entail. In Sebeok's formulation, forms can range from individual signs (like a word or gesture) to elaborate texts or codes, up to figurative assemblages and conceptual networks. This inclusive approach allows phenomena as disparate as a painting, a sentence, a museum exhibit, or a metaphorical narrative to be analyzed under a unified semiotic framework, all are forms modeling some aspect of reality.

The modeling process ultimately results in forms of representation that refer to the world, illustrating how subjects convert sensory input into internal "knowledge" via

modeling. Sebeok delineates three interconnected levels of modeling: primary (PMS), secondary (SMS), and tertiary (TMS), which correspond roughly to Peirce's categories of firstness, secondness, and thirdness [28]. These levels reflect increasing orders of abstraction in symbolic capacity and in the understanding of objective reality. Sebeok's framework fundamentally diverges from Juri Lotman's binary modeling approach [32], although some scholars have argued for retaining Lotman's simpler dichotomy [42]. While Sebeok acknowledges natural language as a modeling system, he contends that it is not a primary system; rather, more foundational nonverbal systems with iconic features underpin it.

The hierarchical nature of MST reveals a progressive evolution from concrete reference to abstraction, with interactions among the levels. MST's principles, such as the extensionality principle and the interconnectedness principle, highlight that higher-level (more abstract) modeling presupposes and builds upon lower-level modeling. In practice, an individual engages all three levels: for example, perceiving an artifact's image (PMS), understanding a descriptive label or story about it (SMS), and situating it within an overarching conceptual narrative or thematic exhibit (TMS).

According to the extensionality principle in MST, a virtual museum experience is often initially an iconic simulation (primary level) before it becomes indicative or symbolic (secondary or tertiary). Undoubtedly, many virtual exhibits and projects involve symbolic content, they can only be created through human representational acts and carry cultural codes. However, the symbolic dimension presupposes iconicity and indexicality. A digital exhibition must first simulate or model reality in some perceivable form before it can convey more abstract meanings. This principle holds true even for cultural heritage digitization, for instance, the Notre Dame Cathedral must first exist in physical space (as an iconic referent), despite its diachronic transformations, to serve as the primary reference for digital sustainability projects built around it. Various digital representations of Notre Dame differ significantly in detail, as they do not replicate all its physical features but instead provide selective visualizations. This aligns with MST's view of modeling: every representation is a transformation that leaves out some aspects of the original; hence "the essence of iconicity is non-iconicity" (see Eco's argument for the codification of iconic/iconicity [43,44]), the model is never the original in full. Even entertainment-focused virtualizations of heritage, such as the portrayal of Notre Dame in the video game *Assassin's Creed: Unity*, modify representations of reality to accommodate interactivity and narrative, constructing what are essentially "possible worlds" [45,46] out of selected elements [47]. Similarly, virtual museums do not simply copy reality; they model it, reflecting both the external world of artifacts and the internal world of curators' interpretive frameworks through digital technology, thereby constructing new interpretative dimensions.

Typically, curators or designers of these systems engage in symbolic modeling when creating a virtual exhibition. They selectively combine and represent elements (text, images, 3D models, sound) to communicate particular meanings. According to MST, once modeling is involved, even if grounded in iconic resemblance, the model inherently deviates from the original referent (hence Sebeok's point that every act of modeling introduces non-iconicity). The process relies on the agency of the modeler (curator or system designer), the specificity of the technology used, and the knowledge of the intended audience. It depends simultaneously on the original referent (e.g., the physical artifact or site) and on the viewer's ability to decode the model, to generate meaning aligned with the goals set by the curators.

MST further emphasizes the relationship between knowledge and its modes of representation [28]. This idea is analogous to the encoding and decoding processes of media, paralleling McLuhan's assertion that "the medium is the message." The "code" of a virtual museum is not simply computer code, but the semiotic code that viewers must grasp

in order to interpret content. For example, understanding a virtual exhibit may require familiarity with its interface conventions and narrative cues, just as reading a newspaper requires knowing its language and format [48]. In essence, discussing the *coding system* of a virtual museum refers to the viewer's ability to decode and generate the intended meanings set by the curator. Often, digital mediation includes explicit instructions or intuitive interface designs to guide the user in this decoding process. The design of interactive systems plays a crucial role in this guidance, appearing as prompts or affordances that assist users in deciphering meaning [48]. Recent syntheses of CH XR map these interface conventions and affordances across AR/VR/MR deployments [36,49].

Such digital mediations are artificially constructed representational systems. Exhibits are modeled through technology into perceivable symbolic forms. Beyond modeling the referents (the artifacts or content), the virtual museum comprises additional layers including user interfaces and interactive components, essentially, human–computer interaction (HCI) elements [50]. These interfaces constitute the operable parts of the representational system, controlled directly or indirectly by the system's creators. In traditional museums, visitors rarely have direct access to touch or manipulate artifacts; the interaction is mainly observational. However, through sophisticated technological mediation and well-designed interactivity, virtual museums enable unprecedented engagement with artifacts that might be otherwise restricted in physical spaces [39]. Prior research has shown that technological mediation can foreground human values and actions [51], fundamentally adhering to human-centered principles [52], in other words, virtual museum interfaces are typically designed around the capacities and preferences of human subjects. Studies in HCI and cultural heritage provide abundant examples of novel interface designs for virtual museums [39,53–58] (for consolidated taxonomies and UX design strategies in cultural-heritage VR, see [59]). The development of advanced interactive technologies, such as VR and AR, has even led museum professionals to envision an idealized future for virtual museums, where immersive mediation is central [23,60].

When simulations take precedence over their referents, the simulation can itself become the perceived reality for the audience. The audience's modeling of exhibits is then heavily shaped by the mediation's performance of meaning, effectively, the medium conditions what meaning can be articulated and what may remain implicit or "unspoken" (much as McLuhan suggested). These mediated possibilities require active implementation by human subjects; within MST, such meaning construction ultimately depends on the will and cognitive framework of the subject, regardless of how we define "subject". The virtual museum medium can suggest and guide but meaning only materializes when a user internalizes the experience through their own modeling processes. Recent reviews of XR and virtual-heritage systems corroborate the need for multi-level, multi-form modeling lenses, documenting the shift from static dissemination to networked, immersive curation and evaluation frameworks in cultural heritage [10,36,59,61–63].

2.2. Meaning Generation, Audience Agency, and Internal Insufficiency

If we recognize that the interpretation of exhibits relies on the cognitive processes of the audience, this process of thought, or semiosis, aligns with the classic notion that communication always involves "some degree of interpretation" on the part of the receiver [64]. From the perspective of MST, this resonates with Yu Hongbing's assertion that:

> "...human semiosis is dependent on logical computations that automatically generate 'meanings' in the same way that computers operate. With some sort of external input (stimuli) perceived from Umwelten, semiosis (sign activity) will take care of the rest of the operations. In some cases, such as introspection

> and meditation, there is even no need for such input, as the attention will be on whatever is cognized in the Innenwelten". [65]

This perspective, rooted in biosemiotics and cognitive science, reflects MST's incorporation of von Uexküll's idea that each subject perceives the external world (Umwelt) in ways specific to its own Innenwelt (internal world). MST expands this concept by emphasizing that perception operates through modeling systems unique to each subject [28]. Yu further argues that meaning generation in humans relies on factors like cultural memory, emotions, and agency [65,66], a position consistent with the arguments of this study. Whether in everyday contexts or within physical or virtual museums, the audience's production of meaning is contingent upon modeling and the reciprocal influence between individuals and their socio-cultural settings. These settings, as noted in field theory, are shaped by the interaction of specific rules, habitual practices, and the symbolic or cultural capital of the agents within the field [67]. Even though subjects can generate meanings seemingly automatically (as if following an internal algorithm), they are inevitably influenced by the iterative interaction between their internal models and external stimuli.

Thus, when a subject reflects on an object seen in a virtual museum, the reflection does not encompass the actual object itself, but rather a modeled interpretation of the object as mediated by the virtual museum. The internalized object (the mental model or image) exists independently of the physical artifact; the model constructed in the viewer's mind is known only to that subject. Such a grasp cannot constitute "knowledge" in the strictest sense if knowledge is taken to mean an objective certainty. This aligns with Yu's critique of MST's inherent epistemological uncertainties [32] and echoes the views of scholars who affirm the conceptual insufficiency of the "aura" in objects once they are removed from their original context [68].

This understanding reveals that meaning generation in virtual museums is fundamentally an individual experience, albeit one situated in a designed environment. From the perspective of modeling, the construction of meaning hinges on semiosis occurring within the viewer. It emphasizes the production and application of models through which the subject—the viewer–develops an understanding of the objectified exhibit. As discussed, virtual museums differ from traditional museums in that meaning generation depends more heavily on the audience's active engagement [69]. This greater reliance on the audience stems from the intrinsic mediating nature of the technology involved. The virtual museum provides not a set of immutable truths, but a platform or possibility space for meaning making. The audience's process of making meaning does not occur through the virtual museum content alone, but through the cognitive model constructed by engaging with that content.

Consequently, the notion of communication as a unidirectional transmission of meaning appears inadequate in this context. There is no guarantee that the target of a transmitted message (the audience) will decode or accept the intended meaning as the curator or designer envisaged. Unidirectional "transmission" thus becomes a hegemonic concept if taken to imply top-down control of meaning. Attempts to measure the effectiveness of such transmission scientifically only reflect the model constructed by the transmitters themselves [70]. Even though contemporary neuroscience and psychology have developed methods to measure esthetic or interpretive experiences [71,72], such experiences remain deeply individual and resistant to broad quantification [73,74]. Therefore, the explanatory framework for virtual museums should center on cognitive modeling rather than on simplistic notions of message transmission [75]. Parallel reviews of virtual tours and online museum design likewise foreground interpretation and evaluation frameworks over one-way transmission [76]. In this view, virtual museums serve as essential conditions for meaning construction rather than as one-way instruments of dissemination.

Within the framework of meaning generation in virtual museums, we can distinguish multiple interdependent roles and perspectives. Our analysis identifies seven such roles across the curatorial and audience sides (building on earlier discussions of subject positions in the virtual museum):

1. The virtual museum system itself occupies a central, intermediary position as a represented and constructed virtual entity (the "mediator of mediators").

On the curatorial side:

2. The curator's own cognition, i.e., the curator as a subject with knowledge, biases, and intentions (a knowledge level that informs everything they do).
3. The curator's conceptualization of the virtual museum—how the curator imagines and models the virtual platform as a medium (including its capabilities and constraints).
4. The curator's conceptualization of the audience—assumptions and models about who the viewers are, what they know, and how they might interpret the content.

On the audience side:

5. The audience's self-concept—the viewer's pre-existing cognitive models, prior knowledge and expectations (which they bring into the museum experience).
6. The audience's conceptualization of the virtual museum—how the viewer understands the platform/interface and its authority or reliability (e.g., do they treat it like a real museum? a game? an educational tool?).
7. The audience's modeling of other subjects—how the viewer perceives and models the curator (or authors) and potentially other virtual visitors or commentators, mediated by the virtual museum (for instance, through interactive features or social sharing).

Central to this structure is the virtual museum itself as an active model, an objectified representation that both curators and audiences engage with. The virtual museum can be seen as the result of curatorial modeling activities and simultaneously as the input for audience modeling activities [77].

According to modeling theory, meaning lies not in the content itself but in how that content is understood by someone. If a representation (like a virtual exhibit) is intended to convey meaning, that meaning only truly exists when generated by a viewer, listener, or user [48]. It is not enough for the transmitter (curator or system) to produce meaning for its own sake; otherwise, the process becomes a mere soliloquy. However, acknowledging the audience's role does not necessarily privilege the audience as an all-powerful interpreter either; rather, both transmitter and receiver occupy equivalent positions as modeling agents with their respective cognitive worlds (Innenwelten). The meaning generated in virtual museums thus stems from an interplay: it originates in the curator's modeling of content and is completed in the audience's re-modeling of that content. In fact, audience-driven meaning-making may at times bypass the curator's explicit intentions, arising instead through the user's embodied exploration within the virtual environment.

In this sense, the classical concept of "transmission" becomes inadequate or even misleading. Within the context of the virtual museum, meaning generation by the audience is better described as an embodied activity of interpretation and re-creation. Among the seven roles outlined, the virtual museum occupies a pivotal middle position. The curator's vision of an exhibit or a virtual experience often begins as an amorphous concept, human cognition cannot independently articulate such amorphous ideas without externalization [78]. These ideas take shape through modeling processes and require a medium to become concrete. Technology provides the curator with a medium for materializing visions, serving as a generative extension of thought constructing a "possible world" that acts as a mediator of mediators, the virtual museum itself becomes a model that mediates other models.

Unlike language, which MST identifies as a secondary modeling system, the virtual museum here can be viewed as a tertiary system (cf. Sebeok and Danesi 2000, 83–85 [28]). It is highly specific in its purpose, with clear referents, yet it is also abstract in that it encapsulates complex esthetic, historical, and technical values. It is undeniable that meaning generation within virtual museums relies heavily on the semiosis of both curators and audiences. However, this process often occurs in what might be described as a dialogical soliloquy, a structured but one-sided conversation. If museums aim not only to generate meaning but also to facilitate exchange, then in virtual museums this exchange is less open dialog and more a constrained monolog with two participants. The curator "speaks" through the medium; the audience "responds" through interpretation. In this process, the physical object may be absent or represented only by data, subject-subject interactions are mediated and often asynchronous, and the internalized object concept in the viewer's mind remains ultimately private and uncertain.

Within the meaning generation framework of virtual museums, it becomes clear that all participants and components are interrelated. As earlier outlined, the curator's cognition informs the creation of the virtual museum, which in turn frames the audience's experience. The audience's interpretation can only operate on what the virtual museum presents. The virtual museum's content is the result of curatorial choices (the curator's modeling), and that content is transformed into personal meaning through the audience's modeling. This loop suggests a hermeneutic circle of sorts: curators anticipate audiences, who reconstruct curator intentions, all mediated by technology. The roles of curator and audience, though distinct, are mutually dependent and defined through their relationship with the virtual museum medium.

In many discussions of museums, terms like curatorial subjectivity, audience agency, or even intersubjectivity arise. Yet focusing only on the human subjects (curator and audience) risks overlooking the active role of the museum-as-medium in shaping meaning. If these perspectives aim to illuminate dynamic meaning-making, they must account for the virtual museum's own agency in the process. Traditional Cartesian dualisms might regard the museum as a passive backdrop for interactions between curator and viewer, but as we argue and as Adorno would agree, this is a misleading simplification. The virtual museum appears to provide a space for free interaction with subjects, but it is itself an actor in that space, embodying choices and constraints. From Adorno's perspective, such Cartesian separations are to be critically rejected [79]. Adorno asserts that the subject is never a purely rational, isolated entity but is inherently intertwined with objects; likewise, objects, especially cultural objects, carry imprints of subjectivity. In the context of virtual museums, the seven interrelated roles we described, while analytically distinct, form a dynamic and interdependent network that resists reduction to any single axis of subject or object.

2.3. Subject–Object Critique: Non-Identity and the Dialectics of Meaning

Adorno's philosophy of non-identity offers a crucial critical lens to understand the phenomenon unfolding in virtual museums. For Adorno, non-identity refers to the idea that the concept or the subject's categorization can never fully capture the richness of the object; there is always a remainder that escapes identification [29]. This inherent insufficiency of the concept means the object cannot be wholly reduced to subjective thought without loss. Adorno thus emphasizes a dialectical approach that gives precedence to the object's specificity. However, this object primacy does not imply ignoring the active roles of audience or curator as subjects, nor does it invalidate the earlier framework of mediated roles. Instead, giving dialectical priority to the object means acknowledging that

meaningful engagement begins from something external to the subject's mind, the object "speaks" through its otherness.

In an Adornian reading of virtual museums, the object's precedence lies in its entry into the subject's cognitive field through a process of reflection. The artifact (or its digital surrogate) is apprehended via the subject's modeling activity; meaning emerges when the subject reflects on models which are themselves products of thought. In other words, the virtual exhibit as an object enters consciousness not in raw form but through modeled representation, yet it retains a non-identical element, aspects not fully determined by the subject's concept. The moment of meaning occurs when the subject's concept and the object's particularity confront each other.

Habermas famously critiqued Adorno's stance on object primacy, arguing that if objects are given too much precedence, the autonomy of the subject (and intersubjective reason) is diminished [80]. While Habermas's critique raises important points about the need for communicative reason, Adorno would counter that the more a subject isolates itself from real relations with objects and others, the more it loses its own substance as a subject. Conversely, by relinquishing a domineering stance and truly encountering the object's otherness, the subject can actually strengthen its own position [79]. In Adorno's dialectical framing, object primacy is not absolute but a moment in a process: first, the subject must allow the object to exert influence to be more than just a subjective construct, and then the object can be understood as if it had a "voice" or agency of its own (quasi-subjectivity). Adorno deliberately refrains from collapsing the subject–object distinction entirely in language; he maintains the distinction as a necessary tension while constructing a new logic of thought within the subject that recognizes the non-identical.

In museum studies and practice, it is evident that both the audience and the curator are implicated in meaning-making. The virtual museum, as the result of curatorial modeling, inherently reflects the curator's subjectivity [81–83]. At the same time, it is built for an audience and thus anticipates an audience's subjectivity. The virtual museum stands between them as a structured object. If one were to limit the virtual museum's role to a mere conduit or technical platform, one would overlook the complexity of its semiotic system and its dual role in meaning production. The virtual museum is not just an empty channel; it is an authored, content-rich environment, an object that is continuously interpreting and representing other objects. To reduce it to a neutral tool is to devalue the cultural and artistic representations it embodies, a perilous stance that can lead to ignoring how technology shapes interpretation.

Adorno warns that when the intrinsic qualities of the object are disregarded, the object risks being reduced to a mere instrument, subject to domination by the subject's will [79]. This reflects a broader power dynamic: instrumental reason leads to the unchecked expansion of control over both nature and culture [33]. Habermas notes that a traditional epistemological stance emphasizing only the subject's cognitive activity while neglecting the object's independent existence aligns with Enlightenment assumptions he critiques [84]. Although Habermas himself rejects Kantian transcendental subjectivity, he still largely attributes agency and meaning-making to the subject. MST, in a parallel way, tends to categorize all perceivable phenomena as potential modeling outputs of a subject. Such frameworks, whether in critical theory or semiotics, risk exhibiting a lack of trust in the object, a skepticism towards anything not generated by the subject's rational or cognitive process. They harbor an implicit doubt about what lies beyond the subject's conceptual grasp.

From both MST's perspective and Adorno's, we accept that the subject can never fully apprehend the external in its entirety whether that external is physical objects or other subjects. There is always an unknowable aspect, a remainder. Adorno insists that

the external, be it objects or the "other" demands engagement on its own terms and a form of coexistence, rather than a relentless assertion of subjectivity over it. This stance is why, in our analysis, the virtual museum itself is treated not just as a passive medium but as an existing system (an object) that actively participates in knowledge processes. It is a concretization of knowledge, though "distorted and reshaped" by those processes. Addressing interactions between curators and audiences thus requires acknowledging the virtual museum as an object with its own structuring influence in meaning-making.

The task of the subject (curator or audience) is to recognize and respond to expressions that come from objects or other subjects, rather than only to project one's own intentions. In a virtual museum context, this means the curator cannot rely solely on instrumental rationality to dictate meaning, because the digital representations themselves, being models, have qualities and effects beyond the curator's full control. These representations are products of representational activities and have a life of their own once released to the audience. A purely instrumental rationality that tries to engineer a single "correct" meaning in the audience is bound to fail or misfire, because interpretation escapes total planning. As Adorno would say, such rationality, being an abstraction model itself, cannot be treated as absolute reality. Adorno thus shifts our focus back to the object itself, in our case, the virtual museum content and the original artifacts it mediates. His philosophy of non-identity emphasizes that the relationship between subject and object is not a simplistic opposition but a complex interplay of mutual constitution. In virtual museums, the roles of curators and audiences are not fixed essences; they are continuously reshaped through their interaction via the museum. For example, curators construct exhibition content through the virtual medium (imparting their interpretive structures into it), while audiences reinterpret that content through their own cognitive models, potentially altering its significance. Conversely, audience feedback might influence curators' future designs. In this dynamic, the virtual museum is both a space for subject interaction and, in a sense, a manifestation of object agency [85,86].

To clarify certain aspects of the virtual museum's "field": in traditional museology, the focal element is the exhibit (object). In the virtual museum functioning as a "mediator of mediators," we have a two-stage mediation: the first mediator is the exhibit itself, the artifact or content, already a mediated representation of culture or nature; and the second is the virtual museum that re-mediates this content. The former (exhibit) is a conceptualized intermediary, while the latter (the digital platform) reconstructs and reinterprets this concept. Within MST terms, both can be seen as models or results of modeling processes. Adorno argues against reducing all phenomena to standardized mediation, emphasizing instead the specificity of objects [29]. In essence, whether we consider exhibits or whole art collections, these intermediaries gain meaning only through their connection to what is being mediated. This aligns with Saussure's notion that meaning arises from relations and context rather than inherent properties [35]. Thus, intermediate representations (like a virtual exhibit) require a primary referent, an original or real-world counterpart to anchor the mediation and be comprehensible to interpreters. Virtual museums, as mediators of mediators, must therefore also prioritize the first mediator (the artifact or primary content) to achieve effective mediation. In other words, even if an audience encounters an artifact for the first time virtually with no knowledge of the original, the virtual museum should clarify its relationship to that original referent. As long as the virtual museum elucidates its connection to the material or historical reality it represents, there is no need to fear that the virtual will completely supplant the real (the virtual can enrich understanding rather than replace the original context). Audience studies suggest that users can distinguish the museum as medium from the content and still value the museum experience itself [87], meaning they recognize the layers of mediation.

If a virtual museum instead confuses or obscures the connection to its referents, for instance, prioritizing flashy simulation without context, its primary meaning-making becomes about concepts rather than about concrete referents. Technological mediation risks reifying concepts into an impression of reality. While concepts (virtual models) facilitate understanding, such understanding is rooted in the conceptual framework itself rather than the full reality of the object. To truly approach the object, one must move beyond the concept to acknowledge what lies outside it what the concept fails to capture, which for Adorno is where the "authentic object" of knowledge resides. From this perspective, the virtual museum is inherently insufficient as a substitute for reality, but this insufficiency is not a failure of technology per se; it stems from the fundamental limitations of human cognition and representation. No model, however advanced, can exhaust the reality it models. Recognizing this is key to avoiding the trap of instrumental reason in virtual museology. They should leverage sophisticated modeling techniques to present cultural content (embracing their nature as tertiary modeling systems), but they must also remain critically aware of the gap between model and reality (honoring non-identity).

The next sections will translate this framework into a concrete methodology for analyzing virtual museum meaning systems and then present an empirical analysis that reveals how different virtual museums embody or neglect these principles.

3. Materials and Methods

To investigate meaning-making dynamics in virtual museum experiences, we developed a methodology grounded in Modeling Systems Theory's levels and forms of modeling, combined with a content analysis approach. The goal was to systematically capture how virtual museums construct meaning and how subject–object relationships are configured within them. This section outlines our research design, including case selection, coding scheme, reliability measures, and the derived metrics used for comparing cases.

3.1. Case Selection

Five representative virtual experiences were selected to encompass a broad range of cultural contexts and technological platforms. This purposive sample spans Western, East Asian, and Global South contexts, ensuring that insights are not limited to a single cultural paradigm. We also included a mix of VR-based, 3D immersive, and web-based virtual museum experiences, reflecting the spectrum of technologies employed in the field. Table 1 summarizes the selected cases and their key characteristics. Additional sampling criteria are described in Appendix C (Sample Selection Criteria).

Table 1. Selected cases and key characteristics.

Case	Intro
Case A: British Museum Bronze Age VR Experience (UK, VR).	The British Museum's first virtual reality weekend exhibit (2015) which allowed visitors to virtually enter a Bronze Age roundhouse and examine 3D-scanned artifacts in situ. This case represents a Western national museum using VR to enhance storytelling around real objects.
Case B: The Museum of the World—British Museum/Google (UK, Web Interactive).	An interactive timeline and world map of objects curated by the British Museum in partnership with Google Arts & Culture. This browser-based experience links thousands of objects across time, geography, and themes in a highly networked interface.

Table 1. *Cont.*

Case	Intro
Case C: Digital Beijing Central Axis (China, 3D/VR).	A digital heritage project presenting Beijing's Central Axis, a newly UNESCO-inscribed World Heritage site through immersive media. It integrates 3D models of architecture and AR/VR elements to convey the "ideal order" of the historic capital. This East Asian case highlights a concept-driven virtual reconstruction of urban heritage.
Case D: Virtual Angkor (Cambodia, 3D Simulation).	An educational 3D simulation of the city of Angkor around 1300 CE, created by a collaboration of historians and technologists. It recreates the sprawling metropolis at the height of the Khmer Empire's power, allowing exploration of environments and scenarios (e.g., a stone workshop, temple rituals) in a game-like interface.
Case E: National Museum of the D.R. Congo Virtual Tour (DRC, 360° Web Tour/VR).	A virtual tour of the National Museum in Kinshasa, developed in partnership with tech firms to enable remote 3D exploration of galleries and artifacts. Viewers can navigate the museum's interior with high-resolution 360° imagery or VR headsets. This Global South case exemplifies an object-preserving approach, virtually replicating a physical museum for broader access.

These cases were chosen to illustrate a range of meaning-modeling strategies, from highly object-centric presentations (Case E), through interactive networks of context (Cases A, B), to heavily conceptual reconstructions (Cases C, D). Each case can be seen as a "virtual museum" for the purposes of analysis, even if some (like B) are not traditional museums but digital experiences curated with museological intent.

3.2. Coding Scheme: Modeling Levels and Forms

We analyzed each case by breaking down its content into discrete "model instances", units of content or interactive components that carry meaning, examples include an individual 3D artifact model, a panoramic scene, a narrative text panel, an interactive map widget, etc. Each instance was coded along two dimensions derived from MST.

First is three-level modeling, Primary (iconic, directly representing something real), Secondary (indexical/contextual, building associations or narrative around primary content), or Tertiary (symbolic/abstract, representing conceptual or thematic constructs).

Second is four model forms, Singularized (a single sign or unit of meaning, e.g., a standalone image or object), Composite (a combination of elements forming a compound message, e.g., an exhibit that groups multiple items or a multi-media sequence), Cohesive (a structured system that provides an overarching form, e.g., the interface logic or storyline that binds content together), or Connective (a form that explicitly links different models or contexts, e.g., a hyperlink, an interactive map connection, or a metaphor bridging content). For consolidated definitions and illustrated examples of all three modeling levels and four forms, see Appendix A (Table A1).

Each "level-form" dyad captures the role an instance plays in the meaning system. For example, a photorealistic 3D model of an artifact would be coded as Primary-Singularized; a virtual gallery room containing several artifacts arranged to tell a story might be coded as Secondary-Composite because it combines items with spatial context to convey a narrative or comparison; a site-wide search function or timeline linking disparate objects would

be coded as Tertiary-Connective; a VR environment's underlying simulation engine or narrative arc could be seen as Tertiary-Cohesive.

The coding schema was developed iteratively. First, an initial codebook of definitions and examples for each level and form was created (see Appendix A for the complete twelve-category coding matrix and definitions). We then pilot-tested the coding on a subset of content from two cases to refine category boundaries. For instance, distinguishing secondary vs. tertiary levels can be subtle, we used cues like whether the content primarily extends a real-world context (secondary) or introduces a self-contained conceptual layer (tertiary). Similarly, distinguishing composite vs. cohesive forms required judging if something is simply an assemblage of parts (composite) or an overarching structure/rule (cohesive). Any ambiguous instances were discussed among researchers to reach consensus definitions.

To ensure reliability of the coding, two researchers independently coded a 10% sample of the model instances from each case (selected randomly), approximately 30 out of a total ~300 instances across all cases. Using a standard intercoder reliability assessment on this sample is a common practice in content analysis to validate the scheme [88]. In line with recommended approaches [89], we calculated Cohen's kappa for the level codes and form codes. The overall agreement was high: kappa = 0.82 for modeling level (indicating almost perfect agreement) and kappa = 0.79 for model form (substantial agreement). Disagreements were examined and resolved; the codebook was adjusted slightly for clarity before proceeding with the full coding. These reliability metrics give confidence that the coding scheme can be consistently applied. After establishing reliability, one researcher completed the coding of all instances, with spot-checks by a second coder to prevent drift. Detailed coding procedures and the full intercoder reliability protocol are provided in Appendix C (Methodological Notes).

3.3. Quantitative Metrics

From the coded data, we derived three quantitative metrics to summarize key aspects of each virtual museum's meaning-modeling profile:

- Abstraction Ratio (AR): A measure of the degree of conceptual abstraction in the content. We operationalized AR as the proportion of modeling instances coded at the tertiary level out of all instances in a case. This ratio indicates how much the virtual museum relies on symbolic or highly abstract modeling (e.g., overarching narratives, gamified experiences, conceptual metaphors) as opposed to more direct or contextual representation. A higher AR suggests a more concept-dominant approach, whereas a lower AR suggests content stays closer to direct representation of objects or straightforward context.
- Connectivity Ratio (CR): A measure of how networked or interlinked the content is. We defined CR as the proportion of instances coded as cohesive or connective forms out of all instances. These two forms (cohesive and connective) both deal with linking multiple elements: cohesive forms provide systematic structure, like unified interfaces or consistent design languages; and connective forms explicitly link disparate elements, like interactive links or relational metadata. A higher CR indicates a highly interconnected meaning system, the virtual museum encourages nonlinear exploration and synthesis (a "network-symbolic" quality), whereas a lower CR indicates a more discrete, isolated presentation of content.
- Object Primacy Score (OPS): A measure devised to capture the emphasis on original artifacts or direct object representation. We calculated OPS as the proportion of instances at the primary modeling level (iconic representations) out of all instances. This serves as an indicator of how strongly the virtual museum foregrounds authentic

objects or faithful reproductions thereof, relative to more interpretive content. A high OPS means the virtual museum is largely object-preserving (the bulk of content is direct depiction of artifacts or tangible elements), whereas a low OPS means the virtual museum gives primacy to concepts, context, or narrative over raw object display. In Adorno's terms, OPS reflects the degree of "object precedence," how much the real object is allowed to "speak for itself" in the virtual space.

Formal definitions of AR, CR, and OPS are compiled in Appendix B (Glossary of Key Terms). AR relates to MST's level distinctions and Adorno's notion of conceptual abstraction; CR relates to MST's form distinctions and the idea of a networked (nonlinear) museum discourse; OPS directly relates to the subject–object balance and Adorno's object primacy concept. While these ratios simplify complex content, they provide a useful overview that can be correlated with qualitative observations. They allow us to see patterns, such as whether high abstraction correlates with lower object primacy, or whether strong connectivity coexists with certain levels of abstraction.

For transparency, categories contribute to metrics as follows. OPS counts all Primary-level instances; CR counts all Cohesive and Connective instances at any level; AR counts all Tertiary-level instances. Consequently, some categories contribute to two metrics: Primary-Cohesive and Primary-Connective contribute to both OPS and CR; Secondary-Cohesive and Secondary-Connective contribute to CR only; Tertiary-Cohesive and Tertiary-Connective contribute to both AR and CR. All other categories contribute to denominators only. We provide an enumerated summary of all twelve categories and their ratio contribution in Appendix A, Table A2.

Finally, to identify overarching typologies among the cases, we performed an exploratory clustering of the cases based on the three metrics. Given only five cases, this was done primarily by examining distances in the 3-dimensional space of (AR, CR, OPS) and confirming with a hierarchical cluster analysis (Ward's method) for objectivity. In the resulting dendrogram (Figure 1), the first merge occurs between B and D (Euclidean distance ≈ 0.206), after which C joins that cluster at a height of ≈ 0.328; A merges next, and E remains the most distant case. Rows (cases) are clustered with Ward.D2 (Euclidean); columns (AR, CR, OPS) are not clustered. Darker tones indicate higher values. Note that this procedure privileges geometric proximity in the AR, CR, OPS space; it does not by itself adjudicate curatorial intent or evidential warrants. We read this dendrogram as an empirical prompt, highlighting how metric proximity may diverge from curatorial, concept-dominant affinity rather than a definitive typology.

The dendrogram indicates the closest empirical proximity between B and D, followed by the addition of C at a higher distance.

Reflecting this, we classify B and D as Network-Symbolic (high CR with moderate-to-high AR and non-trivial OPS), C as Concept-Dominant (very high AR with moderated CR and low OPS), and E as Object-Preserving (high OPS with low AR/CR), with A as a mixed, object-preserving-leaning case. Note that some interpretive features in D (e.g., macro-historical narration) resemble C's concept-dominant stance, which explains prior discussions pairing C and D; our classification follows the metric geometry (B-D proximity) while keeping that interpretive kinship explicit in the case discussions.

The next section presents the analytical results and interprets the dendrogram in relation to the proposed modeling patterns.

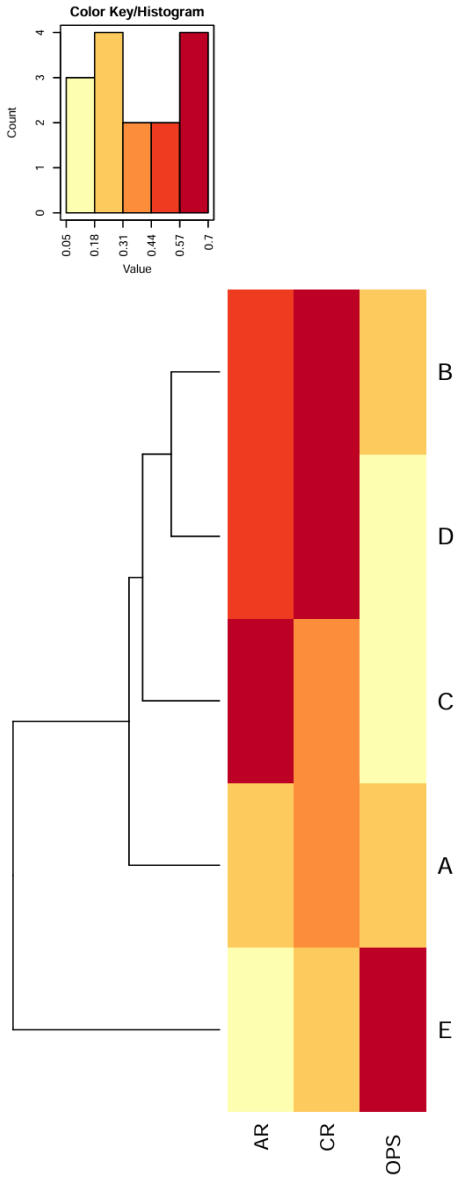

Figure 1. Ward hierarchical clustering of the five cases based on AR, CR, OPS.

4. Dialectical Patterns in Virtual Museum Experience Meaning Construction

In this section, we present the empirical findings of our analysis, focusing on how the five cases instantiate different patterns of meaning-modeling. We begin by briefly describing each case's content and notable features, then examine the coding results and metric values, and finally identify three typological clusters of virtual museum meaning systems. We interpret each cluster through the dual lenses of MST modeling and Adorno's dialectics, shedding light on how virtual museum experiences negotiate or fail to negotiate the tension between conceptual mediation and object authenticity.

4.1. Case Descriptions and Coding Results

4.1.1. Case A: British Museum Bronze Age VR (UK)

This virtual reality experience takes visitors into a simulation of a Bronze Age roundhouse, where three excavated objects, a dagger, gold earrings, and a "Sussex loop" bronze item, are placed in their putative original domestic context. Users, wearing VR headsets, can look around the hut, see a virtual fire burning, and inspect the digitally reconstructed

artifacts up close. Meanwhile, museum curators offer commentary in parallel real-life gallery talks. In our coding, Case A had a mix of Primary instances (the 3D artifact models are iconic reproductions of real finds) and Secondary instances (the contextual environment: the hut, fire, ambient sounds, which indexically situate the objects in time and place). A few Tertiary elements were present as well, such as the interactive affordances and the underlying narrative premise (e.g., using VR to "travel back in time" involves a conceptual framing beyond the immediate context). In terms of forms, the scanned artifacts were singularized forms, each presented individually, while the whole hut environment was treated as a composite form combining artifacts with setting. The VR application itself acted as a cohesive form, a structured program guiding the experience. Case A's metrics reflect these: a moderate Abstraction Ratio (the content remains fairly concrete, AR = 0.30), a moderate Connectivity Ratio (CR = 0.40, mainly from the cohesive VR system linking objects and context), and a noticeable Object Primacy Score (OPS = 0.20, since a portion of content is direct artifact representation).

4.1.2. Case B: Museum of the World (British Museum/Google)

This web-based interactive timeline is richly networked. Users navigate an interface where dots represent artifacts from around the world, positioned along a timeline and across continents. Clicking on a dot opens an object's description, images, and often an audio clip by a curator. Crucially, the interface draws connections between objects: for example, one can filter by themes like "leadership" or "trade" to see items from different cultures linked by concept or see what else was happening globally when a given object was made. In our analysis, Case B contained a high number of Tertiary modeling instances, the entire timeline system and thematic linking are conceptual constructs far removed from any single artifact's physical reality. It also includes Secondary elements, such as textual descriptions and curatorial commentary providing context to each artifact. The artifacts themselves are Primary representations. For forms, each artifact entry (image + text) is a singularized form; the thematic or temporal groupings of multiple artifacts act as connective forms (explicit links across items); the interface framework, timeline, filters, map is a cohesive form providing structure. We did not identify many simple composites, because content is either singular or massively connected. Quantitatively, Case B exhibits a high Abstraction Ratio (AR = 0.50, reflecting the significant presence of conceptual linking over simple depiction), a high Connectivity Ratio (CR = 0.60, owing to numerous interactive links and a cohesive global timeline that encourages nonlinear exploration), and a moderate Object Primacy Score (OPS = 0.30, since about a third of instances are the artifact images themselves, the rest being connectors or context). This profile suggests a strongly Network-Symbolic approach: meaning emerges from the network of relationships among objects rather than from the objects in isolation, aligning with an interactive and comparative mode of engagement.

4.1.3. Case C: Digital Beijing Central Axis (China)

This project digitizes the Beijing Central Axis, a sequence of historic sites running through the old city including the Forbidden City, Temple of Heaven, etc., and presents it through immersive media. The digital experience allows users to explore virtual reconstructions of architecture and urban space, often supplemented by narrative explaining the cosmological and cultural "order" that the axis represents. It is as much an interpretation of an idea "the city's ideal layout" as it is a presentation of individual buildings. In coding Case C, we found a prevalence of Tertiary instances: for example, a virtual panoramic view aligning all the monuments, which is something impossible in reality but symbolically emphasizes the alignment, this is a tertiary construct highlighting the concept of "ideal

order." Likewise, any gamified or stylized representation, a mini-map or schematic of the axis, would be tertiary. There were relatively few strictly primary elements, since the project is not about individual artifacts but about a spatial concept though detailed 3D models of buildings can be seen as primary iconic representations of those buildings. Secondary elements include historical anecdotes or photos embedded to give context to sites. In terms of forms: the project's entire digital city model acts as a cohesive form (an integrated simulation), specific compound scenes like a temple interior with interactive hotspots function as composite forms, and any linking, for instance, jumping between sites or comparing past/present, would be connective. The metrics for Case C show a very high Abstraction Ratio (AR $\approx$ 0.70), indicating an intensely concept-driven experience. The Connectivity Ratio is more moderate (CR $\approx$ 0.40) because, while the project is unified, it may be relatively guided/linear (one follows the axis top to bottom) rather than freely networked. The Object Primacy Score is low (OPS $\approx$ 0.10), reflecting that the focus is not on autonomous objects but on a conceptual narrative and virtual reconstruction. This firmly places Case C in the Concept-Dominant cluster: meaning is dominated by the overarching idea (cosmic order of the city) facilitated by extensive abstraction, with the original "objects", buildings in their actual state largely subordinate to the digital re-imagining.

4.1.4. Case D: Virtual Angkor (Cambodia)

This project provides a simulated world of Angkor, incorporating 3D models of temples, landscapes, and population. It is used as an educational tool, with modules that highlight different aspects of 14th-century Angkor life. The environment is rendered with attention to historical detail, but inevitably choices are made to visualize uncertain aspects like the appearance of ordinary wooden houses, which left few traces. Our coding of Case D found a significant number of Secondary instances, much of the content is an attempt to contextualize known artifacts (e.g., placing bas-relief art in situ on temple walls, or animating scenes described in inscriptions). However, Tertiary modeling is also prominent, the entire act of filling in gaps to create a living city, and the narrative framing for educational use, are highly symbolic. For example, one module invites users to walk through Angkor's streets. This "experiential narrative" is a tertiary construct overlaying modern imagination onto historical data. There are few pure Primary instances except perhaps static depictions of artifacts like statues or reliefs shown as part of the educational content. Virtual Angkor's interface allowing jumping between viewpoints or activating informational overlays, introduces connective and cohesive forms. For instance, a guided tour mode that moves through locations is a cohesive script; an interactive map to choose locations is a connective hub. The metrics for Case D indicate a high Abstraction Ratio (AR ~0.55), a relatively high Connectivity Ratio (CR ~0.60), and a very low Object Primacy Score (OPS ~0.10 or lower). While the narrative orchestration introduces concept-dominant risks, Case D's strong connective tissue and distributed linking place it empirically with the Network-Symbolic group.

4.1.5. Case E: National Museum of the D.R. Congo Virtual Tour

This case represents a straightforward digital twin of a physical museum. The virtual tour consists of panoramas of the actual museum galleries, through which users can navigate, zoom in on displayed objects, and read captions. Essentially, it mirrors the real museum in digital form. We coded many instances here as Primary: each artifact on display is present as a high-resolution image or 3D point in the panorama, these are direct visual representations of real objects (iconic modeling). Additionally, each panoramic viewpoint is like a "bubble" that gives an authentic spatial context also largely iconic of the real space. Some Secondary modeling comes in through text labels which provide context or

interpretation and the sequencing of the tour. Hardly any Tertiary content is added, the tour does not introduce new narratives beyond what the physical museum had, nor does it gamify or metaphorically link content; it strives for realism and authenticity. In terms of forms: singularized forms are dominant, each individual artifact or display case is its own unit to examine; composite forms appear as one moves from one exhibit grouping to another; the virtual tour platform provides a cohesive form, it's a consistent interface, arrows to move, a floorplan for navigation; connective elements are minimal aside from the ability to jump via the floorplan, which is a mild connective feature letting users skip to different rooms. The quantitative profile of Case E underscores its Object-Preserving nature: Abstraction Ratio is extremely low (AR $\approx$ 0.05, essentially negligible symbolic layer beyond the straight documentation), Connectivity Ratio is also low (CR $\approx$ 0.20, since the experience is mostly linear or spatially contiguous rather than richly hyperlinked), and Object Primacy Score is very high (OPS $\approx$ 0.60, indicating well over half the instances are direct representations of artifacts). This means the virtual museum here prioritizes letting the objects speak for themselves in their original curatorial arrangement. Indeed, Africell's project description emphasizes extending the museum's reach while preserving heritage and narrative integrity. The virtual DRC museum exemplifies a philosophy where the virtual medium's role is to faithfully deliver the object to the audience, with minimal reinterpretation or added layers.

Table 2 below compiles the metric results for each case. AR = fraction of instances that are tertiary level; CR = fraction of instances that are cohesive/connective forms; OPS = fraction of instances that are primary level (object-focused).

Table 2. Quantitative profile of each virtual museum case.

Case	Region/Tech	Abstraction Ratio (AR)	Connectivity Ratio (CR)	Object Primacy (OPS)
A. British Museum VR (UK, VR)	Western, VR experience	0.30 (moderate)	0.40 (moderate)	0.20 (low-moderate)
B. Museum of the World (UK, Web)	Western, web interactive	0.50 (high)	0.60 (high)	0.30 (moderate)
C. Digital Central Axis (China, 3D)	East Asian, 3D/VR heritage	0.70 (very high)	0.40 (moderate)	0.10 (very low)
D. Virtual Angkor (Cambodia, 3D)	Global South (Asia), 3D sim	0.55 (high)	0.60 (high)	0.10 (very low)
E. DRC Museum Tour (DRC, Web/VR)	Global South (Africa), 360°	0.05 (negligible)	0.20 (low)	0.60 (high)

4.2. Typological Clustering of Meaning Systems

Analyzing the above results and observations, we identify three salient types of meaning-modeling patterns:

- Network-Symbolic Museums: These are characterized by high connectivity and considerable symbolic abstraction, while still incorporating a mix of object representation. Cases B (Museum of the World) clearly falls here, and Case A (BM VR) shows some affinity albeit with lower abstraction. In these systems, knowledge is constructed through a network of relationships; the meaning emerges from how elements are connected across time/space/themes rather than from the elements alone. The "symbolic" aspect refers to the heavy use of tertiary modeling, conceptual frameworks like timelines, global maps, or narrative metaphors shape the experience. The presence of real artifacts is still important, but they are embedded in a rich matrix of links and conceptual overlays. This type aligns with an interactive, exploratory paradigm. It resonates with Adorno's idea of a "constellation" of concepts around an object rather than a single defining idea, here the object's meaning is approached via multiple connections, acknowledging it cannot be reduced to one context. However, the

risk is that the network of references itself might become reified; users might hop from object to object, skimming meanings, possibly treating the whole network as an infotainment web.

- Concept-Dominant Museums: These feature very high abstraction and typically moderate connectivity, with low emphasis on original objects. The hierarchical clustering pairs D with B at the nearest-neighbor level, with C joining subsequently; this as a prompt for interpretation, not a final classifier. This reading distinguishes local proximity in the dendrogram from conceptual patterning across all three ratios, which is why we treat B-D as nearest neighbors while interpreting C-D as the clearest exemplars of the high-abstraction profile. Here, a unifying concept or narrative dominates the design, be it the "ideal city" or an immersive historical story. The virtual museum becomes a narrative or simulation environment. The actual artifacts or factual authenticity may be secondary; they serve the story more than the story serves them. Connectivity may be present (Virtual Angkor allows exploration), but often within a controlled narrative flow. This type is akin to a virtual exhibit as a coherent story or theme. The advantage is a strongly coherent interpretive message and potentially deep engagement in one narrative. However, from a dialectical perspective, this runs the risk of what Adorno would call identity-thinking: the concept (the narrative of Angkor, or the curatorial thesis) subsumes the object completely. The object's non-identity, the parts of the artifact's meaning that do not fit the story are suppressed. Instrumental reason is at play: technology is used to enforce a certain interpretation, albeit for education or entertainment. Such experiences might be very engaging, but they can sacrifice the open-ended, critical engagement that museums traditionally aspire to. The missing element is the object's ability to surprise or contradict the narrative.
- Object-Preserving Museums: These are marked by low abstraction, low connectivity, and high object primacy. Case E (DRC virtual tour) represents this cluster, and to an extent some traditional online collections or simple museum websites would as well. The design philosophy is to showcase objects with minimal interpretation beyond what a physical museum would provide. The virtual museum acts almost as a high-fidelity mirror of a real museum or collection database. Users can examine artifacts, often getting closer via digital zoom than in person, and read catalog information, but they are not led far beyond that. It resists imposing too much conceptual structure, thereby reducing the chance of misrepresenting the object. It also aligns with MST at the primary level, focusing on iconic representations. The experience can be akin to walking through a museum quietly, valuable for access, but potentially overwhelming or under-explained for those without prior knowledge. The dialectical shortcoming here, from an Adornian view, could be that it leaves the subject relatively passive, or conversely, it leaves meaning entirely up to the subject's own background, if the museum doesn't provide connections, the user might not make any new ones. This approach avoids the pitfalls of overt instrumentalization, but it may also miss opportunities to illuminate by context or to engage broader narratives that give objects significance.

It is worth noting that these categories are not airtight compartments; some virtual museums have hybrid traits. For instance, the British Museum's VR (Case A) was network-symbolic in some respects (multi-modal, linking to gallery talks, etc.), but also maintained object focus.

The Network-Symbolic type could be viewed as a dialectical synthesis of sorts; it attempts to mediate between the concrete object and abstract concepts by placing objects in a web of multiple concepts and by encouraging active exploration, thus partially handing agency to the audience. The Concept-Dominant type corresponds to a case of conceptual

identity overshadowing the object. In Adorno's terms, the object is fully subsumed under the subject's (curator's or designer's) concept, risking a form of cultural "industry" where uniqueness is lost in a standardized narrative. The Object-Preserving type represents a reaction against over-conceptualization, it holds on to the object's uniqueness (non-identity) but possibly at the expense of greater understanding or engagement.

4.3. Theoretical Interpretation: MST Modeling Meets Adorno's Dialectics

The empirical patterns identified above can be interpreted through the combination of MST's modeling theory and Adorno's critique of instrumental reason. Each cluster demonstrates a different dialectical pattern in how meaning is constructed:

In Network-Symbolic cases, many particular objects and facts are brought into relation with broader themes and categories (universals) without a single one consuming the rest. This recalls Adorno's notion of a constellation, the truth of the object emerges from viewing it under multiple aspects, none of which alone is adequate. For example, an artifact in Museum of the World can be understood in relation to time, geography, and theme simultaneously, giving it dimensionality. The technology here acts as a facilitator for multi-perspectival viewing (a potentially non-dominating use of technology). However, if the interface simply provides a slick, smooth experience that the user consumes without friction, it could become what Adorno and Horkheimer described as part of the "culture industry", an experience that, with an air of free choice, disguises standardization [90]. The British Museum–Google interface, for instance, is highly user-friendly and visually pleasing. Does it encourage critical reflection, or just clicking through a curated set of connections? There is a tension, on one hand, networked exploration can empower users to find their own meaning paths (aligning with a non-authoritarian approach); on the other, the network is pre-structured by the museum, the selection of objects and themes is curated, which could lull users into a false sense of comprehensiveness, a kind of pseudo-individualization [91], where one feels one is choosing freely but the choices are anticipated by design. The dialectical opportunity here is to use the network to reveal complexity and contradiction (e.g., showing conflicting interpretations or provenance issues among linked objects [92]) rather than to create a seamless package of knowledge.

In Concept-Dominant cases, the dialectic of subject and object is heavily skewed toward the subject (curator/designer). These virtual museums reflect what Adorno called the identifying tendency of the Enlightenment subject, to subsume the world under its concepts [90]. Virtual Angkor, for all its educational value, constructs a world in which everything has meaning insofar as it fits the narrative of Angkor at its peak. There is little room for what is not known or what doesn't fit the glorious reconstruction. In reality, there are ambiguities and unknowns about Angkor that a more self-reflexive design could highlight, for instance, there could be markers indicating where evidence is scant and the visualization is speculative. In Adorno's terms, a concept-dominant virtual museum might inadvertently present a totalized image of history or culture, echoing the totalizing systems he critiqued. On the MST side, these cases leverage tertiary modeling strongly creating elaborate possible worlds, which showcases the power of human modeling capacity. Yet MST also warns implicitly that these models are models, not reality. If the audience takes the simulation at face value, the result is a reification of the model. The critique of instrumental reason comes in when we ask: why was this simulation created and presented in this way? Often to engage and educate but also possibly to entertain or to market cultural heritage in a palatable form, instrumentalizing heritage to hold attention. The dialectical pattern here might be described as thesis without antithesis, a strong curatorial thesis is put forward, and the medium doesn't encourage questioning it. For a healthier dialectic, even these narrative experiences could incorporate moments of reflection.

In Object-Preserving cases, the object is presented largely in isolation, with minimal conceptual mediation. Adorno would appreciate the respect for the object's particularity here, the museum is saying, "Here is the thing itself, we will not subsume it under grand narratives." This allows the object's uniqueness to persist (non-identity in a literal sense, it is not forced into identical form with others). However, purely object-centric presentations run the risk of mute particularity, the object's meaning potential is not realized if the subject does not engage or lacks context to interpret it. In Adorno's philosophy, while the object should not be violated by simplistic concepts, it still needs a dialectical process with the subject's thought for meaning to emerge. Without any concepts or relations, the object "speaks" only in a whisper that many might miss. In MST terms, sticking to primary modeling and raw data means we might not progress to the richer secondary and tertiary modeling that humans naturally use to make sense of things. The DRC virtual tour's relative lack of connective tissue requires the user to bring their own knowledge or curiosity. If they do, it can be rewarding. If they don't, the experience might be underwhelming or confusing. The challenge for object-preserving approaches is to introduce just enough secondary or tertiary mediation to guide understanding without imposing too much interpretation. For instance, the DRC tour could include optional audio from community members or scholars about select objects like mini testimonies, providing context (a bit of secondary modeling) while still focusing on the object and its significance (the object is primary, but now in a relational network of voices, albeit still relatively contained).

To visualize the relationships among curator, audience, and virtual museum in these patterns, we offer a simple conceptual diagram (Figure 2) of the dialectical triangle formed by these actors. The curator–museum side involves curation and design (the curator models content in the virtual museum); the museum–audience side involves interaction and interpretation (the audience engages and interprets via the virtual medium); the curator-audience side represents potential dialog (feedback, shared understanding). In different virtual museum types, the balance of these relationships shifts. For example, concept-dominant puts heavy weight on curator to museum, while object-preserving relies on audience to museum.

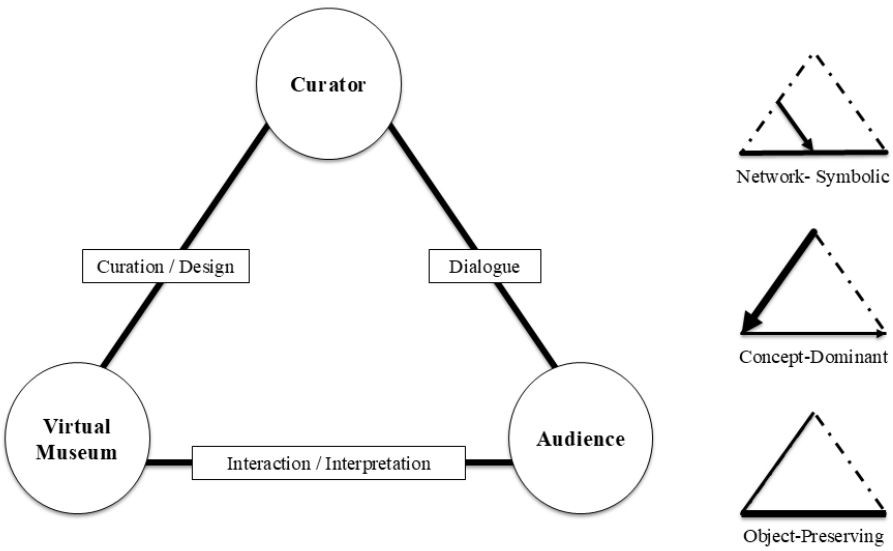

Figure 2. Dialectical relationship in a virtual museum.

In network-symbolic approaches, the Audience–Virtual Museum interaction is especially emphasized (heavy user exploration) but guided by the Curator–Museum design (the network structure built by curators). In concept-dominant ones, the Curator–Museum link is strongest (curator's narrative heavily determines the museum's form), and the

Audience's role is more to absorb the designed experience (weaker audience agency). In object-preserving contexts, the Museum–Audience link is straightforward (the museum simply presents objects to the audience), with relatively minimal curatorial imprint beyond selection and basic arrangement (curator's presence is subtle, and audience's interpretation might be personal/inward, not explicit in the system).

A robust dialectical approach to virtual museums would seek to strengthen all sides of the triangle. That means empowering the audience's active interpretation, without losing curatorial scholarship, making the curator's presence transparent and open to dialog (e.g., explaining rationale, inviting feedback), and having the virtual museum system facilitate two-way interaction, not just delivering content, but possibly capturing user input or providing multiple modes.

The typological clustering and dialectical interpretation suggest that virtual museum meaning systems can be tuned along dimensions of abstraction, connectivity, and object emphasis. Each configuration has trade-offs. Taken together, the spectrum we propose remains intact: B-C-D occupy the concept-network side of the space, A is intermediate, and E is object-preserving; the divergence between geometric clustering (B-D first) and interpretive pairing (C-D) is analytically productive and is made explicit in the text. The next sections will discuss these implications further, considering what the theoretical and empirical findings together tell us about virtual museums as mediators of cultural meaning, how MST's framework holds up when tested empirically, and how Adorno's concept of non-identity and critique of instrumental reason can inform the future design and study of virtual museums.

5. Discussion

5.1. Theoretical Implications

The successful application of MST's levels and forms to real-world (or rather, virtual world) cases demonstrates that semiotic modeling can serve as a rigorous analytical tool in museology. We were able to systematically dissect complex digital experiences into modeling categories, revealing the underlying structure of meaning-making. This suggests that MST, originally formulated for general semiotics, is highly applicable to the multi-media, multi-modal domain of virtual museums. It extends the idea that museums are fundamentally semiotic spaces. Every exhibit, interface, or narrative is a sign or model representing some aspect of culture or knowledge.

Our MST-based coding brought to light patterns like heavy tertiary modeling or connective forms that might not be obvious with a less formal analysis. For example, identifying a high proportion of tertiary modeling in a given virtual museum immediately flags that the experience is concept-heavy and possibly less rooted in direct reality. This, paired with Adorno's theory, raises a red flag about potential "conceptual supremacy", exactly the kind of situation where non-identity might be undermined.

Virtual museums that maximize interactivity and user choice (like the network-symbolic ones) might embody a more dialectical museology, aligning with progressive ideals of visitor agency and multi-vocal interpretation. This resonates with constructivist learning theories in museum studies, where learners construct knowledge actively [93]. Our analysis suggests that such designs, if done thoughtfully, can approximate Adorno's vision of not fully circumscribing the object with one concept but rather approaching it from multiple angles. In practice, this means supporting interpretive plurality. A dialectical virtual museum embraces the idea that no single narrative about an object is final; instead, it provides a platform for many partial narratives to intersect, an idea supported by earlier semiotic scholars like Hodge and D'Souza, who showed that museum meanings are a result of complex interactions of signs [94].

Conversely, virtual museums that present a seamless, closed narrative (concept-dominant) illuminate what Adorno warned about the culture industry in a new light. It's not just Hollywood films or pop music that can have a formula, even an educational VR can become formulaic if it leaves no room for user interpretation or objects' specificity. Instrumental reason can manifest in virtual heritage as the drive to make content maximally engaging and controlled, possibly at the cost of authenticity and critical engagement. This underscores the importance of critical museology perspectives (cf. Witcomb 2007 [4]) that stress the need for reflexivity in exhibition design.

Bridging MST and Adorno gives us a more comprehensive theory of virtual museum mediation. MST provides the structural understanding (the "how" of meaning-making structures), and Adorno provides the critical understanding (why those structures matter ethically and epistemologically). A theoretical proposition emerging from this study is that the quality of meaning in a virtual museum is a function of its modeling balance. If we denote primary content (P), secondary context (S), and tertiary concept (T), an ideal dialectical museum might maintain a dynamic equilibrium: enough P to stay grounded in objects (Adorno's object), enough S to situate those objects (contextual knowledge), and enough T to inspire broader connections (conceptual insight) but not letting any one level dominate absolutely. Similarly, among forms, it would blend singular, composite, cohesive, connective forms to enable both focus on particulars and understanding of wholes.

This dynamic view aligns with the idea of museums as "contact zones" [95] or dialogic spaces. The virtual museum can be seen as a mediator of mediators as we called it, and theoretically that means it should mediate between subject and object in a way that neither is eclipsed. Adorno's non-identity tells us the object should never be fully consumed by the subject's models; applied to MST, it suggests no matter how advanced our tertiary modeling, we should remain aware of, and perhaps even highlight, the gap between the simulation and reality. Some cutting-edge virtual museums are indeed doing this by including meta-commentary on their own reconstruction process (e.g., showing what data is missing, or showing alternate reconstructions) [10,36,38,49]. Our work adds empirical backing to these theoretical calls, showing diverse examples of what happens when you do or don't incorporate that reflexivity.

5.2. Empirical Findings and MST Validation

From an empirical standpoint, our study produced tangible data on how virtual museums differ in meaning construction. One key finding is that the MST-based metrics (AR, CR, OPS) effectively discriminated between different types of virtual museum experiences. It shows that even complex multimedia experiences can be analyzed in terms of fundamental semiotic patterns [10,36]. Our approach quantifies some of those differences. For instance, a game-like immersive reconstruction will have high AR and likely low OPS, whereas a database-like collection site will have low AR and high OPS. In that sense, our results offer a methodological contribution: future researchers or evaluators of virtual museums could use similar coding to diagnose the strengths and biases of a given project. This is akin to what usability experts do with user experience metrics, but here it's about meaning metrics.

The patterns we found across the five cases also point to broader trends in the field around 2025. Many high-profile virtual museum initiatives (like Google collaborations) favor a connective, global approach to content. This is in line with the ethos of the internet age, emphasizing interconnected knowledge and cross-cultural comparison. Virtual museology is trending toward platforms that break disciplinary or geographic silos and encourage thematic exploration. This supports Werner Schweibenz's observation that virtual museums often strive to be more accessible and networked than physical ones [6].

On the other hand, traditional object-oriented principles are not dead; they persist especially where authenticity is paramount (as in the Congolese museum case, likely driven by a preservation ethos). The low AR and high OPS of that case underscore that, despite tech possibilities, some projects choose restraint, focusing on digitization quality over fanciful features. This underscores digital collections can maintain the "aura" of objects by fidelity and context rather than spectacle [25].

A notable empirical insight is the heavy reliance on tertiary modeling in many virtual museums. Three of our five cases had AR ≥ 0.50, meaning at least half of what they present is at the highest abstraction level. This indicates that storytelling and conceptual framing are central to most virtual museum experiences. It's rarely just raw data. Empirically, a collection without narrative is just a database, and many virtual museums try to be more than databases by adding narrative layers [27]. The risk, as we discussed, is when that narrative overwhelms the data. But the prevalence of tertiary content suggests that to engage audiences, virtual museums feel the need to step beyond showing artifacts to telling stories or conveying messages (be it education, identity, a moral about cultural theft).

Another point is interactivity does not always correlate with object emphasis. Our results show that the most interactive cases (B and D) were not the ones with high OPS. In fact, they had moderate or low OPS. The highest OPS case (E) had relatively low connectivity. This might mean that deep object-centered engagement in a virtual medium is often achieved through straightforward viewing tools (zoom, rotate models, etc.) rather than highly networked interactions. Meanwhile, highly networked experiences incorporate lots of content that isn't the object per se (like maps, categories, stories). Networks connect multiple objects and context, hence by nature they shift focus among them rather than delving into one. This empirical observation highlights a potential trade-off in design, do we want the user to really spend time with a single artifact (deep dive), or to traverse across many artifacts (broad exploration)? Rarely can an interface optimize for both simultaneously. Perhaps future designs might attempt layered approaches where a user can do both.

Even with five cases, the differences were stark enough to cluster reliably. This suggests our sample, though limited, covered the extremes and a middle ground effectively. Possibly, most virtual museums out there might be combinations or variations in these archetypes. Future studies with more cases could test if these three clusters hold across a larger universe of projects. If so, it could be akin to a classification system for virtual museums in terms of their meaning approach, like how we classify museums by type (art, science, history), we could classify virtual museums by meaning-modeling type.

5.3. Non-Identity in Digital Cultural Spaces

Our investigation into non-identity, the idea that objects and concepts are never fully equivalent is particularly salient in the digital context. Digital representations are often treated as surrogates for real objects. A recurring question in digital heritage is, does the digital copy replace the original, augment it, or distort it? Adorno's non-identity gives us a philosophical stance, the digital model is not identical to the original, there is always something that escapes.

Much debate revolves around whether a digital artifact can be authentic [15,96–98]. Adorno's lens shifts authenticity discussion to relational, authenticity is about whether the representation allows the object's otherness (its context, its full being) to be sensed or whether it fully assimilates it to concept. In practical terms, a highly stylized VR that just entertains might be seen as less authentic in this sense, whereas a thoughtfully contextualized 3D model with caveats might be more authentic.

Our study also extends Adorno's critique of instrumental reason into a contemporary technological domain. Instrumental reason in culture often manifests as using culture as a means, for profit, for propaganda, or at least for simplified consumption. Virtual museums could fall into an "edutainment" trap where everything must be fun, digestible, and sponsor friendly. The British Museum's partnership with Google (Case B) is extremely polished and user-friendly, but one might ask, does Google's design optimize for serendipitous deep thought, or for quick, gratifying nuggets (so users stay on the platform)? Spiegelhalter highlights that metrics themselves reflects the model-maker's mindset [70]. If a virtual museum's success is measured in clicks or time spent, designers will instrumentally tweak it for those metrics, possibly at the expense of contemplative engagement. That would be instrumental rationality creeping in.

Non-identity in digital cultural spaces thus becomes an ethical principle, to design with respect to the irreducibility of cultural objects and narratives. It means designing interfaces that encourage users to reflect on what they cannot see or do in the virtual environment, not only on what they can. This might involve incorporating emptiness, ambiguity, and user-generated questions into the experience, rather than presenting a shiny totality.

One promising approach in line with non-identity is the inclusion of multi-vocal content, e.g., indigenous community voices about an artifact alongside academic voices. That shows that no single concept (the curator's or the community's) exhausts the object; instead, the object sits at the intersection of many interpretations. In MST terms, that multiplies the modeling processes (different interpreters, different models), preventing any one from claiming absolute truth, an enactment of non-identity.

5.4. Limitations and Future Research

While our study yielded significant insights, it is important to recognize its limitations. First, the sample size and selection, we examined five cases, chosen to represent diversity and noted projects. This is a small fraction of the ever-growing universe of virtual museum initiatives. Our sample spans virtual museum experiences both affiliated with physical institutions and stand-alone heritage productions; the typology concerns experience-level meaning structures. Our clusters and findings, though plausible, would benefit from testing against more examples. For instance, where would we classify a virtual museum that uses a social media platform, like a museum in Minecraft or on Instagram? User-generated content could increase connectivity and unpredictability. Also, we didn't explicitly include an augmented reality example. AR museum experiences might lean towards object-preserving, since they are in the presence of real objects but with added digital context [99], a space possibly between object-preserving and network-symbolic.

Secondly, the coding process, while reliable, inevitably involved some subjective judgment. Distinguishing levels or forms is not always black-and-white. We addressed borderline cases through coder discussion, but other researchers might code a particular element differently. Still, the coding scheme could be refined, more granularity in levels (e.g., distinguishing different types of tertiary modeling, did we lump all symbolic content together, when in fact conceptual narrative vs. thematic classification vs. theoretical commentary are different flavors of tertiary content?). Future research might expand the scheme or correlate it with user perceptions: do users sense these differences? E.g., do they find some experiences "more abstract" and does that correlate with our AR measure? That would validate that AR affects user experience.

Another limitation is that we did not incorporate user study data. Our analysis is content-centric. But actual user research could reveal, for example, that a highly networked interface confuses certain audiences or that an object-preserving site only satisfies experts.

Investigating how different meaning-modeling styles affect learning outcomes, emotional impact, or satisfaction would be a valuable extension. It can also test Adorno's claims: does a concept-heavy VR lead to less critical thinking than a more open-ended one? It's plausible but should be empirically tested via, say, interviews or think-aloud studies with users experiencing each type.

Additionally, we focused on web and VR mainly; mobile apps or virtual museums in games or metaverses are another realm. For example, the "Animal Crossing Museum" might have interesting MST coding. Possibly more playful and less rigorous. Our framework could be applied there.

In terms of MST itself, future research could refine our metrics. The abstraction ratio, connectivity ratio, etc., were simple proportions. They weighed each coded instance equally. But in reality, not every element is of equal importance (a main immersive scene might carry more weight than a small text blurb). One could weigh instances by estimated user attention or centrality in interface, maybe using analytics if available, or designations of primary/secondary content. Also, connectivity ratio could be expanded to differentiate cohesive vs. connective contributions. Perhaps cohesive (structured narrative) vs. connective (hyperlink network) have different effects, though both count as linking. A network where user chooses paths (connective) might foster more agency than a strict cohesive linear story. Our CR lumps those, which is a simplification.

We should also acknowledge that our alignment of patterns with "better" or "worse" in dialectical terms is somewhat interpretative. A concept-dominant experience might still be very valuable for certain goals. So while we critique it from a philosophical angle, in practice there are trade-offs. Future research or design could strive to combine the strengths, e.g., have an immersive narrative but include moments of user choice or reflection to break the smoothness. Perhaps similar in VR: occasionally remind the user this is a model. These innovative design ideas need both theoretical justification and user testing.

As technology evolves (AI, more sophisticated personalization, etc.), new modeling phenomena will emerge. For example, if an AI curator personalizes the virtual museum for each user like recommending objects based on profile, that introduces a kind of algorithmic modeling layer, one our analysis didn't cover. Adorno's pseudo-individualization in a new form, as Pariser's "filter bubble" concept suggests. There is already research [92] on algorithmic curation meaning.

Revisiting RQ1-RQ3, the distribution of levels across cases differentiates concept-dominant and object-preserving tendencies (RQ1); connectivity aggregates differently across interface families and co-varies with abstraction but not monotonically with object primacy (RQ2); triangulation of AR, CR, OPS yields the three patterns reported, with the B-D proximity clarifying the Network-Symbolic type (RQ3). Finally, our sample is dominated by experiences affiliated with physical museums; independent virtual-heritage productions warrant a dedicated follow-up [37]. Accessibility and inclusion remain critical design axes [100]; the same holds for metaverse-native deployments, where social presence and persistence introduce new modeling layers [38,101].

As the merging of semiotic and critical theory proved fruitful, future research can carry that spirit forward, perhaps looking at other critical lenses (post-colonial theory, feminist theory) on virtual museum content. One could modify the codebook to also track perspective or narrative voice, adding a sociocultural dimension to MST's more formal categories. While limited in scope, our research provides a foundation and a set of tools that future scholars can refine and apply broadly, ensuring that as virtual museums proliferate, we have the means to evaluate and guide them in line with both semiotic richness and philosophical integrity.

6. Conclusions

Virtual museums are increasingly prominent as spaces of cultural knowledge production, and our study demonstrates that analyzing them through the joint prism of semiotic modeling and critical theory yields deep insights. We began with the observation that the virtual museum is a "mediator of mediators", a phrase encapsulating its dual role: it mediates between traditional museum content (artifacts, narratives) and audiences, and it also mediates between human cognition and digital representation. Our findings, both theoretical and empirical, reinforce this characterization and add nuance to it.

On one level, the virtual museum indeed functions as a dynamic modeling system that constructs a "possible world" of meaning. We saw how curators (or designers) model content at primary, secondary, and tertiary levels, using forms that range from singular exhibits to extensive interactive networks. On another level, this system operates dialectically: meaning is not produced by technology alone or by curators alone or by audiences alone but by the interaction of all three within the mediated space. Curators imbue the virtual environment with structure and narrative; audiences enter with their own models and actively interpret; and the technology shapes what can be done or seen. When balanced, this triad can transcend a simplistic subject–object dichotomy, yielding a collaborative meaning-making process where objects (and their digital likenesses) are given room to "speak" and subjects (curators and viewers) engage in dialog rather than monolog.

Our expanded theoretical framework underscores that a virtual museum is neither merely a repository of digitized artifacts nor purely a product of curatorial intent. Instead, it is a dialectical arena where technology, human agency, and cultural objects converge. By applying Adorno's concept of non-identity, we highlighted the importance of preserving the otherness and specificity of cultural objects even within highly modeled virtual experiences. The empirical patterns, whether network-symbolic, concept-dominant, or object-preserving, each carry lessons. The most fruitful approaches appear to be those that avoid the extremes of rigid narrative or total fragmentation, instead fostering an environment where multiple connections can be made without losing sight of the unique value of each artifact. A concrete instantiation is a hybrid path that begins with object-preserving cores (high-fidelity models and close-looking tools) and then unfolds a network-symbolic layer that lets visitors pivot among multi-scalar relations (time, region, theme) while exposing link provenance.

Our research validates the "mediator of mediators" thesis: the virtual museum mediates not just between objects and audiences but between different layers of meaning (sensory, contextual, conceptual) and between different stakeholders' perspectives. In doing so, it has the potential to become an autonomous system of cultural production. Virtual museums are not passive windows into reality; they actively shape the trajectory of meaning. For instance, a virtual exhibit may bring artifacts together that would never meet in a physical museum, creating new contexts and interpretations, an act of cultural production in its own right. At the same time, if designed with reflexivity, the virtual museum can make users aware of its own mediation, encouraging a critical stance that aligns with the goals of education and cultural reflection. When curators leverage MST's insights to design multi-layered, multi-form content and simultaneously heed Adorno's warnings by keeping the mediation transparent and the object central, the virtual museum can transcend being a "cool tech gimmick" and truly function as a new epistemic platform. It can engage audiences in dialogical soliloquy, a conversation with themselves, the content, and the makers rather than a one-way transmission.

This study's comprehensive analysis from abstract philosophy to concrete interface details contributes to a more mature understanding of virtual museums. It reinforces that as we digitize and virtualize cultural heritage, we must remain conscious of the balance between innovation and authenticity, between narrative and openness, and between subject

and object. A virtual museum is most powerful when it does not simply continue the paradigms of the traditional museum in digital form but when it reimagines museum experiences in a way that acknowledges and exploits the unique strengths of digital technology (interactivity, connectivity, immersion) while also critically addressing its weaknesses (the risk of detachment from reality or overwhelming simulation).

The virtual museum stands as a testament to human creativity in meaning-making, a tertiary modeling system that encapsulates and extends the forms of meaning that humanity has always built, from cave paintings to cabinets of curiosity to grand national museums [5]. As we have shown, understanding it requires both a structural lens (semiotic modeling) and a critical lens (philosophy of non-identity and instrumental reason). By retaining both, scholars and practitioners can ensure that the virtual museum evolves as a medium that not only informs and entertains but also enlightens and challenges, fulfilling its promise as a mediator among mediators, a bridge between worlds, and ultimately a platform for a richer, more dialectical engagement with culture in the digital age.

Author Contributions: Conceptualization, P.C. and H.G.; Methodology, P.C.; Writing—original draft, H.G.; Writing—review and editing, C.L.K. and P.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: We would like to thank the anonymous reviewers and editors for their advice and work. We would also like to thank Hongbing Yu at Toronto Metropolitan University for his guidance during the writing of this study.

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

Appendix A. MST-Based Coding Schema for Virtual Museum Content Analysis

This appendix presents the comprehensive coding framework used to analyze virtual museum content based on Modeling Systems Theory (MST). The framework operates as a matrix combining three hierarchical modeling levels with four distinct model forms, yielding twelve analytical categories for systematic content classification.

Appendix A.1. Overview of the Coding Matrix

MST posits that human meaning-making occurs through the interaction of modeling levels (primary, secondary, and tertiary) with modeling forms (singularized, composite, cohesive, and connective). This creates a twelve-cell matrix (Table A1) that captures the full spectrum of semiotic possibilities in virtual museums. Each cell represents a unique combination of representational level and organizational form, providing a nuanced framework for understanding how virtual museums construct and convey meaning. For a per-category view that lists typical examples and metric contribution, see Table A2.

Table A1. Four model forms across three modeling levels.

	Singularized Modeling	**Composite Modeling**	**Cohesive Modeling**	**Connective Modeling**
Primary modeling system (PMS)	iconic sign	iconic text	iconic code	Metaform
Secondary modeling system (SMS)	secondary singularized modeling (extensional modeling, indicational modeling)	secondary composite modeling	secondary cohesive modeling	Meta-metaform
Tertiary modeling system (TMS)	Tertiary singularized modeling (symbol)	Tertiary composite modeling	Tertiary cohesive modeling	Meta-symbol

Table A2. Enumerated categories and metric contribution.

Level	**Form**	**Category**	**Ratio Contribution**
Primary modeling system (PMS)	Singularized Modeling	Primary-Singularized	OPS
Primary modeling system (PMS)	Composite Modeling	Primary-Composite	OPS
Primary modeling system (PMS)	Cohesive Modeling	Primary-Cohesive	OPS, CR
Primary modeling system (PMS)	Connective Modeling	Primary-Connective	OPS, CR
Secondary modeling system (SMS)	Singularized Modeling	Secondary-Singularized	none
Secondary modeling system (SMS)	Composite Modeling	Secondary-Composite	none
Secondary modeling system (SMS)	Cohesive Modeling	Secondary-Cohesive	CR
Secondary modeling system (SMS)	Connective Modeling	Secondary-Connective	CR
Tertiary modeling system (TMS)	Singularized Modeling	Tertiary-Singularized	AR
Tertiary modeling system (TMS)	Composite Modeling	Tertiary-Composite	AR
Tertiary modeling system (TMS)	Cohesive Modeling	Tertiary-Cohesive	AR, CR
Tertiary modeling system (TMS)	Connective Modeling	Tertiary-Connective	AR, CR

Note. Ratio contribution indicates inclusion in numerator for Object Primacy Score (OPS), Connectivity Ratio (CR), and Abstraction Ratio (AR). All categories contribute to denominators. See Appendix C.3 for metric definitions.

Appendix A.2. Primary Modeling System

Primary modeling operates at the level of direct, iconic representation, maintaining clear resemblance to real-world referents through sensory-based signs.

1. Iconic Sign (Primary-Singularized): Individual iconic representations that function as discrete units of meaning. In virtual museums, this category includes standalone

photographs of artifacts, individual 3D scans of objects presented in isolation, single architectural elements reproduced digitally, and discrete visual representations of collection items. For example, in the DRC Museum virtual tour, each high-resolution image of an individual artifact viewed through the panoramic interface constitutes an iconic sign.

2. Iconic Text (Primary-Composite): Combinations of iconic elements that create compound representations while maintaining direct resemblance to reality. This category encompasses virtual gallery spaces showing multiple objects together, panoramic views combining multiple architectural elements, composite 3D scenes recreating historical spaces, and grouped artifact displays maintaining spatial relationships. The British Museum VR's Bronze Age roundhouse, combining multiple authentic 3D object scans within a reconstructed dwelling, exemplifies iconic text.
3. Iconic Code (Primary-Cohesive): Systematic frameworks for organizing and presenting iconic content according to consistent rules. This includes standardized 3D modeling conventions, uniform photographic documentation systems, consistent virtual space navigation protocols, and systematic visual representation standards. The 360-degree panoramic system used throughout the DRC Museum tour represents an iconic code, providing a cohesive framework for experiencing the physical museum space.
4. Metaform (Primary-Connective): Linking mechanisms that create relationships between discrete iconic representations. Examples include visual comparison tools for artifacts, morphological linking systems showing object evolution, visual genealogies of artistic styles, and image-based search functions. When the Museum of the World allows visual comparison between artifacts from different cultures through side-by-side display, it employs metaform structures.

Appendix A.3. Secondary Modeling System

Secondary modeling introduces indexical and contextual relationships that extend beyond direct representation, building interpretive frameworks around primary content.

1. Secondary Singularized Modeling (Extensional/Indicational): Individual contextual elements that provide interpretive information for specific objects or spaces. This category includes individual object labels and descriptions, single historical contextualization notes, discrete provenance records, and standalone interpretive texts. In Virtual Angkor, individual explanatory panels describing specific architectural features represent secondary singularized modeling.
2. Secondary Composite Modeling: Grouped contextual elements that create interpretive frameworks through combination. Examples include thematic exhibition narratives combining multiple objects, historical timelines integrating various artifacts, comparative cultural analyses, and multi-object storytelling sequences. The British Museum VR's combination of curatorial commentary with multiple Bronze Age objects creates secondary composite modeling.
3. Secondary Cohesive Modeling: Overarching interpretive systems that provide consistent contextual frameworks throughout the virtual museum. This encompasses unified curatorial voices across exhibitions, consistent historical periodization schemes, standardized educational frameworks, and systematic interpretive methodologies. Virtual Angkor's consistent approach to explaining Khmer architectural principles across different temple sites demonstrates secondary cohesive modeling.
4. Meta-metaform (Secondary-Connective): Complex linking systems that connect interpretive contexts across different content areas. This includes thematic pathways linking diverse cultural contexts, comparative interpretation tools, cross-cultural ana-

lytical frameworks, and networked scholarly annotations. The Museum of the World's ability to connect objects through interpretive themes like "power" or "belief" across cultures exemplifies meta-metaform structures.

Appendix A.4. Tertiary Modeling System

Tertiary modeling operates at the highest level of abstraction, creating symbolic and conceptual frameworks that organize and reinterpret lower-level content.

Tertiary Singularized Modeling (Symbol): Individual symbolic or conceptual elements that convey abstract ideas. This category includes isolated conceptual metaphors, individual symbolic representations, discrete theoretical frameworks, and standalone abstract visualizations. In the Beijing Central Axis presentation, individual symbolic representations of cosmic order function as tertiary singularized models.

Tertiary Composite Modeling: Combined symbolic elements creating complex conceptual narratives. Examples include overarching thematic exhibitions, integrated conceptual storylines, composite symbolic interpretations, and multi-layered theoretical presentations. Virtual Angkor's reconstruction of daily life scenarios combining multiple speculative elements represents tertiary composite modeling.

Tertiary Cohesive Modeling: Comprehensive conceptual systems providing unified abstract frameworks for entire virtual museums. This encompasses overarching museum philosophies, integrated theoretical approaches, unified conceptual navigation systems, and systematic symbolic architectures. The Beijing Central Axis's consistent presentation of ideal urban order throughout the experience exemplifies tertiary cohesive modeling.

Meta-symbol (Tertiary-Connective): Abstract linking systems connecting symbolic and conceptual content across boundaries. This includes philosophical connection systems, theoretical framework integrations, conceptual network visualizations, and abstract relational databases. The Museum of the World's temporal-geographic matrix that allows users to explore abstract connections between human societies represents meta-symbolic structuring.

Appendix A.5. Application Guidelines

When applying this twelve-category framework, analysts should first identify discrete content instances within the virtual museum, then classify each according to both its modeling level and form. The modeling level is determined by the degree of abstraction from physical reality: primary for direct representation, secondary for contextual extension, tertiary for conceptual abstraction. The modeling form is identified by examining how content elements relate to each other: singularized for independent units, composite for meaningful combinations, cohesive for systematic frameworks, connective for linking mechanisms.

Boundary cases should be resolved by considering the primary function within the virtual museum system. Content serving multiple functions should be coded according to its predominant role in meaning construction. The framework's matrix structure ensures comprehensive coverage while maintaining analytical precision.

Appendix B. Glossary of Key Terms

Abstraction Ratio (AR): The proportion of content instances coded at the tertiary modeling level (AR = (tertiary instances)/(total instances)) within a virtual museum, indicating the degree of conceptual and symbolic representation relative to more concrete representational modes.

Cohesive Form: A model form that provides systematic organizational frameworks governing how content is structured and accessed within the virtual museum environment.

Composite Form: A model form combining multiple elements to create emergent meanings through the relationships between components.

Connectivity Ratio (CR): The proportion of content instances exhibiting cohesive or connective forms, measuring the degree of systematic organization and interlinking (CR = (cohesive + connective)/(total instances)) within the virtual museum.
Connective Form: A model form creating explicit links between disparate elements, enabling networked exploration and relationship discovery.
Dialectical Mediation: The dynamic process through which meaning emerges from the interaction between subjects and objects, rather than being determined by either alone.
Extensionality Principle: MST's principle that complex models develop from simpler ones, with higher-level modeling systems building upon and extending lower-level systems.
Iconic Code: The primary-cohesive category representing systematic frameworks for organizing direct representational content.
Iconic Sign: The primary-singularized category consisting of individual direct representations of real objects or spaces.
Iconic Text: The primary-composite category combining multiple iconic elements into compound representations.
Innenwelt: The internal cognitive world that subjects bring to interpretive encounters, shaping how external phenomena are modeled and understood.
Instrumental Reason: The form of rationality oriented exclusively toward efficiency and control, potentially reducing cultural objects to mere means.
Meaning-Modeling: The cognitive process through which subjects construct internal representations of external phenomena through systematic semiotic activity.
Mediator of Mediators: The characterization of virtual museums as systems that mediate already-mediated cultural content, creating multiple interpretive layers.
Meta-metaform: The secondary-connective category linking interpretive contexts across different content areas.
Meta-symbol: The tertiary-connective category creating abstract conceptual links across symbolic content.
Metaform: The primary-connective category establishing relationships between iconic representations.
Modeling Systems Theory (MST): Sebeok's framework proposing that humans understand reality through hierarchical modeling systems operating at primary, secondary, and tertiary levels.
Non-identity: Adorno's principle that conceptual representations never fully capture object reality, preserving an irreducible remainder.
Object Primacy Score (OPS): The proportion of primary-level modeling instances, indicating emphasis on direct object representation (OPS = (primary instances)/(total instances)).
Primary Modeling System (PMS): The foundational modeling level dealing with iconic, directly representational signs.
Secondary Modeling System (SMS): The modeling level introducing indexical and contextual relationships extending primary representations.
Semiosis: The process of sign production and interpretation generating meaning through modeling activity.
Singularized Form: A model form consisting of discrete, independent units of meaning.
Tertiary Modeling System (TMS): The highest modeling level involving symbolic and abstract conceptual representations.
Umwelt: The species-specific perceptual world shaping interpretive possibilities, extended in MST to human cultural perception.

Appendix C. Methodological Notes

Appendix C.1. Sample Selection Criteria

The five virtual museum cases analyzed in this study were selected through purposive sampling to maximize variation across key dimensions. Geographic and cultural representation guided selection to ensure findings transcended single cultural contexts. Cases span Western institutions (British Museum), East Asian contexts (Beijing Central Axis), and Global South perspectives (DRC Museum, Virtual Angkor), enabling cross-cultural comparison of meaning-making strategies.

Technological diversity constituted another selection criterion. Cases represent major virtual museum technologies including web-based interactives, VR headset experiences, panoramic tours, and immersive 3D simulations. This variety enables analysis of how different technological affordances shape meaning construction.

Institutional scale ranged from well-funded international collaborations to preservation-focused efforts with limited resources. Temporal distribution across the 2015–2025 study window captures evolution in virtual museum design, though we acknowledge potential temporal confounds in typological patterns.

Appendix C.2. Coding Procedures

Initial coder training utilized practice materials to establish shared understanding of the twelve-category framework. Two researchers independently coded practice content, discussing disagreements to refine category boundaries and application guidelines.

For actual coding, researchers conducted systematic walkthroughs of each virtual museum, documenting all identifiable content instances. Screen recordings enabled repeated viewing of interactive elements. Each instance received codes for modeling level and form, with explanatory notes for ambiguous cases.

Intercoder reliability assessment used stratified random sampling of 10% of instances from each case, with minimum thresholds ensuring adequate representation from smaller cases. Following satisfactory agreement (kappa = 0.82 for levels, 0.79 for forms), one researcher completed all coding with periodic reliability checks to prevent drift.

Appendix C.3. Metric Calculation

All three ratios take values in [0,1]; we did not standardize or transform them prior to clustering, preserving the geometric meaning of Ward (Euclidean) distances. Quantitative metrics were calculated as simple proportions to maintain interpretability and comparability. Abstraction Ratio represents tertiary-level instances divided by total instances. Connectivity Ratio sums cohesive and connective instances divided by total instances. Object Primacy Score equals primary-level instances divided by total instances.

Equal weighting of all instances was maintained despite recognized limitations. Alternative weighting schemes would introduce additional subjective judgments and complicate cross-case comparisons. Future research might develop empirically grounded weighting through user behavior data.

We report unweighted proportions to retain interpretability and comparability across heterogeneous interfaces; alternative weighting schemes risk embedding curator- or platform-specific priors and are left for future behavior-grounded work.

Appendix C.4. Cluster Analysis

With five cases, clustering served primarily to visualize distances among cases rather than to fix a definitive taxonomy. We therefore present a Ward (Euclidean) hierarchical dendrogram as a descriptive prompt: the first merge is B-D (height ≈ 0.206), followed by C

(≈0.328); A merges next (≈0.386); E is most distant (≈0.880). The dendrogram motivates interpretation in the main text and is not used to determine the number of clusters.

References

1. White, M. Where is the Louvre? *Space Cult.* **1999**, *2*, 47–70. [CrossRef]
2. Schweibenz, W. Museum Exhibitions—The Real and the Virtual Ones: An Account of a Complex Relation. *Uncommon Cult.* **2012**, *3*, 38–52.
3. Dallas, C. The Presence of Visitors in Virtual Museum Exhibitions. In Proceedings of the Numérisation, Lien Social, Lectures Colloquium, University of Crete, Rethymnon, Greece, 3–4 June 2004; pp. 3–4.
4. Witcomb, A. The Materiality of Virtual Technologies: A New Approach to Thinking about the Impact of Multimedia in Museums. In *Theorizing Digital Cultural Heritage*; Cameron, F., Kenderdine, S., Eds.; The MIT Press: Cambridge, MA, USA, 2007; pp. 35–48.
5. Virtual Museums, F.; Becker, I.; Böhmer, O.; Gröne, R.; Günter, B.; Heinzelmann, R.; Kircher-Kannemann, A.; Mahmoudi, Y.; Römhild, J.; Simon, H.; et al. *Virtual Museums—A Plea*; Deutscher Kunstverlag (DKV): Berlin, Germany, 2024.
6. Schweibenz, W. The virtual museum: An overview of its origins, concepts, and terminology. *Mus. Rev.* **2019**, *4*, 1–29.
7. Schweibenz, W. Wer sind die Besucher des virtuellen Museums und welche Interessen haben sie? (Who are the Visitors of the Virtual Museum and What are they Interested in?). *i-com* **2008**, *7*, 11–17. [CrossRef]
8. Benjamin, W. The work of art in the age of mechanical reproduction. In *A Museum Studies Approach to Heritage*; Routledge: London, UK, 2018; pp. 226–243.
9. Zeller, C. From Object to Information: The End of Collecting in the Digital Age. *arcadia* **2015**, *50*, 389–409. [CrossRef]
10. Li, J.; Zheng, X.; Watanabe, I.; Ochiai, Y. A systematic review of digital transformation technologies in museum exhibition. *Comput. Hum. Behav.* **2024**, *161*, 108407. [CrossRef]
11. Calvi, L.; Vermeeren, A.P.O.S. Digitally enriched museum experiences—what technology can do. *Mus. Manag. Curatorship* **2024**, *39*, 335–356. [CrossRef]
12. Meehan, N. Digital Museum Objects and Memory: Postdigital Materiality, Aura and Value. *Curator Mus. J.* **2022**, *65*, 417–434. [CrossRef]
13. Doering, Z.D. Strangers, guests, or clients? Visitor experiences in museums. In *Museum Management and Marketing*; Routledge: London, UK, 2007; pp. 331–344.
14. Sun, Y.; Zheng, Y. A Study of Visitor Interaction with Virtual Museum. In Proceedings of the HCI International 2022—Late Breaking Posters, Virtual Event, 26 June–1 July 2022; pp. 354–358. Available online: https://link.springer.com/book/10.1007/978-3-031-19679-9 (accessed on 16 November 2025).
15. Schweibenz, W. The "Virtual Museum": New Perspectives For Museums to Present Objects and Information Using the Internet as a Knowledge Base and Communication System. In Proceedings of the Knowledge Management und Kommunikationssysteme, Workflow Management, Multimedia, Knowledge Transfer—Proceedings des 6. Internationalen Symposiums für Informationswissenschaft, ISI 1998, Prague, Czech Republic, 3–7 November 1998; pp. 185–200.
16. Song, Z.; Evans, L. The museum of digital things: Extended reality and museum practices. *Front. Virtual Real.* **2024**, *5*, 1396280. [CrossRef]
17. Hetherington, K. From Blindness to Blindness: Museums, Heterogeneity and the Subject. *Sociol. Rev.* **1999**, *47*, 51–73. [CrossRef]
18. Hetherington, K. Museums and the Visually Impaired: The Spatial Politics of Access. *Sociol. Rev.* **2000**, *48*, 444–463. [CrossRef]
19. Bayne, S.; Ross, J.; Williamson, Z. Objects, subjects, bits and bytes: Learning from the digital collections of the National Museums. *Mus. Soc.* **2009**, *7*, 110–124. [CrossRef]
20. Maurstad, A. Cod, curtains, planes and experts: Relational materialities in the museum. *J. Mater. Cult.* **2012**, *17*, 173–189. [CrossRef]
21. Gerasimov, G.I. The ideal essence of a museum object. *Issues Museol.* **2021**, *12*, 116–130. [CrossRef]
22. Wang, S. A Bodies-On Museum: The Transformation of Museum Embodiment through Virtual Technology. *Curator Mus. J.* **2023**, *66*, 107–128. [CrossRef]
23. Huhtamo, E. On the Origins of the Virtual Museum. In *Museums in a Digital Age*, 1st ed.; Parry, R., Ed.; Routledge: London, UK, 2009; pp. 121–135.
24. Becker, I.; Stärk, T. On The Terminology of the Virtual Museum. In *Virtual Museums—A Plea: Around the Clock, Around the World*; Forum, V.M., Ed.; Deutscher Kunstverlag (DKV): Berlin, Germany, 2024; pp. 19–22.
25. Latham, K.F.; Simmons, J.E. *Foundations of Museum Studies: Evolving Systems of Knowledge*; Libraries Unlimited: Santa Barbara, CA, USA, 2014.
26. Tsichritzis, D.; Gibbs, S.J. Virtual Museums and Virtual Realities. In *International Cultural Heritage Informatics Meeting*; Sheraton Station Square: Pittsburgh, PA, USA, 1991; pp. 17–25.

27. Pujol, L.; Lorente, A. The Virtual Museum: A Quest for the Standard Definition. In *Archaeology in the Digital Era*; Philip, V., Graeme, E., Eds.; Amsterdam University Press: Amsterdam, The Netherlands, 2014; pp. 40–48.
28. Sebeok, T.A.; Danesi, M. *The Forms of Meaning*; De Gruyter Mouton: Berlin/Heidelberg, Germany; Boston, MA, USA, 2000.
29. Adorno, T.W. *Negative Dialectics*; Seabury Press: New York, NY, USA, 1973.
30. Stone, A. Adorno, Hegel, and Dialectic. *Br. J. Hist. Philos.* **2014**, *22*, 1118–1141. [CrossRef]
31. Danesi, M. Signs, forms, and models: Thomas, A. Sebeok's enduring legacy for semiotics. *Chin. Semiot. Stud.* **2021**, *17*, 473–493. [CrossRef]
32. Yu, H. *On Semiotic Modeling*; Suzhou University Press: Suzhou, China, 2019.
33. Horkheimer, M. *Critique of Instrumental Reason*; Verso: Miamisburg, OH, USA, 2014.
34. Biedermann, B. 'Virtual museums' as digital collection complexes. A museological perspective using the example of Hans-Gross-Kriminalmuseum. *Mus. Manag. Curatorship* **2017**, *32*, 281–297. [CrossRef]
35. De Saussure, F. *Writings in General Linguistics*; Oxford University Press: Oxford, UK, 2006.
36. Bekele, M.K.; Pierdicca, R.; Frontoni, E.; Malinverni, E.S.; Gain, J. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *J. Comput. Cult. Herit.* **2018**, *11*, 1–36. [CrossRef]
37. Xu, H.; Li, Y.; Tian, F. Contrasting Physical and Virtual Museum Experiences: A Study of Audience Behavior in Replica-Based Environments. *Sensors* **2025**, *25*, 4046. [CrossRef]
38. Buragohain, D.; Meng, Y.; Deng, C.; Li, Q.; Chaudhary, S. Digitalizing cultural heritage through metaverse applications: Challenges, opportunities, and strategies. *Herit. Sci.* **2024**, *12*, 295. [CrossRef]
39. Lee, H.; Jung, T.H.; tom Dieck, M.C.; Chung, N. Experiencing immersive virtual reality in museums. *Inf. Manag.* **2020**, *57*, 103229. [CrossRef]
40. Peirce, C.S. *Collected Papers of Charles Sanders Peirce*; Harvard University Press: Cambridge, MA, USA, 1974; Volume 5.
41. Danesi, M. The concept of model in Thomas, A. Sebeok's semiotics. In *New Semiotics. Between Tradition and Innovation*; IASS Publications & NBU Publishing House: Sofia, Bulgaria, 2014; pp. 1495–1506.
42. Kull, K. Umwelt and modelling. In *The Routledge Companion to Semiotics*; Routledge: London, UK, 2009; pp. 43–56.
43. Eco, U. *A Theory of Semiotics*; Indiana University Press: Bloomington, IN, USA, 1976.
44. Polidoro, P. Umberto Eco and the problem of iconism. *Semiotica* **2015**, *2015*, 129–160. [CrossRef]
45. Leibniz, G.W.; Remnant, P.; Bennett, J. *Leibniz: New Essays on Human Understanding*, 2nd ed.; Remnant, P., Bennett, J., Eds.; Cambridge University Press: Cambridge, UK, 2012; Volume 2.
46. Juul, J. *Half-Real: Video Games between Real Rules and Fictional Worlds*; MIT Press: Cambrigde, MA, USA, 2011.
47. Mochocki, M. Heritage Sites and Video Games: Questions of Authenticity and Immersion. *Games Cult.* **2021**, *16*, 951–977. [CrossRef]
48. de Souza, C.S. *The Semiotic Engineering of Human-Computer Interaction*; The MIT Press: Cambrigde, MA, USA, 2005.
49. Boboc, R.G.; Băutu, E.; Gîrbacia, F.; Popovici, N.; Popovici, D.-M. Augmented Reality in Cultural Heritage: An Overview of the Last Decade of Applications. *Appl. Sci.* **2022**, *12*, 9859. [CrossRef]
50. Caputo, F.M.; Corsi, D.; De Stefani, M.; Giachetti, A. Gestural Interaction and Navigation Techniques for Virtual Museum Experiences. In Proceedings of the AVI*CH 2016 Advanced Visual Interfaces for Cultural Heritage, Bari, Italy, 7–10 June 2016; pp. 32–35.
51. Bannon, L. Reimagining HCI. *Interactions* **2011**, *18*, 50–57. [CrossRef]
52. Fitzpatrick, G. A Short History of Human Computer Interaction. In Proceedings of the ACM SIGUCCS Annual Conference, Orlando, FL, USA, 7–10 October 2018; p. 3.
53. Pietroni, E.; Pagano, A.; Fanini, B. UX Designer and Software Developer at the Mirror: Assessing Sensory Immersion and Emotional Involvement in Virtual Museums. *Stud. Digit. Herit.* **2018**, *2*, 13–41. [CrossRef]
54. Liarokapis, F.; Sylaiou, S.; Basu, A.; Mourkoussis, N.; White, M.; Lister, P.F. An interactive visualisation interface for virtual museums. In Proceedings of the 5th International Conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage, Oudenaarde, Belgium, 7–10 December 2004; pp. 47–56.
55. Giangreco, I.; Sauter, L.; Parian, M.A.; Gasser, R.; Heller, S.; Rossetto, L.; Schuldt, H. Virtue. In Proceedings of the 24th International Conference on Intelligent User Interfaces, Marina del Ray, CA, USA, 17–20 March 2019; pp. 119–120.
56. Zidianakis, E.; Partarakis, N.; Ntoa, S.; Dimopoulos, A.; Kopidaki, S.; Ntagianta, A.; Ntafotis, E.; Xhako, A.; Pervolarakis, Z.; Kontaki, E.; et al. The Invisible Museum: A User-Centric Platform for Creating Virtual 3D Exhibitions with VR Support. *Electronics* **2021**, *10*, 363. [CrossRef]
57. Wojciechowski, R.; Walczak, K.; White, M.; Cellary, W. Building Virtual and Augmented Reality museum exhibitions. In Proceedings of the 9th International Conference on 3D Web Technology, Monterey, CA, USA, 5–8 April 2004; pp. 135–144.
58. Li, J.; Nie, J.-W.; Ye, J. Evaluation of virtual tour in an online museum: Exhibition of Architecture of the Forbidden City. *PLoS ONE* **2022**, *17*, e0261607. [CrossRef]

59. Gong, Q.; Zou, N.; Yang, W.; Zheng, Q.; Chen, P. User experience model and design strategies for virtual reality-based cultural heritage exhibition. *Virtual Real.* **2024**, *28*, 69. [CrossRef]
60. Ariya, P.; Wongwan, N.; Worragin, P.; Intawong, K.; Puritat, K. Immersive realities in museums: Evaluating the impact of VR, VR360, and MR on visitor presence, engagement and motivation. *Virtual Real.* **2025**, *29*, 117. [CrossRef]
61. Puig, A.; Rodríguez, I.; Arcos, J.L.; Rodríguez-Aguilar, J.A.; Cebrián, S.; Bogdanovych, A.; Morera, N.; Palomo, A.; Piqué, R. Lessons learned from supplementing archaeological museum exhibitions with virtual reality. *Virtual Real.* **2019**, *24*, 343–358. [CrossRef]
62. Sylaiou, S.; Fidas, C. Virtual Humans in Museums and Cultural Heritage Sites. *Appl. Sci.* **2022**, *12*, 9913. [CrossRef]
63. Rodriguez-Garcia, B.; Guillen-Sanz, H.; Checa, D.; Bustillo, A. A systematic review of virtual 3D reconstructions of Cultural Heritage in immersive Virtual Reality. *Multimed. Tools Appl.* **2024**, *83*, 89743–89793. [CrossRef]
64. Ogden, C.K.; Richards, I.A. *The Meaning of Meaning: A Study of the Influence of Language Upon Thought and of the Science of Symbolism*; Harcourt, Brace & World, Inc.: New York, NY, USA, 1946.
65. Yu, H. Meaning Generation. *Chin. Semiot. Stud.* **2019**, *15*, 429–447. [CrossRef]
66. Yu, H. Modeling in semiotics: An integrative update. *Chin. Semiot. Stud.* **2021**, *17*, 639–659. [CrossRef]
67. Fligstein, N.; McAdam, D. *A Theory of Fields*; Oxford University Press: Oxford, UK, 2015.
68. Choi, K.; Nam, Y. Do Presence and Authenticity in VR Experience Enhance Visitor Satisfaction and Museum Re-Visitation Intentions? *Int. J. Tour. Res.* **2024**, *26*, e2737. [CrossRef]
69. Chang, S.; Suh, J. The Impact of VR Exhibition Experiences on Presence, Interaction, Immersion, and Satisfaction: Focusing on the Experience Economy Theory (4Es). *Systems* **2025**, *13*, 55. [CrossRef]
70. Spiegelhalter, D. Why probability probably doesn't exist (but it is useful to act like it does). *Nature* **2024**, *636*, 560–563. [CrossRef]
71. Herz, R.S. An Examination of Objective and Subjective Measures of Experience Associated to Odors, Music, and Paintings. *Empir. Stud. Arts* **1998**, *16*, 137–152. [CrossRef]
72. Munar, E.; Nadal, M.; Castellanos, N.P.; Flexas, A.; Maestu, F.; Mirasso, C.; Cela-Conde, C.J. Aesthetic appreciation: Event-related field and time-frequency analyses. *Front. Hum. Neurosci.* **2011**, *5*, 185. [CrossRef]
73. Maquet, J.J.P. *The aesthetic experience: An anthropologist looks at the visual arts*; Yale University Press: New Haven, CT, USA, 1986.
74. Lankford, E.L. Aesthetic Experience in Constructivist Museums. *J. Aesthetic Educ.* **2002**, *36*, 140–153. [CrossRef]
75. Gernsbacher, M.A.; Derry, S.J. *Proceedings of the Twentieth Annual Conference of the Cognitive Science Society*; Routledge: New York, NY, USA, 2022; pp. 208–213.
76. Yezhova, O.; Zhao, J.; Pashkevych, K. Exploring Design Aspects of Online Museums: From Cultural Heritage to Art, Science and Fashion. *Preserv. Digit. Technol. Cult.* **2025**, *54*, 35–50. [CrossRef]
77. Gahrn-Andersen, R.; Festila, M.S.; Secchi, D. Systemic Cognition: Sketching a Functional Nexus of Intersecting Ontologies. In *Multiple Systems*; Springer: Cham, Switzerland, 2024; pp. 89–99.
78. Barrett, L.F. *How Emotions Are Made: The Secret Life of the Brain*; Macmillan: New York, NY, USA, 2017.
79. Adorno, T.W. Subject and Object. In *The Essential Frankfurt School Reader*; Andrew, A., Eike, G., Eds.; Urizen Books: New York, NY, USA, 1978.
80. Habermas, J. Theodor Adorno: The Primal History of Subjectivity—Self-Affirmation Gone Wild. In *Philosophical-Political Profiles*; MIT Press: Cambridge, MA, USA, 1985; pp. 99–109.
81. O'Neill, P. The curatorial turn: From practice to discourse. *Issues Curating Contemp. Art Perform.* **2007**, *25*, 13–28.
82. Wray, L. Taking a position: Challenging the anti-authorial turn in art curating. In *Museum Activism*; Janes, R.R., Sandell, R., Eds.; Routledge: London, UK, 2019; pp. 315–325.
83. Arnold, K. From Caring to Creating: Curators Change Their Spots. In *The International Handbooks of Museum Studies*; McCarthy, C., Ed.; Wiley: Hoboken, NJ, USA, 2015; pp. 317–339.
84. Habermas, J. *The Theory of Communicative Action: Volume 1: Reason and the Rationalization of Society*; Beacon Press: Boston, MA, USA, 1984.
85. Sparacino, F.; Davenport, G.; Pentland, A. Media in performance: Interactive spaces for dance, theater, circus, and museum exhibits. *IBM Syst. J.* **2000**, *39*, 479–510. [CrossRef]
86. Gahrn-Andersen, R. Nexuses of performativity: Systemic generalities, infrastructures and practical ontologies. *Thesis Elev.* **2025**, *187*, 56–71. [CrossRef]
87. Kwak, S.-B.; Kwon, C. Preference Factors of the Korean MZ Generation vis-à-vis the Online Programs of Museums Abroad. *J. Digit. Converg.* **2022**, *20*, 565–573. [CrossRef]
88. Neuendorf, K.A. *The Content Analysis Guidebook*; SAGE Publications: Thousand Oaks, CA, USA, 2017.
89. Lombard, M.; Snyder-Duch, J.; Bracken, C.C. Content Analysis in Mass Communication: Assessment and Reporting of Intercoder Reliability. *Hum. Commun. Res.* **2002**, *28*, 587–604. [CrossRef]
90. Horkheimer, M.; Adorno, T.W.; Noeri, G.S. *Dialectic of Enlightenment*; Stanford University Press: Redwood City, CA, USA, 2020.
91. Adorno, T.W.; Simpson, G. On Popular Music. *Z. Für Sozialforschung* **1941**, *9*, 17–48. [CrossRef]

92. Guan, H.; Chen, P. Meaning in the Algorithmic Museum: Towards a Dialectical Modelling Nexus of Virtual Curation. *Heritage* **2025**, *8*, 284. [CrossRef]
93. Hein, G.E. *Learning in the Museum*; Taylor & Francis: London, UK, 2002.
94. Hodge, R.; D'souza, W.; Rivière, G.H. The museum as a Communicator: A semiotic analysis of the Western Australian Museum Aboriginal Gallery, Perth. *Mus. Int.* **1979**, *31*, 251–267. [CrossRef]
95. Clifford, J. Museums as Contact Zones. In *Routes: Travel and Translation in the Late Twentieth Century*; Harvard University Press: Cambridge, MA, USA, 1997; pp. 188–219.
96. DaCosta, B. Historical Depictions, Archaeological Practices, and the Construct of Cultural Heritage in Commercial Video Games: The Role of These Games in Raising Awareness. *Preserv. Digit. Technol. Cult.* **2024**, *53*, 113–132. [CrossRef]
97. Hazan, S. The Virtual Aura—Is There Space for Enchantment in a Technological World? In Proceedings of the Museum and the Web 2001, Seattle, WA, USA, 14–17 March 2001.
98. Latour, B.; Lowe, A. The Migration of the Aura Exploring the Original Through Its Fac similes. In *Switching Codes Thinking Through Digital Technology in the Humanities and the Arts*; University of Chicago Press: Chicago, IL, USA, 2011; pp. 275–297.
99. Parry, R.; Dziekan, V. Critical digital: Museums and their postdigital circumstance. In *Art, Museums & Digital Cultures: Rethinking Change*; Barranha, H., Simoes Henriques, J., Eds.; Universidade NOVA de Lisboa: Lisbon, Portugal, 2021; pp. 16–26.
100. Creed, C.; Al-Kalbani, M.; Theil, A.; Sarcar, S.; Williams, I. Inclusive Augmented and Virtual Reality: A Research Agenda. *Int. J. Hum. Comput. Interact.* **2024**, *40*, 6200–6219. [CrossRef]
101. Sepe, F.; Luongo, S.; Di Gioia, L.; Della Corte, V. Cultural heritage experiences in the metaverse: Analyzing perceived value and behavioral intentions. *Eur. J. Innov. Manag.* **2024**, *28*, 2054–2079. [CrossRef]