

DIGITAL HERITAGE 2025

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Siena, Italy

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- dh.20253349 | Tactile Embroidery Reproduction Exploiting Machine Vision for Visually Impaired Engagement
George P. Jenkinson, Myrsini Samaroudi, and Xavier Aure Calvet
- dh.20253023 | Exploring Anamorphoses in Immersive Virtual Reality on the Web: Design and Challenges of the Anamorphic Gallery of Anamorphoses (AnGA)
Sofia Menconero, Chiara Florise Amadei, Giorgio Gosti, and Bruno Fanini
- dh.20253082 | Full-fledged Virtual Exploration of Sacred Spaces
Desislava Paneva-Marinova, Zsolt László Márkus, Tibor Szkaliczki, Maxim Goynov, György Szántó, Detelin Luchev, Miklós Veres, Radoslav Pavlov, Zsolt Weisz, Lilia Pavlova, Patrik Martonosi, Attila Hidán, and Konstantin Rangochev

Immersive and Interactive VR/AR Experiences in Cultural Heritage

- dh.20253213 | Augmented Reality Workflows and Prototype Tools for Museums
Fadilah Arief and Erik Malcolm Champion
- dh.20253265 | Cultural VR for the elderly: setting up the experience
Angeliki Antoniou, Stella Sylaiou, George Lepouras, Anastasios Theodoropoulos, and Maria Kyriazi
- dh.20253340 | ARise: an Augmented Reality Mobile Application to Improve Cultural Heritage Resilience
Angelica Urbanelli, Marina Nadalin, Mario Chiesa, Rojin Bayat, Massimo Migliorini, and Claudio Rossi
- dh.20253344 | Co-Designing XR Exhibits: Insights from a Domain Expert Workshop on UI and Interaction Features for Cultural Heritage
Tiago Nunes, Armanda Rodrigues, and Nuno Correia

Reconstructing the Past

- dh.20253016 | Remaking Lost Communities in Virtual Cultural Landscapes
Junyu Zhang, Miriam Sturdee, Alan Miller, Iain Oliver, and Jacquie Aitken
- dh.20253044 | Rediscovering Mural Paintings: Experiencing Medieval Art as Originally Conceived Through Historical Light Simulation
Imanol Munoz-Pandiella, Manvir Kaur-Singh, Carles Bosch, Carlos Andujar, and Xavier Pueyo
- dh.20253062 | From Site to Story: A Virtual Archaeology Project in Arzachena (Sardinia, Italy)
Daniele Ferdani, Bruno Fanini, Diego Ronch, Alfonsina Pagano, and Augusto Palombini
- dh.20253202 | Reconstructing Gladiator Combat: A Multisensory Virtual Reality Training Environment
Ronan Gaugne, Stéphane Salvan, Ewen Cazuc, Valérie Gouranton, and Charles Pontonnier

Digitization and 3D Visualization for Heritage Accessibility

- dh.20253065 | Modern Digitization and 3D Visualization Technologies for Virtual Access to Hard-to-reach or Perished Historical Sites
Piotr Tokarski, Marek Milosz, and Jacek Kesik
- dh.20253279 | Spatiando con gli Occhi: Delivering an Interactive 3D Reconstruction of 17th-Century Rome
Joanna Mundy, John Halbert, and Ian Burr
- dh.20253342 | ESILab: An efficient software for immersion and exploitation of large point clouds
El Mustapha Mouaddib, Jordan Caracotte, Dorian Kempf, Noël Villette, and Thibault Potin

Narratives, Multimodality, and Emotional Engagement in Heritage

- dh.20253107 | Riding the Hippogriff: a VR Exploration of Orlando Furioso Epic Poem
Annalisa Mombelli, Elisa Silva, Gianluca Genovese, Fabrizio Bondi, and Roberto Montanari
- dh.20253045 | Evaluating the role of video within multi-sensory cultural experiences
Stamatia Ladikou and Anastasia Chourmouziadi
- dh.20253234 | Reinterpreting Heritage Site Through Collective Memory and Augmented Reality - The Case of Nanjing's Great Bao'en Temple
Yimeng Chen, Mingdong Song, and Yuying Li
- dh.20253353 | Bridging Psychological Distance from Climate Change through Experiential Learning within Heritage Organisations
Maria Andrei, Sonja Heinrich, Jason Jacques, Iain Oliver, Sharon Pisani, Alan Miller, and Richard Bates

AI and Generative Techniques for Heritage Reconstruction

- dh.20253011 | GenAI-Based Reconstruction of Prehistoric Remains
Juan A. Barceló and Endoxia Tzerpou
- dh.20253085 | A multimodal approach to 3D modelling of Spanish cultural heritage buildings for visualization and management based on generative AI and geospatial data
Miguel Antonio Barbero-Álvarez, Javier Rodríguez Peña, Cristian Olmedo Ferrero, and Marina A. Álvarez Alonso
- dh.20253282 | Bringing the Gonzaga Equestrian Heritage to Life: AI-Enhanced VR Storytelling for Cultural Dissemination
Zhou You, Daniele Treccani, and Andrea Adami
- dh.20253238 | Integrating Artificial Intelligence in the Design of Interactive Experiences. An Overview for Digital Cultural Heritage Practitioners
Manuele Veggi

Storytelling and Interpretation in Digital Heritage

- dh.20253214 | Contextualism and Music Annotation: Exploring the Role of Digital Storytelling about a Composer's Life on Music Perception
Dimitra Petousi, Lori Kougioumtzian, Akrivi Katifori, Maria Boile, Katerina Servi, Yannis Ioannidis, Vera Kriezi, Valia Vraka, Stefania Merakos, and Alexandros Charkiolakis
- dh.20253268 | Beyond Street Signs: Ethical and Situated Cultural Storytelling using AI and Extended Reality
Marina Toumpouri, Marios Constantinides, Václav Milata, Sophia Ppali, Lampros Alexopoulos, and Fotis Liarokapis
- dh.20253220 | 360° Virtual Tours at the National Roman Museum. Making Culture Heritage Participatory, Accessible, and Personalized
Eliana Maria Torre, Antonella Poce, Diana Andone, and Marius-Cosmin Tătaru
- dh.20253203 | The Secret of Bastet: Integrating VR and 3D Printing for the Study and Exhibition of a Cat Mummy
Ronan Gaugne, Jérémy Lacoche, Odile Hays, Théophane Nicolas, and Valérie Gouranton

Track 8 – Digital Technologies for Colour

PERCEIVE: Exhibiting the "Unexhibitable"

- dh.20253350 | Perceptive Enhanced Realities of Coloured Collections through AI and Virtual Experiences
Sofia Pescarin, Birgitte Aga, I. Y. Arteaga Kiyomoto, Cristiana Barandoni, Federica Bonifazi, Beatrice G. Boracchi, Lucia Burgio, Ivana Cerato, Irina Ciortan, Arthur Clay, Bruno Fanini, Gemma Chiara Fedon, Daniele Ferdani, Holger Graf, Jon Y. Hardeberg, Donata Magrini, Marcello Massidda, Paschalis Panteleris, Giorgos Papadopoulos, Marios Pitikakis, I. C. A. Sandu, S. N. Sinha Neil, P. Siozos, S. Sotiropoulou, S. Spotti, P. Stavroulakis, L. Travaglini, G. Trumpy, and M. Veggi
- dh.20253147 | An Atlas-based Approach for Appearance-aware Virtual 3D Restoration and Simulation of Fading in Fugitive Textiles
Saptarshi Neil Sinha, Irina M. Ciortan, Tom Kneiphof, Paul Julius Kühn, Brenda Doherty, Lucia Burgio, Richard Palmer, Catarina Pinto, Laura Martel, David Buti, Letizia Monico, Reinhard Klein, Arjan Kuijper, and Michael Weinmann
- dh.20253102 | Interactive and immersive discovery of diagnostic processes on multi-layered 3D collections on the web: the MuLaX tool
Bruno Fanini, Marcello Massidda, Daniele Ferdani, Federica Bonifazi, Donata Magrini, Roberta Iannaccone, and Cristiana Barandoni
- dh.20253061 | Text2Autochrome: Text guided autochrome synthesis using generative models
Paul Julius Kühn, Saptarshi Neil Sinha, Duc Anh Nguyen, Robin Horst, Arjan Kuijper, and Dieter W. Fellner
- dh.20253314 | What can a historic black and white photograph tell us about the original colours of a painting? A case study on Edvard Munch's the Scream (1910?)
Panagiotis Siozos, Irina Crina Anca Sandu, Petros Ioannis Stavroulakis, and Sophia Sotiropoulou
- dh.20253108 | Implementing Curiosity Hooks and Caring Practices in the Reconstruction of Lost Polychromy: Design Prototypes for Interactive Experiences.
Federica Bonifazi, Manuele Veggi, Marcello Massidda, Daniele Ferdani, and Sofia Pescarin
- dh.20253148 | Designing Authentic Digital Experiences
Samuele Spotti, Federica Bonifazi, Marcello Massidda, Sofia Pescarin, and Laura Travaglini

Track 9 – Collaborative Cloud for CH (ECHOES)

Collaborative Cloud for CH (ECHOES SESSION)

- dh.20253188 | Application of LiDAR Sensors for the Reconstruction of the Production Techniques of Artificial Conglomerate Blocks: the Case of the Maconi Tower - Siena (Italy)
Gioele Rossi, Jacopo Bruttini, Stefano Camporeale, Fabio Gabbrielli, Marco Giamello, and Enrico Tavarnelli
- dh.20253194 | Designing a Virtual Museum Ecosystem for the Cloud
Alan Miller, Catherine Cassidy, Sharon Pisani, Maria Andrei, Junyu Zhang, Sarah Kennedy, Iain Oliver, Jacquie Aitken, Ray Williams, and Vanessa Martin
- dh.20253278 | Straniere: a Digital Archive on the Reception of non-European Arts and Cultures in Italy (1945-2000)
Caterina Toschi, Livia de Pinto, Biancalucia Maglione, and Rachele Zanone
- dh.20253302 | Smart Collection Ingestion in the European Cultural Heritage Cloud: Toward Scalable, Semantically Enriched, Interoperable Cataloguing
Paolo Ongaro, Sam Habibi Minelli, Daniele Duranti, Naomi Poli, Martina Rossi, Daniele Ugoletti, Rubino Saccoccio, and Alberto Raggioli
- dh.20253160 | The IMPULSE Project: Advancing Immersive Digitization for Sustainable Digital Cultural Heritage Integration within ECCCH.
Lorela Mehmeti, Margherita Ascari, Valentina Gianfrate, Zaneta Zeglen, Dimitris Charitos, and George Anastassakis
- dh.20253358 | The collaborative Basilica Iulia Project: A Digital Knowledge Ecosystem for Integrated Archaeological Research
Emanuel Demetrescu, Tommaso Ismaelli, Simone Berto, Sara Bozza, Giacomo Casa, Marika Griffò, Rachele Manganelli del Fà, and Eleonora Scopinaro
- dh.20253325 | Towards the Definition of the Heritage Digital Twin Ontology for the European Collaborative Cloud for Cultural Heritage
Maria Theodoridou, Florian Hivert, Athina Kritsotaki, Béatrice Markhoff, Martin Doerr, and Sorin Hermon

Track 10 – H2IOSC Project Development (H2IOSC SESSION)

H2IOSC Project Development

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| dh.20253009 | Prototyper: a web3D platform for collaborative design and simulation of hybrid museum exhibitions
<i>Marcello Massidda, Bruno Fanini, and Sofia Pescarin</i> |
| dh.20253055 | Shaping a Web3D framework for different scientific communities: ATON as a service in H2IOSC
<i>Bruno Fanini, Giorgio Gosti, Chiara Florise Amadei, and Sofia Menconero</i> |
| dh.20253210 | The Illuminated Manuscripts pilot project: a hub dedicated to the interdisciplinary study of ancient codices, integrated into the DigiLab-IT platform
<i>Eva Pietroni, Alessandra Chirivì, Matteo Greco, Andrea Pandurino, Alberto Bucciero, Alessandro Lupinacci, Romano Aloisi, and Marco Cozza</i> |
| dh.20253236 | StoneVerse: Models and Methods in Cultural Heritage. The Open-Science Platform for Reproducible Modelling of Stone Decay
<i>Elia Onofri, Sofia Bizzarro, Sandro Tassa, Michela Czech, and Gabriella Bretti</i> |
| dh.20253258 | Estimating Cultural Heritage Processes Using Approximate Bayesian Computation
<i>Paola Stolfi, Elia Onofri, and Gabriella Bretti</i> |
| dh.20253320 | Merging Knowledge and Tools in Heritage Science and Digital Archaeology. Practices from H2IOSC WP2
<i>Giacomo Mancuso, Alessandra Caravale, Antonio D'Eredità, and Paola Moscati</i> |

Track 12 – Digital Technologies for CHANGES

Digital Technologies for CHANGES (CHANGES SESSION) - Part 1

- dh.20253051 | Designing Augmented Reality Storytelling in Historical Palaces: The Royal Palace of Caserta as a Case Study
Roberta Presta, Yulia Tikhomirova, Francesca Nicolais, Leonardo Chiechi, Roberto Montanari, and Gianluca Genovese
- dh.20253117 | Flexible, Integrable and Accessible Digital Tools for a Dynamic and Adaptive Experience of Museum Environments. The CHAMELEON project
Federica Maietti, Ursula Thun Hohenstein, Loreno Arboritanza, Marco Medici, Stefano Settimo, Davide Borra, Stefano Santo Sabato, Ornella De Curtis, Giovanni Serafini, Andrea Perez, Chiara Parisi, Silvia Zanazzi, and Giorgio Poletti
- dh.20253255 | 3D Digitisation for Geological and Paleontological Specimens: Challenges and Solutions
Luisa Ammirati, Alice Bordignon, Federica Collina, Francesca Fabbri, Daniele Ferdani, Maria Felicia Rega, and Mattia Sullini
- dh.20253334 | A Virtual Gallery Platform for Exploring Cultural Heritage collections and Practicing Digital Curatorship in a University Context
Roberta Presta, Chiara Tancredi, Marianna Cuomo, Roberto Montanari, and Gianluca Genovese
- dh.20253043 | Multi-scalar Risk Mapping of Climate Change Impacts on Outdoor Tangible Cultural Heritage: the Case Study of Tortona, Italy
Angelo Figliola, Adriano Ruggiero, Alberto Calenzo, Andrea Canducci, Livia Calcagni, and Alessandra Battisti
- dh.20253060 | PALEOTWIN. A Platform for Creating Integrated Digital Experiences: the case study of the Collezione di Geologia "Museo Giovanni Capellini"
Michela Contessi, Davide Borra, Stefano Santo Sabato, Diego Mammo Zagarella, Giuliana Benvenuti, Chiara Caruso, Annalisa Managlia, and Roberto Balzani
- dh.20253153 | Supervised Models to Support Investigations of Ancient Coins
Luca Naso, Lavinia Sole, Andrea Patti, Francesco Armetta, Fabrizio Lo Celso, Wladimiro Carlo Patatu, and Maria Luisa Saladino

Digital Technologies for CHANGES (CHANGES SESSION) - Part 2

- dh.20253066 | Morphosyntactic Variation in Italian and Romansh Dialects: The Manzini & Savoia (2005) Corpus Within Project CHANGES
Greta Mazzaggio, Carlo Zoli, Neri Binazzi, Luca Andrea Ludovico, Mael Vittorio Vena, M. Rita Manzini, and Leonardo Maria Savoia

- dh.20253221 | Beyond Participation: A Quadruple Helix Approach to Digital Cultural Heritage and Inclusive Stakeholder Engagement
Aelita Skarzauskiene, Monika Mačiulienė, and Kristina Kovaitė
- dh.20253331 | Small Codes: a platform for digital resources and tools for minority languages and dialects
Carlo Zoli, Greta Mazzaggio, and Neri Binazzi
- dh.20253033 | Digital technologies for the "Grazia Deledda" Literary Park in Galtellì (NU): the 3D virtual reconstruction of Pontes Castle
Nicola Mariniello, Federica Giacomini, Sara Obbiso, Francesco Sicilia, Antonio Sanna, Alessandro Iannucci, and Giuliana Benvenuti

Digital Technologies for CHANGES (CHANGES SESSION) - Part 3

- dh.20253048 | Evaluating Zero-Shot Monocular Depth Estimation Models for Tactile Rendering of Paintings
Roberto Magherini, Michaela Servi, Francesco Buonamici, and Rocco Furferi
- dh.20253118 | "There was a scribe, a priest and a thief". Testing the potential of language models for the creation of curatorial narratives in an archaeological museum
Enrico Mensa, Chiara Fulfaro, Flavia Fubini, Andrea Bottino, Riccardo Antonino, Enrico Ferraris, and Rossana Damiano
- dh.20253151 | Community Landscape Archaeology and Digital Technologies for Heritagization and Memorialization Processes
Luigi Magnini, Marco Paladini, Martina Bergamo, Jacopo Paiano, Bendetta De Rossi, Monica Calcagno, and Diego Calaon
- dh.20253375 | Formalising cultural heritage metadata with a multidisciplinary approach: enriching the CHANGES workflow for enhancing a museum collection about ceramics through a FAIR digitisation process
Arianna Moretti and Madeleine Daste
- dh.20253336 | HERIFORGE Polish Hub As Digital Heritage Growing XR Community
Marta M. Swietlik and Gabriela Manista
- dh.20253363 | A Summarization and Analysis of Methodologies for Creating Interactive and Lifelike Historical Characters Based on MetaHuman
Victor Yuan and Alan Miller

Track 13 – Phygital Worlds & XR in Cultural Heritage (XRsalento SESSION)

Phygital Worlds and XR in Cultural Heritage

- dh.20253086 | Scenting Heritage: Real-Time Olfactory Augmentation
Tonia Ramogida and Sarah Kenderdine
- dh.20253181 | From Interpretation to Immersion: XR and the Transformation of Fashion Heritage Story-telling
Eleonora Stacchiotti
- dh.20253267 | ArtifactVM: Exploring Culturally Meaningful Presentations and User Interactions in Virtual Museums
Jiachen Liang, Yue Li, Xueqi Wang, Yuexin Yao, Richard Koeck, and Hai-Ning Liang
- dh.20253304 | A Comparative Study of Virtual and Mixed Reality Blended Environments for Interacting with the Physical World During Virtual Guided Visits
Michele De Bonis, Huyen Nguyen, and Patrick Bourdot
- dh.20253270 | Digital Technologies for Tangible and Intangible Heritage: a Preliminary Study for the Museum of Contemporary Art in San Cesario di Lecce
Carola Gatto, Laura Corchia, Giorgia De Giuseppe, Federica Faggiano, Ileana Riera Pannaro, and Lucio Tommaso De Paolis
- dh.20253319 | Real Time Photogrammetry in Cultural Heritage Applications
Cagin Torkut, Devrim Akca, Armin Gruen, and Gerhard Kemper

Track 14 – Play, Learn, Explore (Serious Games Society – GALA SESSION)

Modern Technologies for Serious Gaming in Cultural Heritage

- dh.20253295 | Comparing VR and AR in Cultural Heritage Active Learning: A Study Based on the Stimulus-Organism-Response Model and the Engagement Theory
Jiayi Zhao, Jiachen Liang, Yue Li, Cheng Zhang, and Yiping Dong
- dh.20253186 | Designing Personalized Cultural Heritage Serious Games through Gamification, AI and Augmented Reality
Federico Martusciello, Antonio Bucchiarone, and Henry Muccini
- dh.20253247 | Digging through the Virtual Sand of Time: Development and Evaluation of Hetepheres Tomb VR
Kevin Körner, Luca Dreiling, and Peter Der Manuelian
- dh.20253377 | Characterization of Games Technologies for Learning in the Context of Intangible Cultural Heritage
Marcos E. Zúniga-Solórzano, Ramon Fabregat, and Teodor Jové
- dh.20253015 | Female Rulers of Medieval Balkans - gamified VR experience
Selma Rizvic, Bojan Mijatovic, Dusanka Boskovic, Aya Ali Al Zayat, Jelena Andjelkovic Grasar, Niall O Hoisin, Belma Ramic-Brkic, and Emir Durmisevic

Game Design Methods and Applications

- dh.20253327 | Promoting Positive Attitudes Through Narrative-Driven Digital Heritage Games
Lukáš Kolek, David Šosvald, Fernanda Flores, and Jasminko Halilovic
- dh.20253297 | Understanding User Experience in Serious Games: The Role of Narratives, Game Design and Player Background
Stavroula Ntoa, Anastasia Ntagianta, Fernanda Flores, Jasminko Halilovic, Lukáš Kolek, Lucie Formánková, Lislely Viraphong, Emilie Divoy, Petra Cernoušková, Petros Selekos, Konstantinos C. Apostolakis, Stefania Stamou, and Constantine Stephanidis
- dh.20253131 | Exploring and preserving Underwater Cultural Heritage through Play and Learning: the case study of CREAMARE
Fabio Bruno, Marco Cozza, Alessandro Cozza, Salvatore Isabella, Raffaele Peluso, Paola di Cuia, Ervin Silic, Felipe Cerezo Andreo, Carlota Pérez-Reverte, Angelos Manglis, Vasiliki Drouga, Barna Petrányi, Daniel Poulet, Roberto Rotondo, and Barbara Davide

dh.20253303 | A Serious Game Strategy from Coastal Leisure to Cultural Discovery of an Archaeological Museum. The "Ozan1982" Application.
Irene Muci, Manuele Veggi, Alessandra Marasco, Alberto Bucciero, Sofia Pescarin, and Samuele Spotti

Explorative Approaches for History

dh.20253215 | Engaging History Through Play: The Potential of Digitally-Enhanced Tabletop Role Playing Games for Promoting Historical Empathy in Museums
Georgia Koutiva, Katerina Servi, Akrivi Katifori, Dimitra Petousi, Maria Boile, Yannis Ioannidis, Evangelos Papoulias, Myrsini Pichou, Foteini Tsitou, Elena Kitta, Eirini Savvani, and Foteini Fragkaki

dh.20253305 | Engaging with History: Towards an Interactive Experience of the 1562 Auto de Fe of Maní (Yucatan, Mexico)
Antonio Rodríguez Alcalá, John F. Chuchiak, Zoraida Raimúndez Ares, Maria Felicia Rega, Hans B. Erickson, and Luis Díaz De León

dh.20253287 | A historiographical method for video games. The proof of concept in the analysis of the game This War of Mine (11 bit studios) and its counterpart Sarajevo's Siege cultural heritage
José Júlio Schulz Melo

dh.20253257 | Exploring Saudi Arabian Traditions Through Roblox Puzzles For Children
Alaa Aljurais and Erik Champion

Posters, Panels, Roundtables, Workshops, Tutorials

Posters

- dh.20253037 | The Digital Archaeological Atlas of Lecce: an Archive for Mapping Ancient Remains in a City that Never Stops Live
Dario Saggese, Ilenia Miccoli, and Giuseppe Scardozzi
- dh.20253038 | Digital Memory as a Tool for Critical Knowledge in Restoration: a digital archive with Omeka S
Caterina Ciccotti
- dh.20253092 | Ugento (Lecce): recent experiences for the documentation and preservation of an ancient city among archaeological cartography, preventive archaeology and public archaeology
Ilenia Miccoli, Fabio Fortinguerra, and Giuseppe Scardozzi
- dh.20253101 | Intangible Heritage and Encoded Memory
Shreepali Patel
- dh.20253138 | The Multimedia Archive of the Academy of Fine Arts of Florence as a Tool for the Enhancement, Promotion, and Preservation of Artistic Heritage
Giovanni Grimaudo, Federico Niccolai, Giulia Vaccari, and Juri Ciani
- dh.20253154 | Ontological Models For Semantic Queries In Cultural Heritage Domain
Roberto Gueli, Miriam Raccuglia, Andrea Patti, and Wladimiro Carlo Patatu
- dh.20253198 | Integrated survey for heritage digitisation. The case study of Venaria Reale within HERITALISE project
Alessio Martino, Beatrice Tanduo, Edward Borgogno, and Filiberto Chiabrando
- dh.20253237 | An Open Access Catalogue for Renaissance Terracotta Sculpture in Northern Italy
Manuele Veggi, Giuseppe Andolina, Andrea Bacchi, Laura Cavazzini, Alessandra Galizzi, Aldo Galli, Francesca Mambelli, and Marco Scansani
- dh.20253286 | A Proposal for Proactive Quality Assurance in Photogrammetry Workflows: Using Smart-device LiDAR for Scaling
Zackary Hegarty and Michael Saari
- dh.20253308 | Ethnographic research and involvement of the Z-generation: the experience of Mediterranean Diet Virtual Museum
Antonio Puzzi
- dh.20253355 | Grace Notes and Ghost Data: Challenges in Digitising Intangible Cultural Heritage
Phil Morris

- dh.20253374 | Architectural Surveying, from Point Cloud to CAD/BIM: Towards Automation of Data Processing for Large-Scale Projects
Carla Muyle and Arnaud Schenkel
- dh.20253380 | Developing MosArt: An Accessible System for High-Quality Technical Photography
Alessandra Marrocchesi and Robert G. Erdmann
- dh.20253390 | Tracing Intangible Heritage from Eurasia to Local Territories: Digital Projects of the I Deug-Su Centre
Martina Paccara and Francesco Stella
- dh.20253392 | AMELIA High performance computing cluster
Gabriella Bretti, Massimiliano Pedone, Massimo Bernaschi, and Pasqua D’Ambra
- dh.20253012 | AI and New Digital Education
Michele Lacriola
- dh.20253250 | Towards Diversity-Oriented Exhibition Planning: Findings from the Kura: Div Study in Austrian Museums
Sandra Draxler, Bernhard Hofer, Claudia Pass, Sabine Fauland, Bente Knoll, and Andrea Aschauer
- dh.20253289 | Photography as an Image of the Intangible and Social Identity
Daniela Lozano and Marcos E. Zúniga-Solórzano
- dh.20253328 | Towards Tourism 4.0: Digitalization, Experience, and New Models of Cultural Engagement
Ivana Cerato, Guido Bozzelli, Maurizio De Nino, and Stefano Ricciardi
- dh.20253225 | Heritage Within the Community’s Reach Through the Use of New Technologies: The Vila Verde House of Knowledge
Diana Mendes, Alexandra Esteves, and José Gabriel Andrade
- dh.20253260 | Defining a New Digital Twin Ontology for Cultural Heritage Preservation - the Case of ARGUS
George Pavlidis, Vasileios Sevetlidis, and Vasileios Arampatzakis
- dh.20253074 | Combining Different Techniques for Documenting Medieval Runic Inscriptions
Letizia Bonelli, Elisabeth Maria Magin, and Sjoerd van Riel
- dh.20253172 | Sihrhis: a geodatabase of Hellenistic and Roman housing in central-western Sicily
Giuseppe Monte
- dh.20253184 | Advanced digitisation and AI-powered data processing for Cultural Heritage: the HERITALISE Project
Francesca Matrone, Filiberto Chiabrando, and Andrea Maria Lingua

- dh.20253275 | Fine-Tuning LayoutParser for the Analysis of Historical Italian Newspapers
Silvano Imboden, Luca Mattei, Gabriele Marconi, Federico Andrucci, and Alex Gianelli
- dh.20253318 | Multisensor 3D Documentation of the Palaeolithic Complex of the Railway Trench (Sierra de Atapuerca, Burgos, Spain)
Adrián Martínez-Fernández and Alfonso Benito-Calvo
- dh.20253368 | Ambiances Integration in the HBIM Process Towards an Ambient Twin: A Literature Review
Nadia Bouzgarrou, Faten Hussein, and Laurent Lescop
- dh.20253372 | HeriTwinned: Digital Twin Application in Heritage Buildings Within the Smart City Bamberg
Rana Tootoonchi
- dh.20253058 | Enhancing South Slavic Cyrillic Manuscripts Research through a Digital Toolkit for Cyrillic Palaeography
Marta Riparante, Maxim Goynov, Desislava Paneva-Marinova, and Lilia Pavlova
- dh.20253078 | App AskGate - Four Steps in Ascalon
Cecilia Maria Roberta Luschi, Alessandra Vezzi, and Federico Niccolai
- dh.20253100 | Using Virtual Worlds in Communicating Archaeology
Sjoerd van Riel, George Alexis Pantos, Ingvild Solberg Andreassen, Søren Handberg, Hege Damlien, Inger Marie Berg-Hansen, and Justin Kimball
- dh.20253110 | From Digitization to Virtual Exhibition of the University of Bologna's "Collezioni di Antropologia"
Federica Collina, Rita Sorrentino, Maria Chiara Malavasi, Alessandro Iannucci, and Maria Giovanna Belcastro
- dh.20253231 | The Intermedit project: democratizing the access to Cultural Heritage of Antiquity through digital technologies
Oriol Vicente Campos, Igor Bogdanovic, Maria Bofill, Marta Santos, Lionel Izac, Benjamí Costa, Jordi H. Fernández, Elisa Hernández, Sophie Izac, Helena Jiménez, Ana Mezquida, and Joaquim Tremoleda
- dh.20253248 | Integration of Kompakkt into a Virtual Reality CAVE Environment: The CAVE-Kompakkt-Viewer
Tom Noack, Daniel Wickerroth, and Øyvind Eide
- dh.20253271 | Personalized Cultural Heritage Recommendation System For Cognitive Exploration Levels
Songie Seol, Yeeun Lee, Hyebin Byun, and Jongwook Lee
- dh.20253284 | Rediscovering the Bauhaus: Experimental recreation of lost Bauhaus Artifacts by digital technologies
Medhat Wassef

- dh.20253365 | Inventing and Re-Inventing the Perception of Color
Arthur Clay
- dh.20253109 | The Hidden Legacy. Byzantine Seals of the Exarchal Age in Italian Museum Collections: a Digital Approach with SigiDoc.
Margherita Elena Pomero
- dh.20253152 | Digital Technologies for the Conservation and Enhancement of the Castle of Gaeta: An Inclusive and Participatory Approach
Ivana Bruno, Luca Bianchi, Paolo Leonini, Marta Salvatore, Laura Saturnino, and Luca Spatola
- dh.20253332 | When meshes Lie: Tracing Flaws and Extracting Knowledge from Expert Intervention in CH Mesh Processing
Mattia Sullini

Panels, Roundtables

- dh.20253269 | Powering 3D digitisation of Europe's heritage: challenges and opportunities
Kate Fernie, Albert Sierra Reguera, Robert Shaw, Valentine Charles, and Marco Medici
- dh.20253288 | Artificial Intelligence and Cultural Heritage in Practice: exploring approaches to operationalising values, law, and responsible openness
Anna Foka, Oonagh Murphy, Anna-Maria Sichani, and Paula Westenberger
- dh.20253311 | Generative AI and the Narrative Turn in Digital Cultural Heritage Education
Maria Economou, Angeliki Antoniou, Erik Malcolm Champion, Angeliki Chrysanthi, and Stella Sylaiou

Workshops

- dh.20253245 | Safeguarding the Past: Blending Digital and Traditional Tools to Combat Illicit Excavations and Cultural Property Trafficking
Dante Abate, M. C. Salvi, Hector Alexis Orengo, Iban Berganzo-Besga, Elisa Mariarosaria Farella, Fabio Remondino, Donna Yates, and Anna de Jong
- dh.20253388 | The GDH LidArc Initiative - Pioneering Global Under-Canopy Archaeology by LiDAR
Stefano Campana, Marcello Canuto, Francisco Estrada-Belli, Thomas Garrison, Herbert Maschner, Carlos Morales-Aguilar, and Fabio Remondino
- dh.20253005 | Enhancing Heritage Communication through Digital Storytelling: Tools, Strategies, and Engagement
Laura Šejić, Jelena Rubic, and Matea Kolendić

- dh.20253264 | Navigating the Digital Shift: Emerging Roles in Cultural Heritage Tourism
Jessika Weber Sabil
- dh.20253370 | Increasing Heritage Accessibility Through Sustainable Digital Content Standards
Ronald Haynes, Athanasios Malamos, and Vincent Marchetti
- dh.20253262 | 3D Data in the Data Space for Cultural Heritage
Sander Münster, Marco Medici, Antonella Fresa, and Alexandru Stan
- dh.20253338 | Opportunities and Tools from the Cultural Heritage Cloud
Xavier Rodier, Dimitris Kotzinos, Mikel Borrás, Georgios Alexis Ioannakis, and Gabriele Gattiglia
- dh.20253352 | Reimagining the Past: Diverse Voices in Virtual Heritage Reconstructions
Juan A. Barceló, Fabrizio Ivan Apollonio, Federico Fallavollita, Riccardo Foschi, Koszewski Krzysztof, Piotr Kuroczynski, Sofia Pescarin, and Evdoxia Tzerpou
- dh.20253360 | Publishing and reusing Collections as Data across GLAM Labs and infrastructures: from principles to practice
Alba Irollo, Sally Chambers, and Gustavo Candela
- dh.20253018 | Transkribus, ChatGPT and EVT. From manuscripts to Digital Twins Workshop
Salvatore Spina
- dh.20253393 | Data Collection and Reuse in Digital Heritage: Approaches and Results from the Digital Cultural Heritage Cluster
E. Ananiadou, Sofia Pescarin, A. Gkiokas, L. Kolek, A. Merono Penuela, D. A. Neagu, and S. Sotiropoulou

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Glen Robson
- dh.20253345 | Aerial point cloud classification in archaeological scenarios
Gabriele Mazzacca, Prospero Cirigliano, Fabio Remondino, and Stefano Campana
- dh.20253290 | Learn to Build Your Own Museum in the Metaverse
Pauline Mackay, Alan Matthews, Neil McDonnell, and Lynn Verschuren
- dh.20253293 | Developing interactive web-based virtual environments using ATON and Godot
Bruno Fanini, Federico Andrucci, Chiara Florise Amadei, Giorgio Gosti, Daniele De Luca, Silvano Imboden, and Antonella Guidazzoli

- dh.20253335 | SHIFTing to Digital: Cultural Heritage Tools for Accessibility and Appeal from the SHIFT Project
Katerina Valakou, George Margetis, Anika Spiesberger, I. Tsangko, Dionyssos Kounadis-Bastian, Krishna Chandramouli, Iacob Crucianu, Ioana Crihana, Milena Milošević Micić, Andreas Bienert, Benedek Varga, and Klaudia Klára Tvergyák
- dh.20253356 | Web3D Publishing Tools and Techniques for Digital Heritage
Aaron Bergstrom, Nicholas Polys, and Donald Brutzman

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9. Collaborative Cloud for CH (EU Project ECHOES)
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10. Humanities and cultural Heritage Italian Open Science Cloud (EU Project H2IOSC)
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12. Digital Technologies for CHANGES (EU Project CHANGES)
 - *Silvio Peroni – University of Bologna, Italy*
 - *Ivan Heibi – University of Bologna, Italy*
13. Phygital Worlds & XR in Cultural Heritage (XRsalento)
 - *Lucio Tommaso De Paolis – University of Salento, Italy*
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Early Stage of Community-Driven UI/UX Refactoring of the Open-Source ATON Framework

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Abstract

The digitisation of Cultural Heritage has become a central practice in recent years, responding to the needs for the preservation, enhancement and study of cultural assets. The increasing production of digital resources has seen the development of online platforms for visualising and sharing 3D models and 360 panoramas, also facilitating access and management of this type of data. The democratisation of these tools, coupled with their increasing user-friendliness, has expanded and diversified the scientific communities involved, widening the catchment area from a single audience of experts to general users. This has led to the emergence of new needs on the part of the users involved, necessitating a re-evaluation of the logic underpinning the consumption of digital services. This paper analyses the case study of ATON: an open-source framework design for creating Web3D/WebXR apps interacting with CH objects and 3D scenes on the Web, which underwent a complete refactoring of the User eXperience (UX) and User Interface (UI) through the H2IOSC project. Starting with the analysis of the framework and its structure, we define which parts are involved in the complete refactoring. We discuss the milestones of the application's development from 2015 to the present, through the framework's increasing involvement in national and international project activities, highlighting the evolving user needs and implementations of new tools and functionalities through a bottom-up design approach. We first illustrate the community's role in the co-creation of ATON and its involvement in UX and UI refactoring activities. We present user research and design parts. Through the research plan, we describe the project from the objectives and research questions, debating the chosen methodologies, the target audience involved and the expected results. Finally, we present and discuss the choices related to the design process, covering the conceptualization of essential components, the development of the Design System (DS), and its implementation as a renewed built-in UI module. We also explore its integration into various ready-to-use blueprints and templates, analysing how it improves performance in the development phase. Additionally, we examine the trade-offs encountered in the components' abstraction level definition and the selection of suitable UI libraries by comparing existing solutions.

CCS Concepts

• **Human-centered computing** → User interface toolkits; **User centered design**; User interface design; Interface design prototyping; User centered design; Interactive systems and tools; **User interface design**; User interface toolkits; Interface design prototyping; **User centered design**; Interactive systems and tools;

1. Introduction

The digitisation of Cultural Heritage has become a central practice in recent years, fostering the development of advanced tools for managing acquired data. Among these, Web3D technologies and new digital standards are significant examples, as they allow data to be visualised, managed and shared directly through the web, thus opening up new perspectives and opportunities for the Cultural Heritage sector. In addition, the rapid spread of these tools among the various scientific communities has made it necessary to adapt them to an ever-widening audience of users with specific needs.

This paper discusses the refactoring case study of ATON, an open-source framework developed since 2015 for creating Web3D/WebXR applications that interact with CH objects and 3D scenes on the Web. Within the H2IOSC project, under task 6.3 (under E-RIHS infrastructure) 'WebXR Services for HS', several refactoring activities are planned. In particular, we explore the initial phase of refactoring from the evaluation of the framework, to the creation of the research plan and the adoption of reusable components. The redesign of the ATON framework followed objectives such as improving the UX, updating the UI and ensuring that the logic behind the product remains intuitive. Close attention will be paid to the role of the community in guiding the evolution of the framework, particularly in identifying usability issues and architectural limitations that have emerged over ten years of development.

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The refactoring process covered both visual and structural aspects, introducing a more modular and maintainable code base and a re-designed interface tailored to WebXR's modern functionality. The focus will be on the user interface and user experience, with attention to the user needs that emerged during the early research phases. The ongoing architectural refactoring of the framework will be discussed in a separate paper. The technical and social aspects of this transformation will be highlighted, assessing its impact on performance, accessibility and long-term community involvement. The accent will be placed on the User Centred Design process chosen to guide the three project phases: project research, project design and project evaluation. This article deals with the first phase and the first results of the second, analysing the methodologies and tools chosen. We close the article by articulating conclusions and recommendations and briefly discussing some possible future solutions for project evaluation.

2. Background

2.1. Overview of the framework's history and its ecosystem

ATON is an open-source framework based on Node.js and Three.js designed to create Web3D/WebXR applications (presenters, applied games, tools, etc.) that interact with CH objects and 3D scenes on the Web [Ato]. A flexible and modular solution, offering innovative and advanced functionalities for the Cultural Heritage sector in terms of 3D presentation, annotation, immersive interaction and real-time collaboration. Its core components and continuously updated functionalities are available to users in cross-sectoral fields to realise and deploy rich, universal and liquid Web3D applications. Among the various components, the framework offers "Hathor" (the official built-in front-end) and Shu (basic back-end). The first is used to present 3D models and scenes to the final users, without any code development required, with the possibility to extend it with custom functionalities. In particular, Hathor offers several built-in components and elements: buttons, toolbars, modal pop-ups, etc [FFD*21]. While the latter (Shu) is the basic back-end where authors, editors or content creators can access to publish and manage 3D collections and scenes. Shu allows authenticated users to create scenes from objects in their collections (e.g., 3D models, panoramas, media) and publish them on the main landing page, making the content publicly accessible from any device. Through the profiler and scalable rendering system, ATON ensures responsive, universal and liquid consumption of 3D content on the web, from mobile devices, PCs, museum kiosks and 3-DoF or 6-DoF HMDs for immersive VR.

The ATON architecture and its components are the product of national and international projects, experiences and user feedback gathered during the last years, which allowed the framework to evolve into the current state (version 3.0). Indeed, the involvement in projects and the continuous developments have opened up a new scenario: the demand to implement custom logic and features within the ATON core. The urge to refactor and offer an internal library of reusable components also stems from the need to offer users the possibility of developing new customised apps in an agile manner, thanks also to the new architecture developed within the H2IOSC project.

2.2. Role of Community in Shaping the Framework

The open-source ATON framework is the result of research and development activities carried out since 2015 through national and international projects. The use of ATON within the projects is growing steadily; this is due both to the increase of digitisation in the field of Cultural Heritage and to the continuous involvement of the community in its improvement (see Table 1). Over the years, researchers and museum organisations (e.g., project participants, researchers, fellows, museums, etc.) have actively contributed to its creation, maintenance, dissemination and improvement. The open-source approach of the framework provided a collaborative ecosystem within the community that fostered project innovation. Community members continue to provide support in various forms: bug fixes, proposals for new functionalities, creation of documentation (e.g., guides, tutorials, use cases), promotion of the framework through participation in conferences and dissemination events [FFD*21]. In addition, its development also depends on bottom-up input from the community through requests derived from recognition of the real-world experiences and contexts of end users from different domains [AVDD20]. We decided to base the refactoring on co-design, trying to merge requests based on theoretical evidence ('top-down input') with requests derived from mapping the lived experiences and everyday contexts of end-users ('bottom-up input'). Our approach to the redesign ATON framework involves the potential users as part of the design team from the very outset, when their perspectives can have the most influence, rather than using them post hoc as part of an analysis team (of) end user representatives [GL85]. The decision to promote these bi-directional strategies (top-down and bottom-up input) enabled the early stages of the co-design process to be improved so as to promote synergy rather than concession.

2.3. Previous attempts around refactoring

2.3.1. Preliminary Attempt: The First ATON UI Toolkit

In the starting phases of ATON's UI/UX refactoring, a first attempt has been conducted on the design of a built-in UI toolkit aimed to support faster realization of UI elements, both for ATON's elements and for web-apps created through it. The intention was to provide a lightweight, internal library that would empower users by reducing effort in creating web interfaces (providing utilities to create from single elements to full interface layouts) without relying on external frameworks. This first work, carried out between 2023 and 2024, allowed us to experiment with different patterns of abstraction and flexibility, identifying key critical points and questions. The emerging considerations have proved to be relevant as remarkable steps toward a more structured design system.

2.3.2. Starting Questions and Early Objectives

This attempt started from two main questions:

- what kind of features should be developed, considering common Web-design requirements into ATON applications contexts;
- how these elements should be proposed, framed within a hierarchical structure of inheritance.

Project	Output	Typology	Year(s)	Reference
SSHOC	EMviq-Extended Matrix Visual Inspector and Querier	Web 3D tool	2015-ongoing	[EMv]
Sarmizegetusa	Turn on the History	Web-app (V1.0)	2016	[CDL16]
ARIADNE	Landscape Services	Set of cloud-based services	2016	[Ari]
ARIADNE	Calore Valley Virtual museum	Web-app (V1.0)	2016	[Val]
THE WINCK-ELMANN300	NIXAMP	Web-app (V2.0)	2018	[GBML*18]
B.A.C.K. TO T.H.E. F.U.T.U.R.E	REDRASK	Web-app (V2.0)	2020	[Bac]
Archeologia e Calcolatori	Archeologia e Calcolatori 3D viewer	Hathor	2021	[RP21]
Montebelluna Posmon	Montebelluna Web-App	Web-app	2021	[Mon]
VAR.HEE	H2O Web-App	Web-app	2021	[LFBB20]
Arzachena Civiltà Milenaria	ArzApp	Hathor	2022	[Arz]
Branacci Project	Branacci POV	Web-app	2022-ongoing	[FRF*23]
e-Archeo	e-Archeo 3D	Web-app	2022	[MFP24]
Segni Archeologia	Segni app	Web-app	2022	[Seg]
N.A.	Geophysics App @ festival della scienza	Web-app	2022	[fds]
N.A.	San Massimo a Forcona	Web-app	2022	[San]
ARTEMISIA	Digital twin	Web-app	2023	[Art]
Bilateral Project	Vani Virtual eXperience	Hathor	2023	[Van]
Codex4D	Codex4D Web-app	Web-app	2023	[POFC23]
H2IOSC, PERCEIVE, Changes	Experiment Planner pilot	Web-app	2023	[MBF*24]
100 Years of Science	100 Years of Science online experience	Web-app	2023	[100]
CHANGES	Aldrovandi Digital Twin	Web-app	2024-ongoing	[BBB*24]
Grotte di Castro	N.A.	Hathor	2024	[GG*24]
PERCEIVE	MuLaX	Web-app	2024	N.A.
MetaMic	N.A.	Web-app	2024-ongoing	[Met]
H2IOSC	/i imagine	Web-app	2024	[FG24]
H2IOSC	HeriVerse, SENNSE, Illuminated manuscript	Web-apps	2024-ongoing	N.A.
H2IOSC	Merkhet (Interlumo pilot)	Web-app	2024-ongoing	[FG24]
PhD in Heritage Science, H2IOSC	illuminaAI	Web-app	2024-ongoing	N.A.
H2IOSC	AnGa	Web-app	2025	[Ang]
Knowledge of Things (KNOT)	N.A.	Hathor	2025	N.A.
TRACE	N.A.	Web-app	2025	N.A.

Table 1: ATON's involvement in national and international projects from 2015 to 2025.

First, we identified a series of UI elements that would be most useful for ATON users, investigating what kind of components, interactions, and composite elements could facilitate interface creation in Web3D applications. We considered the most used UI elements in web design: from low-level elements (*e.g.*, buttons, images, inputs); to mid-level components (*e.g.*, popups, navigation panels); also scouting higher-level aggregations such as forms and data visualizations. Second, we explored the structural approach that could ensure consistency and extensibility. This included reasoning around the level of abstraction to adopt, choosing between functional or class-based structure, defining inheritance or component wrapping patterns, and how to keep the options flexible but manageable. Early on emerged the core principle of maximize reuse and prioritize flexibility.

2.3.3. Implementation and Technical Choices

The toolkit was implemented as a lightweight library, keeping the structure as simple as possible in the early stage of development. We avoided integrating external UI libraries, opting for a dependency-free implementation with core but flexible functionalities to generate UI elements with a small styling footprint.

In progression, components of increasing complexity have been added:

- atomic elements such as `ui.button`, `ui.image`, `ui.input`;
- wrappers like `ui.group`, `ui.container`, `ui.popup`, `ui.sidebar`, `ui.navbar`;
- compound elements such as `ui.card`, `ui.form`, `ui.summary`, `ui.prompt`.

2.3.4. Discoveries Along the Way

During the development of the UI toolkit two key considerations emerged: one referring to the lowest levels of abstraction, into the toolkit's core, and the other one referring to the external sides, questioning the boundaries of our implementation.

2.3.5. Core

During the experimentation, a building block that emerged as a key element was the `createElement` function: a generic utility used to produce Document Object Model (DOM) elements based on a flexible options parameter, which takes several properties (10) to generate a highly customizable object. This function became the internal engine behind most other components. It enabled fast development and reuse, but it also revealed a limitation: as options became more complex, the function became less usable, particularly for non-expert users working with HTML/JS. This function, and others similarly, internally serves as a backbone and proved invaluable for fast and standardized element creation; but externally, its abstraction hindered simplicity of usage, letting emerging the consideration that there is a threshold where reusability conflicted with clarity.

2.3.6. Examples and Use Cases

Despite its exploratory nature, the toolkit highlights several effective scenarios of practical use and experiments within ATON-

based applications. One example is `ui.promptDialog`: a specific component designed to request user input through a modal interaction. It receives a list of `ui.input` components as parameters, automatically assembles a form, wraps it in a popup, and returns the user-submitted data in a structured format. Each of these subcomponents (`ui.form`, `ui.input`, `ui.popup`) can be also used independently, enabling users to build custom interfaces. This component was adopted in the Experiment Planner Prototype [MBF*24], where users are prompted at the startup of the application to configure experiment parameters. Another example is the `ui.summary`: used to visualize the contents of an ATON collection. Using ATON API, the function scans the list of available `.gltf` models and dynamically generates a nested structure of buttons, each of which loads the corresponding model in the 3D scene. This function created a lightweight, interactive browsing interface that could be easily adapted to various collections.

2.3.7. Conclusion comments

Considering insights and tentatives, the first toolkit acted as a playground for design decisions. It helped us understand where flexibility becomes over-complication, and where abstraction loses its usefulness. It revealed the value of layered architecture and moved us to prioritize a sense of balance, where modularity supports flexibility, without sacrificing user's readability.

3. User Research as a Design Driver

The following sections provide an overview of the role of user research in this early stage of refactoring. The methodologies, objectives, participants involved and first results will be analysed.

3.1. Overview: Methodology, goal and target

The initial phase of the refactoring process encompassed conducting research on the end users, organised in a research plan. This process involves the collection of information regarding user demographics, needs, habits, context, constraints and requests. This data serves to guide the future design and development phases of the project. The main objectives of the research plan were to: (a) identify design problems, (b) formulate hypotheses on new functionalities, (c) investigate user and community needs. In particular, to achieve these objectives, the following research questions (RQs) were posed:

RQ1 Are there design problems in the framework?

RQ2 Are there different user requirements that have arisen in recent years?

RQ3 What are ATON's main competitors?

RQ4 How much and why are potential users loyal to the competitor?

In order to obtain results that were reliable and representative of the end users, the selection of testers included both internal laboratory users and external users. For the first category, was selected a sample of users as broad as possible taking in consideration salient user characteristics such as experience, seniority and research focus (*e.g.* archaeology, architecture, diagnostic, museum exhibition). While external users were involved from the ATON community

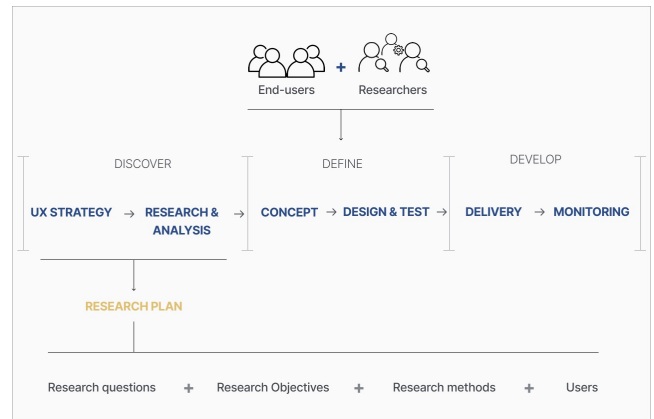


Figure 1: Research Plan: Overview of research activities for the redesign of ATON framework.

members by an open call diffused through the framework's channels. From the outset, it became evident that it would be beneficial to gather feedback from users across different domains and those with varying levels of knowledge of the system. In fact, the User centered design (UCD) principle was adopted. UCD is concerned with incorporating the user's perspective into the software development process in order to achieve a usable system [Mag01]. One of the key principles concerns placing users at the center of design decisions, actively involving them and clearly understanding their needs and tasks.

Once the objectives, research questions, users and principles had been defined, it was necessary to establish the testing method. Since the range of questions and objectives to be achieved was so wide, it was decided to proceed with different research methods, each specific to gain the set objectives. Therefore, different survey methods such as summative and formative evaluations were considered, obtaining both qualitative and quantitative data. Specifically, summative evaluations describe how well a design performs, often compared to a benchmark such as a prior version of the design or a competitor. While formative evaluations focus on determining which aspects of the design work well or not, and why. These evaluations occur throughout a redesign and provide information to incrementally improve the interface. The formative evaluation is done in order to help improve the interface as part of an iterative design process. Its main goal is thus to learn which detailed aspects of the interface are good and bad, and how the design can be improved [Nie94b].

3.2. Research plan

The research phase was structured as a design driver: an iterative process involving a multidisciplinary team. In the next sections, the early stages of the research plan will be discussed (see Figure 1).

3.2.1. Analysis of the existing system and competitors

One of the first steps of the research plan was the evaluation of the current app, to highlight the strengths and weaknesses of the framework and to prioritise re-factoring intervention flows. Through a

summative evaluation, the main workflows of the framework were analysed, with the aim of analysing the UX and determining in which flows a major redesign is concentrated. The analysis phase of the system in its current state was performed from three main flows: the dashboard and login, the creation of a new scene and the modification of an existing scene. To check for pain points and possible loops, user flows were created from three use cases to assess the usability of the framework. The use cases were: (a) visualisation of a public scene (b), creating a new scene (c), modification of an existing scene. The evaluation was based on the 10 Usability Heuristics [Nie94a] and the usability design principles developed for the study of mobile devices [JPLY06], where usability was characterised into five components, namely cognition support, information support, interaction support, user support and performance support. The five components address the impact on user performance, cover a wide range of design considerations, and offer a comprehensive understanding of usability that informs mobile application design. Particular attention was paid to this stage since the appearance of a framework plays a fundamental role in how users perceive its usability [TKI00, HAV16]. Through a comprehensive and detailed evaluation, usability problems were identified and allowed to be corrected in an iterative design process [HB23]. The results of the evaluation are shown in Table 2.

The evaluation phase was an opportunity to uncover some bugs in the use case of modifying an existing scene (c).

Finally, a competitor analysis was conducted to stimulate innovation and improvement. After an evaluation of the competitors, based on the functionality and tools provided by ATON, it was decided to focus on Sketchfab. The selection was determined by the presence of similar functionalities to those of ATON, or to be implemented in the future, and by the widespread use of the tool. Competitor analysis allowed us to find solutions to some of ATON's weaknesses in order to develop similar functionalities and implement design solutions. In particular:

- **UX of the scene creation:** drag-drop of files to upload;
- **Functionality in edit mode:** light management, moving and rotating the model, advanced management of VR/AR settings, post-processing filters

3.2.2. Contextual inquiry

A behavioural research study was also conducted to observe how users interact with the ATON framework through direct observation. Contextual investigation was chosen as one of the methodologies. This approach involved the observation and in-depth interview of a small sample of users, in order to investigate practices and behaviour. The target audience identified for this phase was a group of four users within the laboratory, with varying degrees of expertise and research interests (See Figure 2). Our primary objective was to identify potential patterns of behaviour in the use of the framework and to find out the main needs of the users.

The contextual inquiry was conducted in the laboratory by two researchers, a facilitator who explained the tasks and set the questions and an observer who took notes. The users were given simple tasks to perform, and their performance, thoughts and attitudes were recorded and analysed at the end of each session by the two

User n. 0*	User n. 1	User n. 2	User n. 3	User n. 4
Research Focus Representation, survey, 3D reconstruction of unbuilt architecture	Research Focus Archaeological reconstruction, virtual restoration	Research Focus 3D survey, virtual reconstructions, digital twin	Research Focus Digital archaeology, 2D and 3D survey, virtual reconstructions	Research Focus Image-based Modeling, Virtual Reality, Projection Mapping, Real Time Motion Graphic
Framework Experience Level Medium (3 years)	Framework Experience Level High (10 years)	Framework Experience Level Low (2 years)	Framework Experience Level High (7 years)	Framework Experience Level High (10 years)
Software Rhino3D, Blender	Software AgiSoft Metashape, Blender	Software AgiSoft Metashape, Blender	Software AgiSoft Metashape, CloudCompare, Blender, Potree, CESIUM	Software AgiSoft Metashape, CloudCompare, Blender, RealityCapture, VVVV
File Formats .3dm, .obj, .glTF	File Formats .obj, .glTF, .3Dtiles	File Formats .obj, .glTF	File Formats .obj, .glTF, .3Dtiles	File Formats .obj, .glTF, .3Dtiles

*Pilot tester

Figure 2: Sample of users for contextual inquiry research phase.

researchers. To avoid conducting the test directly on the chosen sample of users, an internal pilot test was planned to verify the effectiveness and efficiency of the script. During the pilot test, a limited help policy was discussed concerning when and how to provide help to the tester.

The test consisted of two parts: in the first part, each user was asked to upload their own 3D model and create a scene from it. In the second part, they were asked open-ended questions and, if necessary, follow-up questions not included in the script. The questions were formulated openly and neutrally, encouraging users to answer in full sentences. During the second part of the contextual inquiry, the following questions (RQ) were set:

RQ1 What kind of files do you upload? What format?

RQ2 In your opinion, are there any weak points in the upload and creation flow of a scene?

RQ3 Have you ever had to modify a scene you have already created? How did you do it?

RQ4 If you could add new features to the ATON framework, what would they be?

RQ5 Is there anything we have not covered that you would like to talk about?

The tasks and questions were chosen to provide reasonable coverage of the most important parts of the framework and user interface. The Thinking Aloud protocol was chosen to conduct the contextual interview, which is considered the most valuable usability engineering method [Nie94b]. This technique was developed and popularised within cognitive psychology by Newell and Simone (1972) for the study of problem-solving [Lew82]. The think-aloud technique is a qualitative data collection technique in which user participants express verbally their thoughts about their interaction experience, including their motives, rationale, and perceptions of UX problems. It is effective in accessing user intentions, what they are doing or are trying to do, and their motivations, the reasons why they are doing any particular actions. Analysis of the results reveals similar needs and behaviour (See Table 3).

Table 2: Results of the ATON framework evaluation phase of the three use cases: (a) visualisation of a public scene, (b) creating a new scene, (c) modification of an existing scene.

Use case	Heuristic	Usability Issue	Severity (1-4)	Recommendation	Support Principle
a, b, c	Help and documentation	No onboarding assistance is available for new users	3	Provide tutorials, help popups, or guides	User Support
b	Aesthetic and minimalist design	The information hierarchy is unclear	2	Review layout and visual priority of UI elements	Cognition Support
	User control and freedom	The "+" button to add a file to the scene is not intuitive	4	Change the user experience of this function	Interaction support
	Visibility of system status	No feedback when loading 3D models or 360° panorama	2	Add a progress indicator	Information Support
	Help users recognize and recover from errors	There is no indication of the file formats accepted during upload	3	Display supported formats near the upload area or on hover	Information Support
	Recognition rather than recall	Light probe settings are unclear when loading PBR maps	2	Add tooltips or short explanations for light probe configuration	Information Support
	Error prevention	Create Scene button is enabled even when required fields are empty	3	Either disable the button or validate required fields with visual cues	Interaction Support
	User control and freedom	Files added to a level cannot be removed afterward	4	Allow deletion of files from the level or offer undo options	Interaction support
	Visibility of system status	Environment section lacks visual previews of available panoramas	1	Add thumbnails or visual cues for each panorama	Information support
	Recognition rather than recall	Scene creation stage lacks a preview before final loading	3	Include a thumbnail before loading a scene	Cognition support
	Match between system and real world	Scene cards miss key information like title and creation date	3	Display essential metadata on scene cards	Information support
Flexibility and efficiency of use	No way to organize or filter scenes in "My Scene" page (e.g., by year)	3	Implement sorting, filtering, or hierarchical folders for scenes	Performance Support	
c	Aesthetic and minimalist design	Modal window appears at the center of the scene, obstructing view of the 3D model	2	Reposition modal or make it movable/resizable	Interaction Support
	Recognition rather than recall	Editing features are deeply nested and toolbar lacks labels, reducing discoverability	3	Flatten menu hierarchy and add text labels or tooltips to toolbar icons	Cognition support
	Match between system and real world	Temporary vs. persistent changes are not clearly distinguishable to the user	2	Add visual indicators or confirmation when making persistent changes	Cognition Support
	User control and freedom	Users may not replace, rotate or modify a model after it has been uploaded	4	Enabling the transformation and complete replacement of added models	Interaction support
		Scene elements like measurements or viewpoints cannot be deleted individually	3	Allow selective deletion of added elements	Interaction support
		No undo/redo for annotation removal or scene changes	3	No undo/redo for annotation removal or scene changes	Interaction support
	Error prevention	Deletion of scene elements (e.g., measurements) does not request confirmation	4	Add confirmation dialogs before destructive actions	Interaction Support

Table 3: Results of the user interview.

User	RQ1 – File types and formats	RQ2 – Weak points in scene upload	RQ3 – Scene modification	RQ4 – Desired new features	RQ5 – Additional comments
1	3D models / .obj .glTF PBR maps	"+" button not intuitive; Lack of panoramas with neutral colours; Modifying the default panoramas	Via cloud or by deleting the scene and creating a new one	Possibility to change the colours of pano, Layers always visible, Orthogonal views and a metric reference, Custom colours for semantic shapes, Modify model material in editor mode	Scalable spherical annotations
2	3D models / .obj .glTF PBR maps	Light management within the framework	Yes, replacing models via cloud	Better UI for editing and preview, metadata editing.	More control over camera positions
3	3D models, point cloud / .las .3Dtiles .obj .glTF	Panel of lights and their management (e.g., direction and position); Annotation ID maximum number of keystrokes; Flow for creating free form annotations; Difference between displaying lights from Blender and imported lights on ATON	Yes, replacing models via cloud or Web Dav	Filtering the scenes in my collection; Panoramas with gradients; Orthogonal views; Metric reference; Cross-section of the model and the possibility of extracting it	Limit the functionality of users in a collaborative environment
4	3D models, pano .3Dtiles / .obj .glTF .png	Picker to display the position of the model within the scene	Yes, replacing models via cloud or Web Dav	Creating a UI to manage virtual tours of 360 panoramas	-

3.2.3. Questionnaire

The first part of the research plan concluded with the conception of a questionnaire, which is one of the best tools to determine the user community composition and what their opinions are, thereby obtaining feedback on a large scale and guiding design decisions [Kun03]. Furthermore, questionnaires are one of the usability methods that makes such extensive coverage feasible, with the possibility to discover differences between various user categories as well as the specific needs of various small groups of users [Nie94b]. For this type of survey the collected sample was broad: mostly users with limited or in-depth knowledge of ATON, interested in the visualisation of digitised objects. In order to reach this type of target group, it was decided to use two ways of disseminating the questionnaire: the telegram group of the ATON community (157 members, updated to March 2025) and to include a call to action with a direct link to the questionnaire in the header of the ATON framework.

The submission of the questionnaire had three main objectives:

1. Define the demographic, technological and scientific profile of our audience
2. Obtain a prioritized rating of the utility of our main features to the survey audience
3. Get a list of ATON competitors for the presentation of 3D models via Web3D/XR.

The questionnaire was structured in five sections, with a combination of open and closed questions, as well as multiple-choice and 5-point Likert-type questions. The initial section is dedicated to gathering information on the use of the framework and its features. This is followed by an examination of competitors and software used for the creation of 3D/360 models. The third section is devoted to an analysis of the framework's weaknesses and user needs. The fourth section provides information on the user, including their scientific field or professional sector, their role and other relevant details. The questionnaire concludes with a section for suggestions and the possibility of being involved in the subsequent refactoring phases [Que].

The questionnaire was subjected to pilot testing by internal users and iterative design before it was distributed to the users in large numbers. The survey is still in progress, analysis and creation of the final report will follow.

4. Early Outcomes and Prototypes

4.1. Design System: UI elements as modular building blocks

Once we had defined the first steps of the research plan and considered the results that emerged during the preliminary attempt of the UI toolkit, we focused on the set of design guidelines through the creation of a Design System (DS). The main incentive for its implementation was to improve the scalability and consistency of the design by minimising redundancy between the various pages and media [DS1]. Following the preliminary attempts the founding building blocks of ATON's DS include: Style Guide (color system, typography system, spacing system, layout system), Design Guideline (usage, accessibility, brand guidelines),

Components (form components, navigation components, grid system, framework-specific components), and Components Libraries (Bootstrap Library, CSS code) discuss in the next section [HKA22] [Mat] [App]. In particular, a modular approach to the development of user interfaces based on multimodal design patterns was chosen for the UI components. The language of patterns of different types and levels of abstraction has been used as a tool to develop interfaces and accelerate the decision-making process between different stakeholders (*e.g.*, developers, programmers, designers) [Kho17] [PHJS12]. Also, creating reusable components across different settings is vital, as it prevents designers from reinventing how users would interact with the application and focuses on the application's content and structure [MLMR20]. Finally, the DS implementation allows the use of an iterative design method: when problems are encountered in user testing, they must be solved. There must be a cycle of design, testing and measurement, and redesign, repeated as often as necessary. With testable behavioural goals and immediate access to user feedback, continuous evaluation and modification of the interface is possible. This approach allows for minimal impact on implementation by planning a modular strategy that allows for easy testing and low-level modification of evolving prototypes. This strategy must provide for rapid and flexible prototyping and a highly modular implementation, achieved through a design pattern approach to adaptive user interfaces [GL85].

4.2. Component Reuse and Interoperability: Bootstrap library

Following a thorough evaluation of the available libraries, it was determined that Bootstrap (version 5.3) was the optimal choice [Boo]. This library is known for its stability, comprehensive documentation and broad community support, which are necessary to achieve long-term sustainability and improvements in framework performance. The Bootstrap library facilitates the realisation of specific objectives, including (a) the standardisation of the user interface within the framework, thus ensuring a consistent user interface; (b) the acceleration of the development phase through the use of ready-to-use components that can be easily integrated with each other to realise more complex components; (c) the opportunity to manage responsive design, ensuring automatic adaptation to different devices (, mobile, tablet, workstation); (d) fostering teamwork by promoting collaboration between the different teams involved. Finally, the future transition of high-fidelity mock-ups into code will be more efficient due to the adoption of the components. Testing and modification of initial prototypes will also be facilitated.

The benefits of employing a DS were significant from the earliest stages of design and prototyping phases, particularly with regard to the implementation of reusable components. The use of a shared component library guarantees a common language and improves collaboration between the developers and designers involved. To test their effectiveness we designed wireframes and later mockups of two pages 'Homepage' and 'My Scene' (see Figure 3). All wireframes and mockups were released in Figma. The first results are promising, showing a noticeable decrease in effort on the part of the entire team involved, both in the design phase and in the implementation phase through code.

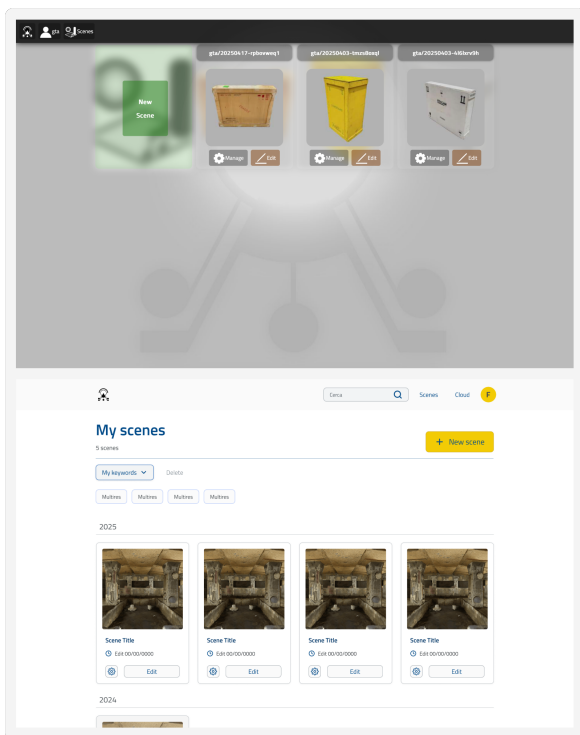


Figure 3: Top: ATON framework version 3.0 'My Scene' page
Bottom: High fidelity mock-up of the 'My Scene' page using DS components.

4.3. ATON.UI

All the presented activities are also fueling the actual implementation of ATON.UI module (<https://aton.ispc.cnr.it/apidoc/client/UI.html>): a new, revisited set of UI components based on Bootstrap (see previous section), part of ATON core. The objective of such module is to provide front-end developers with a set of ready-to-use, responsive, modular and customizable building blocks to accelerate creation of UIs.

The new module provides access to all UI-related base routines (e.g., loading overlays, internal states, etc.), and building blocks emerged from this work, serving as blueprints to craft UIs quickly. During the module design, special attention was paid to components modularity and nesting, with each UI element created through a set of options. The main goal is to provide fast templates, with less code involved, especially targeting web-app prototypes. Initial assessments already report a significant reduction of code required to craft popular components such as buttons, scene cards, modal dialogs, trees or tab groups. Built-in elements in ATON.UI, intend to provide also smart behaviour on different devices: for instance the VR button (to enter immersive VR via WebXR) internally detects device capabilities, thus automatically hiding if not supported.

Web developers are indeed still free to implement their own components using Bootstrap directly or external libraries, depending on

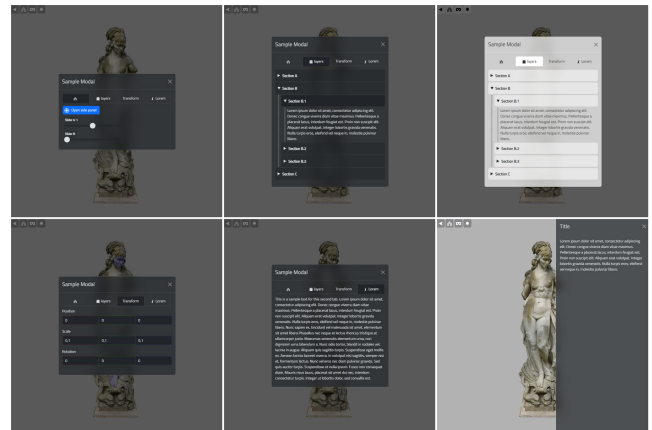


Figure 4: ATON.UI module samples: modal dialog with tab groups, buttons and sliders (top left); trees (top middle and right), transform controls (bottom left) and side panel (bottom right).

interactive web-app requirements. This could be the case of specific solutions that require special approaches or external UI libraries.

5. Conclusion and Future Work

We presented the initial results of the refactoring and redesign of the ATON framework, a decade after its development. The design of the research plan, including the objectives and research questions, was discussed. This was a key step in evaluating the most appropriate research methods to achieve the set objectives. The purpose of the research plan was to investigate user needs, strengths and weaknesses of the framework. The involvement of end-users from the earliest stages of the project was a central aspect, facilitating iterative design and the adoption of an agile approach through the application of research methodologies and design tools. The decision to employ a Design System and a library of reusable components enabled the systematisation of interface design, rendering it efficient and scalable. Initial tests showed a significant reduction in effort for the entire team involved. Moreover, the redesign of the framework and the introduction of a DS facilitate a rapid response to emergent community needs. The creation of new scenes, and in particular custom web applications, has been facilitated by the library of building blocks that can be used individually or combined to create more complex and highly customisable components.

The next steps leading to the full development of the new version of the ATON framework will include several phases: (a) collection and analysis of the data resulting from the questionnaire, (b) completion of wireframes and prototypes of the entire framework, (c) conduct of usability tests. These phases will be carried out following the UCD approach that has been used since the first refactoring phases. Indeed, through a co-design process, it will be possible to ground top-down and bottom-up input as part of an ongoing research-through-design investigation. The prototypes of each workflow, through wireframes and mockups, will be continuously evaluated to verify the effectiveness and efficiency of the design choices. Evaluation of the prototypes with users will be of crucial

importance to gather feedback and insights, thus helping to validate the hypotheses and refine the solution based on the feedback gathered.

The perceived usability of the framework will be measured to see if it has changed between version 3.0 and the redesigned version. The next phase of the study involves determining how and to what extent the new aesthetic influences users' perceptions of usability at all stages: before, during and after use [LDS*11, Kat10, LK10]. New participants, such as users reached through H2IOSC project activities – e.g., Trans-National Access (TNA) and National Access (NA) participants <https://www.h2iosc.cnr.it/tna-na-calls/>, will be involved in these research and design phases through the survey and observation of the use of the framework.

Abbreviations

CH Cultural Heritage

UCD User Centered Design

UI User Interface

UX User eXperience

HCI Human Computer Interaction

HMD Head-Mounted Display

PBR Physically Based Rendering

3/6-DoF 3/6 Degrees of Freedom (Head-Mounted displays and controllers)

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