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The Archive as a Dynamic Entity: an Interactive Concept Map for Architectural Projects

The concept of an archive has undergone considerable evolution over time, transforming itself from a simple repository of memory into a dynamic and versatile tool capable of actively interacting with society. From a place for storing information organized chronologically or by type, the archive has become an essential cultural, political, and social resource for research and knowledge. This transformation reflects a profound change in the archive, which is now conceived not only as a means of recovering historical memory, but also as an operational basis for contemporary design. In this context, the proposal for a dynamic and interactive archive enhanced by artificial intelligence offers an innovative perspective. Designed as an online portal, these archives offer a fluid and multifaceted exploration experience, accessible through two-dimensional and three-dimensional modes. Users can dynamically navigate within a 3D virtual space, interacting with

20th-century architectural content, presented both in high-resolution digital form (2D) and as three-dimensional models, accessible via virtual reality or desktop.

The archive uses complex algorithms and artificial intelligence to adjust the layout of the works within the 3D environment, creating variable configurations based on specific parameters, such as keywords or search areas. With the help of a simple activator, it is possible to switch between 2D and 3D views, revealing further aesthetic and exploratory possibilities.

This methodological approach, based on 2.0 interactions, also offers the possibility of integrating new technologies, such as augmented reality or crowdsourcing mechanisms, in the future. In this way, the archive could evolve autonomously, fueled by collective participation and artificial intelligence management, giving rise to a constantly expanding and self-organizing organism.

Keywords:
Digital Archive, Interactivity, 3D modelling, VR, Artificial Intelligence.

INTRODUCTION

The concept of the archive has evolved considerably over time, changing from a simple container of memory to a dynamic and versatile tool capable of actively interacting with society. From being a repository of chronologically or typologically organized information, the archive has become an essential cultural, political and social resource for research and knowledge. This transformation reflects a profound change in the archive, conceived not only as a means to recover historical memory, but also as a pro-active tool, an operational basis for contemporary planning. From 1800 to the present day, the meaning of the archive has therefore been progressively transformed from a place for storing information, through a chronological or typological order, to an active matter capable of bringing together cultural, political and social elements, an interactive tool indispensable for knowledge and research, aimed at putting mental order, recovering historical memory but also a basis for operating for contemporary planning. The evolution of the archive from analogue to digital is connected to the first digital revolution of the 1990s, when manual drawing was progressively replaced by 2D Cad drawing, and the use of the web and the first digital scanning tools began to spread to all efficient home PCs. In this context, document preservation becomes much more accessible, but other critical issues become apparent, such as the progressive obsolescence of formats and the problem of access to such data only through particular devices. Also the type of cataloguing, initially done through rather simple criteria, with time gains weight as it requires a progressive complexity in the management of interconnected and multimodal information. Thus, digital archives have evolved hand in hand with technological innovation, which has made it possible to manage and preserve documents and data more and more efficiently, while at the same time launching new challenges to overcome new critical issues, such as the necessary and continuous improvement of preservation and retrieval techniques for the data entered. For several decades

now, the long-term preservation of digital archives has been one of the most complex and relevant challenges for the scientific and professional community, both on a theoretical and methodological level and in terms of developing operational solutions that are both economically sustainable and easily implemented in organizational contexts. The main obstacle to such an endeavor is the phenomenon of technological obsolescence, which, while not the only critical issue at stake, is undoubtedly the most pervasive and difficult to combat. While traditional archives can be investigated in their authenticity through the analysis of physical support, written materials, document structure, level of preservation of handwriting and annotations, digital sources are configured as dynamic entities, in continuous structural evolution, whose informational survival depends on the ability of institutions and individuals to constantly update their technological infrastructures and management protocols. Unlike analogue documentary sources - which, under appropriate preservation conditions and in the absence of pathological degradation processes, tend not only to maintain their material integrity over time, but also to increase their cultural and historical value - digital documents are subject to a constant and rapid transformation of the systems and formats that allow them to be accessed, read and enjoyed. In the absence of effective strategies for the migration of data and their preservation in technologically up-to-date environments, the future accessibility of digital content as well as the possibility of guaranteeing its integrity, coherence and authenticity over time may be seriously compromised. We can distinguish the type of digital archive on the basis of its use and the timing of its consultation, this especially with regard to classic digital archives

- Current Archive, which contains documents needed for ordinary activities.
- Deposit Archive, which contains documents no longer needed for routine activities.
- Historical Archive, containing documents intended for permanent preservation.

Awareness of the complexity and urgency of the issues related to digital heritage preservation

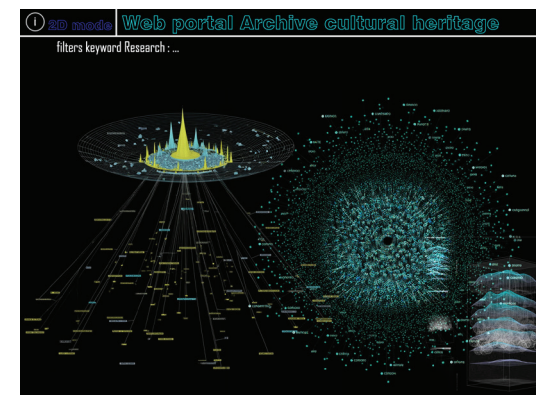


Fig. 1 - Structural hypothesis of the Home of a web portal dedicated to the management of 3D archives of 20th century architectural projects. The 3D representation of space allows the interactive navigation of a wireframe point cloud, in which the vertices correspond to contents that can be consulted in 2D or 3D mode (author's elaboration).

has long been established, especially technical specialists in the field. However, it is only in recent years that we have witnessed the launch of research programs on an international scale endowed not only with adequate financial support, but also with the necessary temporal continuity, both of which are indispensable for achieving concrete and lasting results. The contribution of the technical-scientific literature and the practices experimented in the various application contexts - although still characterized by structural limitations and methodological inhomogeneity - have made it possible to outline a sufficiently solid reference framework, useful to orient future investment strategies and to create favorable conditions for the design and implementation of effective digital preservation policies. One of the most internationally accepted guidelines is the idea that the preservation function should be integrated into digital systems from the earliest stages of the document life cycle, in a seamless and continuous manner. Preservation interventions amplify effectiveness, economic sustainability and

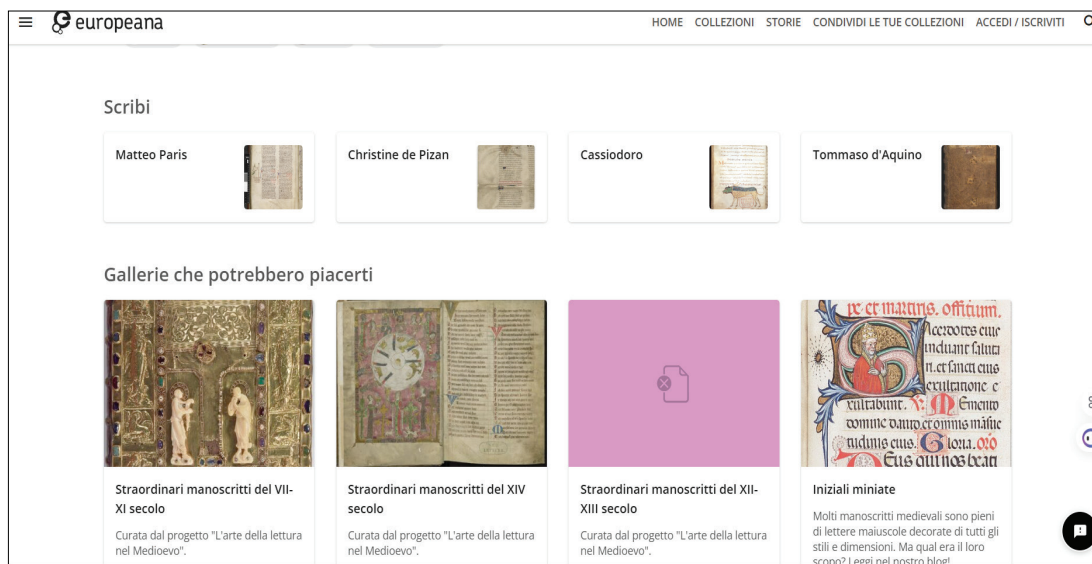


Fig. 2 - EUROPEANA archival web platform_ traditional digitization from (<https://www.europeana.eu/it>),

long-term resilience of memories only if they are timely and contextual to current production and management, excluding standardized solutions and adhering to a diversified heterogeneity of digital products. This calls for flexible approaches, supported by up-to-date professional skills and dynamic knowledge, able to adapt to the constant evolution of technologies and operational needs. Finally, the intrinsic vulnerability of digital media, the ease with which content can be modified or corrupted, as well as the rapidity with which technological innovations are occurring, have made evident - increasingly so, especially in recent years - the absolute urgency of establishing highly reliable archival infrastructures and digital repositories. These systems must be designed to guarantee high standards of security, authenticity and accessibility over time, as will be further explored in the following sections. It is within this articulated scenario that the proposal to conceive a new model of digital archive, dynamic and interactive, supported by the potential of Artificial

Intelligence, fits. This system is no longer merely a static container of data and documents, but an evolved device, itself capable of overcoming the traditional dichotomy between content and container. In fact, it is proposed as an active tool for the enhancement and amplification of historical memory, offering a new experiential dimension to cultural heritage through processes of conceptual and interactive virtualization (Fig.1). Thanks to these innovative features, the archive is thus transformed into an epistemological platform that is not limited to preservation but is configured as a generative space for the production of knowledge, fostering processes of interpretation, re-elaboration and critical investigation. In particular, its potential as an advanced support tool for architectural design is highlighted, contributing to the formation of a conscious, informed and historically rooted concept. In this way, Digital Cultural Heritage is not only an object of protection but becomes an active agent in the construction of future memory (intangible preservation) and in the definition

of innovative design trajectories.
STATE OF THE ART ON 3D DIGITAL ARCHIVES.

In this context, the aim of the article is to demonstrate how important the integration of new technologies can be in improving the digital archive system, with the proposal of a dynamic and interactive archive enhanced by artificial intelligence that can offer an innovative perspective applicable to multiple cultural spheres and more consistently in the field of the valorization of architectural archives. By overcoming the traditional dichotomy between content and container, it can become not only a vehicle for historical memory, but also an active tool for architectural design. This methodological approach, based on 2.0 interactions, also offers the possibility of integrating new technologies such as augmented reality dynamics or crowdsourcing mechanisms in the future. In this way, the archive could evolve autonomously, fuelled by collective participation and the management of artificial intelligence, giving rise to a continuously expanding and self-organizing organism. Numerous attempts have been made to date to structure a complex digital archive capable of integrating the visualization of two- and three-dimensional content. However, such initiatives have often generated conceptual ambiguities, overlapping the notions of virtual museum, gamification, applied games or simple galleries of manipulable 3D objects, but located within traditional structures. The latter, while offering search tools based on keywords through internal engines, are deficient in other respects, particularly in the rendering of an immersive perception of an effectively explorable three-dimensional space, capable of stimulating, through visual input, new and potentially unexpected lines of research. Appropriate examples referring to this type of interactive digital archives enhanced by full 3D visualizers can be Europeana:(Fig.2) (<https://www.europeana.eu/it>), a European platform aggregating millions of digital resources from museums, archives and libraries from all over Europe, public and private. Although not exclusively focused on real-time 3D visualizations, it is possible to find

projects within the network that use 3D models and interactive interfaces to explore collections related to virtual reconstructions of historical sites or architectural artefacts. Another example is Smithsonian Institution - 3D Digitization (Fig.3) (<https://3d.si.edu/>): The Smithsonian institution, a famous education and research organization has undertaken an extensive program of 3D digitization of its collections, making many models accessible online and often navigable interactively. Exploring their gallery and resources it is possible to understand how the technologies and methodologies used make use of 3D rendering for visualization of the works, innovative laser scanner data acquisition and photogrammetric methods of real artefacts in order to generate high quality digital twins. There are many other types of archives of this kind, which retain a rather traditional digital search facility-interface, while still offering a visualization of the content in explorable 3D space. Also very popular is the SketchFab platform, now acquired by Epic Game and now a much more closed platform by the name FAB, which for years has distinguished itself as one of the best archival systems of explorable 3D models, with an efficient internal cataloguing, which according to search keywords (e.g. Heritage content) offers visualization, purchase and in some cases free download of hundreds of 3D models already textured and optimized for good web visualization. It therefore proves to be an excellent tool for various uses, an internal archival use that also privately allows the structuring of archive containers for the uploading of 3D models (e.g. digital twin photomodelled models of buildings or ancient statues), but also a dataset of models, even animated ones, offered for constructing cinematic scenes to be rendered or virtual spaces to set up interactive levels for videogames and serious games. Another popular online portal, OpenHeritage3d (Fig.4) (<https://openheritage3d.org/>), is also moving in this direction. In short, it presents itself as a 3D digital archive of historical content from around the world digitized from real life, a gallery of hundreds of photogrammetric and color laser scans supported in visualizations by 'Potree' interactive/open-

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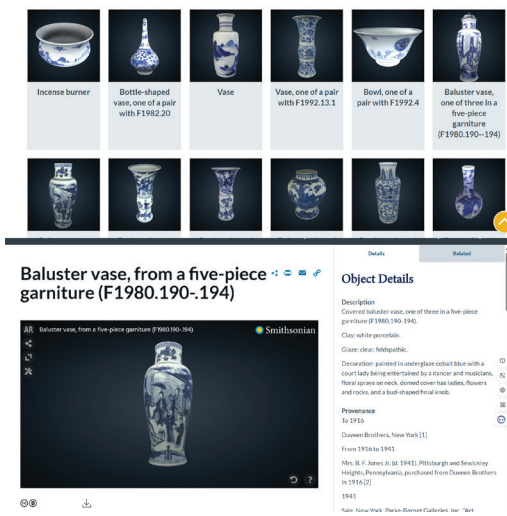


Fig 3 - Smithsonian Archive digital web platform. Well-structured portal with access to information and explorable Digital Twin models. image from <https://3d.si.edu/>

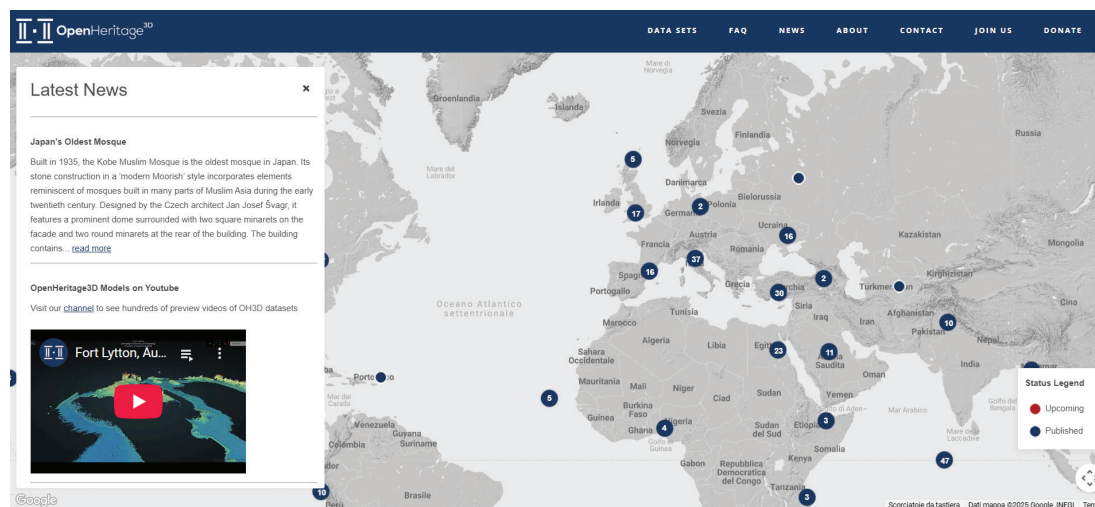


Fig. 4 - Piattaforma web OpenHeritage, offre buoni contenuti ma è legata ancora a dinamiche statiche. image from <https://openheritage3d.org/>,

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source point cloud visualization systems (<https://github.com/potree/potree>) aimed at education, research and any non-commercial use of them. The project developed a few years ago has been funded by the Cultural Heritage Engineering Initiative (CHAI) at the Qualcomm Institute, a division of Calit2, at the University of California, San Diego, but also has international partners linked to the world of academia, such as the Polytechnic of Turin or large companies such as Google Arts and Culture. In the medical sphere, on the other hand, in the commercial and open source offers on various web portals relating to 3D archives, a more educational approach is very interesting, one that has been experimented for some time in various researches, which deploys effective 3D containers, i.e., abstract spaces, useful as real-time web-based workspaces, within which multiple modes of access to the contents coexist, 2D and 3D, in addition to much more interactive dynamics that favor the teaching of anatomy, although only in recent times, thanks to technological advances, has it been possible to access effective tools for full 3D

exploration. (Web-Based Interactive 3D Visualization as a Tool for Improved Anatomy Learning, Helge Petersson, David Sinkvist, Chunliang Wang, O'rjan Smedby) is an example of a medical web platform, dating back to 2009, which proposes one of the first and most interesting uses of virtual reality (VR) aimed at learning anatomy, based on the virtual injection of contrast liquid, which is useful to easily distinguish the various organs to be visualized and analyzed. 3D objects, or rather anatomical parts, are actually acquired from the real thing and then segmented specifically for anatomical learning. This method allows users to relatively easily convert computed tomography or MRI images into scanned models or stereoscopic VR movies using OsiriX software equipped with the CMIV CTA plug-in. Once created using the segmentation tool, the image series were exported in Quick Time Virtual Reality (QTVR) format and integrated within a web framework of the Educational Virtual Anatomy (EVA) programme. A total of nine QTVR movies were produced, covering most of the major arteries of the body. These films were supplemented with associated information and colour legend. Here again, we are in a simulated 3D space, i.e. a 2.5 d that still remains embedded in the traditional digital archive system although the contents actually appear to be in 3D. Today in the medical field, there are many applications that offer study tools enhanced by innovative 3D visualization dynamics, one example is "Complete Anatomy" (Fig.5) (<https://3d4medical.com/>) App designed primarily for medical students and health professionals for learning and understanding human anatomy, offering the possibility to study anatomical structures in a vast archive of interactive 3D models, which helps to prepare for practical laboratory exercises, through desktop visualizations, VR and AR. In any case, today it seems difficult to find online portals hosting abstract virtual spaces that can themselves constitute the digital archive in question, i.e. container & content, somewhat the concept of the contemporary museum. Instead, for reasons of logistics and site maintenance, resource management and general control, it is preferred to opt for a more

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traditional and linear approach in the construction of online archives, i.e. the classic drop-down menu with an internal search engine by keywords from which it is possible to access the actual explorable three-dimensional contents, often presented in different styles and unrelated to the 2D contents that a portal should have anyway.

This approach is rather outdated today because it greatly limits the attractiveness of the content. It may work for scholars, who are interested in a particular research, but it disincentivizes the general public, because it lacks any gaming or simply interaction dynamics that would instead bring a less specialized user base closer to the exploration of virtual spaces and at the same time of the proposed contents. Another critical issue related to the current online 3D archival system is the 'staticity' and 'perishability' of the formats used. Staticity refers to a structure that is heavily boxed and not dynamically decomposable, i.e. a structure for which to access a content one has to click a number of times on other elements until the relevant page is loaded. Perishability, on the other hand, is linked to the problem of digital formats entered and thus for a long time contained in online servers, often for a fee and disconnected from the structure responsible for the archive. This causes a major problem linked to the fact that file formats should be replaced after some time, constantly updated and renewed, and this must be done by the proposing organization in collaboration with the private company that rents the web server service, otherwise the content itself will be discontinued, and the platform itself may no longer be able to read it (contrary to what is thought, digitized content is just as fragile as real content).

A HYBRID DIGITAL ARCHIVE FOR THE KNOWLEDGE OF ARCHITECTURE PROJECTS

The proposal is to structure a hybrid archive, which could have the same search simplicity as the drop-down networks but applicable to an interactive 3D space where visual input is sufficient to orientate. Conceived as an online portal, such innovative ar-

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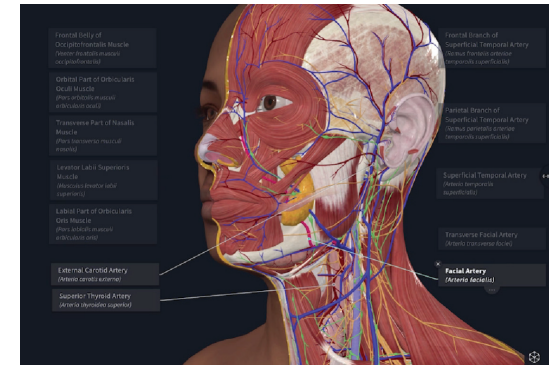


Fig. 5 Educational Virtual Anatomy programme from "Complete Anatomy" App designed primarily for medical students and health professionals for learning and understanding human anatomy. image from <https://3d4medical.com/>

chives offer a fluid and multifaceted exploration experience, usable through two-dimensional but above all three-dimensional modes. Users are able to dynamically navigate within a virtual 3D space automatically defined by artificial intelligence algorithms according to the user's search parameters, within which they can access documentary content related to architectural projects, presented both in high-resolution digitized form (2D) and as three-dimensional models usable via VR mode or desktop. It is assumed that the new dynamic archive will be explorable directly on the web via http links, giving the possibility of fluidly accessing contents through a dual mode 2d and 3d through dynamic actions that allow the user to navigate within a three-dimensional space, thus through the mouse it is possible to dynamically approach the interested contents, themselves structured in a constellation distributed in a three-dimensional space, each piece of content, relating to 20th century architecture projects, can be viewed in two-dimensional mode (high-resolution digitization of the original projects) or three-dimensional mode (in interactive VR/AR/XR or desktop mode), widening the target audience and improving the usability and comprehension of the projects. Complex algorithms will then regu-

late, by exploiting certain AI automatisms, the distribution structure of these elaborates in the 3D navigable space, in a constellation that relates the same projects according to different parameters, for instance in relation to the type of search to be carried out, so as to automatically structure different and unpredictable configurations in the 3D environment according to the keywords entered: an affective map that looks like a wireframe conceptual model, a network of vertices (made up of contents) and connecting filaments between the same multiple contents, linear vector elements that can host infographics or keywords.

This can already be done using online tools such as 'Three.js' (Fig 6). The archive then makes use of complex algorithms integrated with artificial intelligence to adjust the arrangement of the elements within the 3D environment itself, creating variable configurations based on specific parameters, such as keywords or search fields. This process gives rise to an affective map, represented as a wireframe conceptual model that is basically constituted as a network of vertices (the contents) and connecting strands (the actual links that the projects have with each other, e.g. the same author), which allows for a dynamic and unpredictable exploration of a single complex entity formed by multiple cultural elements. Together, content and container thus acquire equal importance, generating a compact, visualizable and explorable model. With the aid of a simple activator, it is possible to alternate between 2D and 3D visualisations, revealing further aesthetic and exploratory possibilities.

WORKFLOW

In order to structure the design of an interactive online 3D archive, accessibility via http links combining 2d and 3d modes will be required, many galleries and frameworks exist to manage the real-time visualization of complex 3d elements. Among the most popular are 'Three.js' (JavaScript) - for envisioning 3D models on browsers, Babylon.js (JavaScript) - for more advanced 3D and VR experiences, A-Frame (WebVR/WebXR) -

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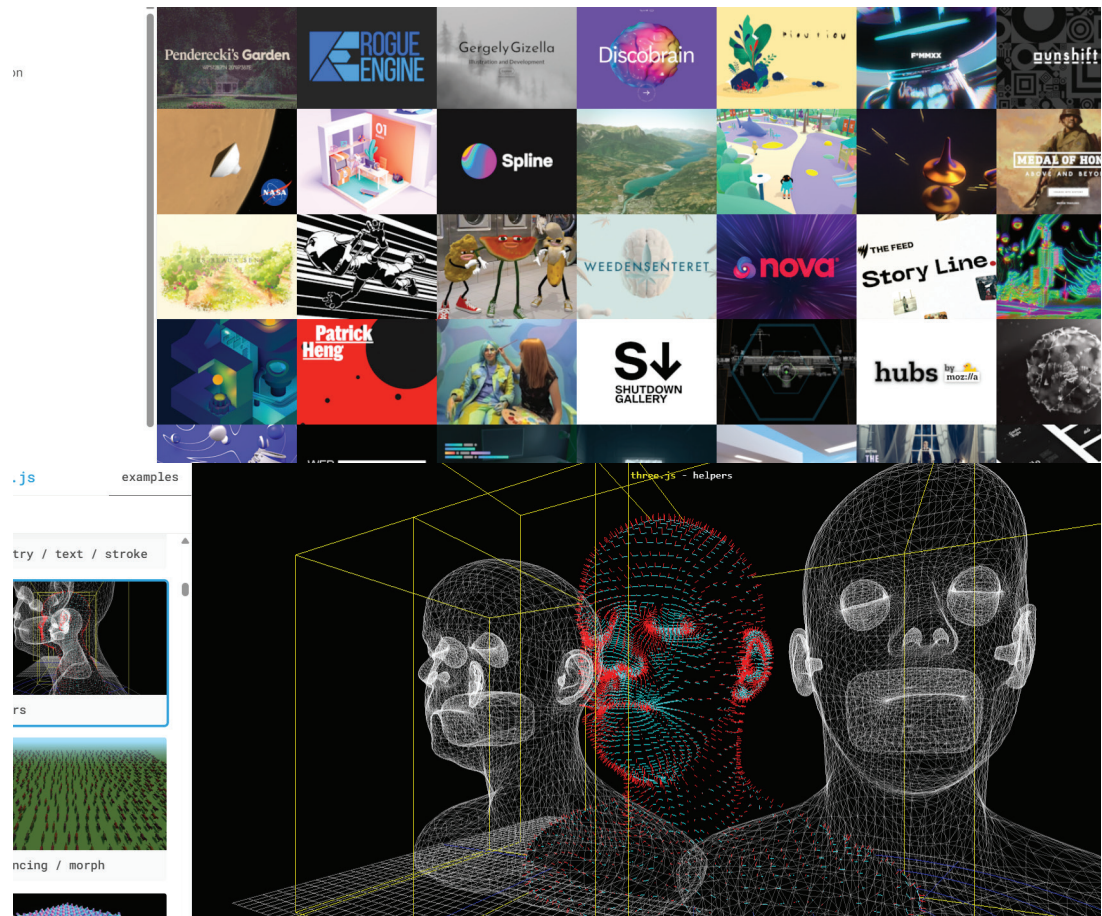


Fig 6 - three.js is a highly versatile tool that offers many tools on the 3D web platform and allows you to manage custom models, including point clouds. Image from official interface portal <https://threejs.org/>

for supporting VR and AR modes directly on the web. Then there is PlayCanvas, one of the most dynamic and easy-to-use WebGL systems for creating interactive 3D environments with excellent performance. PlayCanvas is a JavaScript game engine, so there is no 'build' step, which means you can manage virtual spaces incredibly fast and

create apps faster using real-time collaboration in the style of Google Docs. The best approach, however, is one that brings together a solid and already well-tested framework such as Three.js with WebXR, which is a free open source mode, for excellent compatibility with various browsers supporting VR/AR visualization modes (an exam-

ple is “The Maestro’s Manor_Penderecki’s Garden”, a web project produced by the Adam Mickiewicz Institute, which combines 3D particle/dot cloud exploration with documentary content related to classical music pieces by the well-known Polish composer Penderecki, videos and written information. (Fig 7.).

The proposed design for the Architecture archive also includes a dynamic wireframe map in which the contents are connected by vector filaments and the distribution changes according to searches, while retaining the central outline of the configured space. This requires the use of machine learning and applied Artificial Intelligence tools. The AI technology chosen to generate and structure the virtual map is ‘NetworkX’ (Python) - for the creation of networks and the management of connections between content in a cross-platform manner - in collaboration with another tool, ‘D3.js’ - to display connections between content dynamically. In addition, the system will have to manage a complex database for storing content, both 2d and

3d, and related metadata. To do this, it would be ideal to use a system that is as robust and at the same time flexible as possible, so that the content can be updated at any time. The choice falls on PostgreSQL for stability + Neo4j, which is ideal for archives with complex relationships between elements (if the relationship management is based on an element that can be called up by a keyword). Obviously, the contents must be stored in a virtual server, not visibly accessible to anyone other than the organization owning the project.

Even in this case there are critical issues related to the instability and transience of any online cloud, but precisely for this reason the only permissible solution is to turn to very reliable global companies such as Amazon S3 / Google Cloud Storage for large files and IPFS (Inter Planetary File System) for decentralization. In order to construct the interactive and intuitive user interface to navigate the 3D space, i.e. the so-called Frontend/User Experience, one can turn to various technologies, React.js + Three.js - for an innovative yet simple

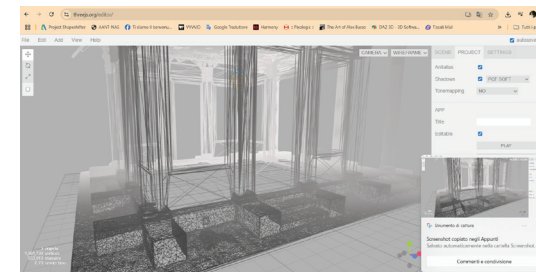


Fig. 8 -Test editing using the Three .js interface tool, a native web space construction platform (author's work).

interface, or Svelte + D3.js - for a lightweight representation of conceptual networks, which in part, at least as far as the navigation of container spaces is concerned, relates to our case study. The development process basically consists of five main phases:

- Prototyping: Create a first version of the 3D environment with ‘Three.js’ using basic elements in .obj or. Fbx 3D format.(Fig. 8)
- Database structuring: Organize 2D/3D content and metadata with ‘Azure PostgreSQL’, which uses large language models (LLMs) to create advanced generative AI applications within the database. + ‘Neo4j’, which generates dynamic graphs controlled by AI based on keywords.
- Implementation of AI sub-dynamics: Automate dynamic content distribution in real time using resources such as ‘NetworkX’ or ‘TensorFlow’.
- UX/UI optimization: Make navigation smooth on browsers and VR/XR devices using ‘Frontend UI’ and ‘react.js’ which is an open-source JavaScript library for creating simplified user interfaces (UI).
- Testing and Deployment: Publish to cloud servers such as ‘Google Cloud’.

In order to realize a web-based 3D archive as described, a combination of technologies supporting 3D exploration (Three.js), advanced AI functionality for automated distribution (NetworkX), relation-

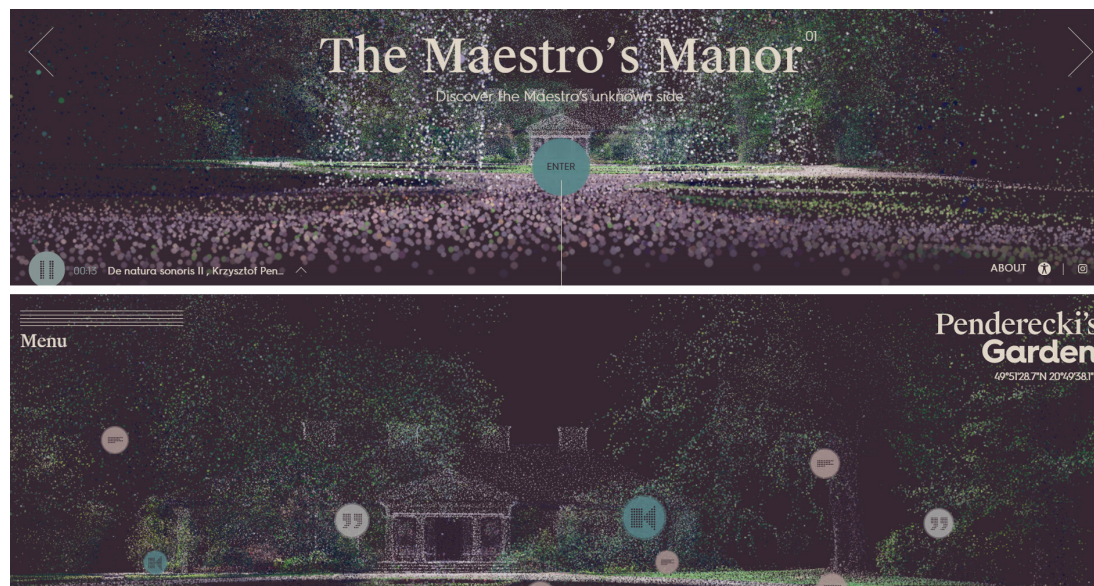


Fig. 7 - Maestro's Manor _project structured entirely using Three.js and content for viewing the experience on the official website.

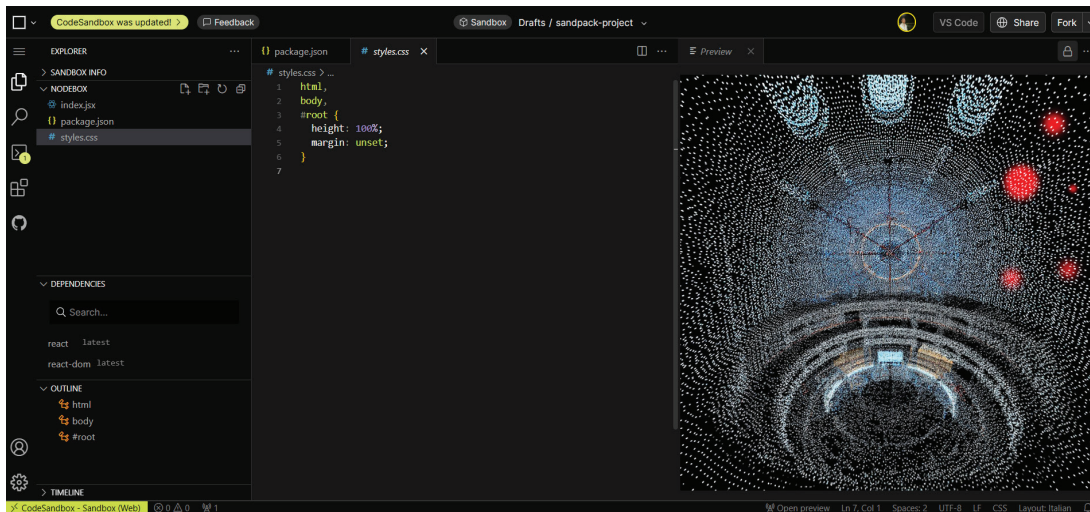


Fig. 9 - Construction hypothesis using the Codesandbox_Three .js editing interface tool, a native web construction platform supporting advanced archives that integrate diverse modes of use: from traditional viewing of digitized documents in high-resolution zoomable formats, such as gigapixels, to simultaneous three-dimensional representation, which allows for clearer interactive exploration of three-dimensional models related to archived documents. (author's elaboration).

al databases (PostgreSQL, Neo4j), and an interactive interface (React.js) is required. The project, currently in the initial stages of development, is configured as a technology stack that has already been extensively tested in numerous projects that are now accessible online (<https://threejs.org/>). Its distinctiveness lies in the combination of heterogeneous processes, integrated according to a common objective (Fig. 9).

CONCLUSIONS

In summary, the new technical possibilities and automated developments offered by algorithms based on artificial intelligence now make it possible to design advanced digital archiving systems characterized by greater accessibility and cultural usability. These systems can broaden the target audience, fostering generalized access to knowledge and cultural heritage, and offer a more robust infrastructure for data preservation. These advanced archives integrate different modes of

use: from the traditional visualization of digitized documents in high resolution zoomable format, such as gigapixels, to the contemporary three-dimensional representation, which allows for clearer interactive exploration of three-dimensional models related to archived documents. This dual mode of access enriches the possibilities of cultural dissemination and enhancement of architectural and documentary content. (Fig. 10).

Furthermore, the introduction of an innovative system of dynamic spatial exploration in 3D environments offers a more immersive navigation experience than before, generating ever-changing and attractive virtual spaces. This approach not only facilitates the search for three-dimensional models and two-dimensional documents, but also activates unconscious gamification dynamics, thus broadening user interest well beyond the professional sphere, involving a wider and more diverse audience. The project proposed here is still a work in progress. Some of the intrinsic compatibilities of the various applications used, which involve ac-

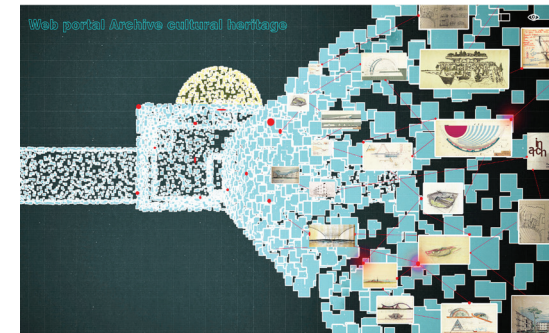


Fig. 10 - Hypothetical visualization of navigation through spaces generated as a wireframe cloud, relative to content. The spatial configurations, which can be navigated in real time, are dynamically adapted by artificial intelligence based on the number and type of content associated with search keywords (author's elaboration).

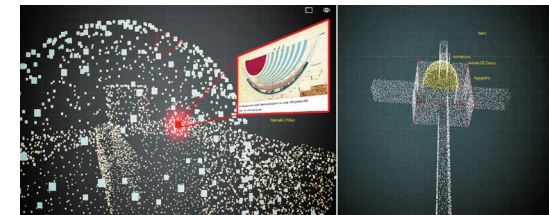


Fig. 11 - Hypothetical visualization of the navigation of volumetric-particulate spaces, relating to 2D content digitized directly from original archival materials and accessible through an automatic AI system (author's elaboration).

tive use of AI tools, still need to be verified, and we are already far from the testing phase necessary to effectively determine how much an integrated system of this type can influence a diverse user base, bringing additional benefits to the use of the 3D archive. In summary, we want to propose a new, highly technological approach that can automate information mapping and information sharing processes in full compatibility with XR use, so as to structure a solid, repeatable, and modifiable systemic base in relation to the archival content to be presented, which at the same time can contain 3D models, digitization of 2D tables, texts, and parallel design hypotheses that have not been realized (Fig. 11).

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