

The IMPULSE Project: Advancing Immersive Digitization for Sustainable Digital Cultural Heritage Integration within ECCCH

L. Mehmeti¹, M. Ascari¹, V. Gianfrate¹, Z. Zeglen², D. Charitos³, G. Anastassakis³

¹Alma Mater Studiorum - Università di Bologna, Italy ²Jagiellonian University, Poland, ³National and Kapodistrian University of Athens, Greece

Abstract

This article critically analyses the assumptions of the European Collaborative Cloud for Cultural Heritage (ECCCH) and explores how the impact and results of the ongoing IMPULSE project can contribute to and integrate within its broader framework. In particular, IMPULSE offers a relevant testing ground for ECCCH to advance the management of immersive digital cultural heritage objects. A key focus is on the sustainability of IMPULSE's outcomes and their potential to address the fragmentation that characterizes the digital cultural heritage landscape. This fragmentation affects different aspects of the digitization process, such as technical issues, standardization, interoperability, user experience, and legal dimensions. Many cultural collections in Europe are still not digitized, with significantly low figures for high-quality three-dimensional representations essential for scientific collaboration. Existing standards and methodologies are neither uniform, traceable, nor fully secure, and practical techniques enabling accurate physical simulations of digitized heritage objects remain largely unexplored. Against this issue, IMPULSE is positioned to develop and test new approaches connected to metadata standardisation and immersive interaction with digital objects that capture not only the visual but also the dynamic characteristics of cultural heritage assets and practices. Starting from the analysis of these aspects and given the alignment with the strategic objectives of the European Commission, IMPULSE's ongoing research contributes to technical de-fragmentation by providing the development of an EU-based Multi-User Virtual Environment (MUVE) for visualising and interacting with 3D assets. Its approach emphasizes interoperability, ensuring that data formats, protocols, and tools align with existing cultural heritage infrastructures, making integration into platforms and digital twins more feasible. IMPULSE research is also aimed at defining protocols and tools to provide data in a standardised and easily understandable format, based on three IMPULSE prototypes. The ongoing research on IMPULSE is relevant when considering uninvolved users, as it provides prototypes and tests of immersive interaction geared towards diverse audiences (academics, artists, cultural and creative industries). By focusing on immersive interaction with CH objects in virtual environments, IMPULSE contributes not only to advancing digital heritage methodologies but also to ensuring their sustainability and integration within the ECCCH.

1. Introduction

The European Collaborative Cloud for Cultural Heritage (ECCCH) represents a flagship initiative by the European Commission aiming to foster cross-disciplinary and cross-sectoral collaboration in the cultural heritage sector towards the digitization of cultural heritage in the European continent. By leveraging advanced digital tools, the ECCCH seeks to address the challenges of fragmentation in the digitization and management of cultural heritage assets. This fragmentation spans technical, legal, and experiential dimensions, hindering the effective use and preservation of Europe's cultural treasures. The ECCCH aspires to create an open digital ecosystem that facilitates co-creation, sharing, and reuse of data while supporting sustainable development in the cultural heritage domain (<https://www.heritageresearch-hub.eu/project/echoes/>).

In this context, the IMPULSE project (Grant Agreement ID: 101132704 <https://cordis.europa.eu/project/id/101132704>) emerges as a significant contributor to advancing ECCCH's objectives. Launched in February 2024 and scheduled to conclude in January 2027, IMPULSE focuses on immersive technologies for digital cultural heritage. It addresses key challenges such as metadata standardization, interoperability, and user experience

evaluation for virtual environments, especially when used via immersive technologies. The project also emphasizes sustainability by exploring innovative standardization and integration methods for managing and visualizing high-quality 3D representations of cultural assets. These efforts align with ECCCH's goals of enhancing accessibility, collaboration, and innovation within Europe's cultural heritage landscape.

The analysis begins with a conceptual framework rooted in European digital heritage strategies and Horizon Europe objectives, contextualizing both the ECCCH's vision for a unified digital ecosystem and IMPULSE's role as an experimental contributor. The second part of the paper describes IMPULSE's objectives (particularly its focus on immersive digitization, legal frameworks, and user-centred design) in alignment with ECHOES's mission to integrate fragmented communities via the ECCCH platform. The final section details how IMPULSE's prototypes, particularly its MUVE platform, could flow into ECCCH's architecture by a) standardization, b) interoperability, c) user-centred innovation. This structure ensures a coherent analysis of IMPULSE's potential to support ECCCH's technical de-fragmentation goals while addressing sector-wide challenges in digital heritage.

2. Methodological Approach: Bridging Gaps Toward the ECCCH

The methodological approach of this paper is based on the comparative analysis between IMPULSE and ECCCH on a dual level: theoretical analysis and practical outcomes related to IMPULSE and ECHOEs project. The analysis is framed in European policy frameworks and Horizon Europe strategies related to cultural heritage digitization. These sources provide insights into the broader strategic objectives guiding both initiatives. Additionally, the paper reflects on partial results from IMPULSE, particularly its work on Multi-User Virtual Environments (MUEs), which offer a testing ground for aligning immersive technologies with ECCCH's infrastructure requirements.

Considering that, at present, both the IMPULSE project and the development of the ECCCH platform - by the ECHOES project - are ongoing, the reflections proposed here are intended as theoretical elaborations based on several aspects. As far as the theoretical analysis is concerned, the main sources analysed refer to the European strategic documentation and to the research results obtained in the first year of IMPULSE's work, in particular with regard to the activation of a MUE platform with a view to development, integration and user experience. The European vision set out in the strategic documentation goes on to define the characteristics that should guide the design of the ECCCH, also with a view to integration with the existing environment dedicated to digital cultural heritage [EC22; EC22B; EC24], which has been supported, among other things, by years of competitive design dedicated to the identification of digitisation methods for different types of objects. The main challenges defined in relation to the ECCCH are related to cross-sectoral collaboration within the CH, to the definition of a permanent, open and secure infrastructure able to aggregate and connect existing digital heritage, as well as to foster ways to enrich it.

The IMPULSE project works in particular on the issue of fostering access and enjoyment of digital heritage for a wide public [WDC23], starting from the analysis of the expectations and characteristics of three groups of users (Students and educators, Artists and CCI professionals), also through the definition of modalities and tools aimed at UX evaluation specific to the field of immersive technologies [LWOF23; SFCW23; BPR*18]. In particular, the choice of adopting Multi-User Virtual Environment and the concept of Social VR is linked [BGH*22; GCSL23], on the one hand, to experimenting simple modes of interaction (object-user and user-user) [WDK*18; RGG17; FC23] for different types of subjects and, on the other, to favouring modes of knowledge exchange between people working in different sectors.

3. Contextualizing IMPULSE Actions and Results

In the quest for a European Collaborative Cloud for Cultural Heritage, it is impossible to overlook the extensive digitization efforts undertaken by European cultural institutions over many years. This meticulous and often underappreciated process has laid not only the foundation but also served as a driving force for creating infrastructural solutions. Digitized objects, characterized by their diversity and sensitivity, require not merely secure storage spaces, appropriate formats, and standards, but above all a coherent and thoughtful approach to its openness. Such an approach must address the varied needs of experts, creators, educators, and the wider public alike.

The IMPULSE project directly responds to these requirements by developing innovative methodologies for sustainable immersive digitization of cultural heritage assets. At its core, IMPULSE addresses critical challenges related to data governance, standardization, interoperability, and collaborative workflows within the digital cultural heritage ecosystem.

Central to IMPULSE's approach is the creation of an in-house prototype platform of MUEs (Multi-User Virtual Environment), designed to facilitate advanced visualisation and immersive interaction with digitized three-dimensional heritage objects. As a team we are strongly convinced that immersive platform significantly enhances accessibility and usability for a wide range of users, including researchers, cultural and creative industries, and the general public.

Furthermore, IMPULSE tackles fragmentation within the digital heritage domain by establishing simplified, but still standardized, metadata frameworks and protocols. These ensure accurate representation, and seamless interoperability across diverse cultural heritage databases and digital twin infrastructures. Through its prototypes, IMPULSE rigorously tests innovative methods for capturing not only visual but also dynamic characteristics of heritage objects, thereby advancing the management and interactive dissemination of cultural heritage.

IMPULSE exemplifies how immersive digital technologies can effectively bridge existing gaps in digital heritage management, offering robust solutions that promote sustainability, interoperability, and enriched user engagement. The project's ongoing research and practical implementations serve as valuable models for the future integration and advancement of immersive digitization practices across Europe. It is our explicit aim as the project team, that IMPULSE will work towards supporting access and presentation of CH content via an immersive interface, leveraging the possibilities for ECCCH to adopt immersive experiences.

4. The Technological Aspects of IMPULSE: Enabling Innovation Towards the ECCCH

The IMPULSE project aligns perfectly with the intents and goals of the ECHOES project. In this section the paper presents a series of arguments in support of this claim, structured according to the four main pillars proposed by ECHOES. With reference to the Communities pillar of ECHOES, IMPULSE will ultimately provide guidelines for the creation and long-term operation of open, multi-user creator communities actively communicating and interacting as part of co-creation activities in virtual environments [OAUO24]. More specifically, ECCCH aims at creating "a new collaborative digital dimension for Cultural Heritage preservation, documentation, analysis, conservation-restoration, interpretation and re-use". In response to this, IMPULSE supports the needs of specific user groups (artists, educators, CCI stakeholders) towards utilising pre-existing digitised cultural heritage assets for co-creating new cultural content. For this purpose, IMPULSE's requirements analysis take into account the practices and needs of communities involved in these practices.

With regards to the Knowledge pillar, IMPULSE will provide a prototype implementation of a multi-user virtual world platform for co-creation with digital heritage assets. With reference to the Innovation Pillar, the IMPULSE platform prototype introduces a distributed, modular architecture that encompasses well-known standards, cutting-edge technologies

and widely adopted practices and tools to ensure scalability, interoperability, extensibility and long-term maintainability. In particular, the architecture consists of (i) a central backend component, (ii) a web-based frontend application, (iii) a centrally managed asset repository, (iv) virtual world servers, (v) virtual world clients, and (vi) external asset aggregator interface plugins.

The central backend is responsible for providing user authentication and authorization services, thus ensuring that a common, wide user base has seamless and secure access to all other aspects of the platform, as well as orchestration of available virtual worlds and asset collections. As such, it also ensures both maximum content accessibility and a necessary level of control of what can be experienced on the platform. The web-based frontend allows users to browse and search through asset collections, manage user profiles, check the state of connected virtual worlds, and maintain own asset collections. The central asset repository offers structured storage and standardized asset access as a default component of the prototype platform deployment as part of the IMPULSE project, thus ensuring that the platform can operate as required from the very beginning. Virtual world servers are responsible for simulating virtual environments persistently populated with assets from the various repositories in real-time and enabling multi-user access and collaborative content editing. Virtual world clients enable immersive access to the virtual worlds and provide a variety of asset browsing, content creation and user communication tools. The above components can communicate over the Internet via standard networking protocols and interoperate according to well-defined specifications and standards. As a consequence, the IMPULSE platform is, by definition: distributed, as the platform's entire operational load is evenly dispersed over numerous infrastructure hosts; scalable, as any number of components of various types can be plugged into it at any time; extendible, as components with diverse functionalities can be developed and added to existing ones; maintainable in the long-term, as new components can replace outdated ones to leverage new technologies and advancements; capable of interoperability with external systems, as the specification for interface plugins is an integral part of the platform's architectural specification.

With regards to the Sustainability pillar, the IMPULSE project will enhance the sustainability of digitised assets in virtual environments. More specifically, the IMPULSE output in the form of guidelines, platform design and prototype implementation may inform the long-term strategy of ECCCH, as a proof-of-concept as well as an operational basis. Finally, IMPULSE's guidelines, distilling research into legal and technical issues relevant to multi-user virtual environments for heritage and education may support ECCCH's legal future viability.

5. Conclusions and future research directions

The IMPULSE project effectively supports the ECCCH vision by developing practical, innovative, and sustainable solutions for immersive cultural heritage digitization, enhancing collaborative community engagement, knowledge sharing, and asset management. Its comprehensive guidelines, prototypes, and technical frameworks provide a robust foundation, ensuring ECCCH's long-term viability, interoperability, and enriched accessibility for diverse user communities.

Ultimately, the output of IMPULSE can be used as a proof of concept to build upon its growing knowledge body, supporting immersive social experiences for working with and presenting CH content within a cloud context in an innovative,

valid and sustainable manner. This support extends not only to the technological advancements related to 3D digitization but also includes legal considerations and the adoption of common standardization frameworks for CH, ensuring that the ECCCH platform is compliant and interoperable among diverse contexts.

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