AURORA
Artwork Unique RecognitIOn and tRacking through chemicAl encoded data, miniaturized devices and blockchain alliance

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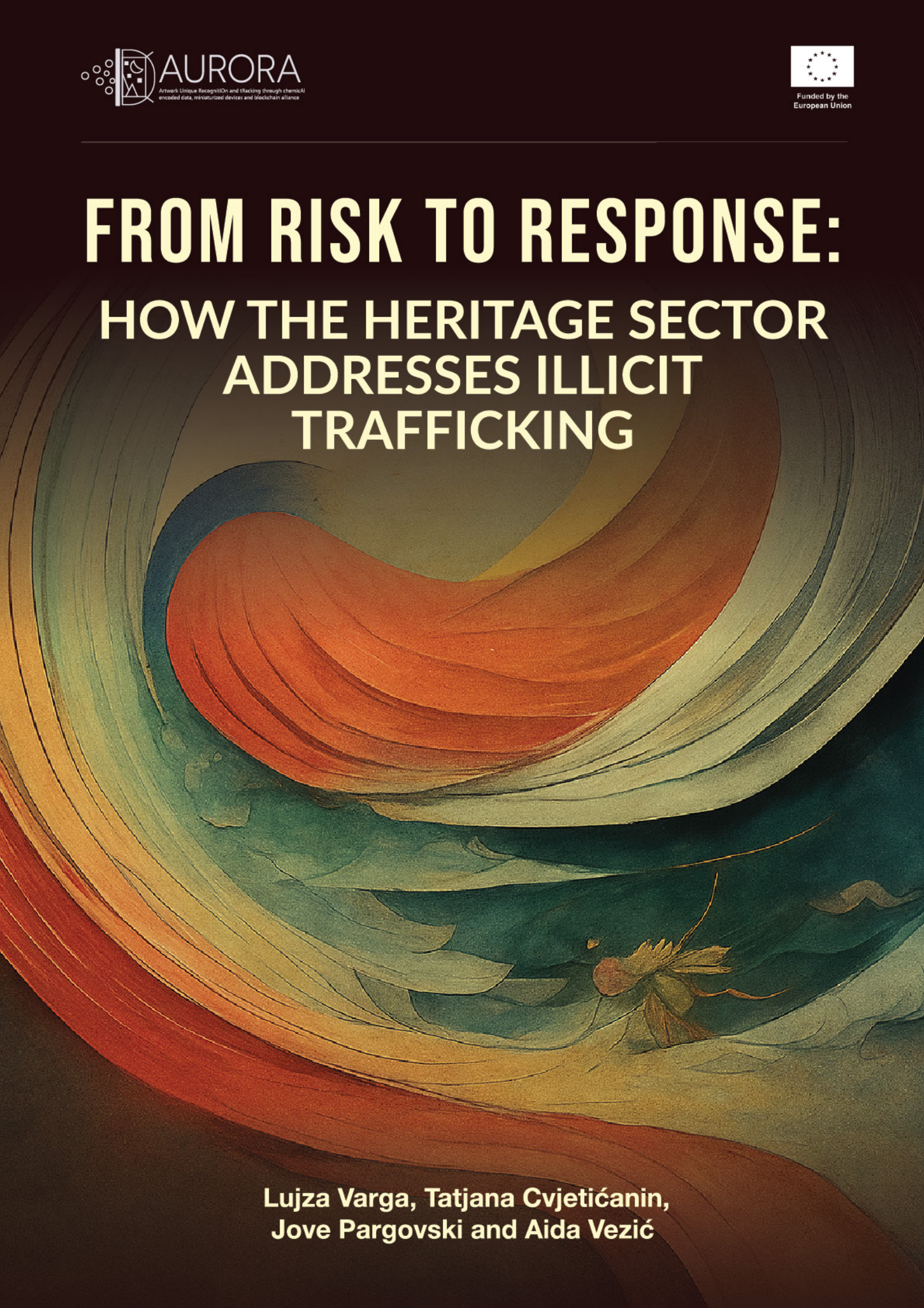
FROM RISK TO RESPONSE:

HOW THE HERITAGE SECTOR ADDRESSES ILLICIT TRAFFICKING



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FROM RISK TO RESPONSE: HOW THE HERITAGE SECTOR ADDRESSES ILLICIT TRAFFICKING

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Table of Contents

Introduction by the Editors

The AURORA Project is committed to developing innovative tools to combat the illicit trafficking of cultural goods, demonstrating the feasibility of a non-destructive, efficient, and cost-effective solution for artwork authenticity verification and tracking. By creating a knowledge bridge between technical experts and cultural heritage professionals, AURORA fosters accessibility and democratization among cultural institutions.

An important objective of AURORA is to raise awareness among stakeholders about methods and tools to prevent the illicit trafficking, theft, and destruction of artworks. In line with this goal, Illicit Trafficking of Cultural Property – Examples from the Heritage Sector brings together diverse case studies and expert reflections on the global fight against the illegal trade in cultural goods.

By gathering insights from museums, archaeological sites, conservation institutes, NGOs, and related organizations, this open-access publication spotlights existing frameworks, identifies challenges, and showcases innovative solutions. Our aim is to strengthen knowledge-sharing and collaboration across the heritage sector and beyond.

With contributions from authors across multiple regions, the publication highlights institutional responses, legal challenges, digital tools, and community-based initiatives. From high-profile restitution cases to the use of satellite imagery, digital databases, and cross-sectoral cooperation, the articles reveal the wide range of strategies used to safeguard heritage. The global scope of the case studies illustrates the complexity of protecting cultural property in both conflict and peacetime. Several contributions emphasize the role of activism, international cooperation, and even gender perspectives in addressing this pressing issue. From the protective framework of Blue Shield to ICESCO's initiatives in the Islamic world, the publication underscores the urgent need for inclusive and multidisciplinary approaches.

Firstly, aiming to be accessible as soon as possible, the editors decided to publish this volume online in two phases. This edition covers both parts, from the halls of the Hungarian National Museum to efforts of the Aurora project itself. Readers embark on a compelling journey through different perspectives, practices, and challenges. These contributions highlight heritage sector initiatives and demonstrate how diverse actors are reshaping the protection of cultural heritage.

Readers will learn how museums are becoming active partners in crime prevention and international collaboration, or about community-led strategies that link heritage preservation with identity and resilience. The articles further show how digital tools—from online databases to artificial intelligence—are becoming powerful allies in tracing looters, and the importance of civic engagement in those efforts. They will also encounter results of cutting-edge interdisciplinary research projects. Taken together, these contributions illuminate the many layers of resistance to heritage crime, inviting readers to reflect, learn, and draw inspiration from innovative responses across different contexts.

By sharing these stories, we hope to encourage further action, collaboration, and innovation in the global fight against the illicit trafficking of cultural property.

Dr. Lujza Varga, Prof. Dr. Tatjana Cvjetićanin, Jove Pargovski, MSc, Aida Vezić, MA

Harnessing the Memory Twin Concept to Combat Illicit Cultural Heritage Goods Trafficking

Anthony Cassar[1]

Abstract

The illegal trafficking of cultural heritage goods is a major problem that undermines global heritage preservation. With the advancement of data acquisition processes for cultural heritage, the Memory Twin concept emerges as an innovative solution for safeguarding cultural assets. Building on the digital twin paradigm, the Memory Twin goes beyond mere replication of physical cultural heritage assets by integrating metadata, paradata, and contextual layers of knowledge, including intangible cultural heritage, to construct a more comprehensive digital representation of heritage objects undergoing digitization. This paper examines how the Memory Twin framework can support provenance tracking, detect unauthorized movements, and facilitate stronger international collaboration in heritage protection. By embedding Memory Twin models within heritage registries and law enforcement databases, real-time monitoring and recovery efforts may become more effective. Drawing on insights from the ENIGMA Project, this study highlights practical applications of the methodology. This paper proposes the broader implementation of the Memory Twin methodology as a strategic tool in the fight against cultural heritage trafficking, emphasizing its potential to enhance detection, documentation, and preservation efforts worldwide.

Keywords: *Memory Twin, Holistic Heritage BIM, Metadata, Paradata, Digital Twin, FAIR CARE.*

Introduction

This paper introduces the Memory Twin concept and examines its significance in advancing cultural heritage protection, with particular attention to the challenge of combating illicit trafficking. It argues that the Memory Twin's integrative framework, encompassing tangible, intangible, and paradata dimensions, offers a comprehensive model for heritage documentation. By promoting the use of metadata and paradata in the data acquisition process, the Memory Twin supports more robust strategies for heritage monitoring, provenance verification, and the long-term safeguarding of at-risk cultural assets.

In 1970, UNESCO adopted the Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property, which commits signatory states to implement legal, administrative, and educational measures to safeguard cultural property and prevent its illicit trafficking (UNESCO, 1970). UNESCO adopted this convention in recognition of the serious threat that illicit trafficking of cultural heritage poses to global heritage preservation. It is a multi-billion-dollar industry that not only results in the loss of invaluable cultural artifacts but also contributes to the financing of organized crime and terrorism. By the end of 2024, 143 countries had signed this convention, demonstrating a collective commitment to mitigating illicit cultural trade (UNESCO, 2024).

1 Heritage Malta

Some of the key highlights of this convention include preventive measures such as maintaining national inventories and export certifications, restitution mechanisms aiding the return of stolen artifacts, and international cooperation to fight illegal trafficking through enforcement mechanisms. These initiatives emphasize the need for stronger monitoring, documentation, and policy enforcement to protect cultural heritage. Advancements in cultural heritage digitization offer unprecedented opportunities for comprehensive documentation and long-term protection against illicit trafficking. However, creating digital twins without embedding contextual layers, paradata, and intangible cultural dimensions risks producing sterile and decontextualized replicas. Without attention to authentic identity and narrative meaning, such digital surrogates may preserve form but fail to safeguard the cultural significance and historical value of the heritage they aim to protect.

The Memory Twin and Its Application in Heritage Protection

The Memory Twin concept represents an evolution of the Digital Twin model, specifically tailored for cultural heritage preservation and protection. While Digital Twins provide a precise virtual representation of an object based on geometric, material, and real-time sensor data (Cassar & Ioannides, 2024), Memory Twins expand on this by embedding historical, contextual, and provenance-related information, offering a more holistic approach to heritage documentation. Unlike traditional Digital Twins, which primarily serve engineering and conservation monitoring purposes, Memory Twins integrate additional layers of critical information.

This concept builds on the Holistic Heritage Building Information Modeling (HHBIM) concept, developed by Fioralba Prendi and Claudio Mirarchi, which enhances traditional Heritage Building Information Modeling (HBIM) by addressing its limitations in geometric modeling and digital representation. HHBIM integrates historical research, material analysis, structural assessment, lifecycle management, stakeholder collaboration, and digital twins, creating a more dynamic and semantically rich approach. Memory Twin introduces a critical, layered methodology for data authenticity, traceability, and cultural embeddedness. It draws directly from and expands upon the Holistic Heritage Building Information Modeling (HHBIM) approach by interconnecting the technical, historical, legal, and societal dimensions of cultural artifacts in a semantically rich, transparent, and ethically grounded digital model (Brumana, Ioannides, & Previtali, 2019).

A Memory Twin records an artifact's evolving story, encompassing its cultural, social, and historical significance over time. Beyond technical modeling, it can also document an object's chain of custody, legal status, and movement history, which is vital in identifying and recovering looted artifacts. Most importantly, the Memory Twin framework integrates both **metadata** and **paradata** to enhance transparency, reproducibility, and contextual understanding in cultural heritage digitization.

While metadata provides structured information describing the digitized object, such as title, creator, date, dimensions, materials, and provenance, paradata records the processes and decisions involved in the creation of the digital representation. This includes details such as the equipment used, software settings, environmental conditions, and interpretive choices made during scanning or modeling. Metadata addresses the "what" and "who" of the object, whereas paradata explains the "how" and "why" of its digital production. The inclusion of paradata ensures intellectual transparency, particularly in cases involving subjective interpretation or restoration, and is crucial for assessing the reliability and accuracy of digital outputs.

By documenting both content and context, the Memory Twin approach supports ethical stewardship and long-term reusability, aligning with emerging standards such as FAIR and CARE and responding to the growing need for certified digitization practices. Unlike purely technical twins, Memory Twins also embed community perspectives, expert insights, and multiple interpretations, enhancing the representation of cultural meaning (Cassar & Ioannides, 2024). By enriching digital replicas with historical and legal dimensions, Memory Twins provide a more concrete tool for tracking, authentication, and restitution of cultural property. This expanded digital framework is particularly relevant in efforts to combat illicit trafficking and ensure the sustainable protection of global heritage.

The Role of Paradata in Ensuring Transparency and Reproducibility in Digital Acquisition

Paradata refers to the documentation of the process, providing contextual information, whereas metadata describes the data itself (i.e., what software was used, or what settings were applied, etc.). Baker (2025), in the chapter "Paradata: The Digital Prometheus," discusses the importance of paradata in research and documentation, and explains how the term originated as a solution to the problem of inaccessible and opaque data. "This lack of intellectual transparency [...] would hinder innovation in 3D visualization-based research and result in an under-exploitation of created assets and a loss of intellectual capital if not addressed" (Baker, 2025).

Moreover, he raises the point that 3D data can often be altered for aesthetic or speculative purposes, leading to further confusion and misunderstandings, especially when there is no clear documentation of the process. The author critiques an overreliance on technology for its own sake and emphasizes the need for standardized practices and seamless transitions to emerging technologies, ensuring that data remains transferable. He concludes that the primary purpose of documenting the research process is to enable a 3D model to be interpreted and analyzed based on its spatial and contextual representation rather than merely its visual appearance (Baker, 2025).

Grellert et al. (2025) emphasize the essential role of paradata in promoting transparency and reproducibility in digital heritage practices. They argue that documenting the interpretive decisions made during the creation of virtual reconstructions, such as the sources consulted and the reasoning behind specific design choices, ensures that the process remains open to scrutiny. This transparency allows others to understand how a model was developed, fostering trust in its scholarly validity. Moreover, by making these processes explicit, paradata supports reproducibility, enabling future researchers to replicate or revise the work based on new evidence.

The authors also highlight that such documentation contributes to the long-term sustainability of digital heritage projects, as it allows reconstructions to evolve over time without losing their scholarly context. Ultimately, paradata is presented not just as supplementary information but as a core component of scientific rigor in digital acquisition and modeling, ensuring that virtual reconstructions remain credible, traceable, and adaptable.

Documentation and Holistic Heritage Building Information Modelling (HHBIM)

Holistic Heritage Building Information Modeling (HHBIM) represents an advanced evolution of Heritage BIM (HBIM), designed specifically for the documentation, analysis, and conservation of cultural heritage assets. Unlike conventional BIM, which is primarily used in the architecture, engineering, and construction sectors for design and facility management, HHBIM integrates historical, semantic, and environmental data alongside geometric information. This approach enables a more comprehensive understanding of heritage structures, incorporating multi-source inputs such as laser scanning, photogrammetry, archival records, and IoT sensor data (Fattore et al., 2025).

HHBIM emphasizes semantic enrichment and the inclusion of paradata to document interpretive decisions, ensuring transparency and reproducibility in heritage modeling. It also supports interoperability with GIS and sensor networks, enabling real-time monitoring and predictive diagnostics for conservation planning (Fattore et al., 2025). In contrast, traditional BIM relies on standardized, parametric components and prioritizes efficiency and performance over historical authenticity (López et al., 2018). HHBIM, however, accommodates irregular geometries and culturally significant features, making it a vital tool for historians, conservators, and archaeologists. Its holistic nature ensures that heritage models are not only technically accurate but also contextually meaningful and adaptable for long-term stewardship.

This paper explores the concept of holistic documentation, examining its implications for how issues of illicit trafficking in cultural heritage are understood and addressed. It highlights how the ENIGMA project not only aligns with this approach but also adapts its suite of tools to tackle illicit trafficking in a comprehensive and integrated manner.

By embedding holistic documentation into its methodology, the project demonstrates the value of this approach across its various components, including the iterative design of pilot studies. These studies have been informed by expert consultations that raise critical questions: At what point and for what reasons are cultural heritage objects flagged at borders? How does the material composition of an object influence detection and classification?

Furthermore, the potential integration of advanced technologies, such as 3D scanning, into ENIGMA's tools could enable automated cross-referencing of documented cultural goods (CG) with satellite imagery, known trafficking routes, institutional red lists, and law enforcement databases. This would not only enhance interoperability but also leverage AI to streamline research across overlapping domains, ultimately increasing the efficiency and precision of efforts to combat illicit cultural heritage trafficking. When implemented accurately, an HBIM framework encompasses not only detailed documentation of workflows related to both contemporary and historical data acquisition but also strategies for dissemination and the development of precise 3D models (Murphy et al., 2025).

The authors of "Holistic Heritage Building Information Modelling (HHBIM): From Nodes to Hub Networking, Vocabularies and Repositories" expand on how HHBIM should be constructed as a dynamic system (Brumana et al., 2019). It is crucial that the various overlapping and corresponding data, whether tangible or intangible, be connected and interlinked thematically and systematically to create an assemblage of integrated information.

"The attribute holistic is here used with the meaning to empower instruments and methods capable to interconnect single HBIM nodes within networks where to find the information collected in a cross sectorial space: vocabularies, libraries of object and semantics, derived from such 'Informative Models'" (Murphy et al., 2025; Brumana et al., 2019). The Memory Twin aims to construct interoperable layers of knowledge, where artifacts are not isolated 3D replicas but living, networked entities embedded with narrative layers, provenance chains, and intangible values. Through this lens, cultural data is no longer static but rather an evolving assemblage of meaning, encoded across time, communities, and disciplines.

Fikardou Village (Cyprus)

An important example discussed in this paper is the tentative UNESCO World Heritage site of Fikardou Village in Cyprus (UNESCO-WHTL), examined in detail in "The Holistic, Digital Cultural Heritage Documentation of the Fikardou Traditional Village in Cyprus" (Ioannides et al., 2025), which concludes the outcomes of three H2020 European-funded projects. The village consists of an assemblage of overlapping architectural styles, some of which are speculated to date back to the fifteenth century, while others incorporate Cypriot folk architectural elements from the eighteenth century. Numerous efforts have been made to preserve and transmit the histories of the place to future generations. The evolution of architectural styles and the way the village is being developed and preserved provide a living case study of the sociopolitical and cultural development of its inhabitants. The structures serve as tangible evidence of how the inhabitants adapted through the centuries, reflecting prosperity levels, professions, cultural values and their significance, and shifting perceptions of what was worth preserving at different points in time, always in relation to the technological advancements of each era. Furthermore, the buildings also reveal environmental changes as well as the long history of human interaction with both land and sea.

The authors explain how the Fikardou village offers an insight into how aesthetics and landscape design converge to serve as testimony to a civilization or tradition that no longer exists. The rural settlement is an entangled artifact of overlapping architectural decisions and influences, making its preservation and maintenance essential. Today, the site has assumed a new role as an open-air museum and touristic destination, attracting visitors to the area. While this role ensures its visibility, it also introduces potential risks to the site itself, including overpopulation of the area, physical alterations to the landscape, dissemination of inaccurate information, and littering. A more organic and participatory approach to managing this evolving identity is therefore essential. As the authors underline, "To ensure that both cultural heritage and the local community benefit from the channelling of tourism to the site, it is essential to include local stakeholders and communities in the decision-making processes" (Ioannides et al., 2025).

This challenge has been addressed through projects such as MNEMOSINE and TExTOUR. Several

workshops addressed the power imbalances surrounding responsibility for defining the identity of a place, promoting a more participatory approach in which end-users were granted autonomy in the decision-making process, leading to what could be described as a user-centered, space-based, digital interdisciplinary archive of the area (Bollini, 2019). Bollini (2019) further critiques the disadvantages of linear representation of historical events, warning that uncritical digitization and curation risk producing sterile, linear, and often biased hierarchical structures that diminish informational richness. However, this has not been the case for e-Fikardou, which has successfully avoided these pitfalls by ensuring that the content of the platform is: **a.** shareable; **b.** functional and useful (e.g., for tourism or policy-making); **c.** usable (with user interfaces accommodating different levels of digital literacy); and **d.** accessible (providing information and data to researchers outside Cyprus) (Ioannides et al., 2025).

E-Fikardou thus stands as a singular, site-specific example of how digital, multilayered, and holistic preservation can be achieved inclusively and holistically, while simultaneously connecting tangible and intangible memories and events, layering them within a user-friendly and user-centered platform (Ioannides et al., 2025). The various ENIGMA tools and methodologies build on the same logic while expanding it to portable artifacts, focusing on creating parallels and nodes between objects that are frequently displaced, reappear on illicit markets, and often remain uncatalogued. As a result, the flow of information and data can be inconsistent and fragmented. Additionally, the ENIGMA tools (see section 2)—including linked metadata and paradata, AI-driven reconstruction tools, data crawlers, and a visual search engine—enable continuous updating and cross-referencing of cultural goods with existing databases maintained by different authorities. This facilitates provenance research and helps define the origin of undocumented objects. By bridging tangible and intangible information, ENIGMA not only monitors and exposes illicit circulation routes but also informs preventative heritage policies in real time and assists in the identification of unprovenanced artifacts.

ENIGMA Tools and the Memory Twin

This section presents the different tools of the Horizon Project ENIGMA and their connection to the Memory Twin concept, while also explaining their potential future applications. In their paper "Fighting Illicit Trafficking of Cultural Goods: The ENIGMA Project" (2023), P. Patias and C. Georgiadis discuss the entanglement of illicit trafficking with war and armed conflict and explore how the project attempts to navigate the multiple anthropogenic dimensions of trafficking. In line with the Memory Twin concept, trafficked cultural heritage (CH) artifacts are understood as tangible evidence of the political conditions that led to their displacement. They document forced migration, black market circulation, and exemplify the lack of documentation and gaps in detecting illegal routes.

The ENIGMA tools are:

1. Authenticity and traceability workflow for registered and unregistered or stolen objects;
2. Remote sensing, monitoring, and safeguarding system;
3. Database and inventory sharing and interlinking;
4. 3D CG reconstruction from incomplete information; and
5. CH training in a VR space.

Patias et al. (2024) emphasize that ENIGMA tools would be particularly valuable for artifacts such as cartographic objects. They describe the "Unique Authenticity Identifier (UAI)" as "a new dynamic composite index based on the holistic documentation of each object. The UAI allows for the calculation of comparison metrics between objects examined by L.E.As and objects reported as stolen" (Patias et al., 2024). The authors further highlight ongoing challenges that the tools aim to address, including the various time constraints such as: **1)** the timeframe between when a CH object is reported and when (if ever) it is confirmed as missing; **2)** the limited time that law enforcement agencies have to confiscate a suspicious item from a passenger; and **3)** the unique nature of many artifacts, which may never have been properly catalogued or documented in any database. These parameters add multiple layers of complexity that must not only be acknowledged but also adequately addressed.

ENIGMA Objectives

The ENIGMA project is structured around three overlapping categories of objectives: scientific, technical, and demonstration/dissemination. **Scientifically**, ENIGMA aims to co-design the Unique Authenticity Identifier (UAI), develop an advanced decision-support platform based on a joint workspace that incorporates existing information on documented CGs, and mitigate threats to heritage sites through earth observation techniques and GIS. **Technically**, it focuses on creating and validating UAI tools, applying machine learning for object clustering and stratification, and enhancing metadata analysis for database interlinking. Finally, the project **demonstrates** and updates these tools in real-world conditions, improves stakeholder communication, and produces policy-relevant outputs through validated pilot cases.

Human-Computer Interaction – Cultural Heritage

The participatory design approach, influenced by Research Through Design principles, ensures the co-creation and co-development with end-users. The ENIGMA project's integration of Human-Computer Interaction (HCI) methodologies has played a critical role in ensuring that technological interventions are ethically grounded, culturally responsive, and inclusive, especially with respect to digital literacy and intuitive interfaces for CH Training. Holistic Documentation, and by extension Memory Twins, which incorporate information from people of different backgrounds, raises multiple questions regarding a) perspective and objectivity and b) the risks of becoming overly Western-centered (Hirsch et al., 2024). Therefore, it is essential to foster a collaborative, co-creative process in which the goal is not to produce a final "perfect" design but rather to embrace an organic feedback loop while prioritizing inclusivity. Through HCI prototyping methods, iterative prototyping, and participatory international hybrid workshops, ENIGMA partners acknowledge that accessibility and usability are not universal or absolute. Feedback has been collected and incorporated into the design process from stakeholders of diverse backgrounds and levels of digital literacy, while creating space for dialogue and experimentation.

Interpretation of Results

An examination of the existing data shows that ENIGMA has identified a number of challenges in the ongoing attempts to better understand and address illicit CH trafficking. Through the tools that this project offers—many of them inspired by the Memory Twin concept—it highlights areas that require further investigation. Creating dynamic routes of the movements of CH artifacts and suspected trafficking routes, maintaining a dynamic archive of ever-changing documentation, and tracing the patterns and reappearances of specific high-risk artifacts will further reinforce the utility of data correlation and the role of historical records in detection and prevention. Memory Twins of artifacts will evolve into interactive preservations with multiple contextual layers, combining community narratives, ethnographic accounts, and cultural details embedded within structural data to provide multi-perspective understandings of the artifacts.

The tools, which are still under development, can become valuable in a number of other ways apart from the ones they were designed for. AI-assisted tools, including visual recognition, identification and reconstruction of fragmented artifacts, and data crawlers, could support cataloguing processes in CH institutions, optimizing the identification of duplicate artifacts across collections, and assist in provenance tracking and authentication. Finally, the participatory methodologies incorporated throughout the various stages of the project (e.g., co-creation through hybrid workshops, consultation with national authorities, and stakeholder feedback loops) show in practice how the Memory Twin concept can contribute meaningfully to cultural heritage conservation, policy development, and the fight against illicit trafficking of CH artifacts.

Conclusion

By incorporating holistic documentation approaches and the evolving concept of the Memory Twin, ENIGMA recognizes that the representation of cultural heritage must remain sensitive to multiperspectivity and the plurality of values across communities and traditions. Furthermore, as Patias et al. (2024) emphasize, "crime networks demonstrate exceptional resilience and adaptability to L.E.As deterrent measurements, and in this spectrum, the ENIGMA effort has to constantly evolve and adapt by incorporating new technologies and new algorithms." The only way forward is to identify existing limitations and adapt to them in an organic and holistic manner. This is why ENIGMA adopts such a multidisciplinary approach, particularly by combining cutting-edge technologies with policy reform and inter-institutional collaboration.

This paper argued that a more holistic approach, combined with interoperability, could significantly optimize current efforts to combat the illicit trafficking of cultural heritage artifacts. Memory Twins can facilitate the cross-checking of diverse sources of information during research and enhance cross-correlation. They also ensure that ENIGMA tools are based on holistic documentation of cultural heritage assets that safeguard their authentic identity. This approach enables curators, researchers, and policymakers to engage with cultural heritage in real time, track provenance histories, detect patterns of illicit movement, and support participatory and inclusive storytelling for future generations.

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Biography of the author

Anthony Cassar is the Head of the Technology and Experience Development Unit, including the IT department and the Digitization Department, overseeing the preservation and digitization of over 90 national cultural heritage sites, including numerous UNESCO sites, entrusted to Heritage Malta, Malta's national agency for cultural heritage. With over 30 years of experience in IT and multimedia, Anthony champions digital transformation initiatives to make Malta's cultural heritage accessible and engaging worldwide. He is an advocate for high standards in digitization, especially in 3D digitization, and promotes the reuse of 3D digital assets in various outreach efforts, ensuring that Malta's rich heritage is preserved and appreciated across borders and generations. He is currently pursuing his PhD at CUT - Cyprus University of Technology, under the supervision of Marinos Ioannides, the UNESCO Chair of Digital Cultural Heritage and the Director of the Digital Heritage Research Lab at the Cyprus University of Technology in Limassol. Together, they have been working on establishing the significance of the evolving concept of the Memory Twin, which introduces a holistic framework for integrating both tangible and intangible dimensions of heritage.

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