Journal of Architectural Sciences and Applications
JASA 2023, 8 (2), 969-987
Research article
e-ISSN: 2548-0170
https://dergipark.org.tr/en/pub/mbud

Digital Approach in Conservation of Heritage: 3D Virtual Reconstruction Applications in Ancient Cities

İrem Deniz AKÇAM ERGİN [1]*

ORCID 1: 0000-0002-2784-0224
[1] *Yasar University, Faculty of Architecture, Department of Interior Architecture and Environmental Design, 35100, İzmir, Türkiye.*
*** e-mail**: *irem.akcam@yasar.edu.tr*

Abstract

Virtual reconstruction through digital methods should be implemented in the conservation process to obtain an accurate representation of cultural heritage, establish its value, and ensure the transfer of information to future generations through a secure, reversible, and cost-effective approach. A critical evaluation of fifteen virtual reconstruction applications will be performed regarding their objective, data collection and reconstruction methods, and visual representation outputs. The selected three studies will be analyzed in detail by their superiorities and competencies in reconstruction. The research performs a literature review on cultural heritage conservation, traditional and digital perspectives on conservation, and virtual reconstruction applications. The analysis intends to guide further studies, offering a deeper understanding and clarification of software preferences as virtual reconstruction becomes prominent in archaeology. The study enables the determination and assessment of methodological alternatives through outcomes by comparative review and, as a result, compiles and showcases the suitable techniques for the reconstruction process.

Keywords: *Virtual reconstruction, cultural heritage conservation, 3D modeling and visualization, complementary modeling in ancient cities, digital representation of the past.*

Mirasın Korunmasında Dijital Yaklaşım: Antik Kentlerde 3B Sanal Rekonstrüksiyon Uygulamaları

Öz

Kültürel mirasın aslına uygun şekilde tasvir edilmesi, kültürel değerinin korunması ve bu verilerin gelecek nesillere aktarılması amacıyla mirasın koruma sürecinde güvenli, geri dönüştürülebilir ve maliyet-etkin dijital yöntemlerle sanal rekonstrüksiyon teknikleri uygulanmalı ve yaygınlaştırılmalıdır. Çalışma kapsamında on beş farklı sanal rekonstrüksiyon uygulaması, görselleştirmenin hedefi, veri toplama ve rekonstrüksiyon yöntemleri ile görsel temsil yetenekleri bakımından değerlendirilecektir. Seçilen çalışmalar sanal rekonstrüksiyon alanındaki üstünlükleri ve yeterlilikleri açısından detaylı bir şekilde incelenecektir. Araştırmada, kültürel mirasın korunması, geleneksel ve dijital bakış açıları ve sanal rekonstrüksiyon uygulamalarına dair literatür taraması yapılmaktadır. Analizler, sanal rekonstrüksiyonun arkeolojide öne çıkmasıyla birlikte yazılım tercihleri hakkında daha derin bir anlayış sunarak gelecekteki çalışmalara rehberlik etmeyi amaçlamaktadır. Çalışma, karşılaştırmalı inceleme yoluyla metodolojik alternatiflerin sonuçlar üzerinden değerlendirilmesine ve belirlenmesine olanak sağlamakta ve sonuç olarak rekonstrüksiyon süreci için uygun teknikleri derleyerek sunmaktadır.

Anahtar kelimeler: *Sanal rekonstrüksiyon, kültürel mirasın korunması, 3B modelleme ve görselleştirme, antik kentlerde tamamlayıcı modelleme, geçmişin dijital temsili.*

Citation: Akçam Ergin, İ. D. (2023). Digital approach in conservation of heritage: 3D virtual reconstruction applications in ancient cities. *journal of Architectural Sciences and Applications*, 8 (2), 969-987.
DOI: https://doi.org/10.30785/mbud.1312738

Received: *11/06/2023* – ***Accepted:*** *10/12/2023*

1. Introduction

Curiosity has always encouraged human beings to research and learn. An individual's curiosity about history, society, and the environment leads to discovering and improving the sense of memory. The consciousness of identity grows alongside memory and history with the support of spatial elements. Society establishes connections and identity with a sense of ownership through moral, physical, and spatial attributes. Due to the sense of identity, individuals have become more aware of their heritage, encouraging them to conserve historical structures and artifacts. The conservation of heritage is the beginning of a process that involves improvement. Rather than merely adapting to the passage of time, conservation is viewed as an ongoing and dynamic process, often involving intricate rebuilding operations to unite fragments into cohesive structures.

Integrating digital tools in archaeology has ushered in a paradigm shift from traditional approaches to conserving and reconstructing cultural heritage. Leveraging advanced technologies such as 3D modeling and rendering, archaeologists can digitally recreate ancient sites precisely, ensuring the preservation of historical artifacts and structures. This digital approach safeguards the integrity of fragile remnants and enables virtual exploration and analysis. Virtual reconstruction, the main focus of this study, facilitates interventions without physical disruption, offering a fresh perspective for visually and technically satisfactory outcomes.

With the widespread use of digital software, many designers and architects have attempted to reconstruct complementary models of ancient cities and relics. The process should be completed with a scientific approach and requires broad research, survey and scanning data, measurements, technical drawings, physical analysis, documentation, and comprehensive interdisciplinary work by archaeologists, architects, designers, and art historians. Although the abundance of these studies creates diversity in the literature, it may lead to methodologic confusion due to multiple disorganized data. Some of these inefficient applications are uncertain and may be intended solely to attract tourists, superficially reconstructed by emphasizing only visual aspects without considering historical consistency, lacking technical and appearance details, and having poor ability to represent the actual structure. The primary goal of digital heritage reconstruction should be to achieve a proper representation, similar to on-site restoration and reconstruction.

Within the scope of this paper, fifteen virtual reconstruction applications will be reviewed critically by comparison due to their objectives, methods, and outputs. The selected three examples -Ádám Németh's Ephesus Reconstruction, Gilbert J. Gorski and James Packer's Roman Forum, and Flyover Zone Production's Rome Reborn Project - will be analyzed by focusing on their representations, methodology, and research-based approaches. The cases are chosen due to their outstanding perspectives regarding sequentially realistic visual quality, accuracy and educational guidance, user engagement and up-to-dateness. Each application is remarkable and has the competency to preserve shape-wise, appearance-wise, and constitutive-wise historical accuracy on a large-scale area while comprehensively interpreting and implementing details with differentiating modeling-rendering software in a highly realistic approach to spatial environments that do not exist today, as well as being capable of setting an up-to-date example for future applications with hardware and software used. The study aims to examine the virtual reconstruction applications, clarify the mass of data of digital 3D outputs, and compare their ability to represent history and reflect the heritage accurately and ethically by reviewing the methods to point a direction to further studies.

1.1. Revival of the Past: History and Heritage

Memory and the history of humankind are built together, yet their connection remains unwritten for centuries. Once the need for historiography strikes, the rapid growth of the notion of memory ensures a reconsideration of historical connections (Malicki, 2017). Processing memory through physical spaces is a component of contemporary culture. Places where people establish a materialistic or moral relation are associated with a sense of belonging, ownership, identity, and heritage. Furthermore, a sense of the place corresponds to people's intense social perceptions of a specific space.

One of the places where a strong sense of identity and heritage can be perceived at a high level is the archaeological excavation sites. The ruins in the archaeological areas are the in-situ representatives of tangible heritage. Exhibiting the archaeological finds in situ and making them available to the public is crucial to understanding the heritage in the spatial context (Keskin & Tanaç Zeren, 2018). Archaeological research provides information about prehistoric cultures and, together with written sources, helps to read the past in a historical context. One of the most critical excavations in history is undoubtedly the Pompeii and Herculaneum excavations. The first excavation attempts in Pompeii and Herculaneum, which were under the ashes for 16 centuries, were carried out by Architect Domenico Fontana in the late 16th century. However, the excavations were damaged due to unconscious or poor reconstruction methods, undelivered conservation attempts, and the II. World War. Nevertheless, until the end of the excavations, the architectural, sculptural, painting, and mosaic heritage in Pompeii was unearthed, and archaeology, art history, and architectural data were still obtained. As the notion of conservation of cultural heritage gains importance, efforts have been made to reverse the damage received before (Kazma Çetiner, 2017).

Although heritage is directly connected to identity and collective memory, it can be transferred to a different country from where it was built and belonged due to political and diplomatic issues. As an example, the Pergamon (Zeus) Altar, which belonged to Pergamon, İzmir, was moved due to an agreement, which Turks realized its unfairness later, for benefiting the Prussian and Ottoman Empire at the end of the 19th century and reconstructed at the Pergamon Museum, Berlin (Bayrakdar et al., 2017). Although conserving cultural heritage thrived in the 18th century, many nations and empires, including the Ottoman Empire, could not understand its importance during this period, and unethical behaviors were realized, including artifact smuggling, illegal sales, and damaging artifacts not under the principle of protection.

In 1972, The World Heritage Convention (WHC) included a significant knowledge and method of heritage. Since then, there has been a considerable impact and development in terms of laws and policies, and it continues to frame the discourse about outcomes and the value of heritage. By highlighting the notion of humanity's shared heritage, the WHC has primarily concentrated on the topic (Smith & Akagawa, 2009).

1.2. Cultural Heritage and Conservation

Conservation of cultural heritage is not trying to catch up with time. On the contrary, it can be considered the start of a process and includes the progress of improvement. What is done to preserve the relics transforms into a rebuilding operation to assemble components into a complete unit (Samuel, 1994).

In terms of conserving cultural heritage, four different purposes can be discussed. First, history should be taught thoroughly to every community member to ensure cultural continuation. The second purpose is to seek to nationalize history and integrate it into communities. The natural desire to preserve beauty and meaning is the third reason for conserving heritage. On the other hand, since beauty and value judgments can change over the years, they cannot develop a clear judgment. The final purpose is to evaluate tourism commercially (Tekeli, 1989). The importance of the heritage of a different culture at a time when it did not belong may play a massive role in this case.

The correlation between cultural heritage and archaeology is indisputable. The subject of archaeology has a significant influence on the recreation of history (Harrison, 2013). In archaeology, conservation intends to preserve the excavation site from damage/destruction and necessitates interventions to keep visual accuracy intact. Proper conservation can be accomplished by both protective and restorative actions (Matero, 2008). According to the ICOMOS Venice Charter, after excavation in an archaeological site, these intervention steps should be pursued: Restoration, restitution, reconstruction, and anastylosis. *Restoration* is a procedure that requires adopting measures to maintain the structures' value by reinforcing the current framework to improve the findings' endurance. *Restitution* is defined as the representation of the initial state of a partially collapsed structure by technical drawings or models. *Reconstruction* relies on accessible documentation, restructuring a finding that was entirely or partially demolished or remains in poor condition. Lastly, *anastylosis* is reassembling damaged or removed structural components (Öztürk, 2016).

Traditional reconstruction techniques provide physical authenticity and a tangible representation and allow for hands-on experience and interaction with the structure or city, promoting tourism and economic development in areas with historical or cultural significance. However, it is essential to note that poorly designed projects can crush or do massive damage to the existing heritage element. The process is costly, can cost thousands to millions of dollars, and is time-consuming, particularly for large or complex structures or cities. It also may not be feasible or appropriate for structures or cities that are too damaged or unstable. Furthermore, it may involve the destruction of existing structures or artifacts.

During the 1980s, the quickly developing research of computer modeling and representation started to be adopted by archaeologists as a means of exploring data from excavations (Beale & Reilly, 2015). Paul Reilly, an archaeologist and computer scholar, put the notion of "virtual archaeology" forward in 1990 to refer to the application of computer-based reproductions of historical investigations. Technological advancements generated an environment that may signal significant enhancement in the types and methods of historical substance collected, organized, analyzed, represented, and shared (Reilly, 1990). The various digital resources and methods that the researchers use have provoked a rapid increase in creative work that has completely transformed the field (Morgan, 2022). With the widespread digital approach in the last thirty years, heritage conservation and intervention techniques started to be applied with a digital perspective, at least in one of the data-gathering or reconstruction phases. Unlike traditional techniques, virtual reconstruction provides a safe, reversible, cost-effective alternative to actual reconstruction. The process generates quicker results and can create 3D models of ancient structures that may no longer exist or are difficult to access and simulate changes over time or under different conditions better to understand the evolution of the city or structure.

Overall, virtual reconstruction and actual reconstruction/restoration offer different benefits and drawbacks depending on the context and goals of the project; however, in the project scope, virtual conservation techniques will be analyzed. Before the broad acceptance and use of digital techniques, preservation actions stood out in the sites rather than reconstruction, and it was encouraged that integrated elements ought to be less outstanding than the majority. The modifications should be kept distinct and made with various textures. The strategy was to keep traces of remains as a component of the totality, and reconstruction is strongly discouraged when using traditional procedures (Ahunbay, 2010). Nonetheless, with the development of fully digitized conservation practices, it is now possible to apply virtually without physical intervention to the area, and these new approaches offer a new viewpoint and a field of application to the notion of conservation through visually and technically satisfactory digital outcomes.

1.3. Digital Approach in Conservation: Range-Based, Image-Based and Surveying Methods

Under the main aim of conserving cultural heritage artifacts in a virtual environment, digital approaches are effectively used for both two-dimensional and three-dimensional outcomes (Remondino & Rizzi, 2009, as cited in Korumaz et al., 2011). In order to analyze and apply many inputs and obtain tangible data within the study, an examination was performed of the virtual reconstruction interventions in digital conservation. The Principle of Seville explains virtual reconstruction as creating a model in a virtual environment to visually restore a structure constructed by previous civilizations from concrete proof and scientifically logical comparisons done by experts (Lopez-Menchero & Grande, 2011). In archaeological areas, there are more lost and destroyed items than protected ones, resulting in insufficient incoming data to see the general situation. To achieve enough data, comparison studies can be carried out in cooperation with other principles, not contented with hypotheses. With the development of technology, starting in the 21st century, virtual reconstruction can create satisfactory outputs and results by addressing the data deficit by applying different methodologies. Actual and virtual worlds constantly exchange information, encouraging innovative iterations of rational reflection and nurturing each other (Pietroni & Ferdani, 2021).

The systematic flow of the virtual reconstruction starts with data collection (surveying/scanning). The measurements are documented digitally, and the physical depiction of the structure is created digitally by using visual, photographic, point, survey, and many other data in various formats to relocate the tangible information to a computer-generated status (Korumaz et al., 2011). Afterward, all the information is managed, and interpretations are completed. Two- or three-dimensional theory is constructed according to data. Finally, a source map is added (Pietroni & Ferdani, 2021).

Two alternative approaches are used to generate digital reconstructions; the primary approach is a representation intended to demonstrate the layout and framework of the artifacts, which utilizes techniques that image and range data and survey are used to create actual 3D reconstructions. The other is creating a dynamic avatar that can be used to navigate the environment (Morgan, 2012). Precision, dimensions, mobility, applicability, competence, budget, primary aim, and outcome are considered when choosing which methods to integrate for data gathering (Remondino & Rizzi, 2009).

Image-based modeling (IBM) originated intending to detect the mathematical planes of sites/objects (El-Hakim, 2002) by adjusting two-dimensional images to collect three-dimensional data and measurements using a digital model with a camera model from different angles (Remondino & El-Hakim, 2006). In archaeology, IBM gathers statistical information about structural elements, visual input, mathematical definition, spatial position, dimension and form, surface qualifications, general features, and characteristics. The prominent data processing IBM software of recent years are Autodesk ReCap, COLMAP, Bentley ContextCapture, 3DF Zephyr (Figure 1), and IMAGINE Photogrammetry. IBM generates output as follows: First, thousands of photos are transferred to these programs. Based on these data, the common points in every visual and the distances between points in space are determined, and a point cloud that can be transformed into a three-dimensional mesh model is created. Sufficient visual data is an essential prerequisite for the software (Von Übel, 2021).

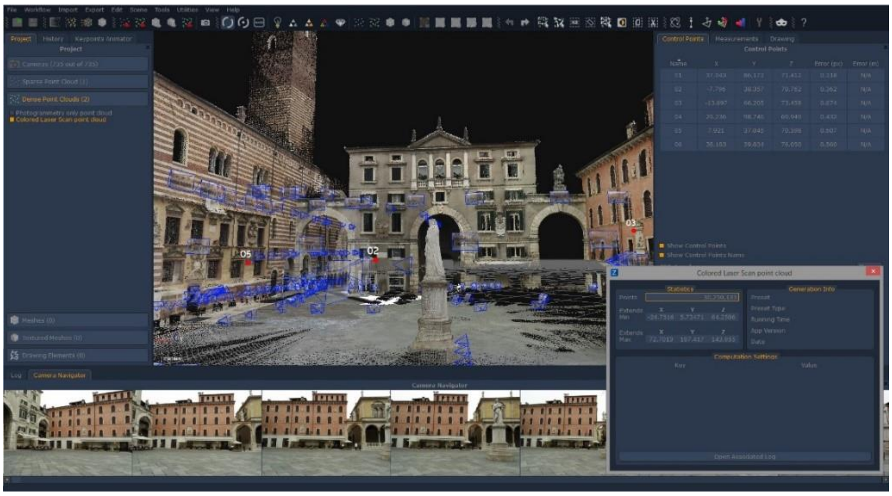


Figure 1. 3DF Zephyr (Alessi, 2016)

In Range-Based Scanning, point cloud data gathered by scanning is converted into a three-dimensional mesh surface created by triangular forms. Geometric precision, modeling that includes all features, affordability, mobility, and versatility of the methodology, can be counted among the beneficial results of the scanning process (Korumaz et al., 2011). While using the method, measuring incorrect sites results in significant inaccuracies (Almagro & Almagro-Vidal, 2007).

When using laser scanners, there are two distinct ways to create three-dimensional models from point cloud data: The initial technique, fundamental structures are determined directly and reconstructed on the cloud. The other approach entails using the point cloud data as a mesh with complicated structures (Chevrier & Perrin, 2008). In Range-Based Scanning, a model can be created by measuring with contact (e.g., Romer) or non-contact apparatus (e.g., LiDaR - Light Detection and Ranging or X-Ray) (Butnariu et al., 2012). To construct a model in three-dimensional format by using RBS, firstly, artifact digitization by gathering info with scanning should be completed. After that process, the monument is fully rebuilt in the artifact reconstruction phase.

Consequently, optimization is carried out to increase certainty by lowering the number of data. Lastly, in the metadata process, the data of the artifacts is organized and transmitted to VR software (recommended) (Neamtu et al., 2012). The hardware designed for Range-Based Scanning includes Airborne Hydrography AB, Bentley Pointools, Leica Geosystems, and RiSCAN PRO (Figure 2).

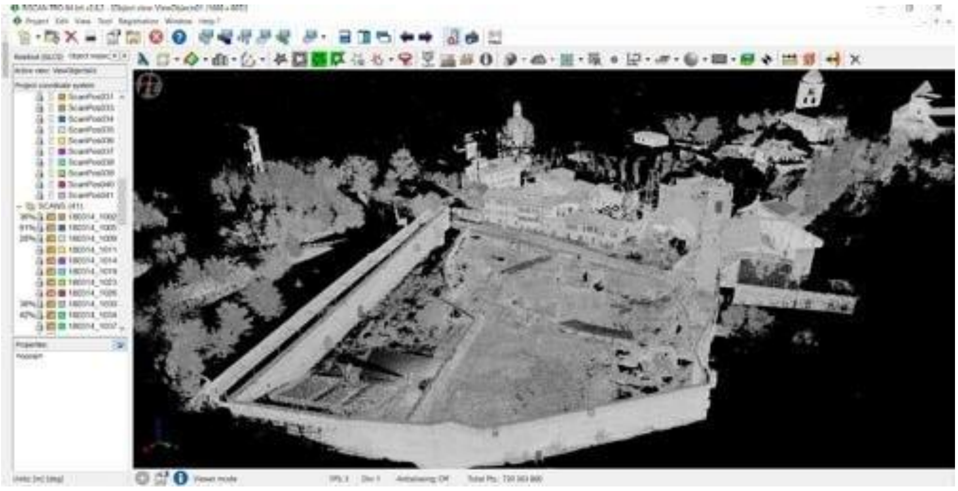


Figure 2. RiSCAN PRO (Malinverni et al., 2018)

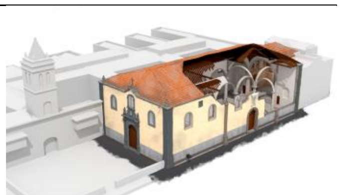
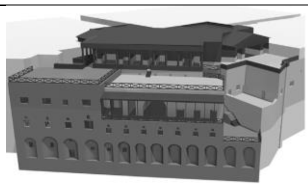
3D Virtual reconstruction can be obtained by traditional or modern surveying techniques, which are now preferred. The modern surveying process starts with utilizing scanned data with measurement range as an initial step. After collecting sufficient data, they will be transferred to a digital environment. The point cloud mesh created in software (for the scanning method) will be transformed into a three-dimensional object (obj) that can be used with various programs for visualization. If the traditional surveying method is applied by adopting the necessary linear measurements, the model is created with layers in CAD/CAM modeling software such as Rhinoceros, Blender, Cinema 4D, SketchUp, Autodesk Revit, and others. For the visualization phase, which reflects the virtual representation of an actual artifact, with software such as Unity, Lumion, 3D Studio Max, Adobe Photoshop, and many other programs, renders are created in accordance with the platform, approach, and purpose of the representation.

As data collecting and reconstruction methods developed and became more accessible, architects/designers began to create virtual copies of relics in all their projects. Nowadays, in most conservation initiatives, digital technologies are used by applying the mentioned software in at least one of the stages, such as measurement, documentation, 3D model design, visualization, and reconstruction. The advantages of being fast, reversible, risk-free, and affordable (compared to actual reconstruction techniques), requiring fewer human resources, and accurate both on tiny and huge scales make it more widespread day by day. However, numerous software/hardware and diversity in output and methodology can create confusion in the research and application process. The primary intention behind the application can be counted as the central aspect that causes this confusion. Although one group of studies proceeds entirely based on scientific data, the other group reaches conclusions far from reality in complementary modeling based solely on visuality and striking elements in detail. In the first group of applications, art historians, archaeologists, architects, and designers work together, and it is a comprehensive process that includes excavation data, literature searches, photographic data, scans, measurements, survey projects, restitution, reconstruction, and visualization stages. In projects that mainly intend to attract the viewer, far from scientific studies, artists generally produce eye-catching illustrations far from a historical basis, with the limited data they have accessed, without employing the crucial survey stages mentioned above and making comparative analyses.

Table 1 is prepared to examine the method-output correlation through 15 virtual reconstruction cases adopting the systematic research approach. They are analyzed in terms of the objective of the study, data collection techniques, methodology of reconstruction, and representation, and selected three projects will be determined deeply about their ability competence and approaches. The study aims to standardize the outputs and results of various methods in this mixed and unarranged data pool in the digital environment with successful examples by considering cases.

Table 1. 3D Virtual reconstruction applications

Heritage	Objective of the Study	Data Collection	Methodology	Visual Representation
Casa di Caecilius Iucundus, Pompeii	Bringing a Significant Contribution to the Archaeological Analysis of Insula V	Archaeological Reports, Image Documentation, Analysis of the Structures and Laser Scanning	MeshLab and Cave Automatic Virtual Environment (CAVE)	
Castell de Vilademàger	Provoking Admiration with Visual Impact Through the Help of Collective Research	Photogrammetry	Blender	
Castellet de Bernabé	Enhancing Heritage Values by Allowing Intellectual Engagement to Cultural Heritage	Archaeological Survey, On-Site Images, Bibliographic and Comparative Research	ArcGIS, Autodesk 3D Studio Max	
Ephesus	Making History Interesting and Accessible for Everybody	Photogrammetry and Laser Scanning	Realworks, Cinema 4D, and Unity	
Kalan Temple in Mỹ Sơn	Suggesting optimized Procedures for Data Processing and Interpretative Methods	Laser Scanning	Rapidform, Modo, Polyworks, Geomagic, Leica Cyclone	
Lecce	Aiming the Realization of Different Outputs to Facilitate the Visit In Situ	Laser Scanning and Image-Based Scanning (SfM)	PhotoScan	
Pergamon or Pergamum	Informative Purposes for Museums and Exhibitions	Research in Collaboration with the Staatliche Museen zu Berlin	Panoramic Drawing and Painting Combined with Digital Installations	

Heritage	**Objective of the Study**	**Data Collection**	**Methodology**	**Visual Representation**
Perugia Fontivegge Station	Proposing to Use the New Devices for Visualisation	Laser Scanning and Photogrammetry	Autodesk 3D Studio Max, Unreal Engine	
Piazza delle Erbe	Providing a Multidisciplinary Approach to Construction	Laser Scanning, Photogrammetry and Historical Documentation	Rhinoceros 3D, Autodesk AutoCAD and Autodesk 3D Studio Max	
Roman Theatre of Fanum Fortunae	Proposing Specific Implementation Guidelines in the Field of Virtual Archaeology	Laser Scanning and Photogrammetry	Layar, GDXLib	
St Augustine Church	Recovering Dilapidated Structures and Creating an Interactive VR Environment	Topography and Terrestrial Photogrammetry	DStretch, Blender, and Unity	
Roman Forum	Providing a Topographically Arranged Series of Chapters that Present the History	Aerial Photography, Laser Scanning, Systematic Surface Collection, Magnetometry, Geochemical Survey	Autodesk Maya, Rhinoceros 3D, Form-Z, and Traditional Drawings Techniques	
Temple of Bel	Piecing Together the Individual 3D Models and the 3D Environment	Data gathering is completed via literature	Autodesk AutoCAD and Autodesk 3ds Max	
The Rome Reborn Project	Supporting New Scholarship by Making It Possible to Re-experience a Vanished Space	Real-world GIS data on ArcGIS	Autodesk 3D Studio Max and CityEngine	
The Sarno Baths in Pompeii	Providing a Quantitative Architectural Evaluation Of the Complex	Laser Scanning and Photogrammetry	Autodesk AutoCAD	

Note. The references are as follows in order: (Dell'Unto et al., 2013) (Resco, 2019), (Portalésa et al., 2016), (Németh, 2017), (Guidi et al., 2014), (Gabellone et al., 2015), (Asisi, n.d.), (Bianconi et al., 2023), (Apollonio et al., 2017), (Quattrini et al., 2015), (Soto-Martin et al., 2020), (Gorski & Packer, 2015), (Denker, 2017), (Frischer & David Massey, 2022), (Bernardi et al., 2019)

2. Material and Method

A literature review was conducted first within the scope of this paper, which is produced from a proficiency in art thesis focusing on 3D virtual reconstruction of a specific ancient city. The relationship between the past and cultural heritage, archaeological excavations, digital approaches to conservation, and visualization are acknowledged by compiling the information in the literature. Following the advent of the technological revolution during the past three decades, the usage of virtual reconstruction in conservation projects has increased rapidly. Obtaining entirely by digital methods or producing some parts of the project, such as data collection and modeling, in a virtual environment is an advantage in increasing the diversity of these studies. However, the fact that studies comparing methods with their advantages or disadvantages are insufficient to the diversity of digitally produced applications may create disorientation for those who make methodological compilations or those who will start a reconstruction project. At the same time, including inadequate studies and inappropriate methods in this data pool may make it challenging to detect meticulous applications.

In the virtual reconstruction process, the preference of the modeling and rendering software carries a crucial role depending on the objected outputs to represent the heritage. The study seeks to conduct a technical exploration of fifteen virtual reconstruction cases derived from rigorous scientific studies, employing a comparative methodology that scrutinizes the study's objectives, data collection methods, software applications, and resultant outcomes (Table 1). Within the subsequent chapter, three selected studies - Ádám Németh's Ephesus Reconstruction, Gilbert J. Gorski and James Packer's Roman Forum, and Flyover Zone Production's Rome Reborn – will undergo thorough critique, dissecting the individual components of the reconstruction tools and processes, including data collection, modeling and rendering languages, methods, and visualization techniques.

Ádám Németh's Ephesus Reconstruction Project is selected for this study due to his successful interpretation of eye-catching and striking coloration, although there is no study on the paints used in Ephesus. The study is among the most successful visual outputs of ancient city models. At the same time, the 3D models he created are millimetrically correct and definitive as he uses photogrammetry and scanning data from excavations. These astonishing representations were featured in the press (Tuna, 2017) and Visit Ephesus (a project of the Selçuk Chamber of Commerce). The realism of the designed model makes the viewer feel like a time traveler visiting Roman cities. His project objective is for public outreach.

Gorski and Packer's study is generally considered guiding and pioneering, regardless of the virtual reconstruction outputs. Gilbert Gorski and James Packer attempted to approach the Roman Forum as an architectural entity with their study, a manual explaining the connections among numerous monuments and structures. Their fundamental area of focus is on the provision of reconstruction drawings, and the objective of their study is educational. The study is among the most accurate representations due to the scientific research and knowledge in the background.

Flyover Zone Production (founded by Bernard Frischer) The Rome Reborn Project is the last selected project to be examined in detail. The first Rome Reborn (Rome Reborn 1.0) was created by Bernard Frischer again in 2007 (the project started in 1996). Rome Reborn 4.0 version of the application is remade with up-to-date digital reconstruction methods. The newest version has become superior due to the user-engaged and interactive approach created using virtual reality, digital tours, and flying simulations over the city to enhance the user experience. The objective of their study is research and discovery. The study is crucial for understanding changes in constantly evolving technologies in the virtual reconstruction process of ancient cities. Rome Reborn Project remains one of the most up-to-date applications for user engagement, steadily adopting advanced software.

The context of the critical evaluation includes the following components: Elaboration of data collection, encompassing the sources of historical data, archaeological surveys, or alternative methodologies employed to procure pertinent information; A comparative exposition provided on the software and digital tools utilized in the virtual reconstruction process, along with an examination of the features that impact the reconstruction; The rationale behind the selection of programming languages and their role in accomplishing the project objectives; How visualization techniques improve the overall representation and contribute to the goals of the study; Specific criteria employed for the comparative assessment of methodologies, including accuracy, visual realism, historical authenticity, and other pertinent factors.

In essence, these cases transcend mere accuracy; they encapsulate a holistic and pioneering approach, making them invaluable for shaping the future of virtual reconstruction in archaeology. In light of these comprehensive analyses, it aims to perform comparative reviews and critical evaluation of the cases according to their methodologies and guide future studies by systematizing the methods while showcasing outputs applicable to the diverse purposes and designs of upcoming research endeavors.

3. Research Findings

As shown in Chapter 1.3 Table 1, although the data collection methods are the same, the outputs of the studies vary due to the study's objective and modeling-rendering methods being altered. This differentiation is valid for all three substances, which form integrity together, creating the final virtual reconstruction output. The applications selected within the scope of this study will be examined in detail from these perspectives.

The virtual reconstruction of the Ancient City of Ephesus by Ádám Németh is one of the most outstanding representations of an ancient city. The artist completed his year-long project by reconstructing numerous significant monuments from Ephesus, including the Library of Celsus (Figure 3), Terrace Houses, Curetes Street, Memmius Monument, Temple of Artemis, and many other monuments. As Németh himself mentioned on his official web page, his primary goal is to generate the past in an exciting way and make it accessible to people (Németh, n.d.). Németh's virtual reconstruction approach primarily focuses on using archaeological data to create exact 3D models of ancient cities. He builds thorough 3D representations of ancient sites by combining photogrammetry, laser scanning, and other 3D scanning methods. Methodology-wise, Németh's strategy seems to be built on an exacting and scientific procedure for gathering and analyzing data. His understanding of Roman architecture and civilizations allowed him to identify the missing features of the structures (Varga, 2021).

Figure 3. Library of Celsus (Németh, 2017)

Németh's method is noticeable for using advanced visualization techniques to build engaging and lifelike virtual environments. He used Realworks to process scanning data Cinema 4D to manage the polygons and transfer from meshes. Using an interactive approach, he could also utilize Unity to produce virtual tours and simulations of ancient cities. He created an application called Wonderful Ephesus with 3D interactive reconstruction that will be adapted to Virtual Reality. With the help of the simulations, users can explore the places in ways that are not conceivable with conventional 2D images or even actual trips to the locations. Regarding visual differences, Németh uses photorealistic textures to create environments close to the original. Although the pigment test was not performed on monuments or structures, he notes that these pieces were believed to be coated in vivid colors and proposes a plausible possibility (Varga, 2021).

As can be seen in Figure 4, which demonstrates a wealthy family's house in Terrace Houses, there is a mosaic depicting a majestic lion with its head pointed in the direction of the viewer, surrounded by geometric patterns and floral motifs. The lion is represented in detail, with realistically sculpted musculature and fur. The mosaic is a prime example of the Roman technique of opus vermiculatum, where small pieces of colored marble and glass are used to create intricate and detailed patterns (Pekridou-Gorecki, 2013). Since the original work contains many finely elaborated mosaic details, its reconstruction must be done with the same care and meticulousness. Németh, in this case, almost gives the impression that all the mosaics and murals have been individual, piece by piece, restored, and reconstructed (Figure 5). To raise the structure, he used vivid colors in mosaics, murals, and material-related textures on walls. He enhanced the work by adding details containing clues about daily life, such as mattresses, chairs, household items, and more.

Figure 4. Terrace houses (Németh, 2017)

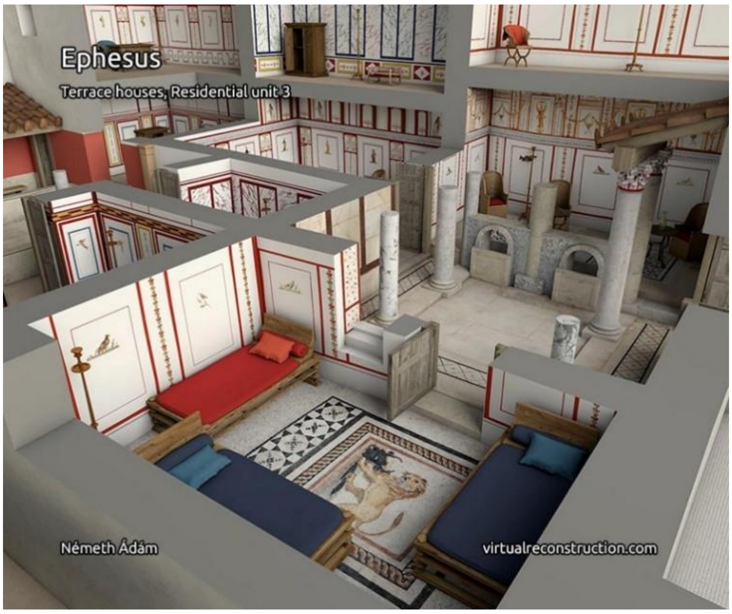


Figure 5. Virtual Reconstruction of terrace houses (Németh, 2017)

As the second example, the visuals created by Gilbert J. Gorski appeared in their books with James E. Packer entitled The Roman Forum: A Reconstruction and Architectural Guide (2015), successfully depict how The Roman Forum, most of its structures and monuments are in ruins today, looked years ago with virtual reconstruction techniques. Gorski and Packer's study on the Roman Forum stands out for its precision and educational value, prioritizing the provision of accurate reconstructions for various monuments focused on architectural entities. The team used aerial photography, LiDAR, systematic surface collection(field-walking), geophysical survey (magnetometry), geochemical survey, and excavation data for data collection. Gorski generally uses Autodesk Maya and Rhinoceros 3D for modeling, including traditional drawing techniques and hand sketches, and Adobe Photoshop and Form-Z for coloring and rendering. He also recommends Houdini, 3ds Max, Cinema 4D, and Revit (Gorski, 2014). Even though they did not mention it in the scope of the text, it can be predicted that he used Maya and Rhinoceros for The Roman Forum to work efficiently on organic forms and Form-Z for rendering to manipulate the visuals. Gorski also prefers using dramatic and intense colors for interior and exterior spaces. He depicted the motifs on the column heads, the mosaics on the floor, and the murals on the walls by examining the historical sources for that period and the data available in a manner closest to reality. The rendered angles of interior spaces (Figure 6) help viewers understand the size and approximate dimensions of the space and its relation to the other structures outside. The human figures placed in the interior, looking at the drawings and talking, aim to give information about the clothing, appearance, and lifestyle of the people of that period.

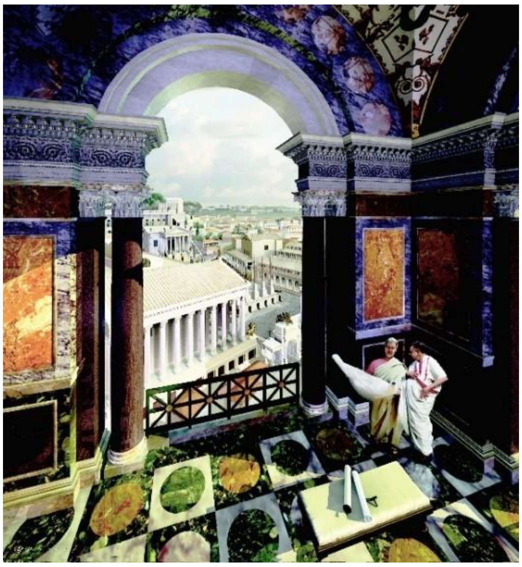


Figure 6. The Roman Forum interior render (Gorski & Packer, 2015)

The exterior renders (Figure 7) are taken at a large scale and from aerial angles that can fit many structures. At the same time, a realistic visual was created by adding the vegetation of the area and the structures that add depth to the background. Although it is created on a vast scale and wide angles, even small details of the sculptures can be seen in the renders.

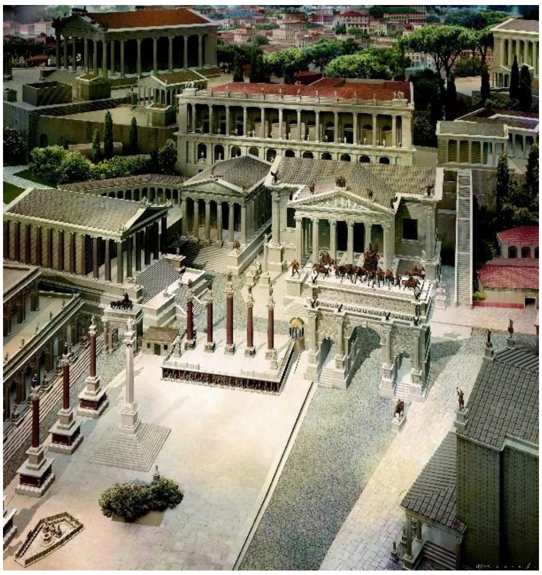


Figure 7. The Roman Forum exterior render (Gorski & Packer, 2015)

Gorski and Packer mainly focus on using virtual reconstructions as a tool for education and public outreach. The outputs serve the purpose of analyzing the relationship of structures for architectural improvement and explaining the background and nature of the structures to the audience by providing a more engaging and immersive experience, helping to promote an understanding and appreciation of ancient cultures. In Gorski's renders of The Roman Forum, he uses texture mapping and lighting to reveal the accurate depiction of the structures by paying attention to the small details to ensure that the models are nearly identical to the original. A supposedly neutral, or maybe "objective," perspective characterizes the stare into the reconstructed Forum, and weather and environment details provide life to the sights. However, selecting views and choices according to the particular moment of day or year results in an inherently subjective representation of the Forum. Within the scope of Gorski and Packer's study, they also explained the construction techniques and historical backgrounds of every architectural element, including foundations, columns, corinthian capitals, architrave/friezes and cornices, roofs, and other details, which makes it an excellent source for reconstruction projects.

The Rome Reborn Project was created by Flyover Zone Productions, founded by Bernard Frischer for the study' 3D Urban Models as Tools for Research and Discovery Two Case Studies of the Rostra in the Roman Forum Utilizing Rome Reborn' by Frischer & Massey (2022). The studies of Rome Reburn started in 1996, and the first version was released in 2007. The team used Autodesk 3D Studio Max and Multigen Creator to reconstruct the first versions (Dylla et al., 2010). In Rome Reborn 4.0, the designers/architects used real-world GIS data and produced a large-scale city using the software ArcGIS. They modeled the area using Autodesk 3D Studio Max and CityEngine, presented the city with advanced visualization techniques and real-time rendering, and adapted it to virtual reality. The software enables quick alterations to the city's architectural details and characteristics to quickly build a wide range of design possibilities using existing data. The renders are designed from the perspective of an observer in the ancient city rather than large-scale aerial photography. The perspective and camera angles can be controlled according to the detail intended to be portrayed in the render. As shown in Figure 8, the perspective is arranged for an observer of medium height, leaning against the wall of Regia in an x direction. The sight of the monument's exterior is restricted and requires elevating the head by 60 degrees. In the top right corner, CityEngine displays the scene as it might have seemed in ancient times by a person.

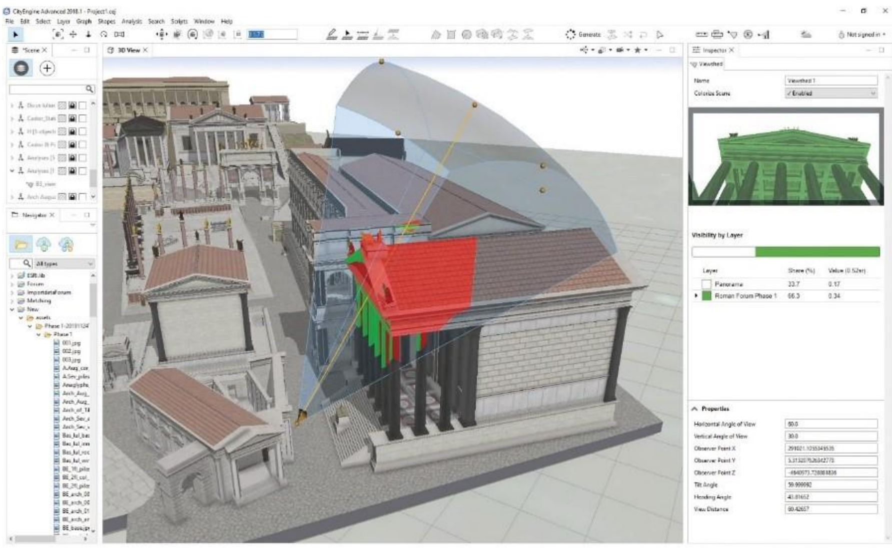


Figure 8. The model of the City of Rome in CityEngine (Frischer & Massey, 2022)

In the exterior renderings (Figure 9), the angle is designed to emphasize how magnificent and enormous the structures are compared to humans. The material differentiation in the structures and monuments can be easily detected as the gold, marble, and stone materials are depicted with textures and reflections of light rather than only colors. Furthermore, in addition to the other two virtual reconstruction cases, hyper-realistic 3D renders, videos, and animations were also created for The Roman Forum.

Figure 9. The Rome Reborn Project exterior render (Frischer & Massey, 2022)

Flyover Zone Productions created many virtual tours of reconstructed cities, such as the Acropolis in Athens, Tenochtitlan in Mexico, and the Tomb of Ramesses VI in Egypt. By taking advantage of gamification elements, the user experience is enhanced in virtual tours and simulations, allowing users to explore the ancient city fun and engagingly.

The selected studies mainly aim to serve public outreach by making heritage accessible for user engagement, using digital representation as a learning tool, designing a gamification element for virtual tourism and increasing interactive user experience. Regarding the three studies selected for this paper, visual outputs are highly rigorous and satisfactory in terms of the proximity to the actual state of the structure. Ádám Németh's approach focuses on coloring, decoration, and realism. In contrast, Gilbert J. Gorski and James Packer's approach is accurate, detailed, and guiding. Bernard Frischer (Flyover Zone Production) is outstanding due to its up-to-date and innovative approach. The data for the studies is gathered using Aerial Photography, Laser Scanning, Systematic Surface Collection, Magnetometry, Geochemical Survey, and Photogrammetry. For modeling and rendering, Autodesk Maya, Rhinoceros 3D, Trimble Realworks, Form-Z, Cinema 4D, Unity, Autodesk 3D Studio Max, and ArcGIS CityEngine are used which provide different prominent features, and each creates altering outputs and visuals compatible with the project objectives (Table 2).

Table 2. Method-result comparative analysis for selected cases

Selected Virtual Reconstructions	Software Preferences	Capabilities and Offerings of the Programs	Standout Features and Qualifications	Results and Outputs
The Ancient City of Ephesus by Ádám Németh	Trimble RealWorks, Cinema 4D, Unity	High-Quality Deliverables, 3D Toolset for Modeling, Motion Graphics, VFX, Powerful Renderings and Animations	Robust, Efficient, Flexible, and Adaptable for AR/VR	Realistic, Effectively Colored, and Adorned with Decorative Details, and VR adapted
The Roman Forum by Gilbert J. Gorski and James Packer	Autodesk Maya, Rhinoceros 3D, Form-Z	Advanced NURBS and Polygon Modeling, Creating and Modifying Animations, Compatibility with BIM, Parametric Design with Grasshopper	Limitless Complexity, Precise, Versatile, Interoperable, Solid and Adaptable to BIM	Accurate Model, Abundant Technical Details, and Guiding Reconstruction Process
The Rome Reborn Project by Bernard Frischer (Flyover Zone Production)	Autodesk 3D Studio Max and ArcGIS City Engine	Procedural Modeling, High-Quality Materials, Computer Generated Architecture, Large-Scale and Dynamic City and Urban Layouts, Customizable UI, Data Interoperability	Dynamic, Geospatial, Interactive, Creative Pipeline and Workflow	Up-to-date Techniques and Results, User Engagement, and Innovative Approach

The software mentioned above used for the data gathering and applications is sufficient to achieve the representational goals and outputs. In addition, Blender (standout for sculpting, retopology, modeling, curves), Solidworks (enables large assembly design, rapid prototyping, mold tool design), Autodesk Fusion 360 (parametric modeling, integrated simulation, cloud collaboration), Autodesk Recap (detailed models of real-world assets, expanded point cloud registration), Autodesk Revit (interoperability, generative design, cloud rendering) and many others can also be utilized during the reconstruction process regarding the compatibility to shape (geometry, size, spatial position), appearance (surface features), and constitutive elements (physical form).

4. Discussion and Conclusion

It is undeniable that virtual reconstruction gives successful outputs; however, several ethical and epistemological questions are involved in the process of virtual reconstruction, especially when determining what constitutes the "true" representation of the heritage. The theory of truth posits that a statement is true if it corresponds to a fact in the existing world. This theory emphasizes the relationship between language and reality and suggests that truth is independent of language but is defined through it (Günday, 2003). The visual representation can only be transferred accurately through appropriate software and design language.

Virtual reconstruction studies deal with different aspects of interdisciplinary fields, establish relationships, and examine the common aspects based on scientific principles of distinctive approaches. One of the main issues is the subjective nature of virtual reconstruction itself. Within the virtual construction process are collective decisions and confident choices about what to include or leave out and how to represent historical features. Architectural descriptions, including technical drawings, angled views, and three-dimensional models, are essential tools for conserving throughout the design stage of the building process methodologically. Modeling and rendering software, the environment, and the design of the structure can be counted as the aspects that affect perceptual accuracy. The design choices are mainly influenced by the assumptions, beliefs, or values of the people or teams undertaking the reconstructions that may lead to varying interpretations and representations of cultural heritage. Virtual reconstruction applications that overlook or downplay these variables risk misrepresenting or losing important historical information, which could diminish the meaning and relevance of heritage. For this reason, multidisciplinary teamwork and quantitative and qualitative testing of multiple software are also essential. No single "true" or objectively accurate view of the past exists. Several perspectives and interpretations of heritage can coexist. It is essential to assess how well virtual reconstructions can precisely and respectfully capture the complexity and diversity of the past while also conforming to various viewpoints and interpretations.

In contemporary conservation efforts within excavation sites, digital methodologies play an integral role in at least one process phase. The increasing prevalence of these methods daily has led to the emergence of rich but, at the same time, numerous and confusing data regarding reconstruction in which different methods are used. The study's objective is to provide precise methodological insights by systematically comparing and examining established practices, deriving appropriate outcomes from the intricate data pool associated with virtual reconstruction methods. In this context, a comprehensive comparison was conducted among fifteen virtual reconstruction applications, focusing on their objectives, data acquisition methods, and modeling-visualization techniques. After the initial comparative analysis of diverse applications, a more detailed examination focused on three specific projects, each distinguished for its expertise within its field. These extensive analyses unfolded across three distinct approaches, thoroughly assessing each project. The first approach delved into software preferences in virtual reconstruction, exploring differences in the selection of data gathering and modeling programs, intricacies, and functionalities. The second perspective aimed to uncover capabilities and offerings within selected programs, examining tools and features. Attention was given to software versatility, efficiency, and adaptability to virtual reconstruction requirements. Concurrently, the analysis focused on standout qualifications unique to each project, identifying attributes that set them apart and seeking innovation, pioneering technologies, or novel approaches to virtual reconstruction. Lastly, the third perspective scrutinized these projects' results and outputs, emphasizing quality, accuracy, and overall effectiveness, evaluating how well these projects translated methodologies and capabilities into tangible outcomes. This analysis aimed to provide a comprehensive understanding of each project's strengths and competencies within the broader context of virtual reconstruction. A compilation of potential methodologies for future studies has been outlined based on the outcomes of the comparative reviews.

As our ability to see ourselves and the environment improves, the virtual and physical definitions constantly change. Marcel Proust defined virtual as "real but not actual, ideal but not abstract." Deleuze argued that the virtual is antithetical to the actual rather than real based on that description. He asserts that real and possible oppose one another (Deleuze, 1988). The virtual is just as real, despite not having a physical reality like the real. In the digital age, this distinction is crucial because it preserves the reality of what is seen or perceived on a digital screen (Buchanan, 2018).

In conclusion, virtual reconstruction can be a helpful tool for comprehending and interacting with cultural heritage. However, it is necessary to approach the subject with critical thinking and moral sensitivity, analyze it from different perspectives through interdisciplinary studies, identify the possibilities of representing the past through digital media, and use appropriate methods according to the objectives.

Acknowledgments and Information Note

This article is produced from a Proficiency in Art thesis that will be completed in the 2022-23 Summer Period at Yaşar University Graduate School, Program of Art and Design. The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

There is only one author who contributed to the study. There is no conflict of interest.

References

Ahunbay, Z. (2010). Arkeolojik alanlarda koruma sorunları kuramsal ve yasal açılardan değerlendirme. *TÜBA-KED Türkiye Bilimler Akademisi Kültür Envanteri Dergisi*, (8), 103-118.

Akgün, Y. (2005). *Perception of space through representation media: A comparison between 2D representation techniques and 3D virtual environments*. (Master's thesis). İzmir Institute of Technology, İzmir, Turkey. Accessed from database Access Address (12.05.2023): https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

Alessi, A. (2016). *3DF Zephyr 3.0 is out now!* 3D Flow. Access Address (22.03.2023): https://www.3dflow.net/3df-zephyr-3-0-released/

Almagro, A. & Almagro-Vidal, A. (2007). Traditional drawings versus new representation techniques.

Apollonio, F. I., Gaiani, M., Fallavollita, F., Giovannini, E. C. & Foschi, R. (2017). A Journey in the Fourteenth Century. A Digital Reconstruction of Piazza delle Erbe in Verona. English version, 35.

Asisi, Y. (n.d.). Discovery of the panoramas. Retrieved from https://www.asisi.de/en/yadegar-asisi/biography

Bayrakdar, B., Kucak, B., Karabulut, İ., Ege, İ. & Öcal, M. (2017). Osmanlı arşiv belgeleri ışığında Bergama Zeus Sunağı'nın Berlin'e götürülüşü hakkında bazı düşünceler. *Çağdaş Türkiye Tarihi Araştırmaları Dergisi*, 17 (34), 43-67.

Beale, G. & Reilly, P. (2015). Additive archaeology: the spirit of virtual archaeology reprinted. *Archaeological Research in the Digital Age*, 120.

Bernardi, L., Busana, M. S., Centola, V., Marson, C. & Sbrogiò, L. (2019). The Sarno Baths, Pompeii: architecture development and 3D reconstruction. *Journal of Cultural Heritage*, 40, 247-254.

Bianconi, F., Filippucci, M., Cornacchini, F., Meschini, M. & Mommi, C. (2023). Cultural Heritage and Virtual Reality: Application for Visualization of Historical 3D Reproduction. The International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences*, 48, 203-210.

Buchanan, I. (2018). A dictionary of critical theory. *Oxford University Press.*

Butnariu, S., Gîrbacia, F. & Orman, A. (2012). Methodology for 3D reconstruction of objects for teaching virtual restoration. *On Virtual Learning*, 46.

Chevrier, C. & Perrin, J. P. (2008). Laser range data, photographs, and architectural components. *ISPRS* (pp. 1-6).

Dağ, M. (2004). Sanal ve gerçek üzerine düşünceler. *Ondokuz Mayıs Üniversitesi İlahiyat Fakültesi Dergisi*, *16*(16), 25-41.

Deleuze, G. (1988). Bergsonism. *New York: Zone Books.*

Dell'Unto, N., Leander, A. M., Dellepiane, M., Callieri, M., Ferdani, D., & Lindgren, S. (2013, October). Digital reconstruction and visualization in archaeology: Case-study drawn from the work of the Swedish Pompeii Project. In *2013 Digital Heritage International Congress (DigitalHeritage)* (Vol. 1, pp. 621-628). IEEE.

Denker, A. (2017). Rebuilding Palmyra virtually: Recreation of its former glory in digital space. Virtual Archaeology Review, 8(17), 20-30.

Dylla, K., Frischer, B., Müller, P., Ulmer, A. & Haegler, S. (2010). Rome reborn 2.0: A case study of virtual city reconstruction using procedural modeling techniques.

El-Hakim, S. F. (2002). Semi-automatic 3D reconstruction of occluded and unmarked surfaces from widely separated views. *International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences*, *34*(5), 143-148.

Frischer, B. & Massey, D. (2022). *3D urban models as tools for research and discovery.* Critical Archaeology in the Digital Age: Proceedings of the 12th IEMA Visiting Scholar's Conference (Vol. 2, p. 23). ISD LLC.

Gabellone, F., Ferrari, I., Giuri, F. & Chiffi, M. (2015, October). The contribution of the 3D study for new reconstructive proposals of Lecce in the Roman age. In IMEKO TC4. Proceedings of the 1st International Conference on Metrology for Archaeology (Benevento 2015) (pp. 534-538).

Gorski, G. (2014). Hybrid drawing techniques: Design process and presentation. Routledge.

Gorski, G. J. & Packer, J. E. (2015). The Roman Forum: a reconstruction and architectural guide. *Cambridge University Press.*

Guidi, G., Russo, M. & Angheleddu, D. (2014). 3D survey and virtual reconstruction of archeological sites. *Digital Applications in Archaeology and Cultural Heritage*, 1(2), 55-69.

Günday, Ş. (2003). Doğru ve doğruluk kuramları. *Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, *2*(1-2), 187-195.

Harrison, R. (2013). Heritage. In *The Oxford handbook of the archaeology of the contemporary world*.

Kazma Çetiner, M. (2017). *Napoli Pompei arkeolojik sit alanındaki koruma amaçlı müdahalelerin değerlendirilmesi* (Master's thesis). Yıldız Teknik Üniversitesi, İstanbul. Accessed from database Access Address (19.04.2023): https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

Keskin, Y. & Tanaç Zeren, M. (2018). Arkeolojik alanlarda bir sunum yöntemi olarak "Arkeoparklar". *Journal of Architectural Sciences and Applications*, 3 (2), 110-124. DOI: 10.30785/mbud.439805

Korumaz, A. G., Dülgerler, O. N. & Yakar, M. (2011). Kültürel mirasın belgelenmesinde dijital yaklaşımlar. *Selçuk Üniversitesi Mühendislik, Bilim ve Teknoloji Dergisi*, *26*(3), 67-83.

Lopez-Menchero, V. M. & Grande, A. (2011). *The principles of the Seville Charter.* CIPA Symposium (Vol. 2011, pp. 2-6).

Malicki, H. E. O. (2017). Günümüz sanatında tarihin yeniden canlandırılması: Jeremy Deller ve Orgreave çatışması örneği. *Güzel Sanatlar Enstitüsü Dergisi*, (39), 116-130.

Malinverni, E. S., Pierdicca, R., Bozzi, C. A. & Bartolucci, D. (2018). *Evaluating a SLAM-based mobile mapping system: a methodological comparison for 3D heritage scene real-time reconstruction.* 2018 Metrology for Archaeology and Cultural Heritage (MetroArchaeo) (pp. 265-270). IEEE.

Matero, F. G. (2008). Heritage, conservation, and archaeology: An introduction.

Morgan, C. L. (2012). *Emancipatory digital archaeology*. University of California, Berkeley.

Morgan, C. (2022). Current digital archaeology. *Annual Review of Anthropology*, 51, 213-231.

Neamtu, C., Comes, R., Matescu, R., Ghinea, R. & Daniel, F. (2012). *Using virtual reality to teach history.* 7th International Conference on Virtual Learning (București: Editura Universitatii din Bucuresti) (pp. 303-310).

Németh, A. (2017). *Virtual reconstruction of the Celsus Library in Ephesus, Turkey | New color scheme | 2018.* Access Address (13.03.2023): https://virtualreconstruction.com/wp/?p=675

Németh, A. (2017). *Virtual reconstruction of the residential unit 3 of the Terrace Houses in Ephesus, Turkey | 2017.* Access Address (13.03.2023): https://virtualreconstruction.com/wp/?p=666

Németh, A. (n.d.). *About Ádám Németh's virtual reconstructions.* Access Address (15.03.2023): https://virtualreconstruction.com/wp/?p=666

Öztürk, H. H. (2016). *Arkeolojik alanların korunmasında planlama ve yönetim: Ören yerlerinin çevre düzenlemesi*. (Ph.D. thesis). Ankara University, Ankara. Accessed from database Access Address (15.04.2023): https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

Pekridou-Gorecki, A. (2013). Mosaics of Ephesus: The Great Theatre, Odeion, Terrace Houses, and the Celsus Library. *Koc University Press.*

Pietroni, E. & Ferdani, D. (2021). Virtual restoration and virtual reconstruction in cultural heritage: Terminology, methodologies, visual representation techniques and cognitive models. *Information*, *12*(4), 167.

Polat, N. & Uysal, M. (2016). Hava lazer tarama sistemi, uygulama alanları ve kullanılan yazılımlara genel bir bakış. *Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi*, *16*(3), 679-692.

Portalés, C., Alonso-Monasterio, P. & Viñals, M. J. (2017). 3D virtual reconstruction and visualisation of the archaeological site Castellet de Bernabé (Llíria, Spain). Virtual Archaeology Review, 8(16), 72-85.

Quattrini, R., Pierdicca, R., Frontoni, E. & Barcaglioni, R. (2016). Virtual reconstruction of lost architectures: from the TLS survey to AR visualization. The International archives of the photogrammetry, remote sensing and spatial information sciences, 41, 383-390.

Reilly, P. (1990, March). Towards a virtual archaeology. In *Computer Applications in Archaeology* (pp. 133-139). Oxford: British Archaeological Reports.

Remondino, F. & El-Hakim, S. (2006). Image-based 3D modeling: a review. *The photogrammetric record*, *21*(115), 269-291.

Remondino, F. & Rizzi, A. (2009). *Reality-based 3D documentation of world heritage sites: methodologies, problems and examples.* 22nd CIPA Symposium, Kyoto, Japan.

Resco, P. A. (2019). The Vilademàger Castle: Shaping a Virtual 3D Reconstruction. Retrieved from https://parpatrimonioytecnologia.wordpress.com/2019/01/29/el-castell-de-vilademager-dando-forma-a-una-reconstruccion-virtual-en-3d/

Samuel, R. (1994). Theatres of memory, Volume 1. *Past and Present in Contemporary Culture*, 280.

Smith, L. & Akagawa, N. (2009). Intangible heritage (p. 1). *London: Routledge.*

Soto-Martin, O., Fuentes-Porto, A. & Martin-Gutierrez, J. (2020). A digital reconstruction of a historical building and virtual reintegration of mural paintings to create an interactive and immersive experience in virtual reality. Applied Sciences, 10(2), 597.

Tekeli, İ. (1989). *Kentsel korumada değişik yaklaşımlar üzerine düşünceler.* Türkiye II. Dünya Şehircilik Günü Kollokyumu, Ankara.

Tuna, B. (2017). Karşınızda, 2044 yıl önceki Efes... Retrieved from https://www.hurriyet.com.tr/kelebek/hurriyet-pazar/karsinizda-2044-yil-onceki-efes-40680176

Varga, T. (2021). This is What Ancient Greece Really Looked Like – Well, Most Probably. Retrieved from https://earthlymission.com/what-ancient-greece-really-looked-like-ephesus-illustrations-adam-nemeth/

Von Übel, M. (2021). *Best photogrammetry software in 2021.* Access Address (29.03.2023): https://all3dp.com/1/best-photogrammetry-software/