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Cultural Relics Restoration Technology in Virtual Reality: Application of 3D Modeling and Rendering Algorithms in Cultural Relics Digitization

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Abstract

Preserving humanity's cultural legacy requires the repair of cultural treasures. Virtual reality (VR), which offers realistic representations and immersive experiences, has become a viable instrument for the restoration of cultural treasures as a result of technological advancements. This research explores the use of sophisticated 3D modelling, rendering, and simplification techniques to digitalize cultural artefacts. The study employs a carefully selected set of 3D models from the publicly available Sketchfab website to examine objects that are representative of cultural heritage, such as the Ashoka Tower, the Tibetan Sacred Props, and the Haihun Marquis Mausoleum. The primary objective is to evaluate how well different rendering algorithms capture and preserve the fine features of these cultural treasures while maximizing computing efficiency. To improve the produced models' visual integrity, the research starts by examining the fundamentals and uses of texture mapping, lighting models, and material attributes. A comparison examination of the original and simplified models is then carried out to assess the trade-offs between rendering time and visual quality in terms of performance. In weighing computing resources against preservation goals, this comparison offers crucial insight on the viability of simplification strategies. The findings highlight how important it is to utilise digital tools to preserve, analyze, and share cultural assets. Through the demonstration of the capabilities of cutting-edge 3D modelling and rendering techniques for capturing and spreading the rich historical and cultural importance embodied by artefacts from many traditions and civilizations, this study adds to the growing area of digital cultural preservation. This study contributes to the continuing conversation about utilising technology in the digital age to protect and promote cultural heritage.

Keywords: *Cultural Relics, Rendering Algorithms, Digitization, 3D Modeling, Virtual Reality*

INTRODUCTION

Cultural artifacts have inherent value due to their rich historical, artistic, scientific, and social significance. The buying and selling of precious historical artifacts is occurring with increasing frequency [1]. When relocating, delicate cultural items should be packed with caution [2]. Utilizing three-dimensional scanning technology seems to be an effective way to preserve cultural artifacts. It is crucial to produce precise and comprehensive 3D models of cultural artifacts for the purpose of digital museums, conservation, and research, as well as for public display [3]. Creating packaging can be done swiftly and easily using 3D models made by hand. However, there are still remaining problems that require resolution to effectively and efficiently capture and recreate cultural artifacts in 3D in a manner that is both realistic and cost-effective [4] [5].

The most popular techniques for creating 3D digital replicas of cultural artifacts are currently laser scanning and capturing detailed photographs [6]. In 2012, Rodríguez-Navarro conducted an experiment on a small stone sculpture and a structural component of a building. The findings were compared from a Nextengine laser scanner and a point cloud created by AGISOFT Photoscan [7], Using photogrammetry, the achievement was accomplished with reduced effort [8]. Demonstrating the significant impact of SFM and IM algorithms on the ultimate outcomes [9]. The data quality for generating 3D models of small objects through images may not consistently match up to other types of 3D scanners. It employed a specialized 3D scanning technique to capture images of the ancient sculptures in the Terracotta Army. This helped to create detailed models and textures of the relics [10]. The edge data is insufficiently precise, and the expense of the technology is prohibitive—a single camera could cost anywhere between eight thousand dollars and thirteen thousand dollars. The expense of this technology is another issue. Xu obtained three-dimensional historical models using Leica's

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HDS8800 3D laser scanner [11]. Detailed information about historical objects can be obtained through laser scanning, although it can be difficult to compile data for intricate sections.There are instances where it's not appropriate to use markers to label things manually, especially cultural artifact [12]. The scanning quality of dark-colored objects is low due to their light-absorbing nature. Furthermore, laser scanning comes with a high cost and lacks sufficient safeguards for protecting cultural artifacts. The technique of close-up photogrammetry was initially employed for surveying buildings. The majority of household activities focused on locating ancient artifacts. Being cautious and having contingency plans are crucial for success in this line of work [13]. Gray code employs a technique for converting images into binary format.To guarantee optimal functionality of the image when the colour or brightness of an object changes rapidly, it is essential to employ developer spray. This aids in obtaining measurements with greater accuracy. Zheng utilized a process to calculate and reconstruct sets of artifacts. Three-dimensional measurement was achieved through the application of structured light technology in the method. The measurement process was complex and the reconstruction was time-consuming [14]. The research presented a sophisticated sensor utilizing a distinct pattern. Relying on a single eye to gauge distances can result in errors due to its limited focus on one point at a time, potentially leading to inaccuracies [15]. Sun proposed a method for capturing the shape of a moving object using a pair of specialized cameras. However, they only conducted a test of the sensor's performance using an object that moved in a linear path [16].

The capacity to precisely capture, represent, and visualise complex three-dimensional objects—like cultural artifacts—in a digital setting is what makes 3D modelling and rendering techniques so important. These algorithms are essential to the preservation of cultural heritage due to their ability make it possible to create accurate and detailed digital replicas of artefacts and monuments that could be utilised for public engagement, teaching, research, and documentation. With an emphasis on mesh and surface reconstruction methods, texture mapping, and sophisticated lighting models, the goal of this project is to investigate and progress the state-of-the-art in 3D modelling and rendering approaches for the digitalization of cultural artefacts. This study is distinctive because it thoroughly examines state-of-the-art 3D modelling and rendering methods designed especially for digitising cultural artefacts, with the goal of pushing the limits of digital heritage visualisation and preservation. The investigation endeavours to accomplish these objectives in order to facilitate the creation of more precise, effective, and aesthetically pleasing techniques for the digital documentation and display of cultural property. This study's primary contributions are as follows:

Examining how well mesh reconstruction algorithms—like Delaunay triangulation methods—capture cultural artefacts' geometry from unprocessed 3D data

Assessing how adding surface textures, colours, and patterns to digital cultural artefacts improves their visual authenticity using texture mapping techniques

Evaluating the advantages of sophisticated lighting models, such as global illumination and ambient occlusion, in replicating authentic lighting effects and improving the produced image' overall realism

LITERATURE REVIEW

Preserving cultural artifacts through technology is crucial for maintaining, protecting, and arranging them. 3D point cloud data utilized in the analysis of historical items only depicts their appearance without providing any information about their nature. This suggestion involves the use of 3D models to visually represent the details and shapes of cultural artifacts for a better comprehension. It devised a technique for structuring 3D historical object information using intelligent point clouds. This This allows us to present various aspects of the objects in a variety of ways. The suggested paradigm enables the linking of smart clouds of points, or just a portion of them, with relevant texts or information about semantics. Thus, high-level geometric features and rich semantic content could be explained through this creative data modelling approach. The suggested data architecture has extensive semantics data that could potentially be linked to documentation in addition to expressing the intricate geometrical characteristics and complicated geometrical framework of the historic objects. With its many complicated configurations, the Dazu Thousand-Hand Bodhisattva monument provides an illustration analysis that demonstrates the great adaptability and expansibility of the suggested approach for modelling and analysing the monument. This study offers valuable perspectives on the long-term growth of the preservation of cultural heritage worldwide. But this technique fails to convey the three-dimensional form and features of cultural artefacts with complicated geometric designs because it obscures geometrical components [17].

When reconstructing metal cultural treasures in three dimensions, there is a low extracting effectiveness and matching of features, leading to in a poor reconstructing impact. Consequently, a strategy for optimizing the three-dimensional reconstructed of metal cultural objects by minimising information from three-dimensional laser scanning is offered. This diagram represents the technique's entire technical structure and path. In accordance with this representation, a three-dimensional restored visual simulation is created by employing the three-dimensional scanning laser technique for gathering 3D views of metal objects, along with colour space and two-dimensional entropy detection techniques for pre-processing three-dimensional images. Additionally, comparing the features of cloudy points is done to obtain and optimize the significant importance of super pixels. The use of affine transformation enables us to locate identical characteristics on metal artifacts, regardless of how they are illuminated. This technique is employed to ensure that the 3D renderings of the artifacts appear uniform in varying lighting situations. This could make an adjustment to the brightness, color and saturation of the light using a specific method. The rigid and non-rigid registration methods are used to help line up the point cloud. Utilizing the product quantization algorithm can result in a linear error function and the development of a block feature detection and matching model for spatial images. The loudness is determined by a certain level, and a special technology is used to create a 3D model of metal objects. According to the test findings, this approach excels in producing clear images, accurately identifying characteristics, and enhancing the capacity to produce 3D models of metal artifacts. The new method for creating 3D images of metal objects using lasers may be ineffective due to its inability to account for the varying textures, shapes, and reflective properties of different metals. This could make the images less accurate [18].

Artificial intelligence, systems, sensor technologies, graphic design, and numerous additional areas are all included in the field of virtual reality technologies. It could represent its technological methods through visual, tangible, and audio techniques while offering substitutes to the initial approach by utilizing the enormous computational and graphical processing powers of computers. Data from historical study, documentation, and virtual restoration and simulation exhibition of the lost heritage of culture all support this. A novel approach to cultural heritage preservation called "digital protection" uses computer technology as well as electronic machinery to gather, store, manage, outcome, and distribute the necessary data, such as data bases built on computer platforms, in order to fulfil the goal of sharing information and communication. The primary focus of this paper is the investigation of the virtual reality technology's applicability in digital cultural artefact protection. Furthermore, utilize the computer-generated representation of materials cultural safeguarding for creation and utilise landscapes to produce and modify content. Initially establish a fully immersive setting for users through displaying the items accurately in the virtual reality framework, therefore digitizing the scientific safeguarding of cultural treasures. To attain its location and give the impression that it is in the natural environment, the gadget mimics its topography. In order to achieve more precise digital preservation of historical material, the quantity is then determined in a virtual setting employing the radial foundation function. According to research findings, the percentage of individuals who are more inclined to engage with 3-dimensional items utilizing the handle varies between 35.54% and 64.46%. According to them, the control is now more accurate, and the handle's velocity has altered. The outcomes of the research study indicate that: When it comes to digitizing cultural collections, the virtual environment reality technology requirement is superior than the initially developed technologies. However, the investigation fails to fully address issues that could affect the precision and authenticity of computer-generated reconstructions, including the inability to accurately capture cultural artefacts' intricate details or possible prejudices brought about by subjective assessments of archaeological data during the process of reconstruction [19].

Studying architecture is becoming more advanced with the help of new technology. This trend has been occurring over the last decade. Some new technologies include using lasers and cameras to make detailed maps from far away. The laser scanning process provides precise documentation of the site, even in cases of building damage. This study demonstrates the effectiveness of laser scanning and photogrammetry in preserving and enhancing the first site, while also highlighting their role in creating digital and mixed reality representations of the second site. In Lod, Israel, the first location is a historical soap factory, while in Apollonia, Greece, the second location is an ancient bathhouse. The building's partial collapse and the dangerous interior made it difficult for both places to document things. The digital documents enabled us to efficiently and precisely assess the building and comprehend the obscured areas due to the collapse. Using digital documents simultaneously, the cultural heritage site could integrate with the local community socially, economically, and culturally. However, despite its effectiveness, this process cannot promptly reverse the harm caused by both time and human activities, which contribute to the site's instability [20].

Preserving cultural heritage often proves to be a complex task that necessitates the expertise of professionals from diverse fields. It also requires the organization and management of various types of information. The standard approach to handling these issues includes employing different historical building information model (H-BIM) solutions. This article presents a new online platform that serves as a virtual archive of historical artifacts and architecture. Formed with a basic framework, this tool is designed for universal online use and features an adaptable 3D viewer for effortless information display. The concept requires a method similar to the one employed in video games for creating highly intricate 3D models and displaying multiple layers of images. Its compatibility with numerous databases allows for seamless integration with upcoming open-source versions. investigation was conducted to assess the suitability of the internet for documenting a 17th-century historic church in Romania. It also discusses the most recent platform advancements and the limitations that currently exist. This paper shows that while the current version lacks features, it effectively demonstrates the capabilities of the underlying technologies [21].

The paper provides a demonstration of reconstructing three-dimensional models of historical objects from 2-dimensional microtomographic digital images through the utilisation of an evolutionary method. An artefact discovered in the Ljubljanica River close to Sinja Gorica, which dates back over forty thousand years, served as the subject of the tomographic restoration. A conventional method of preparing waterlogged wood with melamine glue was employed to preserve the edge over 2013 and 2017. Volumetric variations and departures of the exact point were discovered by computerised volumetric examination of 5 surface 3D representations collected before, during, and following to the stabilisation. There was a noticeable bend to the tip. The query regarding the state of the point following the conservation technique and the reasons for the divergence that was identified remained unanswered by surface modifications on models in three dimensions. In order to create a volumetric 3D model from 2D microtomographic data, we consequently devised a method that was iterative. Through the utilisation of the volumetric three-dimensional approach, it has been capable to add to the surface three-dimensional model's information and validate the internal framework of the artifact's realistic and critical condition both volumetrically and visually. Computerised tomography (CT) is an important non-invasive diagnostic technique for archaeological evidence intervention, particularly for the preparation and execution of processes related to the preservation, repair, and storage of valuable opposes of historical cultural significance. This was demonstrated by the reconstruction of three-dimensional models from two-dimensional microtomographic images, and the outcomes gathered from the massive three-dimensional framework. However, the investigation fails to investigate the generalizability of the findings beyond the particular artefact analyzed, nor does it discuss any difficulties or constraints relating to the reliability or dependability of the iterative technique in reconstruction three-dimensional models from two-dimensional microtomographic images [22].

In order to aid researchers in understanding and deciphering the place that they are studying; archaeologists employ digital technology more and more to offer them access to three-dimensional measuring data. The generation of accurate and dynamic three-dimensional models that are viewable and interpretable by more viewers is one of the main benefits of photogrammetry across the various mapping techniques. It is also inexpensive, dependable, and quick. This offers info accessibility from any location and undoubtedly simplifies the experience of websites. The article presents three noteworthy instances where photogrammetry has been utilised to assist with archaeological investigations. Archaeology necessitates the digitalization of objects in some contexts, which these investigations illustrate. Gortyn, Greece, is home to the renowned Temple of Apollo. The second one is about the ancient city of Nora in Sardinia, Italy. The third one is about the Museo Civico of Eremitani in Padua, Italy. The report talks about how 3D measurement surveys have been used to study the layers of old buildings at the Gortyn site, create virtual tours of historical sites at Nora, and document small objects at the Museo Civico of Eremitani. It looks at the benefits and challenges of using this method. However, issues with visual synchronisation might lead to mistakes and erroneous perceptions on the part of the observer [23].

Aspects of digital documenting, reconstruction, and preservation of cultural heritage through the use of modern technologies like laser scanning, photogrammetry, virtual reality, and computational algorithms are covered by the literature that is provided. Numerous disadvantages and difficulties are noted throughout the research, despite the fact that these techniques provide a number of benefits in terms of accessibility, accuracy, and effectiveness. In the field of point cloud data processing, 3D point clouds are useful for representing intricate geometric structures of cultural artefacts, but they do not provide data with semantics. In an attempt to overcome this issue, the suggested technique of smart point clouds arranges point cloud data according to several temporal dimensions and spatial scales, enabling the addition of significant semantic information. It could not be able to adequately depict intricate geometric features, though, because to issues like geometrical structure interference [17]. Issues with extracting and matching of features arise when reconstructing metal cultural artefacts in three dimensions, leading to subpar restoration outcomes. While an optimisation technique based on the reduction of three-dimensional laser scanning information is presented, it falls short of dealing with issues such the reflecting qualities and different texture characteristics of the metal's surfaces, which could have an impact on the precision and authenticity of the reassembled structures [18]. Furthermore, there are issues with collecting minute details and potential biases in the reconstruction process, even if virtual reality equipment provides accurate representations of cultural heritage and complete immersion. These issues are not fully addressed. Inaccuracies and distorted views of ancient sites could also emerge from problems with improper picture alignments in photogrammetry, which could influence the precision and dependability of computerised reconstructions. The study does not address any difficulties or restrictions on the accuracy and dependability of the iterative procedures used for reconstructing 3D models from two-dimensional microtomographic images, despite the techniques' capability to provide dimensional information for historical artefacts. Although the sector of cultural heritage preservation and documentation has greatly benefited from the implementation of technological advances, issues like the incorporation of information with semantics, the precise the reconstruction of intricate geometry, and the mitigation of prejudices and mistakes during the process of reconstruction still require more research and growth.

Research Gap

A variety of digital technologies and techniques used for the recording, rebuilding, and conservation of historic sites are highlighted in the literature study. Computational algorithms, virtual reality, photogrammetry, and laser scanning are some of these technologies. These techniques have many benefits in terms of precision and effectiveness, but they additionally come with drawbacks, such as the inability to capture fine details in virtual reenactments, inconsistent feature matching in metal relic reconstruction, and the absence of semantic information in three-dimensional point clouds. Although digital technologies have made significant progress in the preservation of cultural heritage, there remains a dearth of all-encompassing methods which could adequately tackle the problems of integrating information from semantics, precisely reconstructing intricate geometries, and minimizing mistakes and prejudices during the process of reconstruction. Current approaches concentrate on particular facets of the preservation procedure, including feature matching or point cloud organisation, but they are unable to offer comprehensive solutions that cover the full documentation and reconstruction process. For the area of cultural heritage preservation to advance and for cultural artefacts to be accurately represented and preserved across time, it is imperative that this research gap be filled. The dependability and fidelity of digital reconstructions could be improved by both researchers and professionals by creating thorough procedures that incorporate semantic information, increase reconstruction accuracy, and address biases and errors. Better interpretation, analysis, and distribution of cultural heritage resources will be made possible as a consequence, helping to ensure their preservation and accessibility for future generations. The research gap that has been found highlights the necessity of adopting a comprehensive strategy for preserving cultural heritage that takes into account the constraints and difficulties posed by current digital technologies. This would contribute to advance the field and encourage sustainable practices in heritage conservation.

MODELING AND RENDERING PROCEDURE FOR CULTURAL RELICS DIGITIZATION

The article presents a methodical approach to the precise digital representation and visualization of historical spots, monuments, and cultural artefacts. There are several processes involved in this process, starting with data collecting. To obtain comprehensive 3D information about the relics, sophisticated scanning methods like photogrammetry are used. The obtained data is then pre-processed to guarantee geometric correctness and completeness. This includes noise reduction, point cloud alignment, and mesh reconstruction. Following the generation of the 3D models, high-resolution images are superimposed onto the relics' surfaces utilising texture mapping techniques, which adds visual authenticity and detail. After that, lighting models are employed to enhance the produced images' overall visual quality and replicate realistic lighting situations, such as ambient occlusion and global illumination. Further adding to the realism of the relics are the meticulously calibrated material characteristics and shaders that faithfully capture their surface traits and material compositions. To evaluate the quality, correctness, and aesthetic appeal of the digital artefacts, thorough assessment and validation methods are carried out at various stages of the procedure. Through the implementation of this thorough modelling and rendering process, experts in cultural heritage could generate accurate digital duplicates that maintain the genuineness and cultural relevance of the artefacts, all the while permitting immersive virtual settings for research and exploration. The suggested approach's workflow is depicted in Fig. 1.

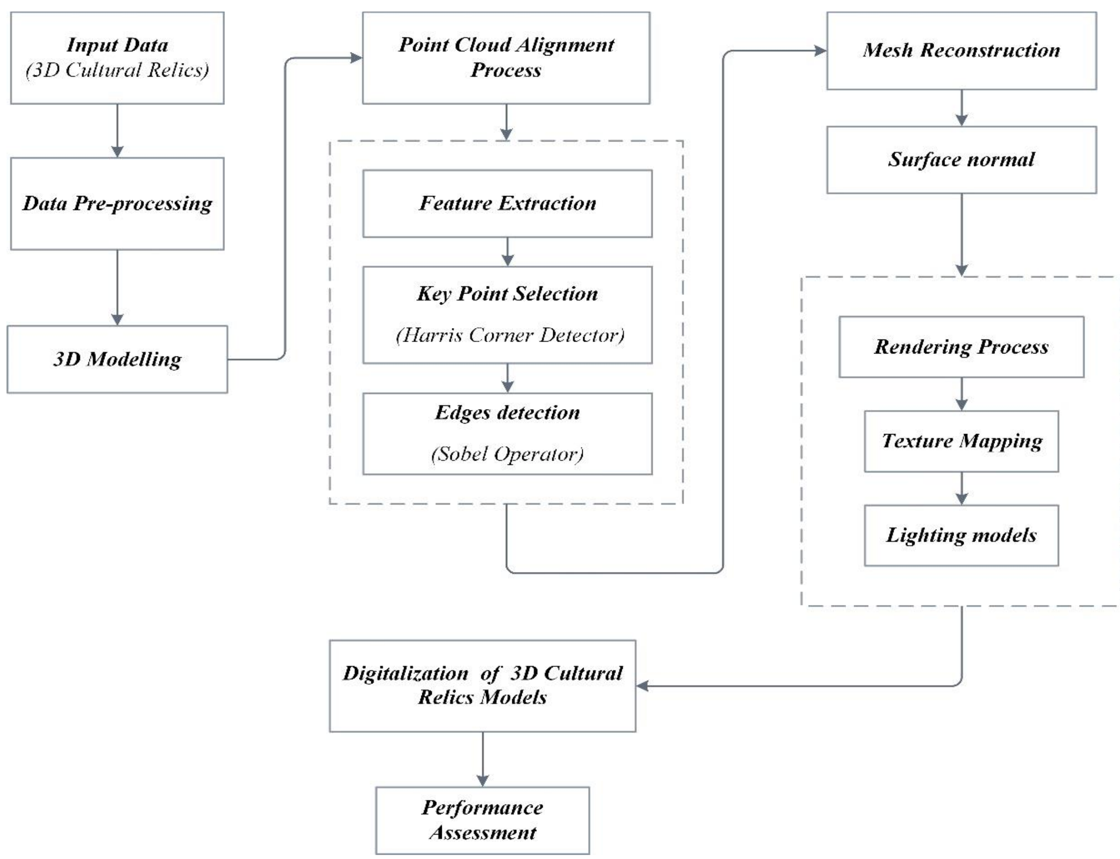

Fig. 1. Workflow of the Proposed Approach

Data Collection

The 3D models for this study were obtained from Sketchfab, an open-source website. These models were chosen for their applicability to the preservation and visualisation of cultural property, and they include artefacts like the Ashoka Tower, the Tibetan Sacred Props, and the Haihun Marquis Mausoleum [24].

Data Pre-processing

Noise Reduction: Optimising 3D images of cultural artefacts requires the adoption of noise reduction techniques like median filtering and Gaussian smoothing. In order to reduce noise and retain key information, Gaussian smoothing entails convolving the image employing a Gaussian kernel. Conversely, median filtering effectively eliminates salt-and-pepper distortion by substituting the value of every pixel with the median value within its neighbourhood. The structural integrity and fine textures of cultural artefacts are precisely preserved in the final 3D scans due to these procedures, which also assist to minimize undesired artefacts and inconsistencies created throughout the procedure of scanning.

Gaussian Smoothing: For reducing noise in three-dimensional images, Gaussian smoothing is a commonly employed method. It performs by convolving the image employing a Gaussian kernel, which weights the probabilities of the pixels that are close to one another. The standard deviation (σ) of the Gaussian kernel characterises its properties; it indicates how much blurring or smoothing is applied to the image. Gaussian smoothing could be utilised to enhance the clarity and authenticity of the images captured in the framework of three-dimensional images of cultural artefacts like the Ashoka Tower, the tomb of Haihun Marquis, and Tibetan sacred props. The following is the expression for the Gaussian smoothing Eqn. (1).

$$I_s(u,v) = \sum_{p=-m}^{m} \sum_{q=-m}^{m} r(p,q) \cdot I(u+p, v+q) \quad (1)$$

Where,

I_s (u, v) indicates the intensity of the smoothed image at point (u, v),

I (u + p, v + q) indicates the original image^' s intensity at point (u + p, v + q),

r (p, q) indicates the location (i,j) of the Gaussian weighting variable,

m establishes the kernel's size, which is usually determined by the desired degree of smoothness.

The Gaussian function determines the Gaussian weighting ratio $r(p,q)$ was expressed in Eqn. (2)

$$r(p,q) = \frac{1}{2\pi\sigma^2} \cdot e^{-{p^2+q^2}/{2\sigma^2}} \quad (2)$$

Gaussian smoothing could be employed when analysing 3D images of the Haihun Marquis tomb in order to reduce noise and artefacts that could have been produced during the scanning procedure. This results in an improved depiction of the tomb's fine features and textures. Analysing and visualising the structural characteristics of these cultural artefacts is made simpler when Gaussian smoothing is applied to three-dimensional images of the Ashoka Tower and Tibetan religious The quality of 3D images of cultural relics can potentially be enhanced with the incorporation of Gaussian smoothing, which assists in ensuring that the scanned data appropriately captures the intricate intricacies and structural integrity of these significant historical artefacts.

a) Median Filtering: A highly effective technique for reducing noise is median filtering, that performs especially well in situations when there is a lot of salt-and-pepper noise. This kind of noise frequently distorts the scanned data's visual clarity, appearing as sporadic, isolated white and black pixels across the image. When utilised in three-dimensional images of cultural artefacts like the Ashoka Tower, the tomb of the Haihun Marquis, or Tibetan ritual props, median filtering is a reliable technique for improving image quality without sacrificing important structural elements. In the median filtering procedure, the value of each pixel is substituted with the median value in its vicinity, which is usually delineated by a rectangle or square window. Its ability to preserve the fine features and textures typical of cultural treasures renders it particularly suitable. This method retains edge information effectively and is resistant to outliers. The following is a description of the median filtering in Eqn. (3).

$$I_s(u,v) = Median\,(\,I(u+p, v+q)) \qquad (3)$$

In order to preserve and accurately depict these priceless historical artefacts, median filtering provides a dependable technique for reducing noise in three-dimensional photographs of cultural relics. Median filtering guarantees that the scanned data correctly preserves the fine details and the structural integrity of cultural relics by successfully reducing noise while maintaining important surface features. This allows for additional analysis, interpretation, and digital preservation initiatives.

Point Cloud Alignment Process

When processing 3D data from several scans or databases of an identical cultural relic, point cloud alignment is an essential step, especially if the information was collected from several angles or origins. Point cloud alignment makes ensuring that all scanned information is accurately registered and aligned in a similar coordinate system, which is essential in applications like the Haihun Marquis mausoleum, Ashoka Tower, and Tibetan sacred props. In order to accurately analyse, visualise, and understand the relics in three dimensions, an integrated and comprehensive picture of them must be created through this alignment procedure.

Feature Extraction: A critical phase in point cloud processing involves characteristic extraction, especially when aligning numerous datasets of an identical cultural relic. Finding unique and repeatable geometric features from each point cloud dataset is the first step in this approach. These features could then be utilized to create correspondences and eventually align the datasets. In order to provide precise registration and alignment among several scans, these characteristics act as landmarks or references.

Key Point Selection by Harris Corner Detector: One popular approach for finding important or interesting spots in point cloud data is the Harris corner detector. It functions by taking numerous crucial actions. It first determines the gradient of colour or intensity values throughout the point cloud data, usually by convolution with derivative filters or finite differences. It then computes the structure tensor for each point, averaging gradient products within a small region to summarise the local picture structure. The corner response function, which indicates the probability that a location is located at a corner or junction, is constructed from this matrix utilising eigenvalues. A greater value of this function indicates stronger corner-like traits. It assesses the divergence from homogeneity within the immediate neighbourhood. To make sure that only the most significant keypoints are kept, non-maximum suppression is used to choose local maxima once the corner response function for each point has been calculated. The corner response values are then subjected to a threshold, and keypoints that are higher than this threshold is chosen as detected key points. The Harris corner detector locates corners or edges in point cloud data by detecting locations that exhibit notable variations in the local curvature or surface normal direction. Accurate analysis and interpretation of the scanned data is made easier by these keypoints, which act as distinguishing landmarks for a variety of activities like registration, alignment, feature matching, and object detection inside 3D point clouds.

Corner Response Function: The corner response function calculates the probability that a given location is situated at a corner or intersection. It has the following definition was expressed in Eqn. (4).

$$R = det(M) - k \cdot (trace(M))^2 \qquad (4)$$

Where, k is an experimentally determined constant, usually in the range of 0.04 to 0.06, and $det(M)$ is the determinant of the structure tensor and $trace(M)$ is the trace of the structure tensor.

Edges detection using Sobel Operator: Point cloud data edges, such as corners with sharp edges or discontinuities in surface curvature, offer important hints regarding the geometry and structure of the item. They function as notable characteristics that could be utilised to indicate cloud dataset alignment obtained from various angles or sources. Researchers and practitioners could precisely register datasets in a shared coordinate system for exact analysis, visualization, and interpretation of the scanned item by matching edges across consecutive scans.

For several applications, including as segmentation, object identification, and point cloud dataset alignment, the detection of these edges is invaluable. Because of its efficiency and ease of usage, the Sobel operator is one of the most utilised edge detection methods. An estimate of the gradient magnitude at each location in the point cloud data is computed by the convolution-based edge detection method known as the Sobel operator. The gradient magnitude highlights areas with notable variations in surface orientation and reflects the rate of change in depth or intensity. In order to do this, the Sobel operator convolves the point cloud data using two 3x3 convolution kernels, one of which detects changes in a horizontal direction and the other in a vertical direction.

The horizontal Sobel kernel is typically defined as:

$$\begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix}$$

The vertical Sobel kernel is defined as:

$$\begin{matrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix}$$

The gradient approximations in both the horizontal and vertical dimensions are computed by applying these kernels to the point cloud data. The gradient magnitudes that are obtained indicate the degree of edge strength in the respective directions. Utilising the square root of the sum of squares to combine the horizontal and vertical gradients, the total gradient magnitude can potentially be calculated after calculating the gradient magnitudes in both directions. In order to efficiently locate edges in the point cloud data, the combined gradient magnitude emphasises edges independent of their orientation. The identified boundaries function as salient characteristics that are applicable to a multitude of applications, such as point cloud dataset alignment, object identification, and segmentation. For edge identification in point cloud data, the Sobel operator is an effective tool that offers significant insights into the geometric characteristics of scanned objects and makes correct analysis and interpretation easier.

Surface normal: The direction perpendicular to the local surface geometry at a given location is indicated by the surface normals, which are important vectors associated with each point in a point cloud. In order to comprehend the form and orientation of surfaces within the scanned object, these normal are crucial. Surface normal, that could be computed by methods like weighted least squares fitting, offer useful data for a range of applications, including feature extraction, point cloud dataset alignment, and segmentation. Fitting a plane or smooth surface to the immediate vicinity of each point in the point cloud is the process of estimating surface normal utilising weighted least squares fitting. The goal is to determine which surface best fits the data by minimising the squared distances between the surface and its neighbouring points. Closer points are given more weight; hence the closest points are prioritised. Weighted least squares fitting is used to compute surface normal by defining a local neighbourhood around each point in the point cloud. The desired degree of local information and the density of the point cloud could be utilised to calculate the neighbourhood's size. After defining the neighbourhood, a least squares optimisation technique is used to fit a plane or smooth surface to the points inside it. The primary objective of this optimisation is to identify the normal vector of the best-fitting surface that, when weighted by the distances to its neighbours, minimises the total of squared distances to those locations. The local shape and direction of the surface are revealed by the surface normal, which may be calculated for every point in the point cloud. When identifying regions of interest inside a scanned item, such as corners, sharp edges, or flat surfaces, surfaces Normal might be utilized as an instance. Furthermore, by offering a consistent representation of surface orientation from various angles, surface normal assist in developing correspondences across various scans or datasets. To comprehend the geometric characteristics of surfaces inside point cloud data, one must compute the surface normal utilising weighted least squares fitting.

In order to accurately analyse, visualize, and understand 3D scanned objects, these serve as helpful characteristics for a variety of point cloud processing applications.

Mesh Reconstruction: In order to develop a more organized and aesthetically pleasing representation of point cloud data, mesh reconstruction is an essential initial step. This procedure allows for the detailed 3D modelling and visualization of cultural artefacts like the Ashoka Tower, the mausoleum of the Haihun Marquis, and Tibetan sacred props. The procedure entails creating a polygonal mesh that faithfully captures the relics' surface geometry while maintaining all of their minute intricacies and complicated structural architecture. Delaunay triangulation is a frequently employed technique for mesh reconstruction. It generates a triangulated mesh by joining the points in the point cloud to build non-overlapping triangles, ensuring that no point is inside the circumcircle of any triangle. Through ensuring that the final mesh is well-conditioned and mathematically precise, Delaunay triangulation produces a realistic depiction of the underlying surface. To rebuild meshes from point cloud data obtained from scanning cultural artefacts, Delaunay triangulation-based techniques are utilised. By repeatedly joining nearby points in the point cloud, these algorithms create triangles that together cover the whole surface of the artefact. The resultant mesh model captures aspects like fine textures, elaborate embellishments, and minor changes in geometry, while preserving the relics' delicate surface details and structural complexity through the incorporation of neighbouring points. A number of applications, such as digital preservation, virtual exploration, and further relics analysis, are built around the mesh model that is created. The mesh model further enables the documenting, archiving, and digital distribution of cultural artefacts, therefore aiding in their digital preservation. The process of turning raw point cloud data into a mathematically precise and aesthetically pleasing depiction of cultural artefacts depends heavily on the mesh reconstruction process, which makes use of Delaunay triangulation techniques. Mesh reconstruction serves to preserve the complex features and structural intricacies of the relics, allowing for in-depth examination, virtual discovery, and digital conservation of these important historical objects.

Rendering Mechanism

When it comes to digitally representing and visualizing three-dimensional things, rendering techniques are essential because they provide a way to convert geometric data that is not visually appealing into visually appealing visuals. Rendering techniques are essential for producing lifelike visualizations that accurately depict the subtleties and complexity of historical artefacts in the context of digitising cultural relics. Rendering methods replicate the method by which light interacts with surfaces to create realistic images that accurately capture the texture, material qualities, and spatial aspects of cultural artefacts. Texture mapping, lighting modelling, and material properties using shaders are the three core elements that would be the emphasis of this introduction to rendering approaches. Texture mapping is the process of adding fine features and surface patterns to 3D objects by applying 2D images to their surfaces. Realistic lighting effects are produced employing lighting models, which mimic the behaviour of light in a virtual world by taking into consideration variables like ambient occlusion and global illumination. The interaction of surfaces with light is determined by material characteristics and shaders, which allow realistic and accurate representation of materials like stone, metal, or cloth. This investigation would cover the fundamentals, working methods, and uses of every rendering element, emphasizing how important they are to the digitization and visualization of cultural artefacts.

Texture Mapping: Through adding textures—2D images—to the surfaces of 3D models, a basic computer graphics method called texture mapping improves the visual realism of the models. The fundamentals of texture mapping are taking colour samples from matching texture pictures and projecting texture coordinates onto the 3D model's surfaces. This approach enhances the look of cultural treasures and other items in generated pictures by enabling the insertion of minute features, surface patterns, and colour changes. Assigning texture coordinates to the 3D model's vertices is a crucial component of texture mapping. Textures are applied to the surface geometry according to this mapping. UV mapping is a popular technique that involves assigning two-dimensional texture coordinates (U and V) to every vertex in a three-dimensional model. The position inside the texture picture from which to sample the colours of each point on the surface is indicated by these coordinates. With the implementation of UV mapping, surface features could be precisely placed and aligned around 3D geometry with exact control over texture wrapping. Parametric mapping is an alternative technique to texture mapping in which textures are applied utilising statistical factors instead of precise UV coordinates. This approach uses mathematical factors to determine how textures change throughout the surface of the 3D object, and textures are created or applied procedurally. When it comes to generating textures, parametric mapping is flexible and especially helpful for producing intricate surface effects or recurring patterns. Texture mapping is an essential component in rendering photographs of cultural treasures, regardless of the mapping technique employed. Texture mapping gives the visual depiction of relics greater depth and richness, giving them a more realistic and authentic appearance. It does this by applying textures that reflect surface characteristics like scratches, fractures, or patterns. Moreover, texture mapping makes it possible to include material characteristics and colour variations that enhance produced pictures' overall visual appeal. When it comes to improving the visual authenticity of 3D models, especially cultural treasures, texture mapping is a crucial approach. Texture mapping allows for the precise mapping of textures onto 3D model surfaces using techniques such as UV mapping or parametric mapping. This allows for the production of visually captivating and immersive representations that capture the minute details and distinctive qualities of cultural artefacts.

Lighting models: Rendering approaches rely heavily on lighting models, which provide simulations of light-surface interactions that are essential to creating realistic digital pictures. Global lighting and ambient occlusion stand out among these models as being crucial to visual realism. Scenes are given depth and realism by the subtle shadowing effects produced by indirect illumination, which are captured by ambient occlusion. Conversely, global illumination goes beyond, taking into consideration direct light sources as well as the complex interactions between light bounces, reflections, and scattering. Renderings that use these models have a more realistic appearance, which improves how artefacts and other things are shown in virtual spaces.

Ambient Occlusion: A lighting concept called ambient occlusion mimics the subtle shadows a scene's indirect lighting creates. In contrast to direct illumination, which originates from certain light sources, ambient occlusion takes into consideration the light that is dispersed and diffused naturally across the surroundings, casting faint shadows in nooks and crannies. Recessed surfaces block more ambient light, which results in darker areas in areas with less light exposure. This corresponds to the basic idea of ambient occlusion. The standard method for calculating ambient occlusion involves projecting rays from every point on the surface and calculating the degree of occlusion—or obstruction—that these rays contact. Darker areas are produced in locations with more occlusion by modulating the shading of the surface using the occlusion factor. Raising the sense of three dimensions and adding visual appeal to simulated scenes, ambient occlusion gives images depth and realism by casting shadows where light would usually be less prominent.

Global Illumination: A more sophisticated light model called global illumination replicates the intricate relationships between light in a scene, including direct light from light sources as well as indirect light from reflections, refractions, and light interactions between objects. With global illumination, light rays are precisely captured through indirect bounce and scattering, which is different from simpler lighting models that solely take direct lighting into account. This leads to more realistic lighting effects like colour bleeding, caustics, and soft shadows. The indirect light contribution in a scene is calculated utilising global illumination techniques like radiosity and ray tracing. Ray tracing follows individual light beams as they interact with various surfaces, absorption or transmission through transparent materials, and reflection off reflecting surfaces. However, radiosity mimics the diffuse inter-reflection of light between surfaces, which explains the variations in colour and intensity brought about by indirect light transmission. Renderings provide more natural lighting effects, such as realistic reflections, soft shadows, and minute changes in brightness and colour. This is achieved by faithfully modelling global illumination. As a consequence, the scene seems more realistic and immersive, and the visual representation of cultural artefacts is made more visually captivating, facilitating a better comprehension and utilization of the objects' material and spatial qualities.

The realism and visual accuracy of produced pictures are enhanced by two crucial lighting models: ambient occlusion and global illumination. While global illumination replicates the intricate interplay of direct and indirect light exchanges, ambient occlusion gives scenes depth and delicate shadowing effects that lead to more realistic lighting and rendering results. The ability to represent cultural artefacts and other three-dimensional objects in digital surroundings with accuracy depends on these lighting models.

Material Properties and Shaders for Realistic Rendering: When it comes to deciding the realistic look and visual appeal of surfaces in produced images, particularly those of cultural artefacts, material properties and shaders are essential elements of rendering processes. Surfaces' interactions with light are determined by their material characteristics, and shaders use these attributes along with lighting parameters to determine a surface's colour and shape. Accurate depiction of material attributes including reflectance, transparency, roughness, and subsurface scattering is necessary for realistic rendering. Whereas transparency regulates how much light goes through a surface, reflectance establishes how much light is reflected by it. Roughness affects the distribution and intensity of reflections by describing the microgeometry of the surface. The phenomena of light penetrating a surface and scattering below it before emerging is simulated by subsurface scattering. This phenomenon is often found in transparent materials such as skin or wax. Programmes called shaders calculate how surfaces would appear during rendering. To ascertain the colour, shading, and texture of every pixel on the surface, they consider the characteristics of the material, the lighting, and additional elements. Complex behaviours of light interacting with materials are simulated by advanced shaders, such physically based shaders. These shaders provide rendering results that are photorealistic by precisely reproducing the optical characteristics of real-world materials utilising mathematical models derived from physics. With consideration for elements like microfacet distribution, Fresnel effects, and energy conservation, physically based shaders seek to emulate the behaviour of light in the actual world. Through taking into consideration the diffuse, specular, and transmission components of light reflection and refraction, they faithfully mimic how light interacts with surfaces. Renderings of cultural artefacts could be made to look more authentic and visually accurate by adding physically based shaders to the rendering process. This allows the pictures to have realistic surface textures, reflections, and lighting effects. Realistic representation of cultural artefacts and other things depends on the material qualities and shaders. Rendering images could improve the visual realism and authenticity of cultural artefacts in digital representations by capturing the complex surface details, reflections, and lighting effects through the utilisation of advanced shaders and precise modelling of material characteristics.

DIGITALIZATION EXPERIMENT OF CULTURAL RELICS

The effort in digitalizing cultural artefacts through the use of 3D photographs of the Ashoka Tower, the Haihun Marquis tomb, and Tibetan holy props is a painstaking procedure that aims to capture, rebuild, and analyse these historical riches in digital form. The investigation begins with the utilisation of cutting-edge scanning technologies such as laser scanning or structured light scanning. It carefully records high-resolution point cloud data, capturing the complex geometric intricacies and surface textures of these artefacts. To improve their quality and get them ready for in-depth analysis, the obtained 3D pictures are next subjected to preprocessing procedures such noise reduction, point cloud alignment, and mesh reconstruction. Subsequently, the 3D models' salient features and landmarks are located utilising feature extraction techniques, facilitating further examination and comprehension. The application of 2D textures to the surfaces of three-dimensional models is known as texture mapping, and it adds surface patterns and fine details that amplify visual realism. Then, using rendering techniques, such as sophisticated lighting models and shaders, realistic representations of the relics are produced, mimicking the way light interacts with surfaces and determining how they seem depending on the attributes of the materials and lighting. The digitally rebuilt antiquities are painstakingly examined, virtually explored, and compared with historical sources to provide a more profound knowledge of their value. The experiment's main objective is to record and conserve these cultural artefacts in digital archives, guaranteeing their accessibility and encouraging more public participation with cultural heritage**.**

Cultural Relic 3D Image Line Mapping

The images of the Ashoka Tower, the Haihun Marquis tomb, and the Tibetan holy props were created using 3D three-dimensional line mapping, which requires a unique method of capturing and examining the geometric features and spatial configurations of these artefacts. With the use of sophisticated 3D scanning technology, this method generates extensive point cloud data that is subsequently processed to identify important elements and produce wireframes or lines that depict the relics in three dimensions.3D line mapping makes it possible to precisely describe the architectural features of the Haihun Marquis tomb, including its walls, columns, and elaborate patterns. This documentation facilitates a thorough analysis of the mausoleum's structural design and historical value. Because of its unusual shape and elaborate carvings, the Ashoka Tower benefits from 3D line mapping, which provides precise dimensions and geometric data necessary for research and preservation. In a same vein, 3D line mapping provides a thorough way to record the complex patterns and spatial arrangements of Tibetan holy props, such as architectural features and religious artefacts, making research and recording for cultural heritage reasons easier**.**

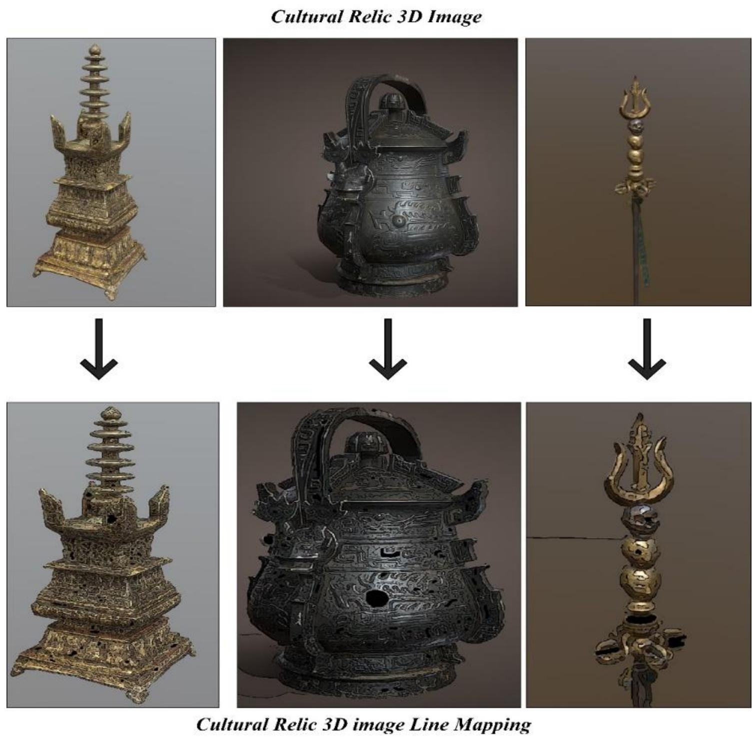

Fig. 2. Before and After Cultural Relic 3D Image Line Mapping of Haihun Marquis mausoleum, Ashoka Tower, and Tibetan sacred props

Through the utilisation of three-dimensional line mapping in three dimensions, scholars and experts in cultural heritage could produce accurate digital depictions of these artefacts, facilitating comprehensive examination, virtual field trips, and conservation endeavor's. In order to conserve and make these artefacts' cultural importance available to future generations, the approach offers a useful tool for recording and researching them. The Before and After Cultural Relic 3D Image Line Mapping is illustrated in Fig. 2.

Cultural Relic 3D Image Edge detection

To identify and emphasize the salient edges and contours of these cultural treasures, a specialized method known as 3D three-dimensional edge recognition is applied to the photos of the Tibetan holy props, Ashoka Tower, and Haihun Marquis tomb. This method makes use of sophisticated algorithms to examine the relics' three-dimensional geometry and identify any notable discontinuities or variations in surface orientation that might be signs of edges or other structural elements. Figure 2 displays the edge detection of the Tibetan holy props, Ashoka Tower, and Haihun Marquis tomb in 3D before and after cultural relics.

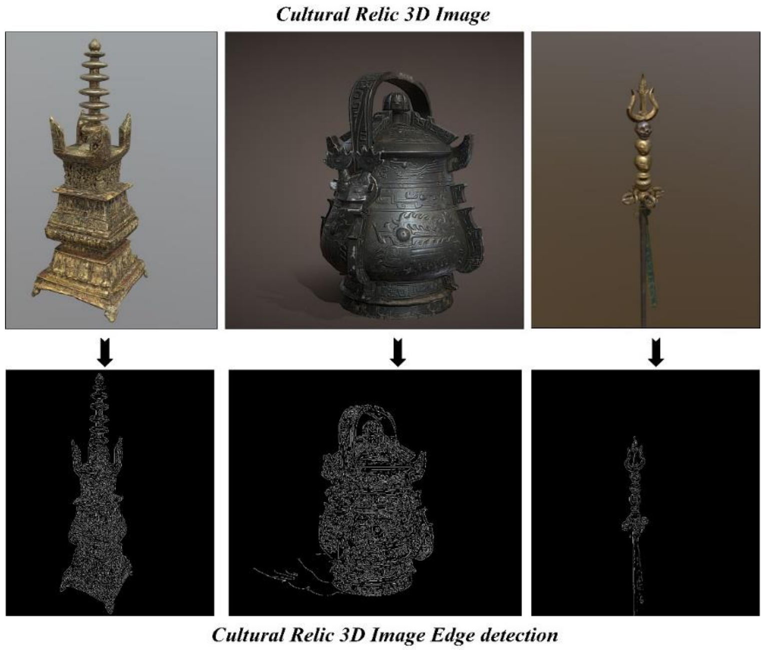

Fig. 3. Before and After Cultural Relic 3D Image Edge detection of Haihun Marquis mausoleum, Ashoka Tower, and Tibetan sacred props

Three-dimensional edge recognition helps identify architectural features like columns, walls, and finely carved details in the Haihun Marquis tomb, which makes it easier to analyse the structure and ornamental patterns of the building. With its complex architectural layout and sculptural reliefs, the Ashoka Tower benefits from 3D edge detection, which makes it possible to precisely define minute features and sophisticated patterns, supporting historical research and preservation initiatives. The same is true for Tibetan holy props, such as architectural elements and religious sculptures; 3D edge detection helps to capture the minute details and distinctive characteristics needed for cultural heritage study and interpretation. Through the utilisation of 3D three-dimensional edge detection, scholars and experts in cultural heritage management may improve their comprehension and admiration of these artefacts by emphasising their unique architectural features and elaborate patterns. The method offers a useful resource for researching and recording these artefacts, aiding in their conservation and guaranteeing that the cultural importance of these items is appropriately conveyed and available to future generations.

TABLE I. PERFORMANCE OF LINE MAPPING FOR 3D CULTURAL RELICS MODEL

3D Model of Cultural Relics	Model Features (Points)	Running Time (Seconds)
Haihun Marquis Mausoleum	45000	112.5
Ashoka Tower	38000	95.2
Tibetan Sacred Props	52000	130

Table I displays the line mapping performance metrics for 3D models of cultural relics, showing how many points each artifact's model feature represents. With 45,000 model elements, the Haihun Marquis Mausoleum is an intricate and meticulously rendered reproduction of a historical building. Comparably, the 38,000 model features of the Ashoka Tower demonstrate the intricacy of its decorative and architectural details. The Tibetan Sacred Props, on the other hand, highlight the complexity and depth of this cultural legacy with their 52,000 model characteristics and greater degree of detail. The resulting graphs offer insightful information on the degree of detail and complexity that was recorded in every 3D model, demonstrating the painstaking care that was taken to record and preserve these important cultural artefacts. The Execution of Cultural Relics of 3D Models is displayed in Fig. 4.

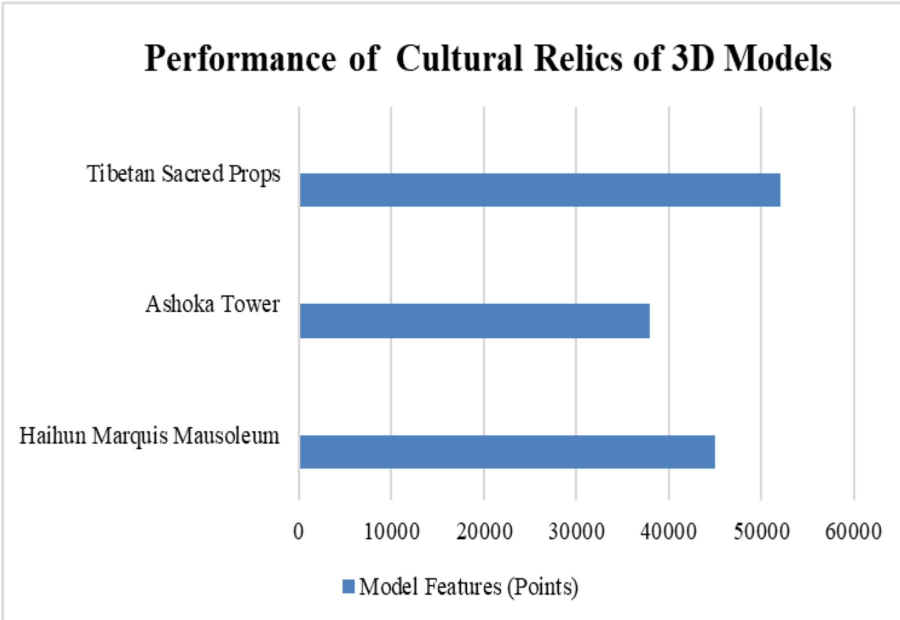

Fig. 4. Performance of Cultural Relics of 3D Models

The time in seconds needed to produce 3D representations of different cultural artefacts is shown in Figure 5. The depiction effectiveness for three important artifacts—the Ashoka Tower, the Tibetan Sacred Props, and the Haihun Marquis Mausoleum—is highlighted in particular. As per the available data, the rendering time of the Ashoka Tower was 95.2 seconds, the Tibetan Sacred Props took 130 seconds, and the Haihun Marquis Mausoleum took 112.5 seconds. This data clarifies the rendering process's effectiveness and computing requirements for every cultural artefact. The variances in rendering times could be ascribed to changes in the 3D models' complexity, their intricate designs, and the rendering system's computing capacity.

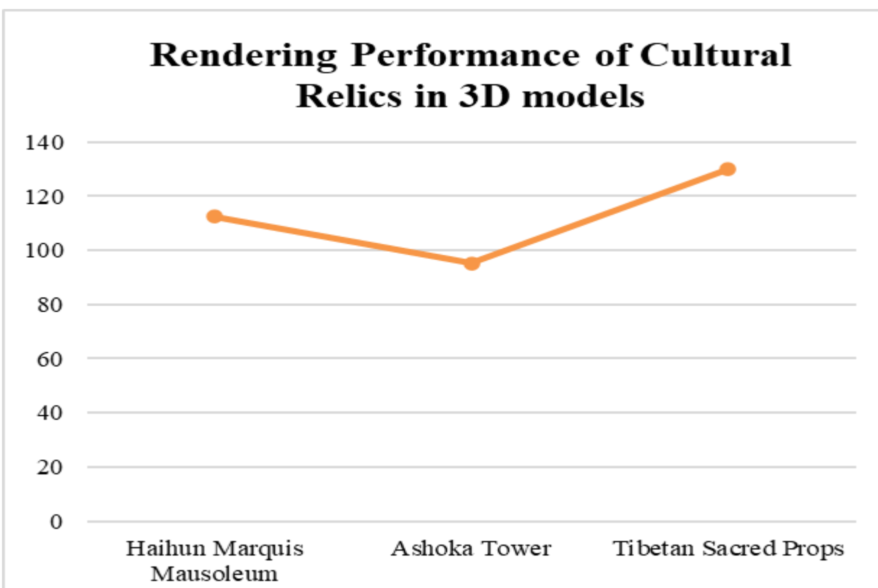

Fig. 5. Rendering Performance of Cultural Relics in 3D models

The Haihun Marquis Mausoleum, Ashoka Tower, and Tibetan Sacred Props are only a few examples of the cultural artefacts for which Table 2 contrasts the rendering performance of original and simplified 3D models. Each relic's original, high-fidelity 3D model's rendering time in milliseconds (ms) is shown in the column labelled "Original Model (ms)". On the other hand, the "Simplified Model (ms)" column displays the rendering time for condensed versions of the identical models, which usually have fewer vertices and simpler geometry.

TABLE II. PERFORMANCE COMPARISON OF ORIGINAL AND SIMPLIFIED 3D MODELS FOR CULTURAL RELICS

Cultural Relic	Original Model (ms)	Simplified Model (ms)
Haihun Marquis Mausoleum	120	60
Ashoka Tower	90	45
Tibetan Sacred Props	80	40

The streamlined model for the Haihun Marquis Mausoleum renders in 60 ms, compared to 120 ms for the original form. Comparably, the streamlined Ashoka Tower renders in 45 ms compared to the previous model's 90 ms rendering time. Similarly, rendering times for the Tibetan Sacred Props drop from 80 ms for the original model to 40 ms for the streamlined version. In order to facilitate fast rendering procedures for cultural heritage preservation and visualisation projects, this comparison demonstrates the enormous performance improvements that may be obtained by reducing 3D models while keeping visual integrity**.** The Performance Comparison of Simplified and Original 3D Models for Cultural Relics is displayed in Fig. 6.

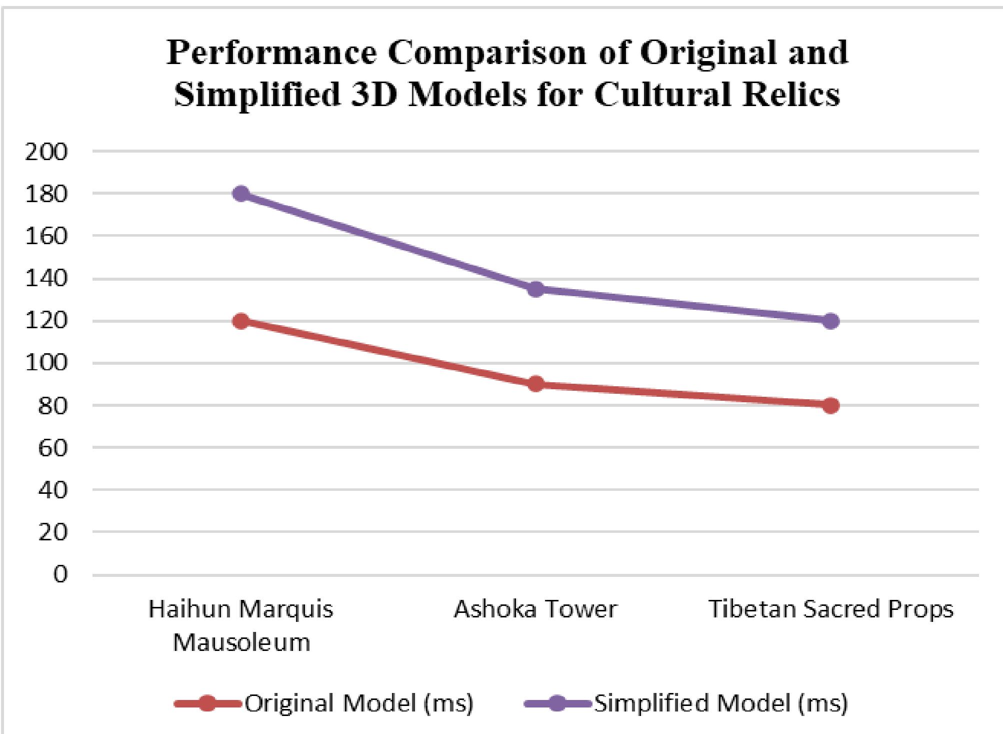

Fig. 6. Performance Comparison of Original and Simplified 3D Models for Cultural Relics

CONCLUSION AND FUTURE WORK

The presented research outlined the complex process of digitising cultural artefacts and demonstrated the usefulness of many methods, including simplification algorithms, 3D modelling, and rendering. This research has illustrated the delicate balance among maintaining historical authenticity and maximising computing efficiency through the examination of artefacts such as the Ashoka Tower, the Tibetan Sacred Props, and the Haihun Marquis Mausoleum. The use of texture mapping, lighting modelling, and material attributes has greatly improved the produced models' visual accuracy, enabling close examination and study of these priceless cultural artefacts. Furthermore, there is a great chance to improve our knowledge of human history and civilization by broadening the scope of digitization initiatives to include cultural artefacts from a variety of historical periods and geographical locations. Through the process of digitizing and cataloguing these artefacts, it could promote worldwide cultural appreciation and understanding, interdisciplinary study, and cross-cultural contacts. Although this study has shed light on the digitization of cultural artefacts, there is still more to be discovered and developed in this area. It could continue opening up new avenues for conserving, researching, and appreciating our rich cultural legacy for future generations through the application of digital technology and multidisciplinary cooperation. Future research in this area might lead to significant improvements in digital heritage protection and accessibility. Sophisticating current algorithms and techniques to get even higher precision and effectiveness in digitizing cultural artefacts is one area of investigation.

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