The Golden Bond: A Metadata-Driven 3D Storytelling Framework for Micro-Heritage

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Abstract. Small cultural heritage artefacts such as coins often suffer from *"invisibility"* in museum environments, where minute details remain inaccessible behind display glass. This paper presents *The Golden Bond: Unfolding the Kapulukaya Hoard*, a cross-platform 3D application designed to transform static displays into interactive, interpretive environments. We introduce a metadata-driven "Semantic Storytelling Origami" framework that binds object identity, mint attribution, iconography and provenance to narrative beats, and document a cross-platform three-dimensional delivery pipeline utilising FARO laser-arm capture, Draco-compressed GLB assets and PCSS-based object annotations, integrated 4D Viewer spatial contextualisation and Rooom XR/WebXR access for the coin assemblage. We report concrete optimisation outcomes, including approximately 95% reductions in binary payload through Draco geometry compression while retaining vertex counts up to over 500,000 per inspection model, and cross-platform validation on desktop browsers and mobile devices. The project is documented through a FAIR-oriented package in which object metadata is aligned with CIDOC CRM, paradata with CRMdig and numismatic entities with Nomisma, with interpretive decisions following the London Charter. All coin models together with the terracotta vessel are released as open assets on Zenodo under CC-BY 4.0. The resulting application demonstrates how guided narrative, immersive inspection, spatio-temporal interaction and transparent documentation can make micro-heritage collections more legible and reusable for both public engagement and future research. The application is publicly accessible at `https://solidi.unimi.it` and the open data package (3D models, metadata and paradata) at `https://doi.org/10.5281/zenodo.20371912`.

Keywords: 3D cultural heritage · numismatics · CIDOC CRM · CRMdig · semantic annotation · interactive storytelling · WebXR · micro-heritage · Kapulukaya Hoard

1 Introduction

A small but particularly rich category of late-Roman finds, i.e., closed gold-solidus hoards, sits at the intersection of imperial monetary history, regional archaeology, and individual lived experience. However, communicating the impact of these assemblages to non-specialist audiences poses a significant challenge. The interpretive distance between what numismatists know about these objects and what museum visitors actually encounter is, in practice, very wide. Such hoards are often difficult for general audiences to understand because their historical value is embedded in features that resist casual inspection: small-scale visual details, abbreviated Latin inscriptions, mintmarks, dynastic context, and patterns of imperial circulation that only become legible when analysed collectively.

This problem belongs to a wider category we call *micro-heritage* [11]: cultural artefacts whose analytical value depends on features below the threshold of comfortable in-vitrine inspection, such as coins, seals, intaglios, miniatures, small bronzes, ivories, inscribed slips. These objects are physically present in museums but interpretively absent, i.e., visitors see them, but they do not "read" them. The micro-heritage problem is partly technological (how can we bring minute die details into the visitor's hand?) and partly narrative (how can we assemble dispersed object-level data into a coherent story?).

The Kapulukaya Hoard[4] offers a particularly clear case for working through both halves of this problem. As the only known 4th century gold-solidus hoard yet recorded from Anatolia, and one whose twenty-one coins were all struck at a single mint, it lets a single closed find speak with unusual clarity about both an imperial mint and a regional economy [1]. Its small number of coins, dominated by a single dynasty and anchored by one unique issue, makes it tractable as a complete digital case study; its near-total absence from public-facing digital presentations, with prior scholarly visibility limited to black-and-white photographs in the work of Arslan [2], makes such a study overdue. Section 3 introduces the assemblage in detail.

To bridge this gap, we present *The Golden Bond*, a web-based cultural heritage application that reimagines the hoard as an interactive 3D narrative for *kiosk*, *browser*, and *mobile* access. The paper makes four contributions:

- *A Conceptual Framework:* We introduce the *Semantic Storytelling Origami* framework, a metadata-driven approach that maps object identity, chronology, mint attribution, iconography, provenance and interpretation to structured narrative beats, and articulate it as a collection-agnostic template (Section 4).
- *A Technical and Documentary Pipeline:* We detail a cross-platform three-dimensional delivery workflow combining FARO laser-arm digitisation, Blender-based asset preparation, Draco-compressed GLB delivery, PCSS close-reading annotations, integrated 4D Viewer spatial contextualisation and Rooom XR / WebXR object access. The pipeline is documented through CIDOC CRM-aligned metadata, CRMdig-informed paradata and FAIR-oriented publication records [6,7,21].
- *Quantitative Optimisation Results:* We report concrete compression and runtime measurements for the inspection-grade coin models and the terracotta

[4] `https://chre.ashmus.ox.ac.uk/hoard/8170`

vessel, including approximately 95% reductions in binary payload through Draco geometry compression at level 6, vertex counts retained up to over 500,000 per inspection model, and cross-platform validation on Chrome and Firefox desktop browsers and iPhone-class mobile devices.
- *An Open, Reusable Implementation:* We present the first interactive 3D application dedicated to the Kapulukaya Hoard and release all coin models, the terracotta vessel and the complete metadata and paradata as open assets on Zenodo under CC-BY 4.0.

2 Related Work

The Golden Bond draws together interactive heritage storytelling, semantic 3D documentation, numismatic linked data, spatial contextualisation and immersive access. These areas are often treated separately, but micro-heritage interpretation requires them to operate together: small objects must be inspectable, historically intelligible and documented for reuse.

Interactive storytelling research has shown the value of structured narrative, meaningful interaction and visitor orientation in museum experiences [12,15,18,20]. Pietroni and Ferdani further emphasise the importance of distinguishing evidence, interpretation and visual hypothesis in virtual heritage communication [16]. We adopt these principles through a guided six-scene interpretation of the Kapulukaya Hoard.

Underpinning this interpretive layer is a commitment to linked-data and semantic standards. The Aldrovandi Digital Twin project provides a close methodological comparator, demonstrating how 3D cultural heritage assets, digitisation records, descriptive metadata, and interpretive context can be organised through FAIR-oriented workflows informed by CIDOC CRM and CRMdig [3]. Our metadata architecture follows the same approach, using CIDOC CRM and CRMdig as organising frames for object and digitisation records and Nomisma.org vocabulary for denomination, mint and imperial authority [3,14]. This alignment keeps the Kapulukaya Hoard's documentation interoperable with the major linked numismatic infrastructures (OCRE[5], CHRE[6]), while the domain-specific focus on a single closed find allows complex numismatic attributes, such as mintmarks, reverse types, weight, die axes, to be synthesised into an accessible narrative without sacrificing scholarly rigour.

The technical challenge of numismatic micro-heritage lies in preserving the legibility of inscriptions, portrait types, mint information and reverse imagery under digital magnification. Previous studies have demonstrated the value of high-resolution and multimodal recording for small heritage objects and ancient coins [10,13]. Spatial and immersive heritage research further informs the project's historical mapping and mobile XR access [5,8,9].

Finally, the London Charter provides the methodological basis for documenting sources, interpretive choices, technical processes, sustainability and access in

[5] `https://numismatics.org/ocre/`
[6] `https://chre.ashmus.ox.ac.uk`

computer-based cultural heritage visualisation [4]. The project's implementation of these principles is described in Section 8.

3 Case Study: The Kapulukaya Hoard

The Kapulukaya Hoard was discovered near the Kapulukaya Dam in Kırıkkale province in central Anatolia and acquired by the Erimtan collection in July 1991; it is held in association with the Erimtan Archaeology and Arts Museum[7]. The assemblage comprises a terracotta vessel and twenty-one Late Roman gold solidi, one of *Valentinian I*, sixteen of *Valens*, three of *Gratian*, and one unique issue of *Valentinian II*. A representative solidus from each of these reigns is shown in Fig. 1, in both obverse and reverse views. All twenty-one solidi were struck at the Antioch mint, giving the assemblage an unusual degree of internal mint coherence. To the best of current knowledge, the Kapulukaya Hoard is the only known solidus hoard for this period yet recorded from Anatolia, which gives it additional archaeological and historical weight as a sealed regional witness to late-fourth-century coin circulation. The relatively slight wear visible on the coins also suggests that they were not heavily circulated before being set aside, consistent with the interpretation of the find as a savings deposit rather than as residual circulation losses.

(a) Valentinian I solidus.

(b) Valens solidus.

(c) Gratian solidus.

(d) Valentinian II solidus.

Fig. 1: 3D renders of the four representative solidi of the Kapulukaya Hoard, each shown in obverse and reverse view.

[7] `https://erimtanmuseum.org/en/collection`

The Star Object: A Case for Close Reading. The unique Valentinian II solidus (Fig. 1d) is the interpretive centre of the application. Its obverse depicts the juvenile emperor in consular dress and identifies him through the abbreviation *IVN*, *Iunior*; its reverse presents Valentinian II and Valens together, accompanied by a cross. Associated with their shared consulships in AD 376 and AD 378, the coin is the latest datable issue in the assemblage and provides its chronological horizon. Its small-scale details make it especially suitable for 3D close reading and annotation. Beyond the star object, the three further representative issues (Fig. 1a–c) are inspected in Scene 6 as a connected Valentinianic horizon.

4 The Semantic Storytelling Origami Framework

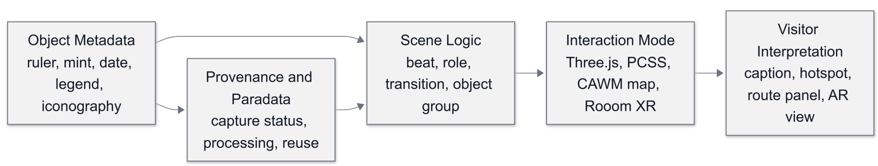


Fig. 2: Semantic Storytelling Origami framework linking object metadata, scene logic, interaction modes, provenance, and visitor-facing interpretation.

We borrow the *origami metaphor* to describe the relationship between the data layer and the visitor-facing narrative. A folded origami crane carries within it all the information of the original sheet of paper (every crease, every panel, every hidden surface) but reveals these features only as the figure is opened. In the same way, the Kapulukaya Hoard sits in its vessel as a folded artefact: all twenty-one coins are there, but the relations among them, between them and the vessel, between the vessel and the imperial geography of AD 378, remain folded inside the assemblage until something, such as a scholar, or a curator unfolds them.

The *Semantic Storytelling Origami* framework (summarised in Fig. 2) treats each scene as a panel of an unfolding interpretive structure: a narrative beat that reveals one aspect of the assemblage while preparing the visitor for the next relation between vessel, coins, mint, route and historical context.

The framework rests on *three core principles* that distinguish the application from a generic 3D viewer by linking object data, digital production, and narrative sequence:

i. Scene-Structured Metadata: Each scene is organised around object records, asset references, and controlled interaction logic. We implement a metadata package using CIDOC CRM-aligned JSON-LD to describe the Kapulukaya Hoard, its vessel, and twenty-one solidi. Nomisma identifiers connect the denomination, mint, and imperial authorities to numismatic linked-data vocabularies.

ii. Documented Provenance and Paradata: The application distinguishes between the digitised hoard assemblage, contextual visual assets and interpretive spatial elements. A CRMdig-informed paradata record documents FARO digitisation, Blender preparation, web optimisation, annotation authoring, XR delivery and the integrated 4D Viewer context. This documentation responds to the London Charter's requirement that visualisation outcomes be understood in relation to their sources, methods and knowledge claims [4].

iii. Annotation-Driven Interpretation: We use object-anchored annotations to guide visitors through legends, portraits, reverse imagery, Christian symbols, mint information and chronological significance. PCSS-based hotspots make small-scale features inspectable on representative 3D coin models, translating specialist numismatic interpretation into concise, visitor-facing explanations.

Architecture and Scene Logic. The metadata package integrates these layers into a unified schema: JSON-LD documents aligned with CIDOC CRM ontologies for object data, CRMdig-informed structures for digitisation history, and a FAIR-oriented catalogue designed for long-term repository management (Table 1). These records are maintained as discrete, valid open-format datasets prepared for publication. Moving from *schema to scene*, each module combines selected objects, narrative beats, and interaction transitions. For Kapulukaya, the narrative unfolds in six scenes, moving from exposition to a chronological climax, with Scene 6 providing a reflexive return to the assemblage first introduced in Scene 2. The framework leverages this structured metadata and documented digital provenance to maintain a narrative sequence aligned with annotation and interaction logic. It does not prescribe a fixed visual design or number of scenes, allowing the approach to be adapted to other micro-heritage collections.

Table 1: Implemented metadata schema sample for the Kapulukaya Hoard.

Field group	**Metadata expression**	**Kapulukaya example**
Object identity	CIDOC CRM object and identifier records	Env No.21; Valentinian II solidus
Assemblage structure	Hoard composition and part relationships	Vessel and twenty-one solidi
Material and dimension	Material and physical description	Gold solidus; 4.45 g; 21 mm
Chronology	Issue date and narrative role	Valentinian II; AD 376–378; latest datable coin
Mint and authority	Nomisma-aligned identifiers	Antioch mint; Valentinian II authority; solidus denomination
Iconography	Legend and visual interpretation	Consular portrait; two emperors standing; cross; *DN VALENTINIANVS IVN P F AVG*
Narrative role	Scene and interpretive status	Scenes 2, 4 and 6; star object; chronological anchor
Digital provenance	CRMdig-informed activity record	FARO capture; Blender preparation; web optimisation
Delivery context	Interaction and access mode	PCSS; integrated 4D Viewer; Rooom XR/WebXR
Optimisation	Recorded paradata settings	WebP at 1024 px; Draco compression; geometry simplification disabled
Repository and reuse	FAIR publication record	CC-BY 4.0; Zenodo deposit; persistent DOI

Transfer to Other Collections. The workflow can be transferred through four explicit steps: (1) map each object's identity, material, chronology, provenance and interpretive features to the common metadata layer; (2) define collection-specific curatorial questions and group the records into narrative beats; (3) select interaction modes according to the scale and evidential character of the objects; and (4) record capture, transformation and interpretive decisions as paradata. Coins may therefore be replaced by seals, gems, small bronzes, manuscript fragments or other micro-heritage objects without retaining the Golden Bond's particular scenes or viewers. What remains invariant is the mapping from documented evidence to narrative purpose; scene count, annotations, spatial context and delivery platform remain configurable.

5 Computational Architecture and Interaction Modes

The Golden Bond is organised as a modular web application in which each interaction mode performs a distinct role in the narrative. The application framework leverages the underlying technological pipeline developed by the 3DBigDataSpace[8] research group, providing a unified architecture where asset loading, spatial data and rendering remain interconnected across scenes. Four interaction modes are described below.

Three.js Vessel Scenes. The vessel-centred scenes are rendered in Three.js, presenting the terracotta vessel as an interactive object with hotspot-driven annotations on the hoard, its dimensions and the coin group. These scenes establish the archaeological context and carry the early narrative beats before close numismatic reading begins.

PCSS Viewer. Built on Three.js, this viewer [17] provides the application's principal close-reading environment for representative coin models. It supports deep zoom, controlled rotation and mesh-anchored interpretive annotations whose positions are stored as object-local coordinate vectors. Obverse and reverse controls ensure that each annotation remains associated with the relevant visible surface. The annotations interpret legends, portraits, reverse imagery, Christian symbols, mint information and chronological significance directly on the coin model.

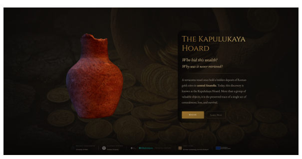
Integrated 4D Viewer Route Experience. This spatio-temporal route interface [22] integrates historical mapping with interactive location panels, a chronicle sequence and selected contextual three-dimensional assets. It connects Antioch, the Cilician Gates, Tyana, Ancyra, Kapulukaya and Constantinople, enabling visitors to explore the relationship between Antiochene mint production, central Anatolian movement and the political history of the late fourth-century eastern empire. CAWM historical mapping provides the geographical substrate for the route visualisation [5].

[8] `https://3dbigdataspace.eu`

Rooom XR/WebXR Access. This module [19] provides mobile three-dimensional access to the vessel and representative coin objects of the Kapulukaya Hoard. Through XR viewing, visitors can examine individual coins outside the fixed narrative layout while retaining the interpretive categories established by the application: emperor, portrait, reverse type, mint attribution and chronological role.

6 The Six-Scene Journey

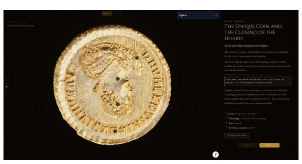
The application[9] is structured as six dedicated narrative scenes, organised as a guided narrative built around five interpretive beats: exposition, complication, evidence, climax and resolution. These beats structure the visitor's movement from initial curiosity through archaeological and historical context to close numismatic interpretation. The full six-scene journey is summarised in Fig. 3.



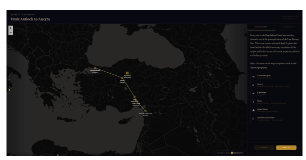
(a) Scene 1: The Hook

(b) Scene 2: The Find

(c) Scene 3: Sealed Savings Deposit



(d) Scene 4: Star Object



(e) Scene 5: Antioch to Ancyra

(f) Scene 6: Reading the Coins

Fig. 3: Six-scene journey of *The Golden Bond*, from the introductory vessel encounter to assemblage discovery, interpretive context, close reading, spatio-temporal route interaction and final numismatic synthesis.

Scene 1 - The Hook (atmospheric entry). Scene 1 establishes the atmospheric and archaeological premise of the experience. A full-screen, darkened landscape background introduces the central Anatolian setting, while a rotating three-dimensional model of the terracotta vessel is rendered in Three.js. The interface withholds the coins and foregrounds two questions: "Who hid this wealth?" and "Why was it never retrieved?" The accompanying text presents the vessel as the preserved trace of concealment, loss and survival. A Learn More panel introduces the gold solidus, explains the $ANT \cdot OB$ mintmark and summarises

[9] The live application is available at `https://solidi.unimi.it`.

the purchasing power represented by twenty-one coins. The narrative beat is exposition.

Scene 2 - The Find (introducing the assemblage). Scene 2 introduces the Kapulukaya find as an assemblage. The opened vessel is animated as an interactive Three.js object with hotspots concerning the hoard, vessel, dimensions and coin group. The twenty-one solidi are presented through grouped visual interfaces and emperor-based distribution, making the dominance of Valens and the distinctive position of the Valentinian II issue legible before close reading begins. A map locates Kapulukaya in relation to Antioch and Ancyra, preparing the geographical interpretation developed in Scene 5. The narrative beat is discovery.

Scene 3 - A Sealed Savings Deposit (archaeological significance). Scene 3 interprets the hoard as a sealed savings deposit and addresses the question of why the vessel was never recovered. A Three.js model of the vessel remains central, whilst hotspots and a Key Observations panel connect the container, coin group, Antioch mint coherence and owner-profile hypothesis. Following the archaeological interpretation developed for the project, twenty-one solidi suggest an owner of secure but middling means, possibly a soldier, officer, official or veteran. The beat is complication: the visitor moves from discovering the objects to considering the human circumstances of their concealment.

Scene 4 - The Star Object (Valentinian II in PCSS). Scene 4 forms the chronological and iconographic climax of the experience. The single Valentinian II solidus stands apart from the remainder of the hoard through its youthful portrait, consular dress, pearl diadem and two-emperor reverse. PCSS annotations open the legend, ceremonial portrait, pearl diadem, mappa, two-emperor representation, cross and Antioch mint information directly on the object. The coin dates to AD 376–378 and is identified as the latest datable coin in the assemblage. It therefore provides the *terminus post quem* for the deposit.

Scene 5 - From Antioch to Ancyra (spatio-temporal imperial geography). Scene 5 presents the imperial geography of the hoard through the 4D Viewer route. The scene combines historical mapping, location panels, a chronicle sequence and contextual three-dimensional assets to connect Antioch, the Cilician Gates, Tyana, Ancyra, Kapulukaya and Constantinople. Selecting Antioch introduces the mint context and the $ANT \cdot OB$ formula, while selecting Ancyra foregrounds its strategic significance in central Anatolia. The chronicle situates the hoard within the Valentinianic political sequence, from the division of imperial authority in AD 364 through the eastern rule of Valens and the chronological horizon established by the Valentinian II coin. The beat is evidence.

Scene 6 - Reading the Coins (numismatic close reading and resolution). Scene 6 presents representative coins of Valentinian I, Valens, Gratian and Valentinian II through the PCSS Viewer (see Fig. 1 for the four 3D-rendered coins). Visitors inspect each coin through object-anchored obverse and reverse annotations addressing titulature, portraits and mint information. Valentinian I represents the western branch of the new imperial house; Valens forms the eastern axis of the hoard through sixteen issues; Gratian introduces victory and shared dynastic authority; and Valentinian II provides the latest chronological horizon. The concluding synthesis reconnects the coins to the vessel and the Antioch-to-Ancyra geography, framing the hoard as a compact testimony to dynastic authority, imperial circulation and uncertainty in the late Roman East. The beat is resolution.

7 Technical Pipeline and Optimisation

The full asset pipeline, from FARO digitisation through Blender-based optimisation to Draco-compressed GLB delivery across the four interaction modes, is summarised in Fig. 4

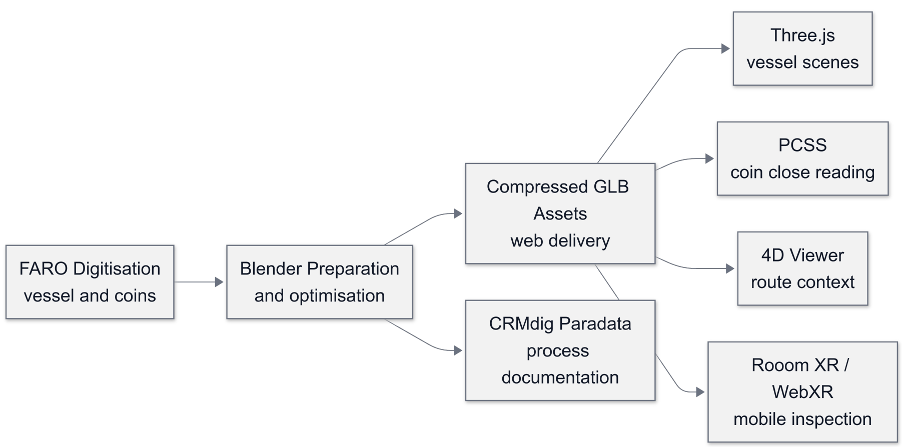


Fig. 4: Three-dimensional asset pipeline from FARO laser-arm digitisation to optimised GLB delivery across Three.js, PCSS, the integrated 4D Viewer and Rooom XR/WebXR, with CRMdig-informed process documentation.

Acquisition. The digital asset pipeline covers the terracotta vessel and twenty-one gold solidi that form the core Kapulukaya Hoard assemblage. The objects were digitised using FARO laser-arm capture, producing high-detail geometric records suitable for the close inspection of inscriptions, portraits, mint information and relief features. Source meshes for the inspection-grade coin models retain vertex counts ranging from approximately 279,000 to over 512,000, with corresponding triangle counts exceeding one million for the highest-fidelity assets; original textures are stored at 2048×2048 px before any web-delivery processing. The resulting digital objects are documented through CRMdig-informed paradata records linking physical artefacts, digitisation events, prepared model files, optimisation processes and delivery contexts.

Asset Preparation and Compression. Following digitisation, the assets underwent Blender-based preparation and optimisation. Recorded optimisation settings include WebP texture delivery at a target resolution of 1024 pixels; removal of duplicate and unused vertices; mesh instancing; node flattening; mesh joining; vertex welding; and Draco geometry compression. Draco compression was applied at level 6, a deliberate compromise between binary payload reduction and decoding latency, with quantisation parameters tuned to preserve inscription edges, fine relief and module boundaries critical to numismatic reading. Topology was preserved without resampling: vertex and triangle counts are unchanged between the source Blender file and the exported GLB, which means that the reductions reported below are obtained without geometric simplification. These processing choices are recorded as paradata in the project's CRMdig-informed metadata package.

Optimisation Outcomes. On representative inspection-grade coin models the optimisation pipeline yields binary-payload reductions of approximately 95% with no loss of mesh topology. Two reference cases illustrate the envelope: solidus 9 is reduced from 81.9 MB to 2.5 MB, resulting in a 96.95 % reduction, whilst solidus 4 was reduced from 96.2 MB to 5.64 MB, corresponding to a 94.14% reduction. Across the deployed catalogue of twenty-two assets (vessel and twenty-one solidi), final GLB sizes range from approximately 2.3 MB to 8.65 MB, depending on the scene role and material complexity of each object.

Runtime Delivery. The application delivers three-dimensional content as GLB assets and decodes Draco-compressed delivery models at runtime through `DRACOLoader`. PCSS close-reading scenes use high-detail representative coin models with object-local annotation vectors and obverse/reverse controls. Vessel-centred scenes provide animated archaeological context, whilst the integrated 4D Viewer route scene connects spatial, historical and object-level evidence. Rooom XR/WebXR extends the Kapulukaya hoard into mobile inspection. Runtime behaviour was validated across desktop and mobile targets: Chrome and Firefox on a standard laptop with an NVIDIA GeForce MX130, and an iPhone 16 Pro for the mobile WebXR target. Across these targets the pipeline exhibited stable loading, smooth rotation and deep-zoom interaction, and no observed rendering artefacts on the inspection assets used in PCSS scenes. Runtime performance is supported through scene-specific loading, selective use of high-detail three-dimensional inspection models, prepared annotation data and optimised web-delivery assets. This pipeline balances browser accessibility with the visual fidelity required for micro-heritage interpretation.

8 Open Science: FAIR Metadata, Zenodo Deposit and Paradata

The Golden Bond adopts a FAIR-oriented publication strategy intended to make its digital assets and interpretive documentation findable, accessible, interoperable and reusable. The project package deposited on Zenodo includes the optimised GLB models of the terracotta vessel and all twenty-one solidi, structured object metadata, digitisation and optimisation paradata, numismatic alignment records and documentation of interpretive decisions under a CC-BY 4.0 licence [23].

The implemented documentation layer consists of four complementary components. First, a CIDOC CRM 7.1.3-aligned JSON-LD record models the Kapulukaya Hoard, its terracotta vessel, twenty-one solidi, materials, people, places and documented events. Second, a CRMdig 5.0-informed paradata record (Table 2) documents FARO digitisation, Blender-based preparation, web optimisation, annotation authoring, XR delivery and integrated 4D Viewer contextualisation. Third, a Nomisma-aligned numismatic record links the solidus denomination, Antioch mint and represented emperors to verified linked-data identifiers. Fourth, a London Charter implementation strategy documents aims, research sources, knowledge claims, technical methods, access and sustainability.

Table 2: Implemented paradata record for the Kapulukaya Hoard digital assets.

Paradata field	**Description**	**Kapulukaya implementation**
Asset identifier	Stable identifier for each physical and digital object.	Env No.21; Valentinian II solidus; vessel; hoard assemblage
Object type	Material category represented by the asset.	Gold solidus; terracotta vessel; contextual route asset
Capture method	Recording method used to produce source geometry.	FARO laser-arm digitisation
Preparation process	Post-capture modelling and export operations.	Blender-based preparation and GLB export
Optimisation settings	Web-delivery processing operations.	WebP at 1024 px; Draco enabled; duplicate and unused-vertex removal; node flattening; mesh joining; vertex welding; no geometry simplification
File format	Delivery format used in application and archive.	GLB and JSON-LD
Interpretive annotation	Relationship between models and explanatory content.	PCSS object-local annotation vectors for legends, portrait types, reverse imagery, symbols and mint information
Spatial context	Contextual visualisation mode.	Integrated 4D Viewer route scene linking Antioch, Ancyra and Kapulukaya
XR access	Mobile three-dimensional delivery.	Rooom XR/WebXR delivery for four representative coins and vessel
Semantic metadata	Interoperability record.	CIDOC CRM 7.1.3; CRMdig 5.0; Nomisma alignment
Numismatic reconciliation	External infrastructure relationship.	Nomisma identifiers implemented; OCRE and CHRE reconciliation prepared
Licence and reuse	Access and reuse conditions.	CC-BY 4.0 through Zenodo deposit
Repository record	Persistent preservation record.	Zenodo DOI: 10.5281/zenodo.20371912

Following London Charter Principle 4, the paradata record distinguishes between digitised assemblage objects, contextual visual resources and curatorial interpretation. It documents the relationship between source objects, three-dimensional capture, derived delivery assets, object-anchored annotations and the visualisation outcomes made available to visitors [4].

The associated JSON-LD records preserve relationships between objects, digitisation processes, annotations and interpretive delivery, whilst the repository provides a persistent preservation context for both assets and documentation. Together, these measures support transparency, long-term accessibility and reuse, contributing to London Charter Principle 5 concerning sustainability and documentation [4,23].

The complete deposit is archived at `https://doi.org/10.5281/zenodo.20371912` (CC-BY 4.0), the live application is publicly accessible at `https://solidi.unimi.it`, and project progress is documented at `https://goldenbond.unimi.it`.

9 Conclusion

This paper has presented *The Golden Bond*, a metadata-driven 3D storytelling framework that addresses the physical "invisibility" of micro-heritage in museum collections. By operationalising the "Semantic Storytelling Origami" framework through the case study of the Kapulukaya Hoard, we showed how sub-millimetre numismatic detail can be bound to layered narrative beats, connecting structured cultural-heritage metadata (CIDOC CRM, Nomisma) to high-fidelity, optimised 3D delivery across web, kiosk and mobile XR. The case study also defines a transferable workflow whose metadata fields, curatorial questions, interaction modes and paradata checkpoints can be reconfigured for other micro-heritage collections.

The present paper is, by design, an implementation and case-study contribution. An empirical evaluation of the storytelling framework and through expert review and privacy-preserving visitor analytics remains for a future phase. The framework is collection-agnostic and can be reconfigured for other micro-heritage collections; all 3D models, metadata and paradata are openly available on Zenodo under CC-BY 4.0 to support reuse and reproducibility.

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