DIGITAL HERITAGE (2025)
S. Campana, D. Ferdani, H. Graf, G. Guidi, Z. Hegarty, S. Pescarin, and F. Remondino (Editors)

# Shaping a Web3D framework for different scientific communities: ATON as a service in H2IOSC

B. Fanini† [1] G. Gosti [1], C.F. Amadei[1], S. Menconero[1],

[1] National Research Council, Institute of Heritage Science, Italy

**Abstract**

*H2IOSC is a pioneering project to create a federated and inclusive cluster of research infrastructures targeting researchers from various disciplines, involved in the humanities and cultural heritage sectors with operating nodes across Italy. Within the project, several tools and services are being redesigned and/or refactored to improve accessibility for targeted communities. Among the solutions offered by E-RIHS infrastructure, the ATON framework - exposed as a service in the H2IOSC federation - was heavily refactored to accommodate the increasing demand of diverse scientific communities and their feedback for the last 10 years. With several H2IOSC pilots depending on ATON, as well as multiple national and international active projects, we discuss how the framework and its architecture evolved to quickly adapt and embrace a variety of scenarios, with a dynamic extensibility model. We report the beneficial impact H2IOSC trans-national and national (TNA/NA) calls had on driving such refactoring, based on concrete scenarios and international/national use cases. Alongside improved scalability, interoperability and mechanisms for integration with external platforms and other ecosystems, we describe plug&play models for vertical and horizontal extensibility. We illustrate the improved plug&play architecture for Web3D/WebXR applications, offering an accelerator to easily develop and deploy vertical applications, embracing the progressive web-application (PWA) model. We report and discuss results obtained in the last few years, including a few ongoing H2IOSC pilots and other projects adopting such models on their own instances of the framework. We also present and discuss the new "flares" architecture, providing a new way to extend horizontally the functionalities of the framework, able to dynamically equip web applications or extend ATON micro-service architecture. We describe a few notable cases and how flares hugely impact the overall extensibility of the framework (both client and server side). We finally present a discussion with lessons learned and how this new architecture accelerates infrastructural deployment while offering new ways to dynamically shape the operating perimeter of the service for different scientific communities.*

**CCS Concepts**

• ***Software and its engineering*** → *Designing software;* • ***Information systems*** → ***Web services;*** • ***Human-centered computing*** → ***Visualization systems and tools; Web-based interaction;*** *Open source software;*

## 1. Introduction

H2IOSC (https://www.h2iosc.cnr.it/) is a pioneering project to create a federated and inclusive cluster of research infrastructures in the ESFRI domain of Social Sciences and Humanities (formerly Social and Cultural Innovation) with operating nodes across Italy. The four involved Research Infrastructures (RIs) are CLARIN (https://www.clarin-it.it/), DARIAH (http://dariah.cnr.it/), E-RIHS (https://www.e-rihs.it/) and OPERAS (https://operas-it.org/). The project has been funded by the European Union Next Generation EU and the Italian Ministry of University and Research as part of the National Recovery and Resilience Plan (NRRP), with a partnership of 12 research institutes from the National Research Council of Italy (CNR) and 18 operating units from the CNR's Department of Social Science and Humanities, Cultural Heritage (CNR DSU).

The Work Package 6 (WP6), in particular, is devoted to activities related to servification, virtualization, and remotization of existing tools maintained from the involved RIs in H2IOSC. The main goal of such activities is to improve (or enable) access to rich tools and services provided by the RIs, targeting a wide range of scientific communities.

The H2IOSC federation also offers free-of-charge Transnational access (TNA) and National access (NA) to advanced digital services and tools from the four RIs, to conduct innovative and computationally intensive research on complex digital data and objects (https://www.h2iosc.cnr.it/tna-na-calls/). The ser-

† bruno.fanini@cnr.it



DOI: 10.2312/dh.20253055

vices exposed in such calls are advanced digital services and tools from the Italian nodes of the four research infrastructures, either refactored in WP6 or implemented during the project. These may also include cross-domain services and proof-of-concept sets of resources developed as H2IOSC community pilots (WP7).

This article illustrates strategies and solutions adopted for the refactoring of ATON as a service in H2IOSC federation, to accommodate the increasing demand of diverse scientific communities and their feedback collected during the last decade. ATON's involvement in cross-domain projects (archaeology, architecture, geophysics, diagnostic, etc...) brought out different needs from each of the scientific communities involved.

This work is structured as follows:

- Section 2 illustrates related work and a few existing approaches on servification routes, deployment of Web3D services, standards, and best practices for service integration and communication.
- Section 3 illustrates challenges and opportunities emerged during the past 10 years related to the ATON framework, through national and international projects - and how these shaped its evolution and current refactoring processes in H2IOSC.
- Section 4 describes architectural refactoring solutions adopted in H2IOSC for ATON as a service (also through the beneficial impact of H2IOSC TNA/NA calls) to improve it as an extensible solution that can be easily shaped for different scientific communities and integrated in a federation.

## 2. Related Work

Service-Oriented Architectures emerged as an architectural model improving the service delivery performance of existing traditional systems to scientific communities, while still retaining their key elements [NIG*20]. Such architectural concepts promote loose coupling, reusability, interoperability, agility and efficiency, with a focus on breaking each process into smaller blocks of tasks and functions such as services. Within such a context, there are mostly two architectural approaches: monolithic and *mirco-services*. In opposition to the monolithic approach, the emerging micro-services pattern [STF23] has the goal of decomposing a specific process into small, self-contained and loosely coupled services. Although migrating existing logic from a monolithic to a micro-services architecture requires effort, it may offer several advantages in terms of scalability, fault isolation, reusability and data security - especially when targeting deployment on RIs.

In order to provide access to functionalities and resources offered by a specific web service, the REST (REpresentational State Transfer) architecture is nowadays widely adopted, with well-known advantages in terms of integration and interoperability [EACM22, LCZL16]. REST emerged as the standard protocol: different surveys and recent literature show that various companies or service providers have migrated in recent years from XML-supported SOAP (Simple Object Access Protocol) to REST [KJT*23].

To discover capabilities of a given service without access to source code, documentation, or through network traffic inspection, the *OpenAPI* (`https://www.openapis.org/`) specification (OAS) offers a standard, language-agnostic interface to HTTP APIs [CCVC21, PR22]. An OpenAPI definition (or OpenAPI document - OAD for short) can be used by documentation generation tools to display the API, code generation tools to generate servers and clients in various programming languages, testing tools, and many other use cases.

Within the development and deployment of services, Node.js [SS17] (`https://nodejs.org/`) offers a cross-platform, open-source back-end javascript runtime environment that allows the creation of scalable network applications. It is one of the largest open-source ecosystems, widely supported and used in several scenarios. Such an environment allows to create quite comfortably micro-services architectures, with rapid definition of routes to design REST APIs.

*Progressive web apps* (PWAs) is a set of standards advocated by the Google Web Fundamentals group. It is an approach to develop mobile apps that can be run on different mobile platforms (e.g., Apple iOS and Google Android) and take advantage of the new possibilities and APIs provided by new web technologies [ADT*19, CFST*22]. PWAs are web-applications with additional functionalities such as offline availability, background synchronisation and the possibility to install the PWA on the user home screen (mobile devices). They have introduced a new path to mobile development, making web-apps look, feel and act similar to native and hybrid apps.

Web3D technologies as well are exhibiting massive advancements in recent years in terms of standardization, integration and performance, for access and delivery of 3D models via common web browsers. This is allowing different scientific communities to investigate how 3D cultural heritage is presented online, and to discuss needs and requirements that future infrastructures must meet, in a post-SketchFab era [PGSS25]. In such a scenario, open-source solutions, employed to build and deploy accessible Web3D services, must take into account complex relationships with different communities, content creators, CH experts and the general public [PCS18]. 3D technologies in Humanities research and education targeting infrastructures indeed should also consider scenarios, UX design, legislation, infrastructures, and teaching programs [Mue22].

## 3. A decade of challenges and opportunities

### 3.1. ATON framework story in brief

ATON project was initially developed as a basic Web3D viewer (only client components) based on the open-source OSG.js library (`https://cedricpinson.github.io/osgjs-website/`) in 2015. Specifically, it was designed for the visualization of large 3D landscapes online [FPP19] under the ARIADNE European project [MSR*17]. It was integrated into a cloud-based architecture, alongside services to process multi-resolution datasets from user-provided input data.

The OSG.js library was a WebGL framework strongly based on the OpenSceneGraph concepts [WQ10] (where the team already had experience) with an API kept as similar as possible to the desktop project. The OSG.js library was mainly maintained by developers of the current SketchFab proprietary platform (https://sketchfab.com/).

Following the results of the ARIADNE project, ATON started an extensive refactoring in 2016 carried out to embrace more use cases related to interactive 3D on the web, mainly among the archaeological communities. Following the advancements of OSG.js library, the viewer was completely redesigned, with improved support to mobile devices, first support to physically-based materials (PBR) and first experimentations with WebVR API (2016), making the open-source project one of the first among the CH communities to provide immersive VR on the web. This marks the 2.0 version of the growing project, enabling its integration in a project at the Capitoline Museum [GBML*18] for augmentation, dissemination and interactive VR presentation of museum 3D collections with responsive, cross-device 3D visualization. Similar projects related to the interactive presentation of 3D collections integrated the project [ABC*16] for virtual museums.

The fertile ground offered by ATON, led also to different experimentations including Web3D tools to inspect captured sessions in virtual environments [FC20], the research of compact data models for panoramic VR [Fd16], interactive discovery techniques for CH like "temporal lensing" [FFD21a], and gamification models (like 3D puzzles) as Web3D applications aimed at re-contextualization [TPC*19].

In 2020, the OSG.js library (MIT license) was discontinued, and its repository archived. The ATON project was highly impacted, with several underlying features starting to collapse or not working properly: it was destined to certain death. In 2020 ATON 2.0 was thus abandoned: the experience gained and lessons learned along the road were inherited by a completely new version of ATON (3.0) developed from scratch, based on a more robust library (THREE.js) with a massive community behind. This moment was particularly crucial as it allowed to rethink and redesign the framework from the ground up, also in terms of architecture, web technologies and interoperability. New ecosystems and robust standards (like glTF format [RAPC14]) were embraced, with ease of integration, reuse and long term storage in mind. A new, modular architecture was introduced beyond mere client components, with a micro-services model based on Node.js ecosystem (see section 2) - offering a flexible and ready-to-use solution for museums, researchers and professionals.

Through the feedback, projects and experience gained so far, the overall architecture of ATON [FFD*21b] was re-designed around:

- Advanced and *liquid* (cross-device) 3D presentation features
- Modular micro-services, with a design suitable for clustering modes (scalability)
- A plug&play architecture for web-apps, also adopting the PWA model
- Multi-user management
- Persistent identifiers for 3D models, scenes and web-apps
- REST API

A built-in advanced viewer was developed ("*Hathor*") offering a ready-to-use and customizable front-end solution with rich functionalities, without any intervention required on code. Alongside Hathor, the flexible plug&play architecture for web-apps guarantees the development and deployment of custom vertical solutions. This necessity emerged directly from the various communities using ATON, as well as requirements from several national/international projects where the framework was involved during these 10 years.

### 3.2. Community Building

The community around ATON grew rapidly among different scientific domains in the past 10 years. The main pillars for community building revolved around:

- a dedicated *website*: including how-tos and tutorials, useful links, architecture and formats overview, publications and projects.
- an *open group* on Telegram: an international space for support, help on specific use cases and discussion of upcoming features, alongside collecting various feedback directly from the community.
- a series of *youtube* videos, for dissemination or showcase of new features, projects adopting ATON, etc.
- *courses* and involvement of schools from multiple grade levels, presenting the framework through hands-on sessions, while also carrying out usability tests for new functionalities.
- organisation of *online events* for the valorisation and fruition of 3D scenes using synchronous collaboration (e.g. guided tours of reconstructed archaeological sites together with remote participants).
- participation in dissemination events aimed at both specialists and the general public.
- through H2IOSC project via access to the main instance of the framework, deployed through *transnational (TNA) and national (NA)* access calls to individuals or teams from academia, business, industry and public services.
- dedicated *documentation for developers* with detailed API, as well as involvement of THREE.js communities and similar projects.

### 3.3. A Matter of Diversity

The open nature of ATON framework, its modularity, the embracement of interoperable standards and modern web technologies allowed its employment in a much wider and unexpected range of use cases, especially in the past few years. Alongside national/international projects targeting different scientific communities and domains, a growing amount of experimental features and novel interaction models were developed to inspect complex or multi-dimensional CH datasets. This was also largely facilitated also by the massive and responsive community around THREE.js, as well as ongoing lab research.

Such diversity led to massive improvements in terms of functionalities for the main ATON front-end (Hathor) thus serving as a modular and all-in-one solution for interactive presentation. Among the various features and corresponding user interface directly offered by Hathor, we cite synchronous collaboration (among remote participants) in the same virtual space; advanced lighting setups, interactive 3D annotation tools and WYSIWYG editor for

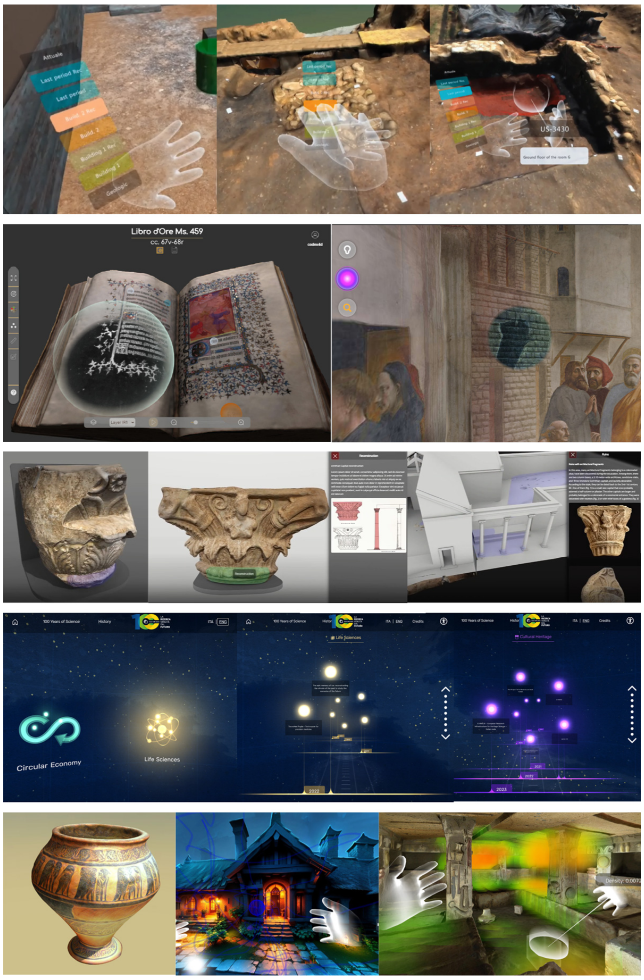


**Figure 1:** *Samples from the variety of vertical applications created with ATON 3.0. First row: multi-dimensional WebXR inspection tools; Second row: diagnostic field applications; Third row: 3D collections and Virtual Museums; Fourth row: online exhibit "100 Year of Science" for National Research Council (CNR); Fifth row: generative 3D content and Visual/Immersive Analytics via WebXR.*

associated content (HTML5), measurements tools, viewpoint management, and much more.

The diversity range of use cases and domains in the last 5 years started to negatively impact Hathor, which was growing out of proportions in terms of user interface (UI) complexity and functionalities demands. Feedback and requirements coming directly from the community on the other hand, were also shaping new features (or consolidating existing ones) under the hood, directly inside the ATON core.

The web-app architecture and its plug&play model started to grow more and more, with different multi-disciplinary projects, creating vertical solutions (see Figure 1). We list a few examples in the past 5 years:

- Advanced semantic tools to inspect multi-dimensional datasets [DFC23, FDB*22] based on specific formalisms [Dem15] and GraphDBs.
- WebXR applied games for Heritage and environmental education targeting distance-learning [LFBB20].
- Web3D/WebXR applications targeting diagnostic field, adopting new discovery models for lost or invisible information [FRF*23, PCFB23].
- Web3D applications for the virtual exploration of different archaeological sites in large-scale projects involving research institutions, universities and academies, creative industries and experts in the CH field [MFP24].
- Web3D for geophysics domain, providing interactive exploration of GPR acquisition volumetric data.
- Online 3D collections and virtual museums, like "Vani Virtual Experience" (`https://www.vanivirtualexperience.com/interactive-experience`).
- Online Web3D applications for multi-sensory journey into National Research Council (CNR) scientific research, for the exhibit "100 Years of Science" (`https://explore100.cnr.it/a/100/`).
- WebXR applications to explore and interact with generative AI content; Visual/Immersive analytics tools to measure and inspect users' sessions [FG24].
- Web3D applications targeting architecture field, like the unrealized architectures of Michelangelo (`https://metamic.it/`), integrating immersiveness, collaboration, interactivity and FAIR principles.

The huge diversity among these projects - including their logic, their design, development and deployment as web-apps under the ATON ecosystem - highlighted a few needs and considerations. Among the general considerations, we report specifically that:

- a few core features, largely used by all involved projects and often discussed among the community, were consolidated (e.g: cross-device presentation, XR modes, navigation system, semantic annotation and other tools).
- the use of "*Hathor*" (built-in front-end) was consolidated for all those projects that did not require particular customization (rely on common functionalities offered by ATON), and/or had short timelines.
- the integration of other open-source libraries, like NASA AMMOS 3D Tiles Renderer (`https://github.com/NASA-AMMOS/3DTilesRendererJS`) to support Cesium 3D Tiles format, led to cross-fertilization in 2021 between the projects - a solid proof of open-source beneficial impact.

Among the emerged needs, we include:

- need to further improve and speed-up the web-app development/deployment model targeting vertical solutions, also introducing reusable components, templates and building blocks
- need to externalize further functionalities, including a few shared across multiple apps, thus avoiding to pollute ATON core
- need for mechanisms to extend main REST API with custom logic or routing to custom micro-services
- need for scalable mechanisms to potentially support other compatible - but not yet standardized - Web3D formats (e.g. 3D Gaussian Splats [KKLD23])

## 4. The new ATON architecture in H2IOSC

The servification work package in H2IOSC project provided a great opportunity to further evolve ATON *"as a service"*, following feedback and challenges highlighted in the previous section (3). More specifically, investigating and developing strategies to maximize its extensibility and improve access to the diverse communities around the framework. In order to perform these evolutionary steps, the refactoring processes involved:

- a complete redesign of the REST API (communication with other services of the federation).
- an improved plug&play architecture for web-apps (vertical extensibility).
- design and implementation of "*flares*" model (horizontal extensibility).

Furthermore, a complete redesign of ATON user interface (UI) is being carried out in H2IOSC resulting from community feedback during the past 5 years. Although this is a large topic that will be discussed in a separate paper.

The trans-national access (TNA) and national access (NA) calls offered by the H2IOSC federation are also playing a crucial role to better direction these actions. Different research teams (often involving different disciplines/domains) are in fact applying to access and use ATON as a service: the variety of their project proposals is providing valuable feedback for architectural refactoring and redesign processes.

### 4.1. Interfacing with the world - The new REST API

The first step was focused on the alignment of ATON as a service with H2IOSC federation needs, and more in general, providing an improved interface for external services, platforms or systems to access ATON resources and functionalities. In H2IOSC, the OpenAPI specification (see section 2) is being adopted, aligned between all services deployed by the four RIs part of the federation. The OpenAPI descriptor offers: A) A standardized way for others to discover ATON capabilities through a format readable by both machines and humans, in the form of OpenAPI document (OAD); B) Automated generation of up to date REST API documentation for developers; C) Early API testing, even before the actual API provider code is written.

The existing REST API of ATON was completely re-designed (v2) following best practices and existing guidelines (see 2 section) around specific resources consolidated in the past 10 years (see section 3):

- Collection items: 3D models (point-clouds or meshes), panoramic content or multimedia files
- 3D scenes: arrangements of collection items (or public resources offered by external services)
- Users
- Apps (described in detail in section 4.2)
- Flares (described in detail in section 4.3)

For each of the above, a persistent identifier allows retrieval or manipulation via REST API. Refactoring actions in H2IOSC were also shaped by the ongoing development of a few E-RIHS pilots requiring ATON. Previous REST API (v1) will be still operational for a time, guaranteeing backwards compatibility.

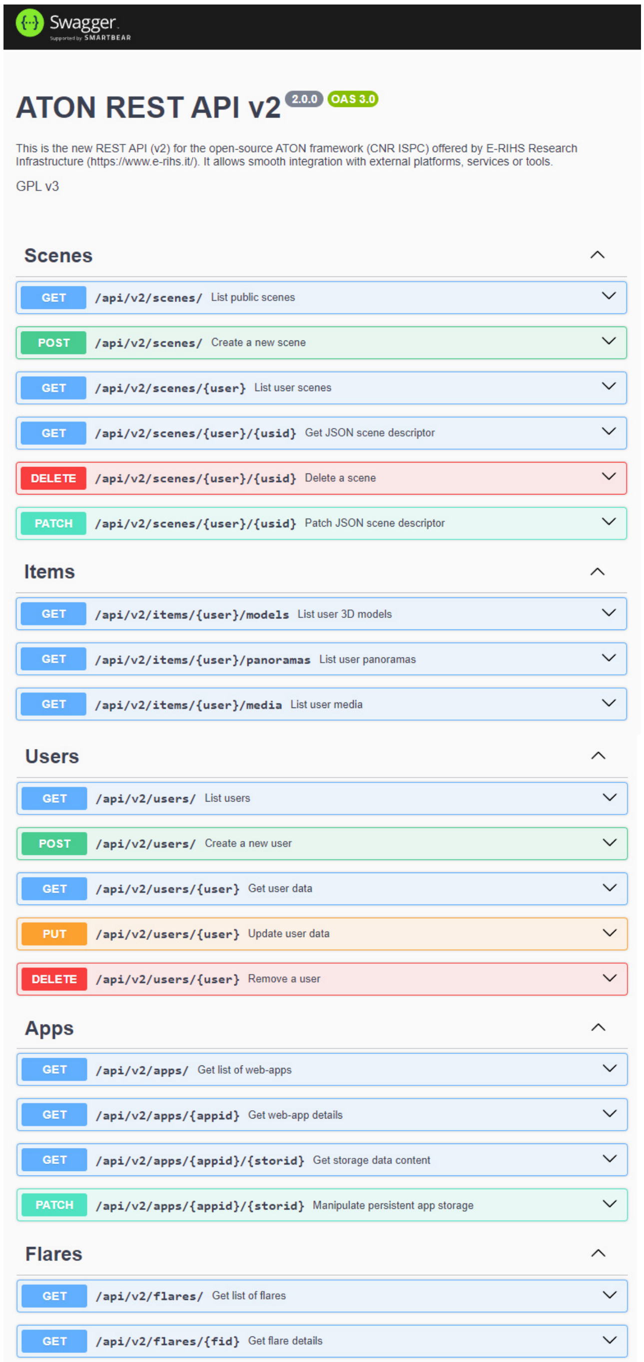


**Figure 2:** *The new REST API for ATON designed in H2IOSC, with documentation automatically generated by OpenAPI descriptor.*

Special attention was paid to HTTP verbs and related best practices: they play in fact a fundamental role in determining how clients interact with resources. In particular considering the specific


Proceedings published by Eurographics - The European Association for Computer Graphics.

action to be performed on the resource: *retrieval* (GET); *creation* (POST); *update* (PUT/PATCH); *deletion* (DELETE). Furthermore, *idempotency* and *safety* properties of verbs were considered during the redesign of the new REST API:

- An operation is idempotent if performing it multiple times has the same effect as performing it once. GET is inherently idempotent, while PUT and DELETE can be idempotent if designed properly. POST, on the other hand, is not idempotent, as creating a new resource each time will have a different effect.
- A safe operation is one that does not modify the state of the server. GET is considered a safe operation, as it does not change anything on the server node. However, POST, PUT, and DELETE are not safe, as they can alter server state

### 4.2. Vertical Extensibility - Apps

The high demand for the development and deployment of custom solutions was already highlighted in section 3, especially in the last 5 years. Furthermore, H2IOSC pilots involving ATON also led to focus several activities on further improving vertical extensibility. The existing plug&play model already proved to be suitable for a wide range of projects and scientific communities, thus the action in this case was to simply improve the existing model.


**Figure 3:** *The established plug&play architecture for web-apps, alongside the built-in front-end ("Hathor").*

The actions targeted several improvements to client building blocks, to speed-up the crafting of a given app, facilitating integration of service workers (PWA), base configurations, UI templates, and routines frequently required by ATON web-apps during the past 10 years. This refactoring led to a series of improvements, resulting in a concrete accelerator to develop and deploy custom apps more quickly (for instance, a few H2IOSC pilots and other Web3D tools).

Such an accelerator is suitable for vertical applications (e.g. specific domain) that require a custom logic or user interface, for example a Web3D tool targeting diagnostic, an architectural WebXR tool or any PWA accessing ATON functionalities (see Figure 3). We also highlight that such improvements enabled new possibilities for quick prototypes (for instance, to quickly test a solution or interaction model) reducing time required to full deployment.

With the exception of "Hathor" built-in front-end, apps are uniquely identified within a given instance of the framework $\mathbb{A}_i$ (for example publicly accessible through a server node of E-RIHS infrastructure) with the form:

$$\mathbb{A}_i/a/ < app_{id} >$$

For example https://sampledomain/a/sampleapp. This also allows flexibility in terms of deployment and distribution of vertical apps (e.g. a centralized instance $\mathbb{A}$ hosting multiple apps, or more instances ($\mathbb{A}_1, \mathbb{A}_2, ...\mathbb{A}_n$) handling separate apps, depending on H2IOSC datacenters configurations, availability and foreseen request volumes.

Under the TNA/NA calls of H2IOSC specifically, ATON as a service offers the possibility to host (plug&play) custom web-applications, on the condition that the app is being developed by the selected applicants.

### 4.3. Horizontal Extensibility - Flares

"*Flares*" for ATON were designed and implemented under the H2IOSC project targeting horizontal extensibility (see Figure 4). Such a model was introduced as a response to specific components or functionalities potentially required by multiple web-applications (described in the previous section 4.2).

Flares are similar to plugins, equipping and extending a given application with specific features or extending server-side core components. Similarly to app architecture (see previous section) in fact, flares can be plugged dynamically (by administrators or service providers) into a given instance, enriching both client and server functionalities. The possibility to extend both client and server components offers huge control to shape the capabilities of a specific ATON instance serving scientific communities.

Just like apps (see section 4.2), flares are uniquely identified within a given instance $\mathbb{A}_i$. They can be developed and published by developers using common repositories (such as github or gitlab) allowing administrators or service providers to shape and enrich their ATON instance depending on specific needs.

A single web-app (e.g. a pilot) is able to define a list of required flares $(F_1, F_2, ...F_n)$ programmatically, depending on specific project needs. Alternatively, current implementation of the architecture allows an app to load a list of flares $F_1, F_2, ...F_m$ at runtime via url parameters, offering unprecedented levels of flexibility without any modifications to the core of the framework.

An example of a mere client-side flare, would be supporting a

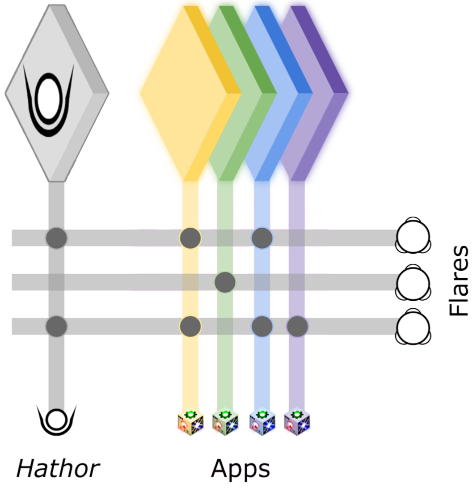


**Figure 4:** *Horizontal (flares) and vertical (apps) extensibility to shape a given ATON instance*

3D format not directly offered by the ATON core, for instance the IFC format. In this case, every app on the instance can be equipped with the IFC flare, supporting the loading of 3D models with IFC format alongside the standard ones (e.g. glTF or Cesium 3D tiles). Another example, would be a flare to support a specific formalism (like Extended Matrix [Dem15]), enabling multiple apps (with different objectives or domains), to provide such functionalities to final users. An example of a server-side flare on the other hand, would be a few enrichments of the REST API, communications with dataspaces (external or part of the H2IOSC federation) or custom authentication routes. This is the case of the integration with the federated authentication service (single sign-on of H2IOSC), as well as other authentication models.

A single flare is represented by a descriptor (JSON) indicating a list of dependencies (typically organized in subfolders), as well as other attributes required for its classification and indexing within the current ATON instance.

In order to validate the effectiveness of the described architecture, we briefly present a few concrete flares developed by integrating external open-source libraries.

#### 4.3.1. Capture Flare

One of the first flares developed with the new architecture was designed and realized under one of the H2IOSC E-RIHS pilots ("*Interlumo*") to allow any web-app to capture users' interactions (see paper [FG24]). The first version of this capture flare included both client and server logic, offering the possibility to any ATON app to track specific spatial attributes at runtime (like camera location, view direction, etc...) by streaming data chunks to the node. The main motivation was the investigation of specific research topics related to analytics, due to the possibility of the flare to produce anonymized data records (in CSV format) on the server node, for later inspection.

The flare was assessed in several occasions and public exhibits with large visitors volumes (ArcheoVirtual 2023, TourismA 2024 and 2025, and many others). Specifically, a few WebXR applications exposed to visitors were equipped with the capture flare: this allowed us to remotely track users' motions in virtual environments while using head-mounted displays, thus providing rich data records directly on the dedicated hub. The flare was then updated to access a new dedicated capture service via its own REST API, thus maintaining only client components. In particular, the upgraded flare now allows more flexible schemes, more options and tracking of custom attributes, with dedicated configuration files directly via the flare (for more details, see [FG24], section 3.1). As described in the previous sections, any vertical web-app can now require (even on the fly) this specific open-source flare to track users interactions targeting specific research or analysis.

#### 4.3.2. Nexus Flare

The Nexus flare intends to offer support for the Nexus multiresolution format developed by CNR ISTI [CGG*05, PD16]. The github repository of the open-source library provides a THREE.js implementation, allowing to explore possible integrations in the ATON framework.

**Figure 5:** *A few ATON scenes referencing sample nexus 3D models, with direct lighting and real-time post-effects (top row); Full integration with light-probing system (bottom left) with a nexus model reacting to a close blue panel; Interactive semantic annotations performed on the 3D model (bottom right)*

In this case, minor modifications of THREE.js nexus adapter were required for a better compatibility and integration with the framework and the most recent THREE.js releases. Following existing examples developed by CNR ISTI, a list of required dependencies are referenced into the flare descriptor, with an internal logic (client component) to handle incoming patches (e.g. view-dependent multi-resolution refinements). Thanks to the flare architecture, the ATON instance automatically adds support for *.nxs* and *.nxz* file formats during the 3D scene composition (Figure 5), allowing to combine nexus 3D models with other supported formats by ATON (such as glTF). Furthermore, common ATON routines are applicable like use of light-probes on nexus 3D models and interactive annotations (Figure 5, bottom row). Presenting those 3D models in both AR and VR sessions via WebXR is also possible.

The current implementation is still experimental, but results obtained so far are promising and could offer incredible opportunities for integration, especially since CNR ISTI is also participating with another E-RIHS service in H2IOSC.

#### 4.3.3. 3DGS Flare

The 3DGS flare, as the name suggests, explores support for 3D Gaussian Splats [KKLD23] in ATON. This implementation is possible thanks to the open-source library based on THREE.js developed by Luma Labs AI (`https://lumalabs.ai/luma-web-library`). In this case, the flare allows to fetch 3D Gaussian Splats directly processed and published via the Luma AI Capture service. For the assessment, we used both existing 3DGS assets published in the main Luma Labs gallery (Figure 6, top right) and a few 3DGS assets processed by the service from short videos captured via smartphones. Specifically these 3DGS were captured in a few locations, including Sermoneta castle (during E-RIHS Training Camp) and the cloister of the Basilica of Santa Maria del Carmine in Florence (Figure 6, top left and bottom row). Built-in markerless AR mode offered by ATON via WebXR is fully operational to present, inspect and walk around a 3DGS in a real space, including support to multiple semantic layers created by the Luma AI service (e.g. Figure 6, middle row).

The loaded 3DGS object can indeed also be combined with other classic 3D representations in the same scene (e.g. glTF) or explored collaboratively using the built-in ATON component (Figure 6, bottom row). These results - including experimentation with AR presentation (via WebXR) directly from ATON - are also showcased in a public video (`https://www.youtube.com/watch?v=EPLvCF9V07M`).

The current implementation is again still experimental, and other open-source 3DGS libraries based on THREE.js are growing very quickly. This will allow us (or other developers) to explore multiple possibilities towards integration of 3D Gaussian Splatting via flares architecture in the near future.

**Figure 6:** *Top row: A few samples of 3DGS loaded in ATON directly from Luma AI service; Middle row: sequence of video-frames of 3DGS presented in AR via ATON on a smartphone, filtering only foreground semantic layer (computed by the Luma AI service); Bottom row: real-time collaborative exploration of 3DGS in ATON.*

## 5. Discussion

We presented challenges and opportunities encountered during the last decade by the development of the open-source ATON framework, its growth and involvement in national/international projects, its relationship with scientific communities and their feedback.

These 10 years and the variety of projects involved, did teach us invaluable lessons and offered directions to improve the framework (see section 3).

Different strategies and solutions were adopted for the refactoring and deployment of ATON "as a service" in the H2IOSC federation (section 4), to accommodate the increasing demand of diverse scientific communities involved. We redesigned the whole architecture to provide the maximum flexibility in terms of extensibility and integration with other services or platforms (part of H2IOSC federation or not).

We also report the beneficial role of H2IOSC TNA/NA calls, where applicants keep providing us fresh feedback, assessing our refactoring and redesign processes. This is greatly helping us to focus efforts, directly from real scenarios where ATON is employed as a service by external national or international teams.

The improved plug&play architecture for web-apps (section 4.2) was already extensively tested on the field during the last 5 years, offering a powerful accelerator for vertical applications (custom Web3D/WebXR tools for specific domains like diagnostic, archaeology, architecture, ..). This model is already being adopted by multiple H2IOSC pilots (WP7) as well as other national/international projects where ATON is involved.

The novel "*flares*" architecture (see section 4.3), allows service providers to extend horizontally a given deployed instance of ATON. Flares are similar to plugins: they equip web-apps with additional functionalities to support new 3D formats, metadata schemas, formalisms, and much more. They also offer the possibil-


Proceedings published by Eurographics - The European Association for Computer Graphics.

ity to extend server-side features as well, such as enriching REST API for integration with dataspaces, authentication systems, and much more. Within this work, we assess the new horizontal extension illustrating results obtained on a few developed open-source flares, providing custom tracking of users' sessions (section 4.3.1) and support to additional 3D formats (section 4.3.2 and 4.3.3).

Regarding ATON growth, the Telegram open group of the framework reports a +25% in 2024 compared to the previous year (2023) also thanks to increased dissemination activities in H2IOSC and TNA/NA calls, as well as via other active national/international projects in 2024. The main website reports over 9500 views (+42%) compared to previous year, with 2800 unique visitors in 2024 (+28%). The main repository on github reports that the current version of ATON (v3.0) in 5 years reached almost 80 stars, with a steady growth.

The main ATON instance is currently deployed as a service under the H2IOSC federation on a E-RIHS server node located in CNR Research Area in Rome: it is hosting over 60.000 3D models and 21 web-apps, uploaded in the associated cloud storage during the past 5 years. The ratio between public 3D scenes (accessible via main landing page) and overall total of 3D scenes created by all users is only 6%, which highlights the users' preference for unlisted 3D scenes (only accessible via generated scene-ID). We are evaluating future strategies to increase this ratio, including rewarding mechanisms, to fuel openness and access to user-generated content.

The new architecture described in this work, will allow to customize and massively extend the ATON core, providing new ways to dynamically shape the perimeter of a deployed instance with vertical and horizontal extensibility, listening to the rich diversity of scientific communities involved.

## Acknowledgments

This research is funded by the H2IOSC Project—Humanities and Cultural Heritage Italian Open Science Cloud (https://www.h2iosc.cnr.it/), funded by the European Union NextGenerationEU—National Recovery and Resilience Plan (NRRP)—Mission 4 "Education and Research" Component 2 "From research to business" Investment 3.1, "Fund for the realization of an integrated system of research and innovation infrastructures", Action 3.1.1 "Creation of new research infrastructures strengthening of existing ones and their networking for Scientific Excellence under Horizon Europe"—Project code IR0000029-CUP-B63C22000730005. Implementing Entity CNR.

## References

[ABC*16] Antal A., Bota E., Ciongradi C., d'Annibale E., Demetrescu E., Dima C., Fanini B., Ferdani D.: A complete workflow from the data collection on the field to the deployment of a virtual museum: the case of virtual sarmizegetusa. In *Eurographics Workshop on Graphics and Cultural Heritage* (2016). URL: https://api.semanticscholar.org/CorpusID:51870458. 3

[ADT*19] Aguirre V., Delía L., Thomas P., Corbalán L., Cáseres G., Sosa J. F.: Pwa and twa: recent development trends. In *Argentine Congress of Computer Science* (2019), Springer, pp. 205–214. 2

[CCVC21] Casas S., Cruz D., Vidal G., Constanzo M.: Uses and applications of the openapi/swagger specification: a systematic mapping of the literature. In *2021 40th International Conference of the Chilean Computer Science Society (SCCC)* (2021), IEEE, pp. 1–8. 2

[CFST*22] Corbalán L. C., Fernández Sosa J. F., Tesone F., Dapoto S. H., Cristina F., Thomas P. J., Pesado P. M.: Recommendations for resilient app development. In *X Jornadas de Cloud Computing, Big Data & Emerging Topics (La Plata, 2022)* (2022). 2

[CGG*05] Cignoni P., Ganovelli F., Gobbetti E., Marton F., Ponchio F., Scopigno R.: Batched multi triangulation. In *VIS 05. IEEE Visualization, 2005.* (2005), IEEE, pp. 207–214. 7

[Dem15] Demetrescu E.: Archaeological stratigraphy as a formal language for virtual reconstruction. theory and practice. *Journal of Archaeological Science 57* (2015), 42–55. 4, 7

[DFC23] Demetrescu E., Fanini B., Cocca E.: An online dissemination workflow for the scientific process in ch through semantic 3d: Emtools and emviq open source tools. *Heritage 6*, 2 (2023), 1264–1276. 4

[EACM22] Ehsan A., Abuhaliqa M. A. M., Catal C., Mishra D.: Restful api testing methodologies: Rationale, challenges, and solution directions. *Applied Sciences 12*, 9 (2022), 4369. 2

[FC20] Fanini B., Cinque L.: Encoding immersive sessions for online, interactive vr analytics. *Virtual Reality 24*, 3 (2020), 423–438. 3

[Fd16] Fanini B., d'Annibale E.: A framework for compact and improved panoramic vr dissemination. In *GCH* (2016), pp. 33–42. 3

[FDB*22] Fanini B., Demetrescu E., Bucciero A., Chirivi A., Giuri F., Ferrari I., Delbarba N.: Building blocks for multi-dimensional webxr inspection tools targeting cultural heritage. In *International Conference on Extended Reality* (2022), Springer, pp. 373–390. 4

[FFD21a] Fanini B., Ferdani D., Demetrescu E.: Temporal lensing: an interactive and scalable technique for web3d/webxr applications in cultural heritage. *Heritage 4*, 2 (2021), 710–724. 3

[FFD*21b] Fanini B., Ferdani D., Demetrescu E., Berto S., d'Annibale E.: Aton: An open-source framework for creating immersive, collaborative and liquid web-apps for cultural heritage. *Applied Sciences 11*, 22 (2021), 11062. 3

[FG24] Fanini B., Gosti G.: A new generation of collaborative immersive analytics on the web: Open-source services to capture, process and inspect users' sessions in 3d environments. *Future Internet 16*, 5 (2024), 147. 4, 7

[FPP19] Fanini B., Pescarin S., Palombini A.: A cloud-based architecture for processing and dissemination of 3d landscapes online. *Digital Applications in Archaeology and Cultural Heritage 14* (2019), e00100. 2

[FRF*23] Ferdani D., Ronchi D., Fanini B., Manganelli Del Fà R., d'Annibale E., Bordignon A., Pescarin S.: Brancacci chapel in florence: Surveying and real-time 3d simulation for conservation and communication purposes. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 48* (2023), 535–540. 4

[GBML*18] Gonizzi Barsanti S., Malatesta S. G., Lella F., Fanini B., Sala F., Dodero E., Petacco L.: The winckelmann300 project: Dissemination of culture with virtual reality at the capitoline museum in rome. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 42* (2018), 371–378. 3

[KJT*23] Kumar K., Jain A. K., Tiwari R. G., Jain N., Gautam V., Trivedi N. K.: Analysis of api architecture: A detailed report. In *2023 IEEE 12th International Conference on Communication Systems and Network Technologies (CSNT)* (2023), IEEE, pp. 880–884. 2

[KKLD23] Kerbl B., Kopanas G., Leimkühler T., Drettakis G.: 3d gaussian splatting for real-time radiance field rendering. *ACM Trans. Graph. 42*, 4 (2023), 139–1. 4, 8

[LCZL16] LI L., CHOU W., ZHOU W., LUO M.: Design patterns and extensibility of rest api for networking applications. *IEEE Transactions on Network and Service Management 13*, 1 (2016), 154–167. 2

[LFBB20] LUIGINI A., FANINI B., BASSO A., BASSO D.: Heritage education through serious games. a web-based proposal for primary schools to cope with distance learning. *Vitruvio-International Journal of Architectural Technology and Sustainability 5*, 2 (2020), 73–85. 4

[MFP24] MENCONERO S., FANINI B., PIETRONI E.: The e-archeo 3d project, an innovative and sustainable cultural proposal based on xr technologies. In *Advances in Representation: New AI-and XR-Driven Transdisciplinarity*. Springer, 2024, pp. 201–216. 4

[MSR*17] MEGHINI C., SCOPIGNO R., RICHARDS J., WRIGHT H., GESER G., CUY S., FIHN J., FANINI B., HOLLANDER H., NICCOLUCCI F., ET AL.: Ariadne: A research infrastructure for archaeology. *Journal on Computing and Cultural Heritage (JOCCH) 10*, 3 (2017), 1–27. 2

[Mue22] MUENSTER S.: Digital 3d technologies for humanities research and education: an overview. *Applied Sciences 12*, 5 (2022), 2426. 2

[NIG*20] NIKNEJAD N., ISMAIL W., GHANI I., NAZARI B., BAHARI M., HUSSIN A. R. B. C.: Understanding service-oriented architecture (soa): A systematic literature review and directions for further investigation. *Information Systems 91* (2020), 101491. 2

[PCFB23] PIETRONI E., CHIRIVÌ A., FANINI B., BUCCIERO A.: An innovative approach to shape information architecture related to ancient manuscripts, through multi-layered virtual ecosystems. from codex4d to dataspace project. In *International Conference on Extended Reality* (2023), Springer, pp. 247–267. 4

[PCS18] POTENZIANI M., CALLIERI M., SCOPIGNO R.: Developing and maintaining a web 3d viewer for the ch community: an evaluation of the 3dhop framework. In *Eurographics Workshop on Graphics and Cultural Heritage* (2018). URL: https://api.semanticscholar.org/CorpusID:53362665. 2

[PD16] PONCHIO F., DELLEPIANE M.: Multiresolution and fast decompression for optimal web-based rendering. *Graphical Models 88* (2016), 1–11. 7

[PGSS25] PAPADOPOULOS C., GILLIKIN SCHOUERI K., SCHREIBMAN S.: And now what? three-dimensional scholarship and infrastructures in the post-sketchfab era. *Heritage 8*, 3 (2025), 99. 2

[PR22] PONELAT J., ROSENSTOCK L.: *Designing APIs with Swagger and OpenAPI*. Simon and Schuster, 2022. 2

[RAPC14] ROBINET F., ARNAUD R., PARISI T., COZZI P.: gltf: Designing an open-standard runtime asset format. URL: https://api.semanticscholar.org/CorpusID:63918130. 3

[SS17] SHAH H., SOOMRO T. R.: Node. js challenges in implementation. *Global Journal of Computer Science and Technology 17*, 2 (2017), 73–83. 2

[STF23] SAIDI M., TISSAOUI A., FAIZ S.: A ddd approach towards automatic migration to microservices. In *2023 IEEE International Conference on Advanced Systems and Emergent Technologies (IC_ASET)* (2023), IEEE, pp. 01–06. 2

[TPC*19] TURCO M. L., PIUMATTI P., CALVANO M., GIOVANNINI E. C., MAFRICI N., TOMALINI A., FANINI B.: Interactive digital environments for cultural heritage and museums. building a digital ecosystem to display hidden collections. *Disegnarecon 12*, 23 (2019), 7–1. 3

[WQ10] WANG R., QIAN X.: *OpenSceneGraph 3.0: Beginner's guide*. Packt Publishing Ltd, 2010. 2