METHODS, DATA AND TOOLS FOR FACILITATING A 3D CULTURAL HERITAGE SPACE

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ABSTRACT:

In recent years, the cultural heritage (CH) sector has experienced a rapid evolution due to the introduction of increasingly powerful digital technologies and ICT (Information and Communication Technologies) solutions. As for many other domains, digital data, Artificial Intelligence (AI), and Extended Reality (XR) are opening up extraordinary opportunities for expanding heritage knowledge capabilities while boosting the research on innovative solutions for its valorisation and preservation. Being aware of the fundamental and strategic role of CH in the history and identity of the European countries, the European Commission has assumed a central role in fuelling the policy debate and putting together stakeholders to take a step forward in CH digitization and use, primarily through initiatives, programs, and recommendations. Within this framework, the ongoing European 5DCulture project (https://www.5dculture.eu/) has been funded to enrich the offer of 3D CH digital assets in the common European Data Space for Cultural Heritage by creating high-quality 3D contents and to foster their re-use in several sectors, from tourism to education. Through 8 re-use scenarios around historic buildings and cityscapes, archaeology, and fashion, the project aims to deliver a set of digital tools and increase the capacity of CH institutions to more effectively re-use their 3D digital assets.

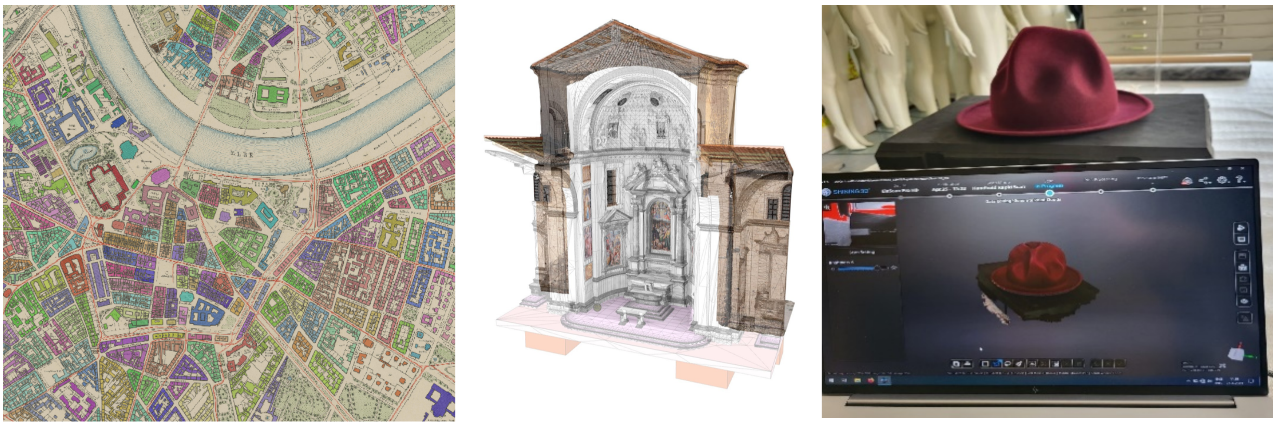

Figure 1: Examples of solutions and 3D data developed and leveraged within the European 5DCulture project in three different CH domains: historic buildings and cityscapes (left), architectural and archaeological (middle), fashion (right).

1. INTRODUCTION

In recent years, the process of digitising cultural heritage in 3D with a high level of detail (Gaiani et al., 2016; Remondino et al., 2013; Remondino et al., 2016) has seen a stark increase within many EU member states, in part fuelled by the acknowledgement that cultural heritage (CH) is vulnerable and at risk (Gruen et al., 2004; Vincent et al., 2015; Alsadik, 2022). A key policy recommendation (Commission Recommendation EU, 2021) has stipulated that, by 2030, Member States should digitise in 3D all monuments and sites at risk and half of all the most physically visited ones. This action has triggered a follow-up EU-wide campaign for digitisation in 2023 (Twin it!, 2023) and has catalysed national 3D digitisation projects. Coupled with the need to accelerate the digital transformation of the CH organisations, as highlighted recently by the COVID-19 pandemic, it is now more important than ever to ensure that the European cultural heritage sector is well-equipped to make the most out of the opportunities offered by 3D data, opening up to more immersive, engaging, informative and sustainable scenarios for future generations.

At the same time, a key European initiative that aims to accelerate the digital transformation of Europe’s cultural sector and foster the creation and re-use of content in the cultural and creative sectors has been launched: the Common European Data Space for Cultural Heritage (CNECT/LUX/2021/OP/0070). This initiative led by the Europeana Foundation pushes us to enrich digital collections, fostering innovation across education, tourism, and creativity.

Nowadays 3D technologies and standards have been recognized as one of the biggest technological opportunities with high demand, as reported in a recent survey among 4.500 heritage professionals and scholars (Muenster et al., 2021b). Moreover, 3D technologies are the focus of many recent EU initiatives, such as the currently forming Cultural Heritage Cloud, which was proposed to provide tools enabling museums and cultural institutions to utilise 3D assets (Brunet et al., 2022). With these fast developments, large ambitions for archives, museums and cultural heritage institutions are raising. To explore the possibilities of 3D technology for the cultural sector, a consortium has set up the creation of a 3D cultural heritage space under a European project named 5Dculture.

1.1 Aim of the project and paper

The 5DCulture project aims to develop various technological solutions to be showcased in different scenarios where 3D heritage assets can play a crucial role. These will empower the CH sector to integrate several key tools for 3D use and re-use (3D model asset manager, storage and viewers, semantic Building Information Modelling (BIM) / Historical Building Information Modelling (HBIM), Augmented Reality (AR), 3D effects, storytelling, etc.) and to set up a community of practice to boost the capacity of CH professionals around 3D technologies and data. With this in mind, the paper aims to recap project methodologies and initial results focused on different domains: historic buildings and cityscapes, archaeology, and fashion (Figure 1). These domains aim to demonstrate new possibilities that allow audiences not only to visit a museum but also explore heritage in an interactive and new way.

2. APPROACH AND SCENARIOS

We take a scenario-driven approach considering the domain from which the 3D content is originating and its possible re-use. This initiative transcends mere 3D digitization. The project envisions a spectrum of re-use scenarios that stretch across three sectors:

- Historic Buildings and Cityscapes: we construct applications that redefine cultural tourism, empower research and transform education through virtual exploration of historical sites. In this scenario, miscellaneous tools are developed and deployed for the realization of virtual exhibitions, 4D model creation with Machine Learning solutions and web browsing of multi-temporal data (Section 2.1).
- Archaeological and architectural 3D contents: by fusing 3D contents with archaeological sites, tourism and education are reshaped, venturing into gaming, conservation, heritage management and arts. ICT solutions are used for enhancing and enriching heritage visualization and fruition (Section 2.2, Section 2.3).
- Fashion collections: our collaboration with museums endeavours to redefine museum experiences, offering immersive engagement with historical attire. Some Extended Reality (XR) tools are proposed to increase the attractivity of fashion heritage assets (Section 2.4).

2.1 Re-use of historic cityscapes

Virtual historic buildings and cityscapes are used in various scenarios (Bekele et al., 2018; Daniela, 2020; Muenster, 2022; Siddiqui et al., 2022; ViMM WG2.2, 2017; von Schwerin et al., 2015), e.g. to teach history and heritage in informal settings like museum experiences, serious games, or television broadcasts (Cranmer et al., 2023; Doukianou et al., 2020; Ferrara et al., 2013; Fisher et al., 2009; Flaten, 2008; Gicquel et al., 2013; Haynes, 2018; Motejlek and Alpay, 2019; Münster, 2023; Richards-Rissetto et al., 2012). As an example, interactive applications for historical city exploration (Ioannidi et al., 2017; Ioannidis et al., 2017; Kim et al., 2009; von Schwerin et al., 2013) allow virtual visits and remote spatial learning (Mortara and Catalano, 2018), guide visitors through the city (Chatzidimitris et al., 2013; De Fino et al., 2020; Ioannidis et al., 2020), provide access to additional information (von Schwerin et al., 2013), and enable users to gather a virtual view of temporal changes, lost historic spaces or hidden areas (Bekele et al., 2018; Chang et al., 2015; Chatzidimitris et al., 2013; Luna et al., 2019; Petrucco and Agostini, 2016; Torres and Qiu, 2011; Vicent et al., 2015). Extended reality (XR) comprises different levels of augmentation of reality by computer-generated content. This is mostly visual content – ranging from augmentation of real-world views by information or graphical elements (augmented reality, AR) up to fully computer-generated virtual worlds (virtual reality, VR) (Luna et al., 2019; Pervolarakis et al., 2023).

2.1.1 Historical cityscape scenarios

In 5DCulture, four historical cityscapes are investigated to be aggregated into the Data Space as well as re-used in various applications (such as 3D viewers, VR/AR, 4D browsers, etc.):

1) Amsterdam Vaalkenbourg City (NL): 3D reconstructions are created for educational visualisations to show the development of the Amsterdam Vaalkenbourg quarter from the 17th to the 19th century (Figure 2). The whole borough, with over 200 buildings, was modelled in Blender at three different times (Waagen and Lanjouw, 2020).

Figure 2. Rendering of the Amsterdam 3D model.

2) Sion Time Machine (CH): this scenario combines 3D scans, 3D parametric models and genealogical data into a city-wide 3D information system ranging from year 1600 to 1815 to show the development of the city and its inhabitants (Roduit et al., 2023; Figure 3).

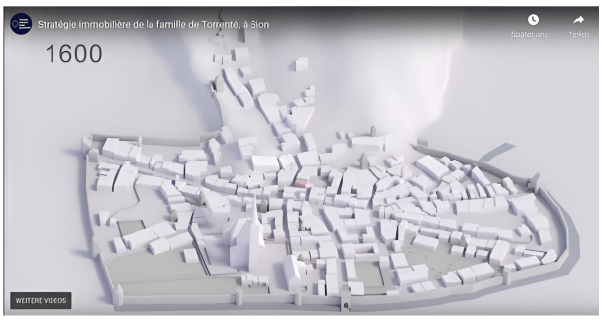

Figure 3. The Sion Time Machine (available at: https://youtu.be/g3EjqBPN7zE).

3) 4D browsing of historical Dresden: the Dresden demo case (Figure 4) started in 2016 within the UrbanHistory4D research project (Münster et al., 2020; Maiwald et al., 2023b). It comprises a 3D dataset of ~1000 buildings provided by the municipality of the current city of Dresden, a 3D dataset of ~100 buildings of

Dresden in the 1930s and a set of 2.500 historical images taken from the Deutsche Fotothek. The 4D Browser interface has been employed since 2019 by the Saxon University and State Library as an alternative interface to the Dresden image collections (Muenster et al., 2021a).

Figure 4. View of the 4D Browser of Dresden (https://4dbrowser.urbanhistory4d.org/).

4) 4D mobile views of historical Jena: the city visualisation (Figure 5) has been created based on LoD2 model data from the municipality of Jena. Within previous projects, a dataset of 5,000 photographs has been collected and employed within school projects to teach digital skills to pupils (Münster et al., 2023) and a city-wide image contest (Maiwald et al., 2023b) to support awareness, tourism and education.

Figure 5. View of the 4D City Jena (https://4dcity.org/).

A part of the project activities is dedicated to the aggregation of the models created in the demo cases into the Data Space. Therefore, an XML-based retrieval pipeline has been developed as part of the Data Space setup and tested with data from the project. The target audiences for this workflow are model owners who already operate a repository for storing and sharing 3D cultural heritage models with a changing model pool. Specific requirements are (1) data objects conforming to the Europeana Data Model, (2) licences compatible with Europeana (Fallon, 2023), (3) presentation derivatives in compatible formats (e.g. GlTF) and (4) a minimum set of metadata (Europeana, 2016). The aggregation workflow comprises a series of PHP scripts to create Europeana EML XML on the repository site to feed into the METIS aggregation pipeline. The workflow is currently in testing for the 3D models from the Jena and Dresden scenarios.

2.1.2 Inferring building heights from historical maps

Most of the used city models of historical landscape viewers are composed of actual LoD1-2 building models. Some historical maps of Jena and Dresden are currently used to enrich the offer of their web viewers evaluating the replicability and generalization of the methodology presented in Farella et al. (2021).

Figure 6. Colour-coded visualization of some features extracted from the digitized historical map of Dresden (1911): distance of the polygon’s centroid from the nearest centroid (top) and number of polygons vertices (bottom).

Figure 7. Other examples of features computed on the Dresden data: colorization based on aggregated building blocks (top) and calculated polygons area (bottom).

Machine Learning regressions will support the automatic inference of buildings' heights using only digitized historical 2D maps (building footprints vectorized) and related features. The procedure includes the computation of several features (or predictors) that can be categorized as geometric predictors (such as the area, the perimeter, or the number of vertices), neighbourhood predictors (like the number of adjacent polygons, the distance of the polygon's centroid from the nearest centroid, the kernel density with different radii), and other positional and categorical properties (such as the buildings function). Current topographic data, excluding modern buildings not present in the historical maps, are used as ground truth for the model learning and training phase. Some results of the digitization of a Dresden map from 1911 and predictors computation are shown in Figures 6 and 7.
Calculated feature values, both on historical and current data, will be used for testing different ML regression models in the forthcoming phases of the project to verify the robustness and reliability of the implemented method in challenging scenarios such as Dresden, broadly destroyed and deeply transformed during wartime. The same method will be further tested on the Jena scenarios, leveraging a historical map of the city from 1936.

2.2 Re-using 3D archaeological and architectural contents

2.2.1 Archaeological contents

Exploiting 3D technologies in archaeology, heritage artefacts and structures can offer digitized contents useful to researchers and archaeologists for virtual platforms, analyses, interpretation and preservation purposes (Farella et al., 2016; Forte et at., 2012; von Schwerin et al., 2013). 3D opens-up new avenues for understanding and studying our collective past while ensuring the long-term conservation of valuable archaeological treasures. Successively, re-use scenarios for archaeological 3D contents enhance visitors' experience of monuments and to support the value of created 3D surrogates for different sectors (tourism, education, gaming, arts, conservation and heritage management).

Figure 8. Sculpture of Warrior of Cerrillo Blanco (left). Original 3D geometric model (centre). Improved and textured 3D model (right).

Archaeological 3D content from the Brú na Bóinne World Heritage site in Ireland and the Iberian culture near Jaén (Spain), are the 5DCulture use cases to demonstrate and explore the re-use of 3D content. The Iberians are one of the most significant peoples who lived between the 6th and 1st centuries B.C. in the south and west of the Iberian Peninsula (Ruiz and Molinos, 2015). Among the 3D models in the collection, the models of the sculptural groups of Cerrillo Blanco (Porcuna) and El Pajarillo (Huelma), and the models of ex-votos from the Sanctuaries of the Cueva de la Lobera (Castellar) and Haza del Rayo (Sabiote) should be highlighted for their great educational potential. In the project activities, the improvement of 3D models and the production of virtual scenarios allow students to have a diverse, inclusive and immersive experience of interaction based on the use of ICT technologies. Since most of the available models are in PDF format, activities included conversion to obj format, mesh refinement and smoothing, hole filling, alignment and re-texturing (Figure 8).
After the improvement, the models are used in different educational events related to archaeology and aimed at groups of students at different levels (primary, secondary and university) (Arias et al., 2022). Along with these events, and considering their special inclusive dimension, it is also worth underlining the use of some 3D models to design activities for people with visual impairments. Printing 3D model plays an essential role for this purpose (Figure 9) and 3D printing settings are crucial to balance printing time and the quality of the final product. For people with visual impairments, it is of special importance to control the size or scale of the model to be able to touch it and the type of filament that allows obtaining a roughness/smoothness sufficient to perceive the shape of the object (Rossetti et al., 2018).

Figure 9. Printed 3D model using bronze filament of Iberian ex-voto (9 cm height - left). Printed 3D puzzle of the wolf of El Pajarillo using PLA filament (right).

During the development of educational events, several dimensions or directions are highlighted through 3D models:

- History: paying attention to iconographic analysis to reveal aspects with symbolic, ritual, social and gender meaning.
- Methodology: explaining the process of scanning (data acquisition and post-processing) and printing 3D model (setup and materials).
- Conservation: emphasising the effectiveness and usefulness of 3D models as a means of conservation and protection of the archaeological heritage.
- Dissemination: stressing how 3D models facilitate knowledge of the past, respect for archaeological heritage and promote its social and inclusive dimension.

The other archaeological case study focuses on the UNESCO World Heritage Site of Brú na Bóinne, a significant archaeological and historical site in Ireland containing one of the world's oldest and most well-preserved megalithic structures and highlights the advanced engineering and architectural skills of Neolithic populations. The first action will be to improve the quality of existing 3D models by reprocessing legacy data, producing higher resolution textures based on photogrammetric and procedural methods, improving photo texturing through delighting and cross-polarisation techniques, and improving the metadata and paradata associated with each model.

2.2.2 Architectural contents

The semantic H-BIM approach (Iadanza et al., 2019) developed within the INCEPTION EU project (Maietti et al., 2020) facilitates the use of 3D digital heritage buildings to access additional content. It interprets each element of a 3D model as an individual entity linked to specific knowledge. The approach consists of transforming all the geometries of a 3D model of a monument or a site into semantic triples that connect one element to another using specific predicates defined in a dedicated

semantic ontology. The 3D models must be supplied in the form of Building Information Modeling (BIM) as an Industry Foundation Classes (IFC) standard file. Once the models and related information are transformed into triples, all of these are stored in a semantic triple store that is accessed via HTTP through a dedicated Apache Fuseki SPARQL server. INCEPTION Core Engine (ICE) technologies can power web applications that allow users to enrich their models with new semantic metadata. Indeed, the web client enables the enrichment of models with new data (e.g., a date, a value, texts) as well as attachments (e.g., pictures, thermographic images, 3D models of specific details, videos, etc.), all of which are related to the Heritage site or a specific geometrical element (López et al., 2018).
This approach allows to connect both tangible and intangible information. A single element of an architectural complex can be linked to an architectural system, as well as to one or more documents, or to some metadata, or even to external information on the web, using semantic triples. Semantic solutions, by using standard and open protocols, foster the system's interoperability, thanks to semantic ontologies that allow the definition of properties and inference rules that link one category to another.

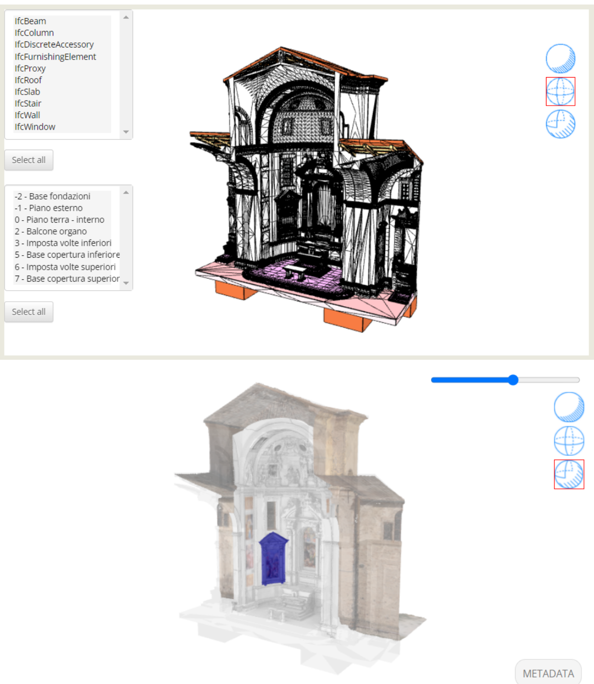

Figure 10. 3D visualization of a H-BIM model processed by ICE services in IFC (top) and hybrid (bottom) visualization modes. Through the selection by elements, it is also possible to access the detailed information of each object.

Among the web applications powered by ICE technologies, there is a 3D WebGL viewer for navigating 3D data processed by INCEPTION services, which enables the visualization of 3D data aggregated from heterogeneous sources (Medici et al., 2022; Figure 10). In fact, on the INCEPTION platform, users can navigate the model in three dimensions and view it in three different modes: IFC, texture and hybrid. The IFC mode enables users to select geometric elements, filter them by levels or classifications, and query their metadata (Figure 11).

Figure 11. Every element of a 3D building can be used to perform a live SPARQL query that returns all the details for that element, according to the HBIM ontology. Each value can be updated via web, thanks to the SPARQL 1.1 update functionalities.

Meanwhile, the texture mode, lacking selectable elements, offers a visualization that provides an intuitive understanding of materials. The hybrid mode superimposes the previous ones by means of an editable transparency layer and allows you to select IFC elements while visualizing their real appearance. It is also possible for each element to access its metadata, such as the unique Global-ID, the name, the IFCType, notes and comments. Through a graphical schema, users can navigate among categories, parameters, and values assigned during the modeling phase. The values may also contain links to internal (other models in the platform) or external (in the web) references. In this way, semantic data can be visually accessed and retrieved, allowing the use of information at different scales for a more informed understanding of how an asset is interconnected (Russo & De Luca, 2021).

2.3 Re-use of 3D fashion collections for immersive museum experiences

In this scenario, the project aims to expand onto new digital assets by utilising 3D and augmented/virtual reality (AR/VR) technologies, bridging the gap between uncharted digital arenas and the physical space of a museum. Aiming to inspire the cultural and creative sector to explore new ways to make their collections more accessible, above all remotely, the purpose is to go beyond traditional web technologies - websites, online catalogues, and social media posts. We have so far experiment with Social Virtual Reality, with the aim to curate an exhibition showcasing 3D costumes from ancient fashion collections belonging to different cultural institutions, thus avoiding the many complexities related to loans (fragility of historical objects, high costs of transportation and couriering, as well as issues related to prolonged display and conservation). Moreover we have looked to extend fashion collections beyond the museum's physical spaces through a virtual try-on web application based on Snap Lens and Snap Camera Kit technologies[1]. Users will be able to virtually try on garments using their smartphone or laptop cameras (Figure 12). A demonstration is available at https://3dom-fbk.github.io/5Dculture_AR/.
Similar to the archaeological domain (Section 2.2), a significant part of the activities is dedicated to the exploration of optimization procedures for 3D models of garments and other fashion objects (like glasses), generated both with active and passive sensors (laser scanner and photogrammetric data). The optimization of the model’s geometry is, indeed, crucial to enhance and improve the augmented experience and guarantee a

[1] https://ar.snap.com/camera-kit

smooth AR fruition. Figure 13 shows an example of mesh simplification and optimization, polygons reduction and geometry smoothing using one heritage hat that will be part of the AR application.

Figure 12. Some examples of historical hats used for the virtual try-on application in 5DCulture.

Figure 13. Geometry optimization for a photogrammetric hat model: from about 680.000 faces (left) to 25.000 (right). Geometrical features and details are preserved in the optimized model.

Once the model's geometry is optimised, the textures generated from high-resolution models can be reassigned to the simplified and low-poly reconstruction through a process called baking (Farella et al., 2022). Some recent rendering techniques and methods (PBR – Physically-Based-Rendering) (Kumar, 2020) are therefore exploited to enhance colours and lights, besides offering a more realistic representation of the physical properties of the object. An example is shown in Figure 14, which compares the graphic rendering by applying a standard texture generated from photogrammetric software (usually the Albedo maps) and adding more textures from the PBR pipeline (in this example, the Normal and Roughness maps) created and modified in image and mesh editing tools.

Figure 14. 3D model enhancement through PBR texture maps generation: only Albedo (left) and adding the Normal and Roughness maps (right).

3. ENABLING TOOLS FOR 3D RE-USE

In a nutshell, within 5DCulture activities, innovation takes a centre stage to support and facilitate re-uses of digital heritage 3D contents. The different tools that the 5DCulture aims to put at the disposal of professionals include:

- Creating 4D urban models from historical maps: this tool enables the creation of multi-temporal 3D urban models leveraging on historical 2D maps and digitized building footprints. Historical building heights are predicted through Machine Learning regressions (Section 2.1).
- INCEPTION Core Engine (ICE) technologies for converting BIM and H-BIM into semantic data (semantic triplet), making them accessible, easier to query and enrich. ICE decomposes the entire BIM or HBIM model, interpreting each 3D element as a single entity that can be connected to a specific knowledge (Section 2.2.2).
- AI reasoning engine exploiting semantic triples: semantic triplet converted from HBIM 3D models by ICE this tool uses AI to exploit metadata and media available on Europeana or external sources to enrich the HBIM model.
- AR visualisation of historical images in urban areas: a SLAM-based solution enables the augmented visualization of historical sources in urban contexts (Torresani et al., 2021).
- 3D effects on historical images: the tool exploits Deep Learning solutions to create 3D effects and animations.
- 3D asset manager and storage capability of 3D models.
- 3D web viewer specialised for BIM models.
- 3D web viewer specialised for 3D models with textures: as for the previous two bullets this will be managed by expanding the solutions developed within the Weave project[2].
- Curation and storytelling: the tool allows for managing all types of content and metadata to create new digital stories and experiences.

To support the sector, the consortium aims to share all these tools with the community by the end of the project.

4. CONCLUSIONS

The paper presented the EU-funded 5DCulture project, which aims to re-use 3D cultural content targeting different application sectors: architecture, archaeological and fashion heritage collections. The project's contribution extends beyond theoretical frameworks to provide practical tools and technologies designed to facilitate 3D asset re-uses. From semantic H-BIM technologies and AI reasoning engines to AR visualisations and 3D asset viewers, a rather vast set of tools will be offered to facilitate stakeholders (heritage organisations, visitors, creative industry professionals, educational actors, researchers, policymakers, etc.) in more effective use of digitised 3D assets. A Community of Practice (CoP) has been recently established (https://www.5dculture.eu/cop), offering stakeholders interested in re-using cultural heritage assets in an intuitive interface with faceted search functionality to discover tools, services, and available resources.

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[2] https://weave-culture.eu/collections/arctur/

CULTURAL-02 (Cloud Data for Cultural Heritage), Topic: DIGITAL-2022-CULTURAL-02-HERITAGE, Project G.A. 101100778.

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