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Enhancing Cultural Heritage Accessibility Through Three-Dimensional Artifact Visualization on Web-Based Open Frameworks

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Abstract: This paper presents an innovative approach to cultural heritage preservation through the development of an open framework that leverages RESTful APIs to make high-fidelity 3D models of cultural artifacts accessible to any application. Focusing on antique kitchenware utensils from the Nakhon Si Thammarat National Museum in Thailand, this research utilizes photogrammetry to create detailed 3D models, which are then made available on a web-based platform, accessible globally via standardized HTTP requests. The framework enables real-time access to 3D cultural content, overcoming the geographical and physical barriers that often limit access to cultural heritage. By integrating these 3D models into RESTful APIs, the project not only preserves delicate artifacts but also enhances their educational and cultural value through interactive accessibility. This system demonstrates the practical application of digital preservation technologies and sets a precedent for future initiatives aiming to digitize and disseminate cultural artifacts more broadly. The implications of this study extend beyond preservation to include enhanced global accessibility, enriched educational resources, and a more inclusive approach to cultural engagement. This project illustrates the transformative potential of digital technologies in preserving, accessing, and experiencing cultural heritage worldwide.

Keywords: cultural heritage preservation; open framework; RESTful APIs; 3D models

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1. Introduction

Cultural heritage holds immense importance as it reflects the identity, history, and values of societies [1]. Ensuring accessibility to cultural heritage sites is crucial to allow everyone, regardless of physical limitations, to experience and appreciate these valuable assets [2]. By redefining accessibility as a social relationship that combines adaptation with the transmission of meanings, museums can offer engaging experiences to a broader audience, as demonstrated by projects like Smart Cultural Heritage 4 All [3]. Additionally, the challenge lies in balancing historical significance with modern accessibility needs, especially in the case of historical buildings, where innovative solutions are required to maintain both aspects without compromising either. In conclusion, accessibility to cultural heritage is not just about physical access but also about fostering understanding and engagement with the past and present values of these sites. Embracing diverse theoretical methodologies and practical projects can lead to critical–conservative solutions

that preserve the historical integrity of heritage sites while making them accessible to all, thus enriching society as a whole. Ultimately, promoting accessibility to cultural heritage ensures that these treasures are not only preserved for future generations but also actively enjoyed and appreciated by a wide and inclusive audience.

Traditional methods of presenting cultural heritage face significant challenges in the modern era. These challenges stem from limited funding and technological infrastructure in developing countries, leading to static displays that fail to engage contemporary audiences [4]. Additionally, the preservation of architectural heritage through traditional construction techniques requires a delicate balance between historical methods and contemporary preservation methodologies [5]. Furthermore, the fixed nature of Virtual Reality (VR) experiences poses a challenge in updating and enhancing cultural heritage presentations without extensive redevelopment [6]. To address these challenges, innovative solutions leveraging technology have been proposed. Projects like i-Treasures aim to enhance Intangible Cultural Heritage (ICH) education through the adoption of new technologies and methods. The widespread use of mobile technology and social media in societies like Brazil presents an opportunity for cultural institutions to engage visitors with novel strategies without heavy technological investments. By integrating contemporary methodologies with traditional construction techniques, there is potential for more effective preservation of architectural heritage and knowledge transmission. Decoupling VR experiences from fixed models through configurable templates offers a promising approach to diversifying cultural heritage presentations with ease.

Another method for preserving and enhancing the accessibility of cultural heritage is providing cultural artifacts' metadata through digital collection and open service framework. Maintaining a proprietary digital collection in a local repository offers clear benefits. It ensures that developers have complete control over the content, allowing for careful curation, consistent quality management, and safeguarding of the digital assets [7]. This self-contained approach can be particularly advantageous in contexts where security and content integrity are paramount. Additionally, a local repository can offer quicker access times, as there is no reliance on external servers or networks, which is crucial for applications requiring high performance and reliability.

However, owning and maintaining a local repository may not always be practical or desirable, particularly when the goal is to enrich user experiences with diverse cultural content. Developers often seek to incorporate a variety of 3D models to enhance their applications, providing users with richer, more engaging experiences [8,9]. In such scenarios, relying exclusively on a local repository could be limiting, as it might not contain the breadth and diversity of cultural artifacts needed to fully realize the application's potential [10].

The impact of making cultural content, including 3D models, openly accessible extends far beyond immediate benefits to developers. It fosters a more inclusive and global approach to cultural engagement, enabling users from diverse backgrounds to access, interact with, and learn from a shared digital heritage. This open-access model promotes collaboration among cultural institutions, developers, and educators, leading to the co-creation of digital experiences that are richer and more meaningful than those developed in isolation.

The open framework facilitated by RESTful service APIs plays a crucial role in this ecosystem [11]. These APIs enable the acquisition of cultural content from existing museum APIs, such as those provided by Europeana [12] and the Victoria & Albert Museum [13]. However, while these museums offer extensive digital collections, they typically do not provide 3D models of cultural artifacts. In contrast, Sketchfab stands out as an online repository that not only offers downloadable 3D models but also exposes REST-like APIs,

allowing applications to request and utilize these models in formats like glTF, GLB, and USDZ [14]. This integration of open access and advanced technology facilitates the creation of innovative and interactive cultural experiences accessible to a global audience.

Web3D is a term used to describe the collection of technologies and standards that facilitate the creation, management, and rendering of three-dimensional (3D) content on the web. It includes a wide array of techniques that enable the seamless integration of 3D models, animations, and interactive experiences directly within web browsers, eliminating the need for additional plugins or software. Web3D has become a crucial component in various fields such as education, entertainment, virtual reality (VR), augmented reality (AR), and cultural heritage preservation [15–17].

The origins of Web3D date back to the mid-1990s, with the advent of the Virtual Reality Modeling Language (VRML), which was one of the first efforts to introduce simple 3D representations to the web. Since then, Web3D technologies have undergone significant evolution. Modern standards such as X3D, WebGL, and glTF have emerged, enabling the development of more sophisticated and interactive 3D experiences. These advancements have broadened the applications of Web3D, making it a vital tool for delivering immersive and interactive content across various platforms and industries [18].

X3D (Extensible 3D) is an ISO-certified standard for real-time 3D computer graphics, primarily designed for web-based delivery. It is the successor to the Virtual Reality Modeling Language (VRML) and supports the creation and rendering of interactive 3D graphics across multiple platforms. X3D integrates seamlessly with other web standards, offering a comprehensive framework for multimedia presentations that include complex graphic scenes with interactive objects and animations. As a crucial technology in the field of 3D graphics, X3D enhances the user experience by enabling immersive environments, and it plays a vital role in various domains such as education, science, and the arts [19].

X3D seamlessly integrates with HTML5 through X3DOM, a powerful framework that enables X3D content to be embedded directly into HTML pages, allowing interaction via DOM (Document Object Model) interfaces. This integration has been the subject of extensive research, particularly in combining X3D with technologies such as CSS3 for styling and JavaScript for scripting. These enhancements empower web developers to create rich, interactive 3D content without the need for external plugins [20]. Moreover, X3D's utility extends beyond general web development; it has proven particularly valuable in the digital preservation and dissemination of cultural artifacts. Museums and archeological sites have leveraged X3D to develop detailed digital replicas of artifacts and historical sites, enabling virtual exploration. This approach not only preserves cultural heritage but also democratizes access to these valuable resources, making them available to a global audience [21–23].

Web-based open frameworks play a crucial role in enhancing transparency and accessibility in various domains. For instance, the Collecting and Analyzing Parliament Data (CAPD) framework enables the collection and analysis of large-scale public governmental data, aiding in monitoring government activities and improving transparency [24]. Moreover, the utilization of open-source visualization technologies in a browser-based 3D visualization framework allows for real-time 3D visualization of oceanographic data, offering efficient volume rendering and interactive analysis capabilities [25]. These frameworks not only provide valuable insights into diverse datasets but also contribute to the democratization of information and services in their respective fields.

The current state of cultural heritage accessibility reflects a dynamic interplay between technological advancements and ongoing challenges in ensuring inclusive access. Digital reconstructions and virtual reality (VR) applications have emerged as pivotal tools in making hypogeum archeological sites accessible, especially in regions like the Mediter-

ranean, where physical access to underground ruins is often hindered by modern urban development. Technologies such as terrestrial laser scanning, photogrammetry, and web-based virtual navigation systems, utilizing WebGL JavaScript open-source libraries, have been instrumental in digitizing and disseminating cultural heritage to a wider audience. These efforts are exemplified in projects aimed at the virtual exploration of ancient Roman cities, highlighting the potential of digital platforms to overcome physical accessibility barriers. However, the transition to digital does not automatically resolve all accessibility issues, as the design and implementation of these technologies must consider diverse user needs to ensure a truly inclusive experience. In the museum sector, significant strides have been made towards improving accessibility for people with functional limitations, though challenges remain in attracting those who still face barriers to museum visits. A performative conception of accessibility, which combines adaptive measures with the transmission of meanings, has been proposed as a way forward. This approach seeks to make cultural experiences more engaging and accessible by redefining accessibility as a social relationship [26]. Despite these advancements, reports indicate that the museum sector and scholarly journals have yet to fully meet the protections and rights of people with disabilities, underscoring the need for continued efforts towards inclusivity. Moreover, the integration of Assistive Technologies and the adoption of universal design principles in museums represent significant progress towards inclusivity. However, research reveals a lack of tools that address multiple disabilities simultaneously, suggesting a need for a more holistic approach to museum accessibility. The pandemic has further complicated access to cultural sites, prompting innovative solutions like the 'CapsulART' device to ensure safe environment accessibility by addressing air quality and contagion risks. These developments underscore the importance of a conscious design that accommodates all visitors, allowing everyone to enjoy cultural heritage safely and inclusively [27].

The application of 3D visualization in cultural heritage has seen innovative uses across various projects, aiming to preserve, document, and disseminate cultural heritage in engaging and interactive ways. For instance, the project focused on Perugia's Fontivegge district utilized three-dimensional reconstruction to create a virtual reality experience, allowing users to explore and understand the historical context of the area through a mobile application developed with Unreal Engine software. This approach not only preserved the historical memory of the city but also enhanced user interaction with cultural heritage sites by leveraging modern technology to bridge the gap between past and present [28]. Similarly, stereolithography has been employed to reproduce objects or missing parts of cultural significance, demonstrating the potential of rapid prototyping techniques in creating faithful replicas for the conservation and study of cultural heritage. This technique underscores the advantages and challenges of applying 3D printing technologies in the field, highlighting its role in the preservation and restoration of artifacts [29]. Neural Radiance Field (NeRF) approaches have revolutionized 3D reconstruction from images, offering new possibilities for documenting and visualizing cultural heritage. By evaluating various NeRF methods on cultural heritage datasets, researchers have shown that these techniques can significantly improve the rendering and reconstruction of scenes, especially for areas with uniform textures or shining surfaces. This advancement opens new frontiers for the documentation, visualization, and communication of digital heritage, making it more accessible and comprehensible to a wider audience [30]. Moreover, the integration of multispectral 3D models combines photogrammetry and multispectral imaging to investigate the materials of historical items, providing a richer understanding of artifacts and supporting conservation efforts with detailed geometrical and radiometric data [31]. Digital storytelling and virtual scene reconstructions offer alternative ways to promote and explore cultural heritage sites. By developing web applications that facilitate the

interaction between 2D and 3D products, researchers have enabled virtual inspections and collaborative digitization efforts. These technologies not only support urban planning and conservation but also enhance the tourism experience through immersive explorations of historical sites, demonstrating the potential of 3D storytelling technologies in disseminating cultural heritage [32]. The use of extended reality in museums and galleries further exemplifies the growing interest in interactive multimedia exhibitions, allowing users to experience 3D digital heritage in novel and engaging ways [33]. These applications of 3D visualization technologies underscore their significance in preserving and presenting cultural heritage, offering innovative solutions to traditional challenges in the field.

The landscape of web-based open frameworks is diverse, catering to a wide range of applications from web development to educational tools and scientific data visualization. This diversity in web frameworks underscores the importance of selecting the right tool based on the project's specific requirements, including the scale of the application and the desired features. In the realm of education and policy analysis, open frameworks play a crucial role in fostering innovation and credibility. Open Education, as discussed by Stracke, lacks a holistic quality framework, but the proposed OpenEd Quality Framework aims to improve learning quality through innovative designs and processes, integrating different quality perspectives into a comprehensive approach. Similarly, the open policy analysis framework proposed by Hoces de la Guardia et al. emphasizes the need for transparency and reproducibility in policy decision-making, advocating for the adoption of open research practices to enhance the credibility of evidence-based policymaking [25]. These frameworks highlight the potential of open approaches to revolutionize traditional fields by promoting accessibility, quality, and trust. Furthermore, the visualization of scientific data benefits significantly from open-source technologies, as demonstrated by the browser-based 3D visualization framework for oceanographic data developed by Qin et al. This framework utilizes Cesium 1.56 and Plotly.js 1.47.0 APIs to provide efficient and interactive 3D volume rendering and analysis, showcasing the feasibility of web-based solutions for real-time, large-volume data visualization [30]. The adoption of such open frameworks across different domains underscores their versatility and the growing recognition of their value in facilitating complex tasks, enhancing educational outcomes, and supporting evidence-based policy decisions.

One significant gap in current research and practices for enhancing cultural heritage accessibility through 3D artifact visualization on web-based open frameworks is the challenge of data sharing and interoperability. While efforts like OpenHeritage3D.org (accessed on 31 August 2024) aim to democratize access to site-scale lidar and photogrammetry data, there remains a critical need for frameworks that ensure data integrity and widespread utility across diverse stakeholder communities [31]. Similarly, the complexity of integrating multimodal imaging data into meaningful and interpretable 3D models highlights the necessity for advanced data fusion and analysis techniques that can enhance the interpretative value of these digital reconstructions [32]. These gaps underscore the importance of developing more sophisticated systems for data curation, sharing, and visualization that can accommodate the rich complexity of cultural heritage data. Another area where current practices fall short is in the inclusivity and accessibility of 3D visualizations for diverse audiences. This highlights the need for more inclusive design approaches that go beyond mere compliance with accessibility standards to truly engage and accommodate the full spectrum of museum visitors and cultural heritage enthusiasts. Furthermore, the application of 3D technology in cultural heritage often overlooks the potential for engaging narratives and storytelling, which can significantly enhance the virtual exploration experience [33]. There is still a vast potential for leveraging digital storytelling to make cultural heritage more accessible and engaging. This includes addressing the lack of critical

and problematized approaches to digital heritage visualization [34], which can enrich the understanding and appreciation of cultural artifacts. Bridging these gaps requires a concerted effort to develop open, accessible, and engaging web-based frameworks that can bring cultural heritage to life for all users.

This study builds upon service-oriented architecture (SOA) in cultural heritage digitization, expanding on prior research that demonstrated how APIs decentralize access to museum collections, enabling dynamic and interactive user experiences [35]. Our work advances this approach by developing an open framework for web-based 3D content visualization using RESTful service APIs, enhancing the accessibility, scalability, and interoperability of cultural heritage artifacts.

To evaluate the framework, we use antique Southeast Asian kitchen utensils, selected for their cultural significance and suitability for 3D visualization. The framework follows a three-stage development process: (1) 3D Content Acquisition, where artifacts are digitized for web-based visualization; (2) API Development, involving the structuring of RESTful service APIs and the creation of a 3D content service provider; and (3) Client-Side Application, which implements an interactive platform for real-time artifact visualization.

By leveraging HTTP requests, our framework enables seamless sharing and interaction with 3D cultural artifacts, making them more accessible to a global audience. Additionally, it allows for integration with existing museum databases and repositories (e.g., Sketchfab, Europeana, and Victoria & Albert Museum APIs). Since many cultural institutions do not yet offer 3D models in their collections, our open framework provides a viable solution for cross-institutional content sharing, enhancing collaboration and accessibility in digital heritage preservation.

2. Materials and Methods

This paper introduces a novel approach to cultural heritage preservation by establishing an open framework that enables real-time access to 3D cultural artifacts through any application. It focuses on a technical framework for 3D cultural heritage visualization using RESTful APIs, integrating several innovative elements:

- Innovative Integration: While RESTful APIs and 3D visualization are established technologies, our framework uniquely integrates them to create an open-access, scalable solution for digital heritage visualization. Unlike traditional museum digital collections, this system allows real-time access and interaction with 3D models via web applications, significantly enhancing cultural heritage accessibility.
- Enhancing Digital Preservation: The framework bridges the gap between closed local repositories (which offer high control but limited accessibility) and open API-driven access, enabling developers and institutions to efficiently share 3D cultural content without requiring extensive infrastructure investment.
- X3D for Web-Based Visualization: While Web3D and X3D are well-known, their implementation within a RESTful API-driven system for cultural heritage preservation represents a novel contribution. This approach enhances accessibility by making historical artifacts interactive and lightweight for seamless web-based exploration.

The following describes the development process, which includes digitization and the creation of RESTful service APIs to expose 3D models of ancient kitchenware on a Web 3D platform. Inspired by earlier virtual museum technologies, such as the Reanimating Cultural Heritage API and the Santa Chiara Virtual Museum [35], our framework integrates modern 3D acquisition techniques, including photogrammetry and laser scanning, with a RESTful API to deliver high-fidelity 3D models. Unlike previous systems constrained by static frameworks or limited real-time adaptability, our approach optimizes both data retrieval and user interaction, ensuring a seamless real-time experience

2.1. Three-Dimensional Acquisition Techniques

The proposed framework provides 3D models of cultural artifacts. We use our existing 3D models of antique kitchenware utensils, for which the real items have been exhibited at the Nakhon Si Thammarat National Museum, Thailand [36], for testing the service requests and responses on our designed framework. These artifacts are widely used in traditional Asian cooking and are not only museum pieces but also remain part of some personal collections. In addition, these artifacts have their unique cultural significance and physical characteristics that make them particularly suitable for 3D acquisition. They are primarily crafted from durable materials, such as wood, coconut shell, metal, brass, ceramic, etc., containing different textures, surfaces, and characteristics. These 3D models have been created in advance using digitizing techniques explained below in order to convert to X3D file format. This section includes creating prototype 3D models of these utensils that will be integrated into the RESTful service APIs for broader accessibility.

In the digitization of these cultural artifacts, we employ both photogrammetry and laser-scanning techniques as illustrated in Figure 1 to capture our detailed 3D models. Photogrammetry is utilized for its cost-effectiveness and superb texture fidelity, making it suitable for artifacts where visual appearance is paramount. Conversely, laser scanning, including structured light and LiDAR, offers unparalleled geometric accuracy, ideal for intricate or large objects. After acquisition, data from both methods are integrated using Reality Capture 1.4 and Artec Studio 11, which aligns and merges points to construct accurate models. This process includes point cloud densification, mesh generation, and texture mapping. To ensure the models are both precise and manageable, they undergo optimization through decimation and retopology, with quality checks against the original artifacts to confirm fidelity and completeness.

Compared to these, time-of-flight scanners measure distances by timing the return of laser pulses, offering speed and efficiency for large-scale digitization projects, such as entire buildings or archeological sites. However, their lower resolution makes them less suitable for capturing fine details. Multi-view stereo (MVS) uses multiple overlapping photographs to reconstruct 3D models, similar to photogrammetry. While MVS is often combined with photogrammetry for enhanced results, its dependence on extensive computational resources and complex processing pipelines can be a drawback.

In our development, we have used the photogrammetry technique to create 3D models of antique kitchen utensils. In Figure 2, one of the cultural objects will be photographed from every angle, with at least 50 images taken to be used for creating a 3D model. All images will then be processed in the Reality Capture 1.4 program.

After completing the model creation using the photogrammetry technique, the resulting 3D model will be imported into the retopology process using Autodesk Maya 2020. This step is to adjust or improve the model's structure that may have distortions or excess parts from the actual object, such as the base used for photographing. This ensures that the model is as esthetically pleasing and complete as possible and can be displayed in an online virtual museum with the highest fidelity. After completing the retopology process as shown in Figure 3, the next step involves arranging and adjusting the texture of the model using ZBrush 2021.6. This is performed using Polypaint and Project techniques to enhance the clarity and minimize imperfections on the surface.

Using the 3D model obtained from the photogrammetry technique as shown in Figure 4, it will be converted into the X3D format. This can be performed using one of the following 3D software options: Autodesk Maya, Blender, or MeshLab, as depicted in Figure 4. The resulting X3D model file will include an XML-based X3D file and a JPG image file of the object's textures.

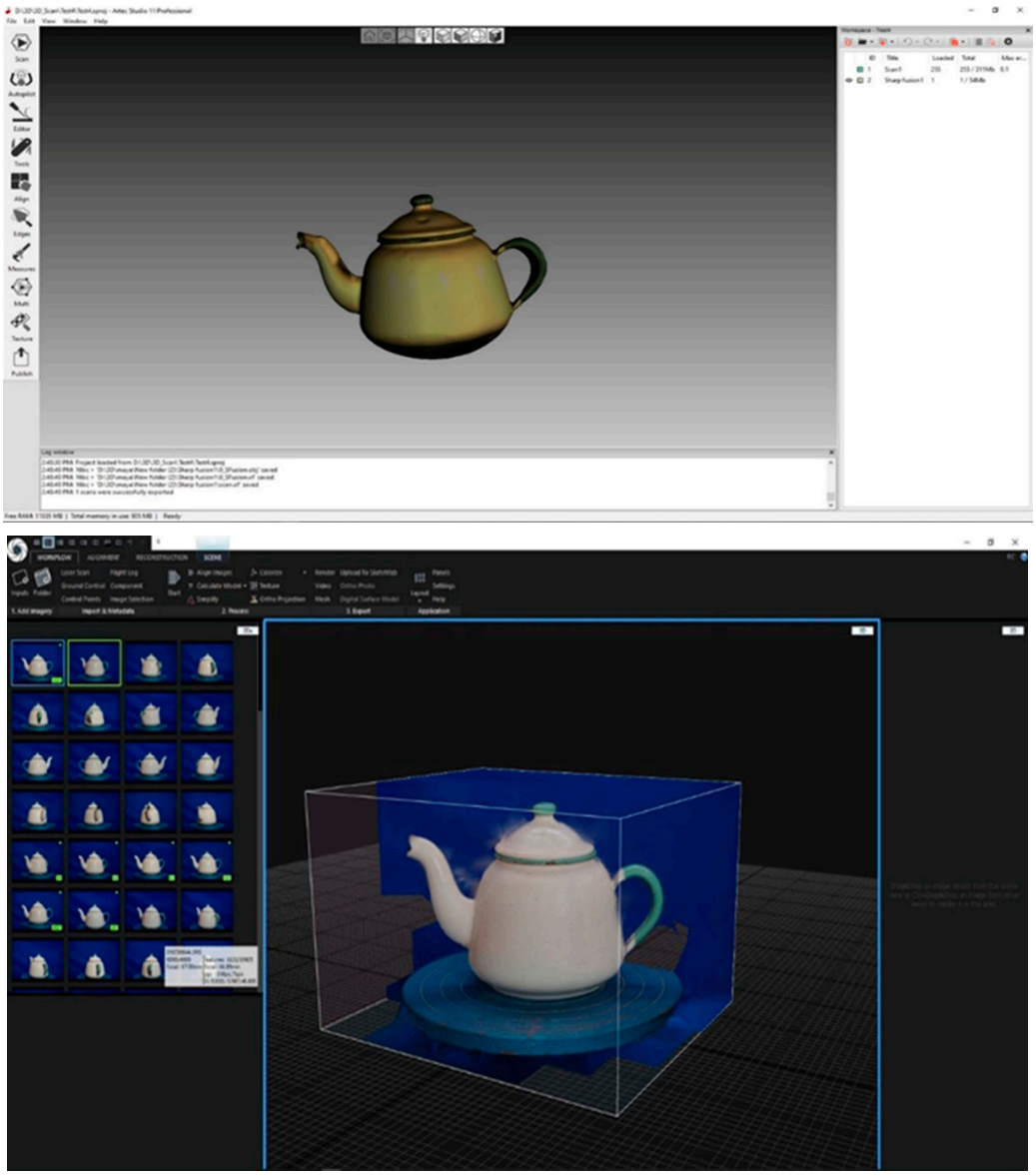


Figure 1. A targeted 3D model was created using 3D scanning and photogrammetry.



Figure 2. The process of preparing a targeted object for creating a 3D model.

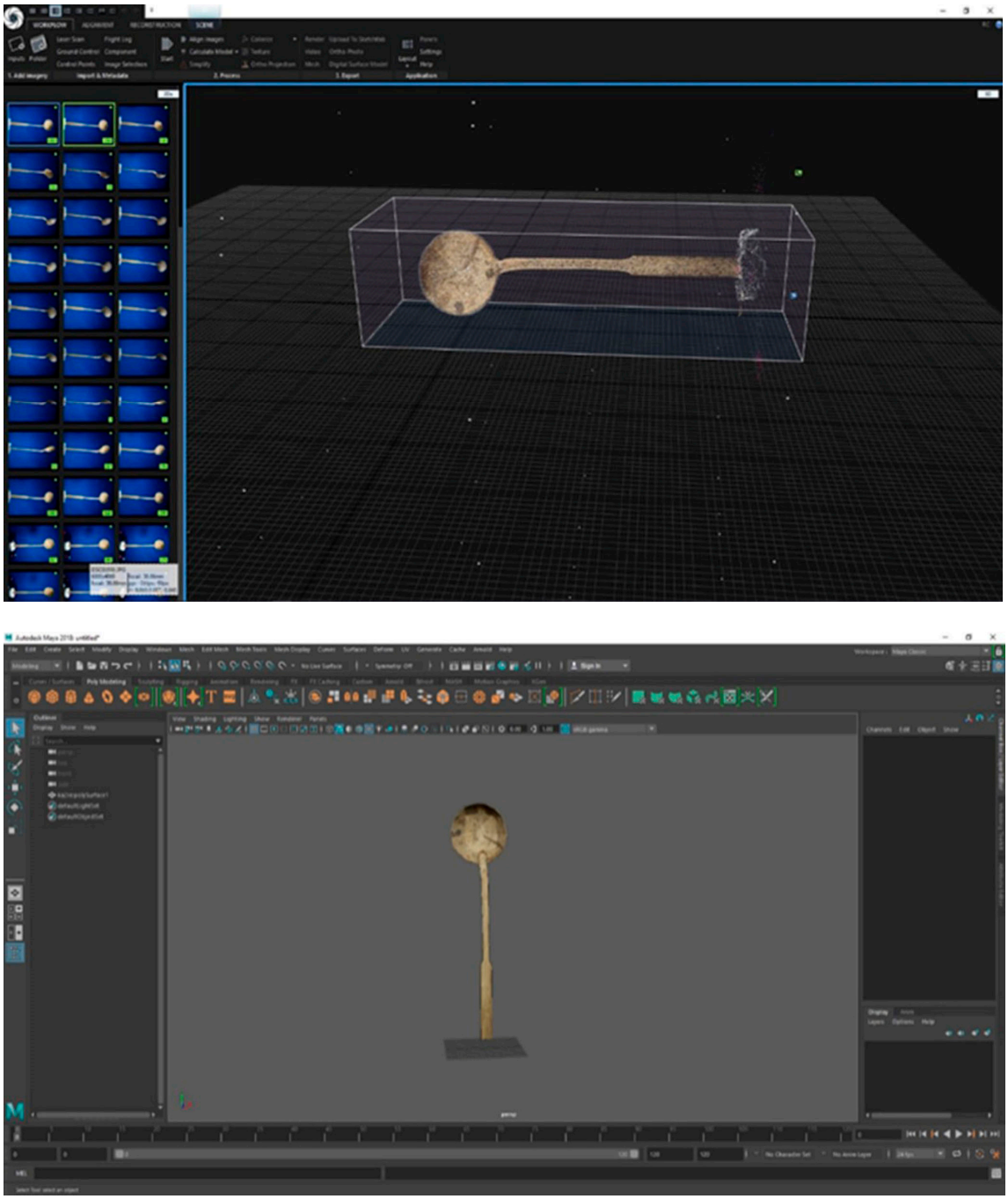


Figure 3. The 3D model is processed by Reality Capture and ZBrush.

2.2. RESTful Service APIs and Framework

We developed a RESTful API framework to provide 3D content on an open platform, enabling seamless integration with client applications, as shown in Figure 5. The decision to adopt RESTful APIs is driven by their efficiency, scalability, and widespread adoption in web-based systems. Compared to SOAP, which relies on complex XML parsing and has higher processing overhead, RESTful APIs use lightweight JSON, enabling faster data exchange. While GraphQL offers flexible queries, it introduces additional client-side processing, making it less suitable for real-time 3D visualization. Similarly, gRPC provides high performance but requires strict client-server compatibility, limiting its flexibility for open-access applications.

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "ISO//Web3D//DTD X3D 3.1//EN" "http://www.web3d.org/specifications/x3d-3.1.dtd">
<X3D version="3.1" profile="Immersive" xmlns:xsd="http://www.w3.org/2001/XMLSchema-instance" xsd:noNamespaceSchemaLocation="http://www.web3d.org/specifications/x3d-3.1.xsd">
 <head>
  <meta name="title" content="Ladle.x3d"/>
  <meta name="description" content="Generated from Meshlab X3D Exported"/>
  <meta name="created" content="15 May 2021"/>
  <meta name="generator" content="Meshlab X3D Exported, http://www.meshlab.net"/>
 </head>
 <Scene>
  <Transform DEF='ORITGT' rotation='0 0 0 0' scale = '0.10 0.10 0.10' >
  <Shape>
   <Appearance>
    <ImageTexture url="&quot;/Ladle/Texture_Ladle.jpg&quot;"/>
   </Appearance>
   <IndexedFaceSet coordIndex="0 1 2 -1 0 2 3 -1 4 1 0 -1 4 0 5 -1 2 1 6 -1 2 6 7 -1 2 8 9 -1 2 9 3 -1 9 10 0 -1 9 0 3 -1 6 1 4 -1 6 4 11 -1 0 10 12 -1 0 12 5 -1 13 14 4 -1 13 4 5 -1 6 15 16 -1 6 16 7 -1 17 8 2 -1 17 2 7 -1 9 8 18 -1 9 18 19 -1 20 10 9 -1
20 9 19 -1 4 14 21 -1 4 21 11 -1 22 15 6 -1 22 6 11 -1 12 10 23 -1 12 23 24 -1 12 25 13 -1 12 13 5 -1 26 14 13 -1 26 13 27 -1 16 15 28 -1 16 28 29 -1 16 30 17 -1 16 17 7 -1 18 8 17 -1 18 17 31 -1 18 32 33 -1 18 33 19 -1 23 10 20 -1 23 20 34 -1 33 35
20 -1 33 20 19 -1 21 14 26 -1 21 26 36 -1 21 37 22 -1 21 22 11 -1 28 15 22 -1 28 22 38 -1 23 39 40 -1 23 40 24 -1 41 25 12 -1 41 12 24 -1 13 25 42 -1 13 42 27 -1 43 44 26 -1 43 26 27 -1 28 45 46 -1 28 46 29 -1 47 30 16 -1 47 16 29 -1 17 30 48 -1 17
48 31 -1 49 32 18 -1 49 18 31 -1 33 32 50 -1 33 50 51 -1 20 35 52 -1 20 52 34 -1 53 39 23 -1 53 23 34 -1 54 35 33 -1 54 33 51 -1 26 44 55 -1 26 55 36 -1 56 37 21 -1 56 21 36 -1 22 37 57 -1 22 57 38 -1 58 45 28 -1 58 28 38 -1 40 39 59 -1 40 59 60 -1
40 61 41 -1 40 41 24 -1 42 25 41 -1 42 41 62 -1 42 63 43 -1 42 43 27 -1 64 44 43 -1 64 43 65 -1 46 45 66 -1 46 66 67 -1 46 68 47 -1 46 47 29 -1 48 30 47 -1 48 47 69 -1 48 70 49 -1 48 49 31 -1 50 32 49 -1 50 49 71 -1 50 72 73 -1 50 73 51 -1 52 35
54 -1 52 54 74 -1 52 75 53 -1 52 53 34 -1 59 39 53 -1 59 53 76 -1 73 77 54 -1 73 54 51 -1 55 44 64 -1 55 64 78 -1 55 79 56 -1 55 56 36 -1 57 37 56 -1 57 56 80 -1 57 81 58 -1 57 58 38 -1 66 45 58 -1 66 58 82 -1 59 83 84 -1 59 84 60 -1 85 61 40 -1 85
40 60 -1 41 61 86 -1 41 86 62 -1 87 63 42 -1 87 42 62 -1 43 63 88 -1 43 88 65 -1 89 90 64 -1 89 64 65 -1 66 91 92 -1 66 92 67 -1 93 68 46 -1 93 46 67 -1 47 68 94 -1 47 94 69 -1 95 70 48 -1 95 48 69 -1 49 70 96 -1 49 96 71 -1 97 72 50 -1 97 50 71 -1
73 72 98 -1 73 98 99 -1 54 77 100 -1 54 100 74 -1 101 75 52 -1 101 52 74 -1 53 75 102 -1 53 102 76 -1 103 83 59 -1 103 59 76 -1 100 77 73 -1 100 73 99 -1 64 90 104 -1 64 104 78 -1 105 79 55 -1 105 55 78 -1 56 79 106 -1 56 106 80 -1 107 81 57 -1
107 57 80 -1 58 81 108 -1 58 108 82 -1 109 91 66 -1 109 66 82 -1 84 83 110 -1 84 110 111 -1 84 112 85 -1 84 85 60 -1 86 61 85 -1 86 85 113 -1 86 114 87 -1 86 87 62 -1 88 63 87 -1 88 87 115 -1 88 116 89 -1 88 89 65 -1 117 90 89 -1 117 89 118 -1 92
91 119 -1 92 119 120 -1 92 121 93 -1 92 93 67 -1 94 68 93 -1 94 93 122 -1 94 123 95 -1 94 95 69 -1 96 70 95 -1 96 95 124 -1 96 125 97 -1 96 97 71 -1 98 72 97 -1 98 97 126 -1 98 127 128 -1 98 128 99 -1 100 129 130 -1 100 130 74 -1 102 75 101 -1
102 101 131 -1 130 132 101 -1 130 101 74 -1 102 133 103 -1 102 103 76 -1 110 83 103 -1 110 103 134 -1 128 129 100 -1 128 100 99 -1 104 90 135 -1 104 135 136 -1 104 137 105 -1 104 105 78 -1 106 79 105 -1 106 105 138 -1 106 139 107 -1 106 107
80 -1 108 81 107 -1 108 107 140 -1 108 141 109 -1 108 109 82 -1 119 91 109 -1 119 109 142 -1 110 143 144 -1 110 144 111 -1 145 112 84 -1 145 84 111 -1 85 112 145 -1 85 145 113 -1 146 114 86 -1 146 86 113 -1 87 114 146 -1 87 146 115 -1 147 116
88 -1 147 88 115 -1 89 116 148 -1 89 148 118 -1 135 90 117 -1 135 117 149 -1 150 151 117 -1 150 117 118 -1 119 152 153 -1 119 153 120 -1 154 121 92 -1 154 92 120 -1 93 121 155 -1 93 155 122 -1 156 123 94 -1 156 94 122 -1 95 123 157 -1 95 157
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103 133 167 -1 103 167 134 -1 168 143 110 -1 168 110 134 -1 163 129 128 -1 163 128 162 -1 135 169 170 -1 135 170 136 -1 170 137 104 -1 170 104 136 -1 105 137 171 -1 105 171 138 -1 172 139 106 -1 172 106 138 -1 107 139 173 -1 107 173 140 -1
174 141 108 -1 174 108 140 -1 109 141 175 -1 109 175 142 -1 176 152 119 -1 176 119 142 -1 144 143 177 -1 144 177 178 -1 144 179 145 -1 144 145 111 -1 145 179 180 -1 145 180 113 -1 180 181 146 -1 180 146 113 -1 146 181 147 -1 146 147 115 -1
148 116 147 -1 148 147 182 -1 148 183 184 -1 148 184 118 -1 117 151 185 -1 117 185 149 -1 186 169 135 -1 186 135 149 -1 187 151 150 -1 187 150 188 -1 184 189 150 -1 184 150 118 -1 153 152 190 -1 153 190 191 -1 153 192 154 -1 153 154 120 -1
```


Figure 4. The XML-based X3D file of the targeted object.

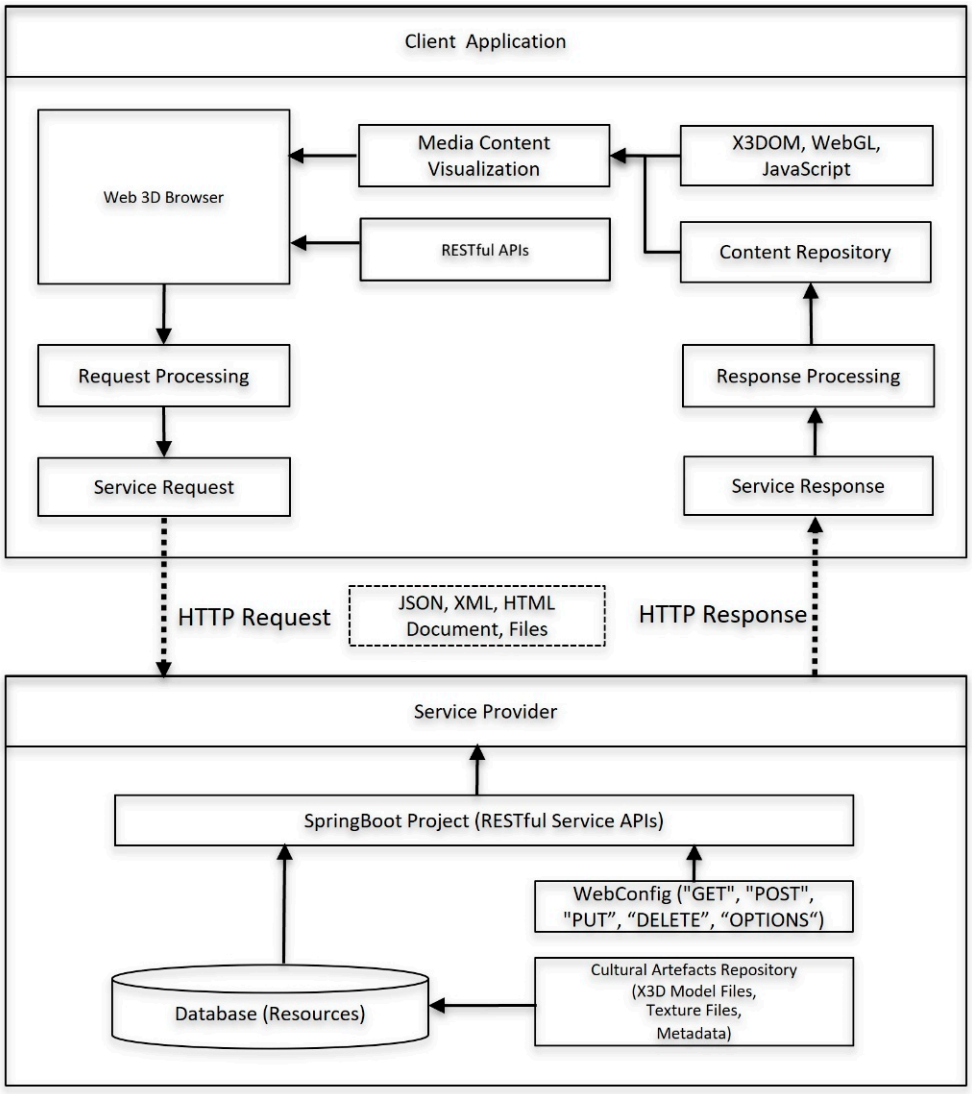


Figure 5. The designed RESTful service API framework.

Moreover, the stateless architecture of RESTful APIs enhances scalability, efficiently supporting distributed systems and handling high request volumes. Their platform-

agnostic nature ensures seamless integration across web, mobile, and desktop applications while benefiting from a well-established ecosystem that accelerates development and debugging. This cost-effective and sustainable approach makes RESTful APIs particularly suitable for smaller museum teams, broadening accessibility and promoting digital cultural heritage preservation.

The service-based architecture offers interactions via HTTP methods where the API is used to send HTTP requests and receive responses in order to acquire 3D models in W3D files by clients on any platform. Users on the client side are able to view and interact with the acquired 3D models that the back-end system sends RESTful service requests and receives responses for visualizing on the X3DOM platform installed in the client's browser. The RESTful service requests are composed of an X3D file request for an edge-based 3D model and a jpg file for the texture of the targeted 3D model. By acquiring 3D models through web-service APIs, web applications can now access cultural content on any open repositories by applying their service APIs.

The service provider project was developed using Spring Tool Suite 4 and consists primarily of a controller and a utility file. The controller includes two service interfaces that provide X3D and texture files for cultural artifacts. These interfaces interact with corresponding modules in the utility file to retrieve the X3D and texture files of targeted objects from the repository. The client web-based application can automatically send requests to the service provider and acquire the necessary X3D content for visualization. Deploying this framework enables client applications to access up-to-date content without requiring any local storage, ensuring efficiency and ease of use. Examples of lightweight, web-based solutions for 3D cultural heritage visualization that minimize storage complexities and data update challenges include OpenHeritage3D [37], 3DViewerOnline [38], and Emb3D [39]. Unlike these systems, our solution supports dynamic retrieval of 3D models via RESTful APIs, eliminating the need for local storage while ensuring high accessibility and real-time content availability.

3. Results and Evaluation Metrics

The digitization of antique kitchen utensils results in the creation of 3D models in X3D files, which are then made available on an open web 3D platform through a RESTful API framework. This API server application is deployed to serve web-based 3D content via HTTP requests. The 3D models are stored in the API server's repository and are accessible through RESTful service APIs by any client-side application. Figure 6 shows the coding in the index.html file of a client application that visualizes the 3D model on a closed platform where all X3D and texture files must be stored in the client-side repository. This contrasts with the approach of connecting to RESTful APIs to request X3D files at URL: https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/item-name.x3d and texture files at URL: https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadTextureFile/texture-item-name.jpg.

Figure 7 illustrates the RESTful API call used to request the texture file of a 3D model. The API request is embedded within the XML code of the X3D model file, enabling X3DOM to request and apply the texture file in real-time during the visualization of the 3D model. For comparison, see Figure 4, which shows the original X3D file with the texture file stored in a local folder.

```
<td file="/TiffinBox/TiffinBox.x3d"><img src="/TiffinBox/TiffinBox.jpg" width="512" height="512" /></td>
<td file="/RiceScoop/RiceScoop.x3d"><img src="/RiceScoop/RiceScoop.jpg" width="512" height="512" /></td>
<td file="/StoneMill/StoneMill.x3d"><img src="/StoneMill/StoneMill.jpg" width="512" height="512" /></td>
<td file="/RicePounder/RicePounder.x3d"><img src="/RicePounder/RicePounder.jpg" width="512" height="512" /></td>
<td file="/TreshingBasket/TreshingBasket.x3d"><img src="/TreshingBasket/TreshingBasket.jpg" width="512" height="512" /></td>
<td file="/GreenPot/GreenPot.x3d"><img src="/GreenPot/GreenPot.jpg" width="512" height="512" /></td>
<td file="/Tray/Tray.x3d"><img src="/Tray/Tray.jpg" width="512" height="512" /></td>
<td file="/Pan/Pan.x3d"><img src="/Pan/Pan.jpg" width="512" height="512" /></td>
<td file="/Pot/Pot.x3d"><img src="/Pot/Pot.jpg" width="512" height="512" /></td>
<td file="/WaterPot/WaterPot.x3d"><img src="/WaterPot/WaterPot.jpg" width="512" height="512" /></td>
```

```
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/Ladle.x3d"><img src="/Ladle/Ladle.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/WaterLadle.x3d"><img src="/WaterLadle/WaterLadle.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/Spatula.x3d"><img src="/Spatula/Spatula.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/Plate.x3d"><img src="/Plate/Plate.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/Bowl.x3d"><img src="/Bowl/Bowl.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/RiceBowl.x3d"><img src="/RiceBowl/RiceBowl.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/RiceMill.x3d"><img src="/RiceMill/RiceMill.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/Basket.x3d"><img src="/Basket/Basket.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/Dipper.x3d"><img src="/Dipper/Dipper.jpg" width="512" height="512" /></td>
<td file="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadX3DFile/WovenBasket.x3d"><img src="/WovenBasket/WovenBasket.jpg" width="512" height="512" /></td>
```

Figure 6. A client-side application calls RESTful service APIs for X3D models.

```
<Appearance>
 <ImageTexture url="https://gcp-tomcat-x3d-zw3xiavvlq-an.a.run.app/data/X3D/downloadTextureFile/Texture_Ladle.jpg"/>
</Appearance>
```

Figure 7. An API call for the texture file embedded into the X3D file.

Figure 8 showcases the client-side web application designed to visualize 3D models of ancient kitchenware, with half of the models retrieved via RESTful API calls (see Figure 6). This demonstrates the feasibility of the designed framework, as it enables real-time visualization of API-acquired 3D models within a web-based 3D application. The application also supports interactive engagement, allowing users to select an image to view the corresponding 3D object and manipulate it using rotate, zoom in, and zoom out functionalities. Figure 6 illustrates the HTML structure, where the first row of images represents X3D models from a local repository, while the second row displays X3D models retrieved via API requests. This approach exemplifies the concept of an interactive museum exhibition, allowing visitors to actively engage with visualized content on the screen, thereby enhancing their experience with cultural artifacts. Similar examples of existing interactive museum displays include LamasaTech [40], The Magic Wall [41], and Intuiface [42], which demonstrate how technology can be leveraged to create engaging and dynamic visitor experiences.

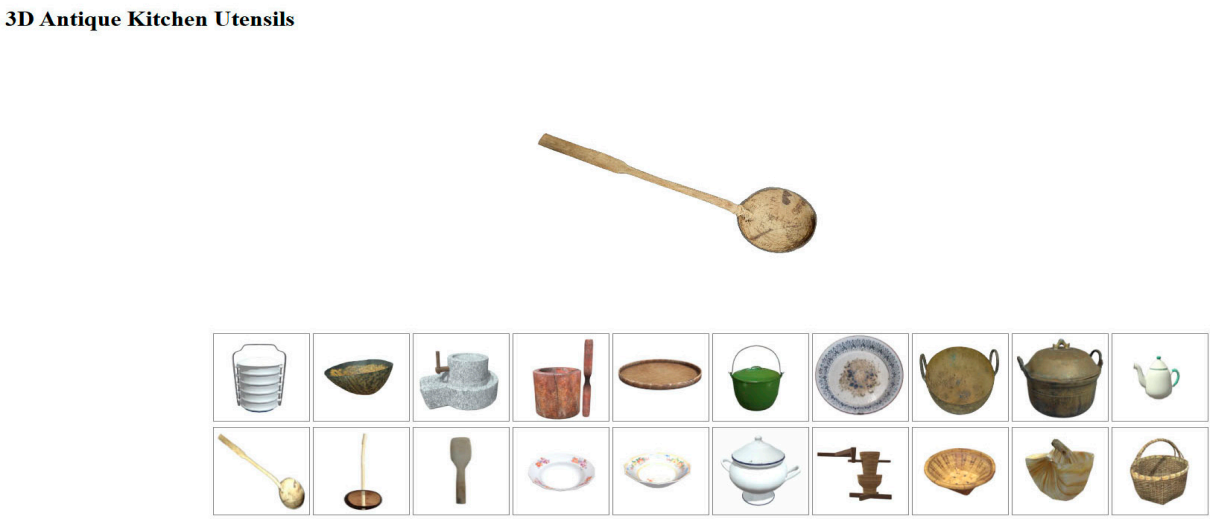


Figure 8. A web 3D-based application visualizing acquired 3D models using X3DOM.

This study focuses on the technical evaluation of the proposed web-based 3D cultural heritage visualization framework using RESTful service APIs, with an emphasis on perfor-

mance benchmarking through response time and API latency. While quality assessment (e.g., usability testing and user experience evaluation) is important for validating user interaction, it falls outside the scope of this research. Instead, future studies will explore user-centered evaluations, assessing ease of use, accessibility, and engagement with the system in real-world scenarios. Table 1 presents the key performance metrics including Total Response Time and API Request Latency. Total Response Time (ms) measures the time taken from a user request to full rendering of the 3D model, including network latency, API processing, and client-side rendering. API Request Latency (ms) measures the time taken for the RESTful API to process and return a response, excluding client-side rendering.

Table 1. The comparison of local vs. API-based 3D model loading.

Model Source	File Type	Size (kB)	API Request Latency (ms)	Total Response Time (ms)
Local Model (file://)	X3D	952 kB	N/A	15 ms
	Texture (jpg)	364 kB	N/A	17 ms
API-Based Model (http://)	X3D	952 kB	296 ms	360 ms
	Texture (jpg)	364 kB	130 ms	170 ms

The performance-benchmarking results highlight the impact of service requests through APIs on 3D model retrieval and visualization efficiency. While local models exhibited near-instant loading times (15 ms for X3D, 17 ms for textures), API-based retrieval introduced network overhead, resulting in higher response times (360 ms for X3D, 170 ms for textures). The primary cause of this delay is API request latency, measured at 296 ms for X3D models and 130 ms for texture files, which reflects the time required for server processing, data transmission, and client-side integration. Despite this increase in response time, the results remain operationally acceptable, as API-based retrieval enables scalability and remote accessibility, essential for cultural heritage applications.

The following section explains the concept behind the designed open framework and highlights the success of delivering X3D models via HTTP requests and RESTful service APIs.

4. Discussion

The client-side application, as displayed in Figure 7, employs both a closed local framework for visualizing X3D models and an open framework facilitated by RESTful service APIs. While both approaches produce the same outcome—rendering the necessary X3D models and their texture files—there are critical considerations when evaluating the sources of these 3D models, especially when models can be requested and obtained from external sources rather than being solely organized within a local repository.

While a local repository offers control and security, the ability to request and integrate 3D models from external sources through an open framework greatly expands the possibilities for developers. It allows for the creation of applications that are not only technically sound but also culturally rich, engaging, and accessible to a global audience. By leveraging RESTful service APIs, developers can tap into existing Museum APIs, such as those offered by Europeana [12] and the Victoria & Albert Museum [13], to acquire cultural content. Although these museums do not provide 3D models of cultural artifacts in their online collections, repositories like Sketchfab do offer downloadable 3D models in formats such as glTF, GLB, and USDZ [14].

Our work provides an additional method for web-based 3D applications to access and visualize X3D models using X3DOM [15]. Since X3D models typically require textures

for realistic display, the open framework we have designed includes two RESTful APIs. These APIs allow the client application to send HTTP requests to retrieve X3D models, which are XML-based files. Each X3D file also contains an embedded HTTP request for its corresponding texture file, ensuring that textures are automatically loaded during the rendering process. This seamless integration enhances the visualization and interactivity of the 3D content, making it a valuable tool for developing immersive digital experiences.

5. Conclusions

The preservation of cultural heritage can adopt various innovative approaches. In our project, we successfully developed two RESTful APIs that deliver X3D and texture files of antique kitchen utensils, significantly aiding in their digital preservation and accessibility. This open framework, which encompasses 3D model acquisition, X3D file conversion, RESTful service APIs, and client-side application development, not only preserves these cultural artifacts but also enhances their global accessibility. The client-side web 3D application demonstrates the practical use of these services, where HTTP requests retrieve and visualize X3D models on a web-based platform. This setup enables interactive user experiences, allowing visitors to engage meaningfully with 3D content. Such frameworks pave the way for expanding digital preservation to a broader array of cultural artifacts, offering a scalable solution for museums and educational institutions worldwide. This project leads to the following conclusions:

1. Cultural Artifact Digitization: Digitizing cultural artifacts is crucial for preserving and documenting cultural heritage, ensuring these treasures remain accessible to future generations. This process represents a significant step toward sustainable heritage management, enabling cultural artifacts to reach a global audience and transcend geographical boundaries and platforms.
2. Advancement in Cultural Content Accessibility: Utilizing RESTful service technology to develop an open framework significantly enhances access to and sharing of 3D cultural content. This advancement facilitates more dynamic and accessible cultural heritage experiences, allowing web-based 3D client-side applications to enrich their offerings by sourcing and visualizing content from diverse repositories.
3. Platform Independence and Scalability: Implementing an open framework with RESTful service APIs for cultural heritage preservation ensures platform independence and scalable access to cultural content from any application capable of processing HTTP requests. This approach supports enhanced visualization of cultural content, including 3D objects, text, and images, across various platforms—not only on Web 3D but also in augmented reality, virtual reality, and beyond.

The objective of this project was to develop RESTful service APIs that provide 3D models of cultural artifacts upon request, facilitating their visualization in web-based 3D client applications. This framework serves as a prototype for museums or online collection sites eager to openly share their cultural artifacts, particularly 3D models, enabling developers and applications to access and visualize them for various purposes. Such accessibility not only promotes the appreciation of digital preservation but also enhances public engagement with cultural heritage in innovative and interactive ways.

The adoption of technologies such as photogrammetry, laser scanning, and RESTful APIs offers significant opportunities for cultural institutions of all sizes. Larger institutions, with greater resources and expertise, can digitize extensive collections, enhance global accessibility, and foster collaborations. For smaller institutions, photogrammetry's low-cost entry and open-source RESTful APIs provide accessible solutions for digitization and online sharing, though challenges like limited budgets and expertise remain. Collaborative frame-

works allow larger institutions to provide support, while smaller ones contribute unique artifacts, promoting inclusivity and enriching global cultural heritage preservation efforts.

Our future work will focus on expanding this framework to include a wider range of cultural artifacts and their associated metadata. This will involve integrating additional content types, such as textual descriptions, images, videos, and historical context, to enrich the user experience and provide a more comprehensive understanding of the artifacts. Additionally, we aim to enhance the scalability and adaptability of the framework by incorporating advanced features, such as real-time interactions, augmented-reality (AR) integrations, and multilingual support. Collaboration with cultural institutions and local communities will also be prioritized to ensure authenticity and inclusivity in the representation of cultural heritage. Finally, usability testing will be conducted with application developers and diverse user groups to refine the framework's functionality and optimize its adoption in both academic and public domains.

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