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Access to Digital Cultural Heritage: Exploring Future Perspectives Through Open Tools of Research †

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Abstract: In line with the research objectives of the SCORPiò-NIDI project, we aim to implement a software platform showcasing the digital models developed during the project. The goal is to develop dynamic and interactive user experiences, expanding access to cultural heritage through digital means, which become spaces for engaging and educational experiences. Using open-source frameworks, users can explore the complexity of Roman siege machines in an immersive way, interacting directly with the digital models. We will focus on the 3D model of the scorpion created by Dr. Claudio Formicola (University of Campania Luigi Vanvitelli), using the 3D modeling software Rhinoceros.

Keywords: digital cultural heritage; storytelling; 3D modeling; virtual tour; digital platform; interactive visualization; open source

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1. Introduction

In 2014, the Council of the European Union [1] recognized digital resources as part of cultural heritage, alongside tangible and intangible assets. This represents a significant change in perception; digital heritage is now seen not just as replicas of physical originals but as independent entities that offer unique ways to access knowledge. This acknowledgment allows for innovative methods of experiencing and interpreting heritage, enhancing access for a broader and more diverse audience. Indeed, digital technologies enhance and amplify the ways cultural heritage can be accessed, shared, and appreciated, offering new opportunities for different communities to explore and engage with it. The Guidelines for the Digitization of Cultural Heritage [2] have also identified the enjoyment and enhancement of heritage assets as objectives of digitization, alongside the conservation of originals, scholarly study, and the recovery of previous digitization efforts.

However, for these digital cultural resources to acquire full meaning and become effective tools for cultural transmission, it is essential to integrate a narrative layer that contextualizes and brings them to life for users. The aim is not only to preserve the materiality of heritage but also to understand and convey the 'why' behind its existence and its value in collective memory.

In the context of the SCORPiò-NIDI project [3], the educational and scientific value lies in the unique opportunity, provided by the distinctive conservation history of Pompeii, to observe and communicate with absolute certainty the ballistic effects attributable to the artillery of the late Roman Republic, used by Lucius Cornelius Sulla during the siege of the city in 89 BC [4,5].

The section of the city walls between the Vesuvius gate and the Herculaneum gate still bears the impact marks caused by the projectiles launched by Sulla's artillery [6]. These imprints, preserved for nearly twenty centuries beneath volcanic ash, are indisputable evidence of the power achieved by Roman torsion artillery as early as the first century BC [6].

The project aims to enhance and disseminate these findings, providing the public with a dynamic reconstruction of historical events, such as the city's siege and the phases of projectile launching. It also seeks to facilitate the understanding of the technical-scientific evolution of Roman military artillery, offering an innovative perspective on Pompeii's history, traditionally known for its urban layout [4].

To ensure that this knowledge extends beyond academic circles, there is a pressing need to make these contents accessible and engaging for a wider audience of cultural heritage enthusiasts. Active engagement becomes a key element in fostering public involvement [7]. This means moving beyond passive reception towards a direct interaction that allows the public to explore, experiment, and interact with heritage narratives in immersive and dynamic ways. In this sense, digital technologies become more than mere communication tools; they enable the generation of new meanings related to heritage through the elaboration and reinterpretation of information.

This interactive approach materializes through digital storytelling, which transforms data, surveys, images, and 3D models into interactive experiences. Storytelling is the art of narrating stories, a human skill deeply rooted in oral traditions dating back to prehistoric times [8]. It has endured through the ages, transcending the simple transmission of information. Storytelling allows us to make the past accessible and meaningful in the present [9], offering a "story to tell" that guides visitors through the entire cultural experience. Thus, engagement becomes dynamic, immersive, and significant, turning the user from a passive spectator into an active participant, capable of transforming from a distracted passerby into an engaged observer [10].

Creating a narrative system that fully involves the user and makes them an integral part of the story means allowing them to participate in the creative process of digital heritage, fostering the co-creation of inclusive narrative forms. In this way, storytelling plays a key role in addressing contemporary challenges in cultural heritage, tackling crucial issues such as inclusion and equity [11].

In research, it is important to blend scientific rigor with storytelling. This approach allows cultural heritage to be presented as both an object of study and an engaging, interactive experience while upholding its authenticity and credibility. Narration is a blend of knowledge, technique, and art [10]; it is necessary to narrate while constantly engaging with scientific research. This paper is structured as follows: Section 2 provides an overview of commodity software tools used in the ATON project, specifically ATON [12] and Blender 4.3 [13]. We explore their functionalities and integration to meet project needs. Section 3 details the methodologies, completed activities, and future developments aimed at optimizing the valorization and accessibility of 3D models for an immersive user experience. We explain the utilization of these tools to achieve the project's objectives. This paper concludes in Section 4.

2. Materials and Methods

When storytelling is integrated into a digital ecosystem, content becomes dynamic, accessible, and customizable, adapting to different audiences and platforms. A digital ecosystem is a collection of tools, technologies, data, and processes that work together to create, manage, distribute, and consume digital content. The idea of an ecosystem implies interconnection and interoperability, with the common goal of disseminating cultural heritage. This is achieved not by a single software but through a network of tools and platforms [2].

The digital ecosystem developed for the dissemination of the SCORPiò-NIDI project mainly uses the ATON framework [12], Blender software 4.3 [13], and the virtual tour as an integrated tool. In a later phase of project implementation, the creation of a dedicated website is also planned, which will serve as a hub for multimedia and informational content. This integrated strategy aims to enhance accessibility, distribution, and engagement in the dissemination of scientific knowledge within the digital ecosystem.

2.1. ATON Framework

ATON is an open-source framework designed, developed, and coordinated by Bruno Fanini (VHLab, CNR ISPC ex ITABC) that enables the creation of cross-device Web3D/WebXR applications [12,14]. These applications are oriented towards online publication and interactive presentation of virtual scenes and objects for cultural heritage. They are accessible from a wide range of devices, from smartphones/tablets to laptops/PCs and immersive Virtual Reality tools (head-mounted devices) [15]. Users can access these applications without any third-party installation by simply typing in a URL from any platform [14].

One of the strengths of the framework is its scientific approach, which originates from the research sector and has evolved through numerous national and international research projects, aligning perfectly with the philosophy of our project [16,17]. Its open-source license makes it an ideal solution because it is accessible to a wide range of researchers, avoiding the costs associated with proprietary software and facilitating maintenance and updates. Moreover, the main rendering system, based on Three.js [18], supports the PBR (Physically Based Rendering) model, which is essential for presenting cultural heritage because it enables a realistic simulation of materials and how they react to environmental lighting conditions.

Another key element of the framework is the dynamism of the front-end and architecture, which allows hosting and distributing custom web applications [14]. The framework offers three usage options:

- Integrated front-end "as is" (if it meets the requirements) to present 3D models and scenes to end-users without the need for any code development;
- Custom extension, if one wishes to expand the front-end functionality;
- Develop and deploy a custom web app through the plug-and-play architecture, taking advantage of ATON's features and building a tailored user interface (UI) with the desired functionalities [12,14].

For the objectives of the SCORPiò-NIDI project, it was decided to integrate the basic software functionalities with the ability to develop a customized web app, thus expanding the ways of presenting 3D content, the CSS style, and the user interface. The official API documentation is also available on the framework's website, providing clear instructions for facilitating web app customization.

There are several scenarios in which ATON can be distributed, both in terms of hardware used and connection mode. Regarding hardware, ATON can be installed on a wide range of devices, from laptops for classroom experiments with a local network, to small servers in laboratories, and even to larger infrastructures with advanced hardware for complex installations [12,14].

From the network proximity perspective, the framework can be used in the following ways:

- Offline: ATON is installed directly on the device on which it is consumed, without requiring any connection, such as for use in a kiosk or touchscreen display in a museum;
- Local network: ATON can stream an interactive experience via an access point to nearby users, who can use a variety of devices without needing the internet, but with a configured local network;
- Online: via a remote server, where ATON can be hosted, allowing global access to content from anywhere in the world [12].

As a framework designed for the dissemination of cultural heritage, ATON offers several features. Among these is the ability to add semantic annotations by linking a subsection of a 3D object or scene to related information [19], which is presented to end-users in the form of texts, images, YouTube videos, audio, embedded pages, and more [12,14].

Other key elements of the framework include the separation and hierarchy between the concepts of collection and scene, which offer various advantages in terms of storage, reuse, and updating of loaded elements [12,14]. A collection is a set of elements added to the framework through a user profile, such as 3D models, panoramas, audio sources, etc., which can be used to create a presentation or an interactive 3D space [12,14]. The main format adopted for 3D models is glTF [20], which, due to its interoperability, provides smooth integration with various tools and 3D software engines (such as Blender, Maya, and Unreal Engine).

A scene is a configuration and integration of one or more elements from the collection, stored as a JSON file, and assigned a unique identifier, which can be used by any web app based on ATON to reference the specific 3D scene [14].

Thanks to this separation, the scorpion model can be added to the collection only once and subsequently reused in multiple scenes. For instance, in the context of enabling multilingual access, it would be possible to create two distinct scenes—one in Italian and one in English—without duplicating the model, but simply differentiating annotations, textual content, or interface elements specific to each language.

Other platforms that have overlapping concepts of a 3D model and a scene require complete reconstruction of the scene for each model update, which is time-consuming and resource-intensive. This limits flexibility in content management. However, since this is an ongoing research project, we can easily update the 3D model, including textures, details, or new components, by simply uploading the revised version into the collection. All scenes referencing the model will automatically reflect these changes without manual reconstruction [14].

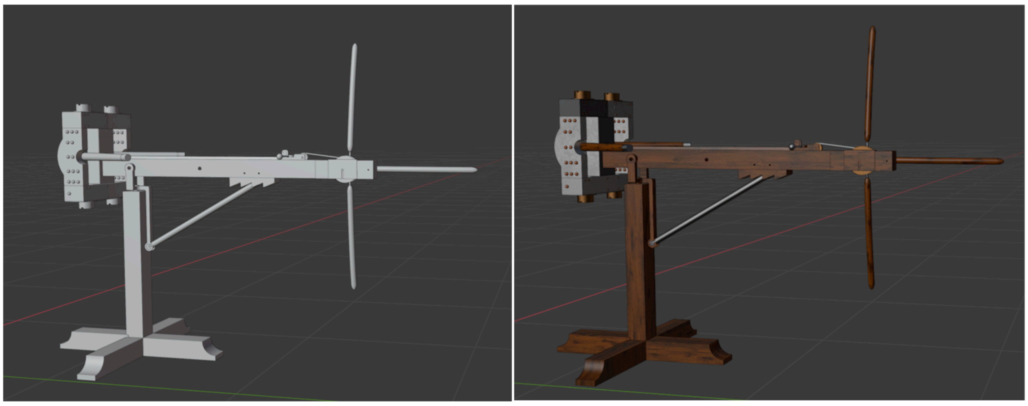
2.2. Blender

Blender is a free and open-source program designed for creating three-dimensional content [13]. It supports the entire 3D production process, including modeling, rigging, animation, simulation, and rendering. Thanks to its versatility, the software allows for the detailed integration of visual and narrative elements, facilitating the creation of engaging and accurate virtual environments.

In the SCORPiò-NIDI project, the workflow in Blender involves the following:

- Importing the 3D model into the software. The model, created by Dr. Claudio Formicola using Rhinoceros 8.0, was previously exported in .glb format [20,21];
- Defining textures and materials to realistically recreate the visual and chromatic characteristics of the original object (wood, metal, etc.) as shown in Figure 1;
- Lighting the scene to create a realistic setting;
- Rendering and post-production to produce photorealistic images for use in ATON, project communication, and storytelling.

- Animation, simulating the dart throw and the movement of the mechanical components of the scorpion.

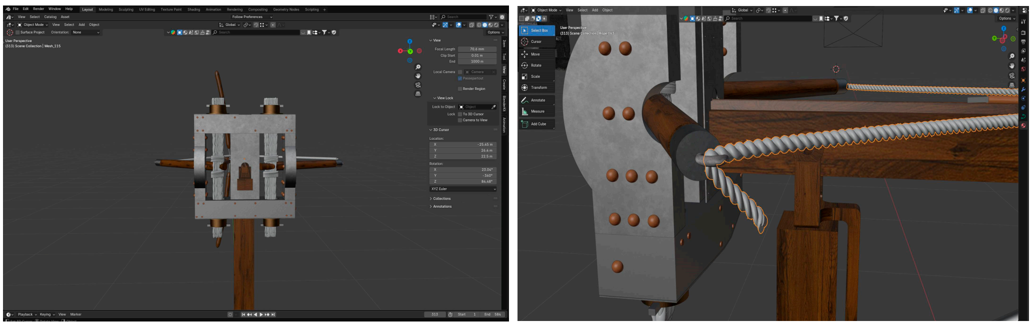


(**a**) (**b**)

Figure 1. The model pre- (**a**) and post-texturing (**b**).

In the context of cultural heritage, one of the crucial phases of creating 3D content with Blender is the definition of materials and textures [22]. These elements are essential for enhancing the authenticity of the models, optimizing the material properties, and realistically managing light interactions, to achieve a convincing and detailed visual appearance.

In Blender, a material defines the physical and optical characteristics of an object, controlling how it interacts with light and how it appears within a scene. The main properties of a material include reflectivity, transparency, roughness, and its composition. Textures, on the other hand, are 2D images applied to the surfaces of a 3D model, enriching its visual detail and simulating features like wood grain, stone irregularities, or reflection on a metal surface [22]. In this phase of the project, the focus is on optimizing the textures and materials of the scorpion's 3D model to accurately replicate the original materials, such as wood, metal and rope, as illustrated in Figure 2.



(**a**) (**b**)

Figure 2. Characterization of the model with threads (**a**) and ropes (**b**).

Blender offers a wide range of lighting tools, with four main types of lights: Point, Sun, Spot, and Area, each with adjustable parameters that allow for the creation of the desired lighting effect. Lighting is a crucial element in enhancing the realism of a 3D scene, as it plays a decisive role in the atmosphere and visual rendering of the project. Through careful management of lights, details can be emphasized, shadows can be played with, and lighting can be achieved that reflects physical reality, thus giving the model a sense of coherence [23].

Once the materials, textures, and lighting are defined, the next step is rendering, which is the process of converting the 3D scene into a 2D image [24]. Blender offers three main rendering engines, each with its own advantages and specific features: EEVEE, Workbench, and Cycles. For the ongoing project, Cycles is being prioritized, as its path-tracing approach enables photorealistic results and effectively manages the interactions between light and objects [24]. Once the rendering is completed, Blender offers a powerful post-production phase through the compositor, which allows for further enhancement of the image with filters, visual effects, color corrections, and adjustments in contrast, brightness, and tones [24]. The final results can be exported in various formats (PNG, JPEG, TIFF, etc.), depending on the needs [24].

In addition to modeling and rendering, Blender was chosen for our project also for its advanced animation support. The ability to animate the 3D model of the scorpion, simulating complex movements such as the dart throw and interactions between the machine's various components, is one of the key features of the software. Blender supports a wide range of techniques for animating a 3D model, with the most common and straightforward method being the use of keyframes (Figure 3), which store the values of animated object parameters [25].

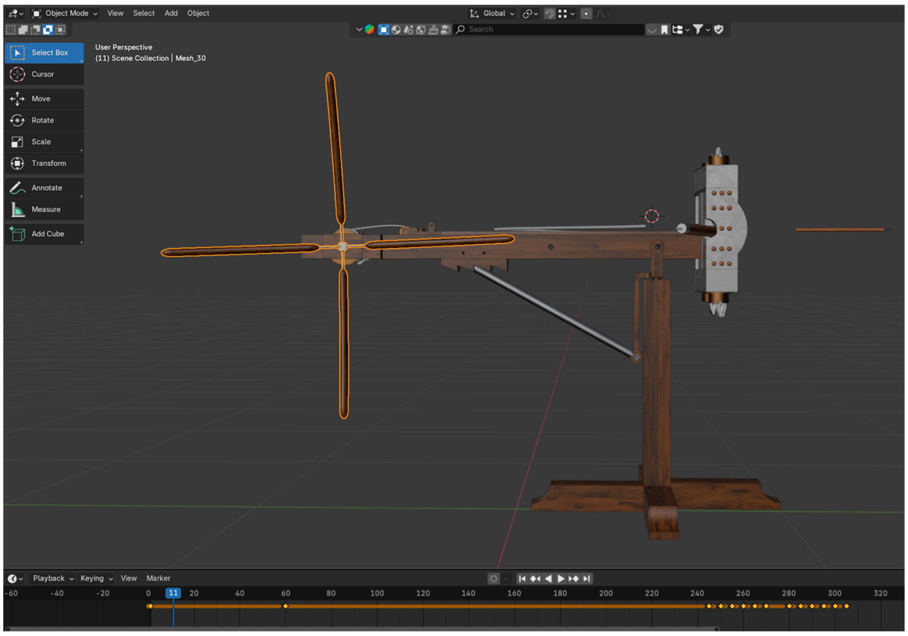


Figure 3. Static image of the dart throw created with keyframes.

The online Blender manual defines a keyframe as follows: "A Keyframe is simply a marker of time which stores the value of a property" [23].

A keyframe is therefore a specific point in time within an animation that records the value of a particular property of an object, such as its position, rotation, scale, or any other parameter that can be animated over time. When two or more keyframes are present, the software creates an intermediate animation by calculating the values between them to achieve smooth and realistic movement [25]. In conclusion, Blender offers a complete workflow with 3D modeling, material definition, lighting, rendering, and animation, making it ideal for the SCORPiò-NIDI project.

3. Results and Discussion

To create user pathways aimed at ensuring the maximum valorization and accessibility of 3D models, to provide users with an immersive and interactive experience, the tools and functionalities described above were employed. Specifically, the ATON framework will allow for a multi-level dissemination approach, ranging from the visualization of 3D models in a gallery to the future creation of a virtual tour [26,27] of the city walls between the Vesuvius gate and the Herculaneum gate.

The first step involved uploading the 3D model of the scorpion into a gallery within the framework, allowing future visualization and manipulation by users, who will be able to rotate the model 360 degrees and appreciate all its functional details. Users will also be able to view additional information and content through semantic annotations. Currently, semantic annotations have been added to the model, both in spherical and freeform shapes, consisting of points interactively placed on the queried surfaces. This allows the user's attention to be focused on specific parts of the model that merit further informational exploration to facilitate understanding. This is further enriched by adding images, videos, infographics, and audio to the annotations [14].

A second level involves the insertion of the animated model of the scorpion into ATON. The animation, which will simulate the dart launch, will be created using Blender software, where the 3D model of the scorpion was imported. Using the keyframe technique described above, all parts of the machine will be animated to allow a realistic simulation of the launch. The animation can also be enhanced with additional elements that help to contextualize it in time and space, such as the 3D model of the city walls, which can also be inserted and integrated into the software. The animated model will be exported from Blender in .glb format and then reintegrated into ATON, where it can be supplemented with additional elements, as described for the static model.

Another level involves the possibility of creating a customized web app accessible from any device, without requiring any installation by the end-users [14,17]. This app will focus on creating a virtual tour of the city walls. It can be enriched with 3D models of the machines, as well as text and annotations, with a focus on the ballistic impressions visible on the walls. The web app could also include an additional communication layer, namely temporal lensing [28], which allows users to interactively compare artifacts, objects, buildings, or large archaeological sites in their current state of preservation alongside their hypothetical reconstructions. This additional functionality could include not only the model of the current state of the walls but also a model showing their appearance around the 1st century BC.

This would help the user understand the dynamics of the siege and how the visible impact craters on the walls should be considered as missed shots. The actual targets of the launches were not the thick walls, but the temporary wooden shielding devices placed at the outer boundary of the walls, used by defenders as protection.

Furthermore, the use of Virtual Reality (VR) and Augmented Reality (AR) applications [29], supported by ATON, could be an exciting future development for the project.

There are therefore several perspectives being pursued that can be integrated and implemented together to achieve results capable of best valorizing the meanings and objectives underlying the project.

4. Conclusions

The promotion of the SCORPiò-NIDI project represents a significant example of how digital technologies can effectively contribute to the valorization and dissemination of cultural heritage. Through the adoption of innovative tools such as the ATON framework, Blender software, and the creation of an integrated digital ecosystem, dynamic, interactive, and accessible user pathways will be developed.

The integration of digital storytelling with rigorous scientific documentation enhances the narrative's authenticity and provides the audience with a meaningful educational experience. Additionally, utilizing open-source tools promotes sustainability through transparency, collaboration, and innovation. The ATON framework, when used online, allows researchers to collaboratively create scenes, share access easily among team members, and facilitates effective remote contributions.

Additionally, in the dissemination of the project, it will be essential to prioritize accessibility to ensure that everyone can use it effectively. This not only enhances inclusivity but also encourages broader adoption among diverse audiences [30].

To achieve this objective, we should refer to the Web Content Accessibility Guidelines (WCAG) [31], which provide a comprehensive set of recommendations for designing accessible web content for desktops, laptops, tablets, and mobile devices. During the platform's development, the following aspects must be considered:

- Text contrast: To ensure readability, high contrast between text and background is crucial. The WCAG recommends a contrast ratio of at least 4.5:1 for normal text and 3:1 for large text [31];
- Text size: The text size should meet the minimum recommendation of 16px for the main body of text [31];
- Text descriptions for non-text content: It is important to provide detailed text descriptions for all non-text content. For instance, comprehensive descriptions should accompany each phase of the 3D animations and the movements of the machines. This will enable users to understand the operations even when using a screen reader [31];
- Subtitles and Italian Sign Language (LIS): Subtitles should be included for videos and audio recordings, as well as content in Italian Sign Language (LIS) and other international sign languages [31];
- Simple and intuitive UI: A user-friendly and intuitive interface is essential for ensuring a positive experience for all users [31].

By following these guidelines, we can create an inclusive platform that is accessible to a wider audience.

To ensure the project's success, it is important to thoroughly study the target audience and review the user interface (UI) and user experience (UX) before the launch [32]. Future actions should include monitoring the project's impact and gathering user feedback to continually improve the experience and enhance overall accessibility.

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