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5DMETEORA FRAMEWORK: MANAGEMENT AND WEB PUBLISHING OF CULTURAL HERITAGE DATA

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KEY WORDS: web-based framework, content management system, 3D visualization, VR, AR, Cultural Heritage, photogrammetry

ABSTRACT:

Cultural Heritage (CH) management software represents virtual information in various ways aiming either at usability and long-term preservation or interactivity and immersiveness. A single web-based framework that couples the organization of geospatial, multimedia and relational data with 4D visualization, Virtual Reality (VR) and Augmented Reality (AR) is presented in this paper (https://meteora.topo.auth.gr/5dmeteora.php). It comprises the 5dMeteora platform and the Content Management System (CMS) for uploading, processing, publishing and updating its content. The 5dMeteora platform integrates a responsive 3D viewer of high-resolution models in the basis of 3DHOP (3D Heritage Online Platform) and Nexus.js multi-resolution library. It offers data retrieval and interpretation mechanisms through navigation tools, clickable geometries in the 3D scene, named hotspots, and semantic organization of metadata. Its content and interactive services are differentiated, based on the scientific specialty or the field of interest of the users. To achieve the sense of spatial presence, VR and AR viewports are designed to give a clearer understanding of spatial bounds and context of 3D CH assets. The proposed CMS allows dynamic content management, automation of 3DHOP's operations regarding 3D data uploading and hotspots defining, real-time preview of the 3D scene as well as extensibility at all levels (e.g., new data types). It is built upon a MySQL Database Management System and developed with PHP scripting, backend JavaScript and Ajax controllers as well as front-end web languages. The database maintains and manages the entities of every type of data supported by the platform, while encryption methods guarantee data confidentiality and integrity. The presented work is the first valid attempt of open-source software that automates the dissemination of 3D and 2D content for customized eXtented Reality (XR) experiences and reaches multiple levels of interactivity for different users (experts, non-experts). It can meet the needs of domain experts that own or manage multimodal heritage data.

1. INTRODUCTION

Photogrammetry and computer vision have advanced to a point that real-world applications can be achieved in a meaningful way. In the field of CH, they are an essential and cost-effective tool in documentation and long-term digital preservation. Once displayed online, the geometrically accurate 3D representations increase the scientific value and public awareness of CH. Enriched visualizations with multimedia, metadata and textual information facilitate cross-disciplinary learning and engage the public. The actual potential landscape is expanded with dynamic services for data retrieval, semantic enrichment and radical new forms of immersion offered by VR and AR. Beyond these front-end features, content storage, indexing and organization provide resilience for institutions, museums, professionals, researchers and stakeholders of the CH community. Their datasets are often large and diverse including spatial 2D and 3D data, metadata, non-spatial and sensitive information as well as different types of multimedia addressed to different users. Considering the difficulty, effort and code literacy needed in promoting online a multimodal repository, they either host 3D models as stand-alone experiences limited to exploring a single artifact or they adhere to the default set of capabilities provided by the software rather than customizing (if possible) its built-in functionalities to their project's requirements (Garcia et al., 2022). Thus, there is a high demand of an end-to-end solution that automates CH content management and publishing to improve the administrator experience.

To fill this gap, this paper presents an open-source web-based framework for the real-time creation of interactive visualizations of multi-modal CH data. The "5dMeteora" framework is the official name of its front-end interface as it currently hosts the 3D geometric documentation data of the UNESCO site of Meteora, Greece. It consists of three technological components: (i) a MySQL Database Management System (DBMS); (ii) a mid-level Content Management System (CMS); and (iii) the platform with integrated 3DHOP's 3D viewer, interactive search and retrieve tools, specialized information as well as VR and AR capabilities. 3DHOP is an open-source framework capable to manage extremely complex 3D meshes or point clouds (tens of million triangles/vertices), created by the Visual Computing Laboratory of ISTI – CNR. (Potenziani et al., 2015). In the context of the platform, clickable geometries, namely "hotspots", placed on the surface of the 3D models, serve as 3D cartographic symbols that link information and multimedia with their spatial reference. The platform also, offers data indexing and sorting in tables as well as advanced querying and filtering of search forms across different multimedia collections. Content can be personalized based on the field of interest, the target audience or the specialization of the end-user. Finally, the users can explore 3D CH assets that are not accessible or do not currently exist through a VR viewport and two types of AR sessions (location-based and relative positioning).

The administrators of the framework can preview, upload, update and maintain these front-end functionalities through the first ever CMS dedicated to multi-resolution 3D models of Nexus library. Nexus is a multiresolution visualization library supporting

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interactive rendering of very large surface models (Ponchio and Dellepiane, 2015). The CMS abstracts 3DHOP's logic into a control panel for customization and preview of the models and hotspots of the 3D scene. Text, images, videos and pdf files are posted online after being uploaded, edited and correlated with the hotspot(s), the tags and the field of expertise they refer to into customizable fields. Therefore, the DBMS records are accessed spatially, by locations, semantically, by attributes and thematically. The CMS maintains log registry of each session, diagnosis of structured errors and exception handling for administrator inputs.

2. RELATED WORK

2.1 Commercial web-visualization software

Multiple web-based frameworks offering multiple forms of data presentations, tools and interactions have arisen (Peinado-Santana et al., 2021). Each one entails different code literacy skills, technological pipeline, data size and 3D formats. Most well-known proprietary ones for automatic content distribution are Sketchfab, echo3D, Vectary and p3d.in, offered at different pricing tiers. Sketchfab is a popular, easy-to-use solution for 3D models hosting and sharing, optimized for fast, on-demand loading and VR/AR inspection (Sketchfab Inc., 2012). Echo3D is a 3D asset management platform for developers that provides tools and cloud infrastructure to manage, update, and stream 3D content to real-time 3D/AR/VR and Metaverse applications and games (echo3D Inc., 2023). It offers a CMS and delivery network (CDN) to build the back-end system of the 3D model viewer and then, integrate into React.js and WebGL for web exploitation, AR SDKs and game engines. Similarly, Vectary is a web publishing software with dashboard for the creation, editing and sharing of 3D experiences without any programming skills (Vectary Inc., 2023). It supports both 2D and 3D files uploading, advanced settings for appearance tuning (lighting, materials, texture, effects) and ready-to-use interactions such as click and action-based events. Finally, p3d.in hosts and instantly visualizes online or integrates into webAR the products of 3D modelling software like Blender, 3DSMax, Rhino etc (p3d.in TM, 2010). Unlike the aforementioned platforms, it does not have an admin interface layout, but it speeds up the publishing procedure.

Since the presented software are not explicitly designed to be deployed for the CH sector, the assets are often presented completely out of context. Moreover, big cost, limits on size, geometric complexity and formats as well as unavailability of code modifications and extensions for customizing or adding new features respectively, are deterrent factors for heterogeneous and high-quality datasets. It must be noted that Sketchfab gives the potential for small institutions with minimal resources to disseminate their own 3D digitised content. In 2020, it launched the program "Sketchfab for Museums and Cultural Heritage" authoring business accounts for museum professionals and cultural institutions including the Minneapolis Institute of Art, Chile's Museo Nacional de Historia Natural and the University of Dundee Museum Collections in UK. The rest of the literature review emphasizes on open-source and commercial software that incorporates automatic or semi-automatic procedures for online 3D visualization.

2.2 Non-commercial CH management approaches

ATON is an open-source framework that lies upon Three.js library for creating cross-platform CH applications of high-fidelity (Fanini et al., 2021). It comes with state-of-the-art modules and components for WebXR displays, querying, semantic annotations, real-time collaborative sessions are more. It is actively deployed by research projects in archaeological 3D reconstructions (Fazio et al., 2022; Demetrescu et al., 2023), museum collections (Gonizzi Barsanti et al., 2018) and gamification (Turco et al., 2019). Resurrect3D, a customizable platform comprising a 3D rendering engine with a toolset for domain experts and a front-end infrastructure, has been proposed as an alternative of Sketchfab (Romphf et al., 2021). Based on Three.js library, it focuses on UI extensibility of its basic scene editing and interaction tools. Kompakkt also adheres to the design principles of Sketchfab with the difference that it enables collaboratively annotation of 3D models with multimedia (Kompakkt.de, 2018). Last but not least, Smithsonian Voyager emphasizes on digital storytelling through a set of customizable set of authoring and quality control tools, including adding annotations, guided tours and articles (Smithsonian Digitization, 2021).

After a comparative analysis of eight institutional and eleven commercial repositories, Champion and Rahaman, 2020 reveal common inadequacies such as specialized and integrated 3D model viewer with measurement tools, more comprehensive and useful metadata, ability to link to archival records as well as assignment of unique DOI or ID to the hosted models. In fact, the design of security features matters significantly for domain experts in order to ascertain data copyright and integrity. From a deployment perspective, data ownership is mainly involved in the control dimension of a robust database architecture (Asswad and Marx Gómez, 2021). Nataska Statham reviews five online platforms (Google Arts & Culture, CyArk, 3DHOP, Sketchfab and game engines), regarding their applicability to scientific 3D visualizations for documentation, restoration, preservation and multi-disciplinary collaboration (Statham, 2019). Among these, 3DHOP outstands in terms of performance, interactivity and extensibility. Being dedicated to CH content, it efficiently visualizes photogrammetric 3D meshes, characterized by their geometric complexity, huge size, metric precision and detailed texture mapping. Besides trackball, visibility, lighting and camera controls, advanced functions for animations, measurements, sectioning and annotations are supported. However, it lacks a management system for dynamically setting up and updating 3D scene entities as well as authoring services.

2.3 Comparison and contributions

The proposed framework advances web publishing of multimodal CH data, addressing some of the issues that previous open-source and institutional approaches have not deal with or offer combined. Firstly, it facilitates the creation of high-resolution 3D visualizations through a CMS of common functionalities as the ones of the proprietary software. To securely protect content's ownership encryption and hashing is applied to file names, credentials and proprietary data. In contrary to the cloud infrastructure of echo3D and ATON, files are stored in the local server of admin.The 3D viewer of the 5dMeteora platform inherits the scientific tools of 3DHOP including distance measurement, coordinates point picking and sectioning of the georeferenced models. An innovative feature for direct spatial and relational connection, is the dynamic animation of 3DHOP's hotspots when selecting their relative records in DataTables panel, and vice versa. Finally, a WebXR module is integrated for 3D assets inspection into a VR session mode or overlay to the real-world through two location-based AR experiences. However, the developed CMS does not currently support customization of the VR and AR experiences.

3. METHODOLOGY

3.1 System Architecture

The 5dMeteora framework lies upon open-source technologies of LAMP stack (Linux, Apache, MySQL, PHP), known for its stability, security and flexibility. The programming toolkit comprises standard web development languages such as HTML, CSS, and JavaScript along with pure PHP scripting and AJAX for handling server-side logic. The CMS is built on a RESTful API service that allows for a modular and flexible architecture. Its web interface provides a user-friendly and intuitive way for non-technical users to create, manage, publish, and edit content on the platform. It consists of the 3DHOP control panel and the media management tools (Figure 1).

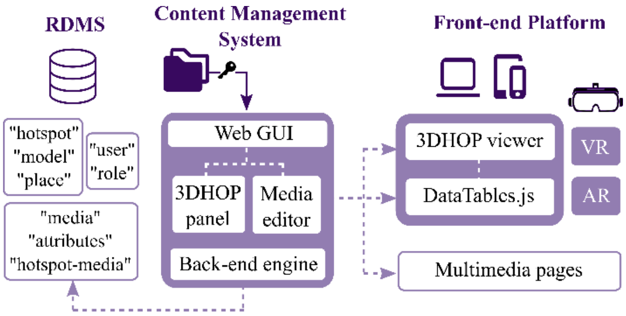

Figure 1. System architecture and main components

The fields of the MySQL Database Management System are dynamically populated with input values of the respective administrator of the CMS and, at the same time, these are retrieved with SQL and PHP queries from the front-end interface for immediate visualization and publishing. Three main entities group emerge; the “models” and “hotspots” of 3DHOP, the “users” and the “media”. 3D rendering and visualization of the high-resolution textured models is delegated to 3DHOP. Its 3D viewer and toolset are embedded in the graphical user interface (GUI) of the CMS for preview purposes and in the front-end platform. The JavaScript libraries jQuery and Bootstrap are also integrated for events handling and responsiveness respectively. Both the GUIs of the CMS and the platform have been designed to be mobile-friendly, with a responsive layout that adapts to different screen sizes. Finally, VR and AR applications lie on A-Frame web framework and Three.js library (A-Frame, 2021). Because they run independently from the rest of the platform, they can be easily updated, deployed, and scaled to meet demand for specific cases and 3D overlays.

3.2 Database Management System

The MySQL DMS creates the logical structure that conceptualizes the framework and develops it into a sophisticated entity-relationship model consisting of 40 tables. A permission mechanism assigns roles and rights to registered user through the “user” entity that handles the encrypted credentials and personal information per administrator (name, surname, mail, password) and the CMS’s usage rights per role. “Role” properties enable the determination of the permission levels per user (viewer tools, data retrieval). Beyond natural persons, the "role" entity is associated with the classification of data into thematic categories ("roles"), based on the specialty or field of interest of the platform's visitors. By default, visitors are characterized as "Tourists" and have access to multimedia of general content. Text, images and videos of specific scientific fields are available on the platform, as long as they select the corresponding thematic category. Serving multiple specialties with in-depth information on specific scientific fields is implicitly related to the “User” entity due to common logic of role retrieval (Figure 2). As each authorized user corresponds to a level of licensing, so does each multimedia file correspond to a thematic category.

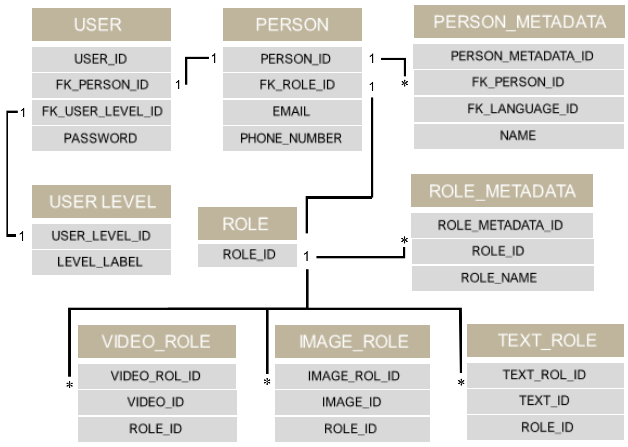

Figure 2. Part of the Entity Relational diagram with the tables and relations of the "user", "person" and "role" main entities

In terms of its spatial dimension, it defines the objects (“models” and “hotspots”) and settings of the 3DHOP’s scene graph. The main entity of “hotspots” is the foreign key that handles records associated with the points of interest of the 3D models, including their position, appearance, geometrical shape, short description, keywords and associations with “models”, “places” and “media”. Figure 3 illustrates part of the database Entity Relational diagram related to the structure of tables and the properties of correlations of the entity of “hotspots”. The organization of heterogeneous dataset often leads to data redundancy, slowing of queries performance and inconsistency, unless the principles of normalization are applied. Each media types, namely “text”, “image” and “video”, has separated tables for the “hotspot” and the “place” they refer to, the field of scientific interest and the “attributes” in the form of keywords. The data are further broken down into more logical units associated with the language and the individual correlation tables and associations. Since tables are populated by the input data of the current admin of the CMS, rules, size restrictions and specific data types in the value fields tables are preset to avoid duplicate entries and incorrect inputs.

3.3 Back-end interface

The CMS is developed with pure PHP, JavaScript, and Ajax, without any code dependencies. It dynamically manages and updates the content of the platform and has the following capabilities:

- Codeless 3DHOP: Mapping of 3DHOP’s scene graph entities and settings into a complete control panel with a viewport for dynamic preview.
- Extension of “hotspots” tool: Creation of annotations in the form of clickable geometries on the surface of 3D models to be used as a spatial reference for related multimedia. Hotspots can be grouped into spatial or thematic ontologies, called “Places”.
- Multimedia editor: Editing of text documents as well as the titles, captions or descriptions of image and video files, linked with related hotspots, keywords and scientific specialty.
- Error exception and handling for invalid admin inputs as well as warnings in case vulnerability and security issues arise.

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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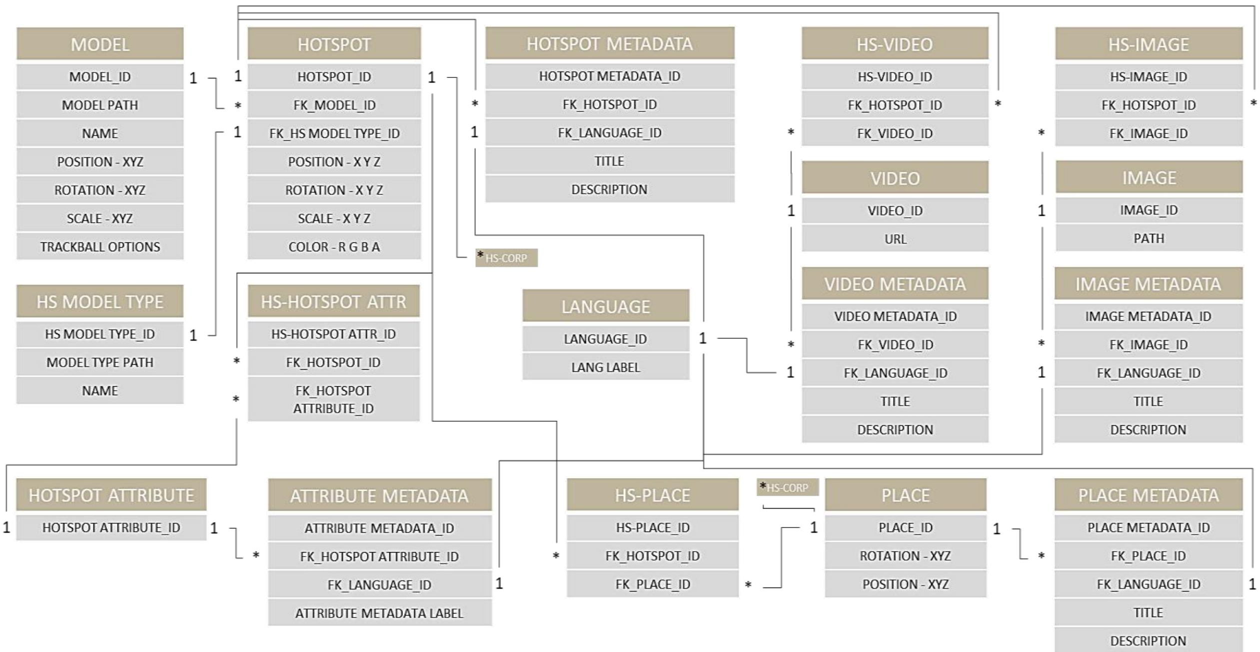

Figure 3. Part of the Entity Relational diagram with the tables and relations of the "hotspot" main entity

As already stated, encryptions specialized for 3D files, hashing for sensitive data as well as an error and exception handling mechanism have been developed for admins. If an exception is thrown within any operation, the database transaction will automatically roll back and the issue will be reported to the technical support team. If execution is successful, the transaction will automatically be committed. Figure 4 illustrates how the admins’ input assigns a “role” on a user, from available roles served by our database. The diagram is a part of the procedure being used to correlate the role to the user profile. It is worth to mention that there are 2 hashing values as attributes of the option element that are being created for the validation integrity between the scripts and the actual data stored into the database. Query logging is also, enabled to keep in memory a log of all queries that have been run for the current request. Furthermore, the association of each admin account with a level of rights or a degree of authorization is a secure method of distinguishing data (timestamp and name or person that uploaded/edited/deleted) and reducing the risks of unauthorized access.

3.4 Front-end interface

The front-end interface of the developed framework integrates a 3D viewer of various high-resolution meshes of CH, intuitive tools for spatial and contextual data correlation, multiple media galleries for storytelling and engaged XR experiences. Before uploading, the 3D files are converted into the multiresolution format of Nexus.js library that enables progressive and view-dependent loading. Regardless of the data size, loading is quick. The 3D model is divided into a series of increasingly detailed sub-models, with each sub-model representing the same geometry at a different level of detail. Its resolution is constantly being optimized, depending on the distance of the camera. In the main page of the platform, the interactive and customizable table system that organizes and filters the attributes for each hotspot of the 3D models is defined by DataTables.js, which is a plug-in for the jQuery Javascript library. It is linked directly with 3DHOP with asynchronous events and Ajax callbacks. It retrieves from the defined RDMS records, the information and metadata of each hotspot of the current visible 3D model of the scene. In server-side processing mode, the DataTables.js plugin sends a request to the server with the parameters of the current visualized model, search criteria, sorting, and pagination. The server then, processes the data and sends back only the required for its hotspots records of the database, reducing the amount of data that needs to be sent over the network and improving performance.
To retrieve the data required from searches of end-users in DataTables and the Multimedia pages, complex SQL queries actions have been developed. In case of Dropdown lists and free-text inputs, only the keyword entities that match the query terms and are relevant to the information requests are retrieved from the RDMS. The following search query relates the selected place with a hotspot for finding its metadata:

SQL Query: Place & hotspot relation to retrieve “Place_metadata” table

```
IF (COUNT $HOTSPOTSMK > 0) {
$query= "SELECT X.*, PLACE_METADATA.* FROM
PLACE_METADATA INNER JOIN IN (SELECT PLACE_ID, HS_ID
FROM PLACE_HS WHERE HS_ID IN (";
FOR ($i=0; $i<COUNT($HOTSPOTSMK);$i++){
$query.= intval(TRIM($HOTSPOTSMK [$i]))."," ;}
$query=SUBSTR($query,0,-1);
$query.=")) AS X ON X.PLACE_ID = PLACE_METADATA _ID";)
…
}SQL QUERY GENERATED FROM A PHP CONTAINER
```

3.5 VR and AR displays

The web XR app is built upon A-Frame that features both marker-based and location-based experiences as well as built-in tracking. The primitives of A-Frame map the relative objects of the Three.js scenegraph, including the loaders that support any 3D file format. In case of 5dMeteora platform, the 3D assets are converted into the glTF format, which is designed to be lightweight and efficient, making it ideal for use on the Web. After gaining access to the VR sensor data of the device through the WebXR API, camera is transformed, and the content of VR session is rendered. To achieve marker-less AR, an object gets and stores the device orientation controls, i.e. accelerometer and magnetic field sensors. Then, the 3D model and the device’s camera are positioned at the given location (long, lat) or, at a short distance (long, lat +0.03) in front of the camera. Regarding technical requirements, a WebXR compatible browser is needed

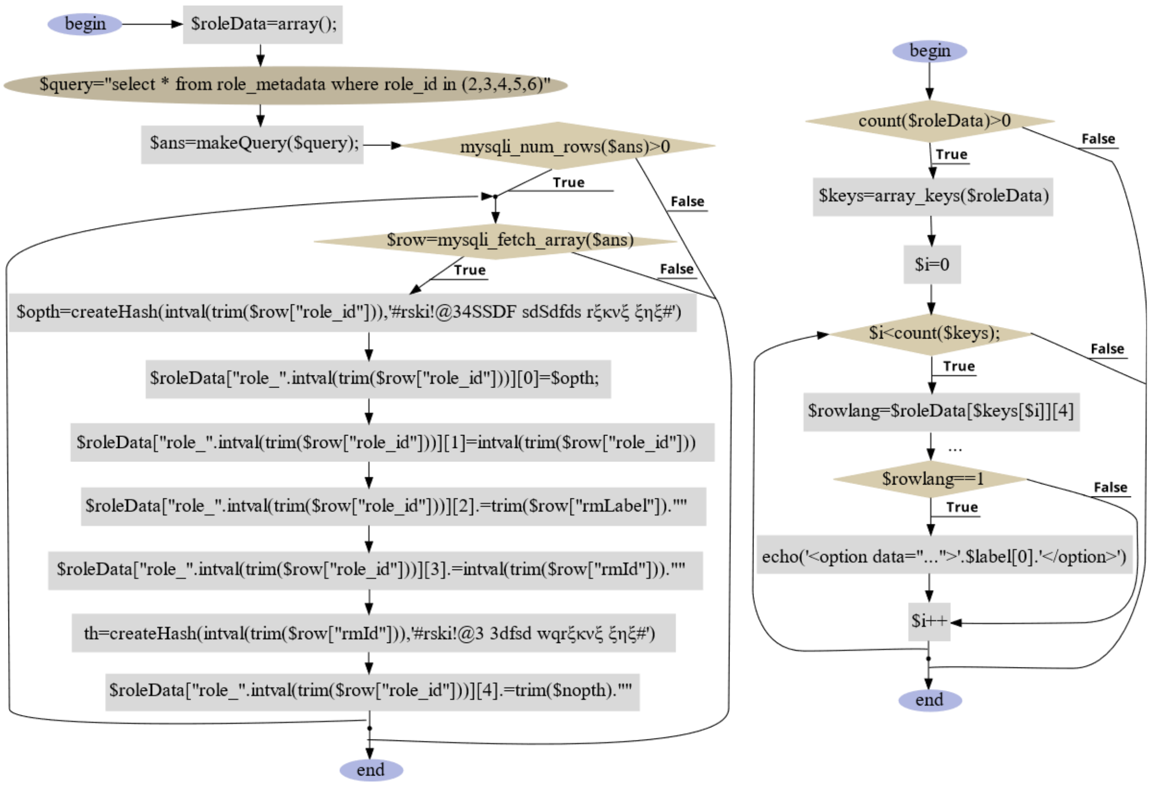

Figure 4. PHP code snippet that retrieves and updates the values of the correlated database tables ("role_metadata", "role" and "person"), after validation procedure

to experience the XR content on the existing devices of end-users, without the need for special gear or hardware. The VR session is also suitable for head-mounted displays (HMDs) such as Oculus Rift and HTC Vive Head-Mounted Display. For AR location-based tracking the device of end-users must have a GPS and an IMU (Inertial Measurement Unit) sensor. The cross-platform applications are supported by Android or iOS mobile software devices with technical features that meet the computational requirements of AR technology. Moreover, on a device with multiple cameras, the Chrome browser may have trouble locating the correct one. If it is found that the wrong camera is being activated, it is recommended to use Firefox.

4. 5DMETEORA FRAMEWORK

4.1 Content Management System

The CMS has an easy-to use and responsive Graphical User Interface (GUI) that comprises various 3D and 2D viewports for real-time data preview, along with buttons, lists and other types of inputs for mapping the described operations (Ioannidis et al., 2021). When the admin logins and uploads a 3D file, the list of the available models for editing is updated (Figure 5). By selecting the desired 3D model, the options that determine its position, rotation and size in the 3D scene are activated for modification and preview. Multiple models can be displayed concurrently by setting up their visibility.

The next 3DHOP’s scene manipulation involves hotspots and places. Hotspots are clickable 3D models or point clouds that can be placed anywhere on the 3D model. A title, a short description and a 3D file of the desired geometry are assigned to each new one (Figure 6). These geometries of any dimension or shape, can be rendered with a solid color with alpha channel and are associated with a single place, specific keywords as well as text, images and videos. When a hotspot is drawn, its preview is displayed in the embedded 3D viewer at the given position and

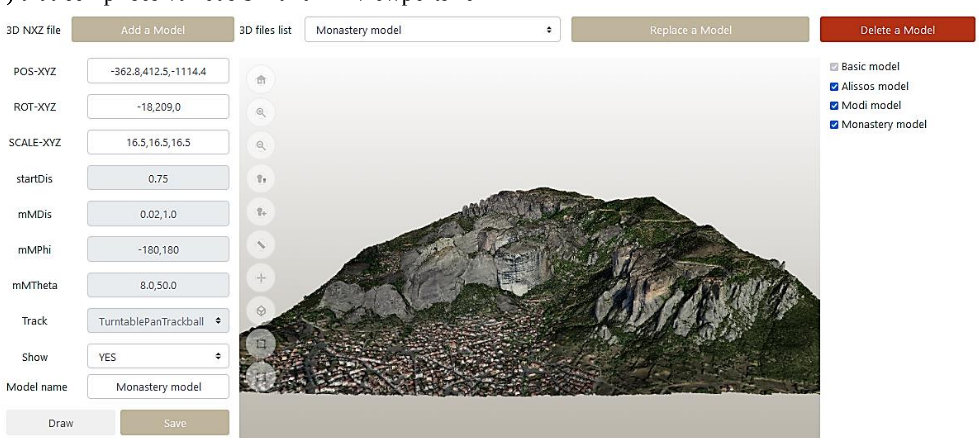

Figure 5. 3D Models settings and preview on the 3D map in the environment of the CMS

with the given rotation and scale. Thus, hotspots are a clear, concise and easily understood type of 3D cartographic symbolization. Places represent collections of hotspots that share the same geographic or thematic basis. Keywords, are assigned to each hotspot and place, specifying their thematic category or content.

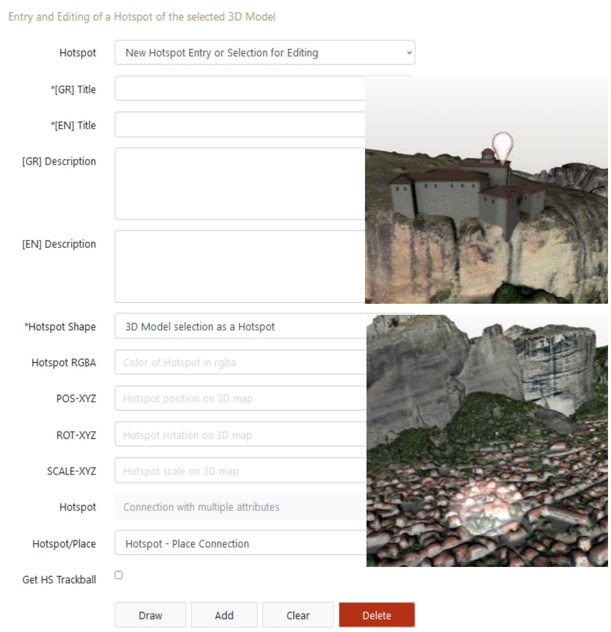

Figure 6. Hotspots settings and preview on the 3D map

The registration and management of the relative non-spatial data are delegated to the second tab of the CMS. Text documents, images of jpeg format and videos can be uploaded along with their title, description and alternative ("alt") text. They can be linked to one or more hotspots and to one or more of the following specialties or fields of interest: (i) theological – historical; (ii) geospatial; (iii) archaeological – architectural; and (iv) educational. 3D models and multimedia are accompanied by descriptive keywords that are displayed into dropdown lists with a free text search field. In addition to easiness of access, they contribute to efficient organization, digital identification and enhanced information interoperability.

4.2 Front-end Platform

The front-end comprises three pages: the Main Page, the Multimedia Pages with the documentation of each hotspot of the scene and, the XR application. The navigation from the Main Page to the Multimedia Page is accomplished via two different ways: (i) either within a pop-up side panel that is depicted on the right side of the 3D viewer after the user enables the hotspot tool and zooms in the target hotspot; or (ii) within the DataTables panel, located below the 3D viewer, providing an overview of the relational data that accompanies each hotspot (Figure 7).

4.2.1 3D viewer: The prominent feature of the Main Page is the 3D viewer of 3DHOP with its built-in toolset for direct interaction with the 3D scene. The viewer supports, in addition to standard navigation tools (i.e., panning, zooming in/out and rotating) scientific utilities for georeferenced models. The calculation of point-to-point distance and 3D coordinates directly on the surface of the mesh, allows for precise measurement of the dimensions of different parts of the asset and perception of its real-world size and scale. In addition, the hotspots tool activates

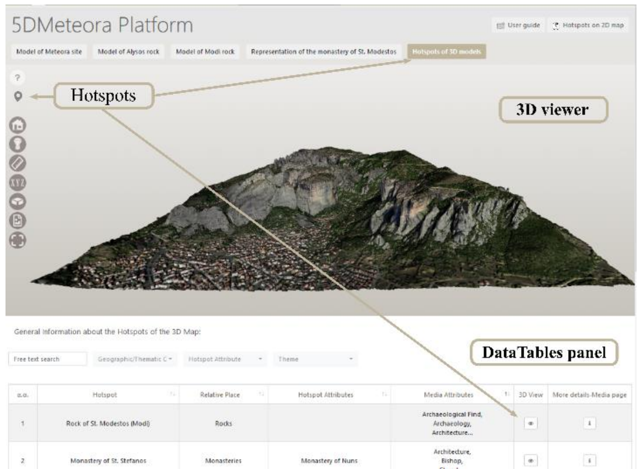

Figure 7. Main Page of the platform, showing the 3D viewer, the DataTables panel and three ways to activate the hotspots tool

the display of the geometries that highlight specific areas or points of interest. The selection of a geometry within the 3D scene leads to a smooth camera movement that frames the correspondent area and the highlighting of the relative row of the DataTables. Then, a side window appears with a short description of the visualized area or point of interest, a short description of the place it belongs to, its attributes as well as a preview of the multimedia material that clarifies it (Figure 8). If the end-users wish, they are redirected to the Multimedia Page for its full documentation.

4.2.2 DataTables.js panel: The 3D viewer is semantically enriched and clarified by the DataTables panel. It improves data accessibility and indexing in HTML tables, with sorting, paging and filtering capabilities. When visualization changes, the panel dynamically updates its content. In addition to free text fields, end-users can narrow down the data based on certain criteria. Dropdown lists enable filtering by the name of 3D models and hotspots, the name of places and the attributes or keywords of each spatial entity. Finally, the button of the second-to-last column performs a smooth animation in the 3D viewer to bring the view in the position of the hotspot of the selected row while the button of the last column redirects to the multimedia page of its complete multimedia documentation.

4.2.3 Multimedia pages: The multimedia pages provide complete documentation regarding multiple aspects of the areas or points of interest to which they refer. The text documents, the images and the video files of each page are organized into separate tabs grouped by data type. The collections are of both generic and specialized content, involving CH-related thematic and scientific fields. Specifically, a dropdown list contains the following categories: (i) theological – historical; (ii) geospatial; (iii) archaeological – architectural; and (iv) educational. Each one gives access to multimedia files that derive of scientific research in the respective field. Besides thematic and scientific categorization, searching and filtering, either through a dropdown list with all the keywords or by entering keywords in a free text field, are integrated. The personalized knowledge access provides a holistic understanding of the significance, context, and value of the CH asset. At the same time, the interactive search and retrieve tools engage non-experts users and convey information in a clear and comprehensive manner.

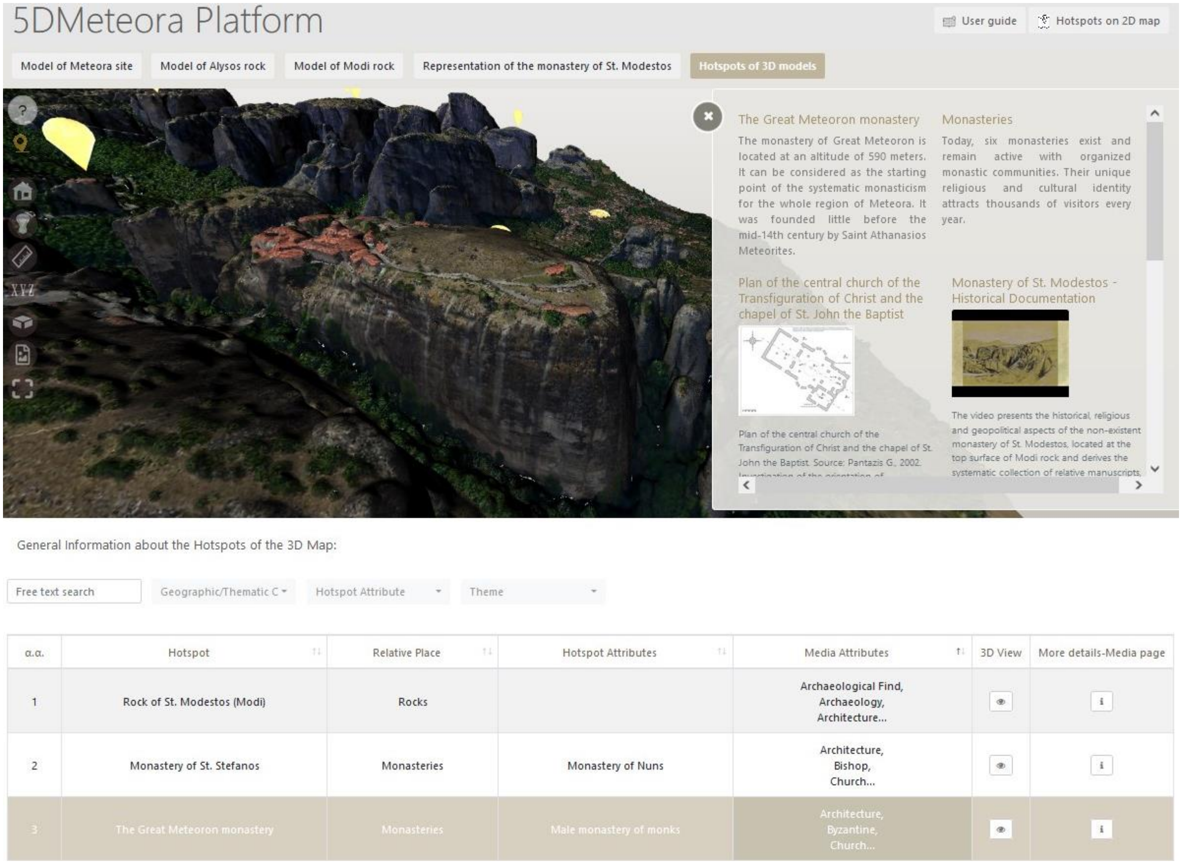

Figure 6. Pop-up that clarifies a user-selected point of interest and highlighting of the relative row of DataTables panel

4.3 Web XR applications

VR immerse the end-users into an interactive 3D environment while AR provides a true sense of scale, depth and spatial awareness. They contribute to the creation of a more memorable and impactful experience for end-users who are interested in learning about the visualized CH asset. Two applications have been developed serving two different use cases depending on the physical location of the end-users. The first AR application overlays 3D assets onto their real-world position and requires their physical presence at the specific geographical location. It enhances the CH site or asset with non-existent, supplementary or non-visible information. The 3D model will be overlaid at the given pose and scaled to its real-world proportions (Figure 9).

Figure 9. Two use cases of the location-based AR application

The end-users have the potential to interact with it by zooming in, for a more detailed and effective investigation. The second application is helpful in case the end-users’ location is not relevant to the information or experience being provided or in situations where the actual physical context is not desirable (e.g., dangerous or inaccessible in the real-world). At initialization, the 3D asset is displayed in VR switching easily and quick in superimposition through the camera, in the current location. Into VR mode, the asset can be explored in its entirety through a viewpoint of first-person perspective (1PP) (Figure 10a). In AR mode, it overlays in a relative position and by a certain pose in the surrounding space in which the end-users are located, without the requirement of scanning any visual marker (Figure 10b).

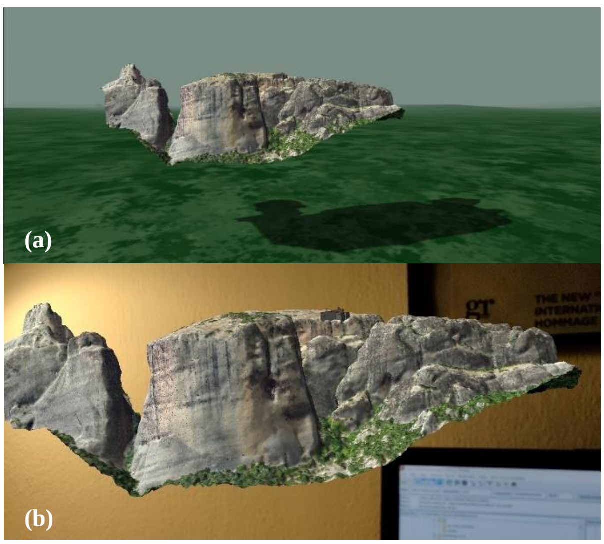

Figure 10. Second XR application of platform: (a) VR viewport and, (b) Relative location-based AR.

5. CONCLUSIONS

The 5dMeteora framework enables non-expert administrators to store, enrich and, finally, visualize their data to the 3D viewer and the multimedia pages of the front-end platform. It offers CH experts the potential to configure interactive tools that connect spatial and non-spatial data and to develop XR experiences with 3D digital content. Its VR/AR features assist a broader public to perceive and engage into CH content. The CMS of 5dMeteora framework has increased efficiency in assigning roles to users and media as well as previewing and final uploading of 3D models along with their associated media directly to 3DHOP. It automates the creation of hotspots and organizes the related information based on the target group's scope, scientific specialty or field of interest. Thus, data of heterogeneous origin, format and field of interest are easily handled by non-expert administrators and disseminated to a variety of target audiences. It can address the needs of various stakeholders involved in CH management that undertake the role of the administrator like government agencies, CH foundations and associations, Museums, libraries, universities and research institutions, scientists and professionals of the field and private companies and consultants, including architectural firms, engineering companies, and conservation specialists. To our knowledge, at the present there is no ready-to-use CMS for the 3DHOP framework. Further work includes the support of additional data formats of media files and the optimization of spatial tracking accuracy as well as occlusion handling of AR applications. The potential of CMS extension in order to customize, preview and publish the XR sessions is in the process of investigation.

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REFERENCES

A-Frame., 2021. A web framework for building 3D/AR/VR experiences. https://aframe.io/ (5 February 2023)

Asswad, J., Marx Gómez, J., 2021. Data Ownership: A Survey. *Information.*, 12, 465.

Champion, E., Rahaman, H., 2020. Survey of 3D digital heritage repositories and platforms. *Virtual archaeol. rev*. 11, 1.

Demetrescu, E., Fanini, B., Cocca, E., 2023. An Online Dissemination Workflow for the Scientific Process in CH through Semantic 3D: EMtools and EMviq Open Source Tools. *Heritage* 6, 1264–1276.

echo3D Inc., 2023. 3D Asset Management for Developers. https://www.echo3d.com/ (5 February 2023)

Fanini, B., Ferdani, D., Demetrescu, E., Berto, S., d'Annibale, E., 2021. ATON: An Open-Source Framework for Creating Immersive, Collaborative and Liquid Web-Apps for Cultural Heritage. *Applied Sciences* 11, 11062.

Fazio, L., Lo Brutto, M., Gonizzi Barsanti, S., Malatesta, S.G., 2022. The Virtual Reconstruction of the Aesculapius and Hygeia Statues from the Sanctuary of Isis in Lilybaeum: Methods and Tools for Ancient Sculptures' Enhancement. *Applied Sciences* 12, 3569.

Gonizzi Barsanti, S., Malatesta, S.G., Lella, F., Fanini, B., Sala, F., Dodero, E., Petacco, L., 2018. THE WINCKELMANN300 PROJECT: DISSEMINATION OF CULTURE WITH VIRTUAL REALITY AT THE CAPITOLINE MUSEUM IN ROME. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*. XLII–2, 371–378.

Ioannidis, C., Tallis, I., Pastos, I., Boutsi, A.-M., Verykokou, S., Soile, S., Tokmakidis, P., Tokmakidis, K., 2021. A WEB-BASED PLATFORM FOR MANAGEMENT AND VISUALIZATION OF GEOMETRIC DOCUMENTATION PRODUCTS OF CULTURAL HERITAGE SITES. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci*. V-2–2021, 113–120.

Kompakkt, Kompakkt.de, 2018. https://kompakkt.de/home (5 February 2023).

Statham, N., 2019. Scientific rigour of online platforms for 3D visualization of heritage. *Virtual Archaeology Review*, 10(20), 1–16.

p3d.in, Brand3D LLC, 2010-2023. https://p3d.in/ (5 February 2023).

Potenziani, M., Callieri, M., Dellepiane, M., Corsini, M.,Ponchio, F., & Scopigno, R., 2015. 3DHOP: 3D Heritage Online Presenter. *Computers & Graphics.*, 52, 129–141.

Romphf, J., Neuman-Donihue, E., Heyworth, G., Zhu, Y., 2021. Resurrect3D: An Open and Customizable Platform for Visualizing and Analyzing Cultural Heritage Artifacts, Proceedings of the 26th International Conference on 3D Web Technology, *ACM*, Pisa Italy, pp. 1–7.

Ponchio, F., Dellepiane, M., 2015. Fast decompression for web-based view-dependent 3D rendering, *Proceedings of the 20th International Conference on 3D Web Technology - Web3D '15*., ACM Press, 199–207.

Peinado-Santana, S., Hernández-Lamas, P., Bernabéu-Larena, J., Cabau-Anchuelo, B., Martín-Caro, J.A., 2021. Public Works Heritage 3D Model Digitisation, Optimisation and Dissemination with Free and Open-Source Software and Platforms and Low-Cost Tools. *Sustainability* 13, 13020.

Sketchfab. 2018. Sketchfab for Cultural Heritage: The Largest Platform to Publish and find 3D, AR and Virtual Reality Cultural Content Online. https://sketchfab.com/museums (5 February 2023).

Smithsonian., 2022. Voyager Overview. https://smithsonian.github.io/dpo-voyager/explorer/overview/ (5 February 2023).

Turco, M.L., Piumatti, P., Calvano, M., Giovannini, E.C., Mafrici, N., Tomalini, A., Fanini, B., 2019. Interactive Digital Environments for Cultural Heritage and Museums. Building a digital ecosystem to display hidden collections. *Disegnarecon* 12, 7-1.

Vectary Inc., 2023. https://www.vectary.com/ (5 February 2023).