3D Scanning & Clustering of Archaeological Objects

SUBMITTED BY –

SAKSHI RAJ, B.TECH CSE 3RD YEAR, NIT ARUNACHAL PRADESH
NANDINI GOUR, B.TECH CSE 3RD YEAR, NIT ARUNACHAL PRADESH

INTRODUCTION

- **Background**
  - 3D scanning digitally recreates information about physical components in a simulated world with exact dimensions.
  - There are several methods for measuring items in 3D. It includes laser scanners, light scanners, Coordinate-measuring machine (CMM) and commercial Computed tomography (CT) scanners.
  - For instance, it is helpful for architecture students to show a teacher how a building retains its structural integrity with the data provided by a scan.
  - 3D scanners measure the finest detail of an object, capture free-form and create precise cloud points for complex geometry and circular surface objects

INTRODUCTION

- **Need Of 3D Scanning**
  - 3D scanner capability can be well aligned with reverse engineering processes.
  - Products of different sizes can be 3D scanned with the exact measurements; this can be used for modelling, analyzed and printed, thereby saving time in designing.
  - The need for this technology is to reduce the number of prototype cycles needed between design and manufacturing.
  - 3D scanners are used mainly because their performance offers an added benefit for making a visual replica.

WHAT IS 3D SCANNING

- 3D scanning is a non-contact, non-destructive technology that digitally captures the exact size and shape of physical objects.
- Using methods like laser scanners, light scanners, CMM, and CT scanners, it creates "point clouds" of data that are converted into digital 3D models.
- This technology is highly precise, capturing intricate details and complex geometries. It's used in various fields such as engineering, film, video games, archaeology, and medical imaging to speed up design, improve accuracy, preserve artifacts, and enhance safety in hazardous environments.

Types Of Scanners

- The 3D scanning devices are usually classified based on the principle employed to enable them to work.
- Based on this fact, the 3D scanners are of six types, namely, laser triangulation, structured light, photogrammetry, contact-based, laser pulse type, and optical-based.
- All these types are associated with several types of uniqueness, merits, and limitations as well.

Types Of Scanners

- **Laser Triangulation 3D Scanning Technology:**
  - **How it works:** This type of scanner uses a laser beam to measure distances to the object's surface by calculating the angles formed (triangulation).
  - **Where it's used:** It's great for capturing detailed features on smaller objects accurately, commonly used in industries for precise measurements and creating digital models.
- **Structured Light 3D Scanning Technology:**
  - **How it works:** It projects light patterns onto the object and analyzes how these patterns change on the object's surface to determine its shape.
  - **Where it's used:** Ideal for capturing intricate details on complex objects, such as in fields like aerospace and art restoration.

Types Of Scanners

- **Photogrammetry Contact-Based 3D Scanning Technology:**
  - **How it works:** This method involves taking multiple photos of an object from different angles and then using software to reconstruct its 3D shape.
  - **Where it's used:** It's useful for capturing large objects or environments where direct contact is challenging, often used in fields like archaeology and architecture.
- **Laser Pulse-Based 3D Scanning Technology:**
  - **How it works:** Uses laser pulses to measure distances to surfaces, commonly found in LIDAR systems for large-scale scanning.
  - **Where it's used:** Applied in surveying and environmental mapping due to its ability to cover large areas quickly and with high accuracy.

Types Of Scanners

- **Contact-Based 3D Scanning Technology:**
  - **How it works:** This method requires physical contact with the object using a probe or stylus to directly record its dimensions and shape.
  - **Where it's used:** Mainly used in industries requiring precise measurements and inspections, like in manufacturing and quality control.
- **Optical-Based 3D Scanning Technology:**
  - **How it works:** Uses optics and cameras to capture the object's shape and texture without the need for physical contact.
  - **Where it's used:** Versatile for capturing objects of various sizes and textures, used in industries ranging from entertainment to medical applications.

Applications of 3D Scanning in Archaeology

➢ Digitise physical object

- 3D Scanning allows users to scan geometries and digitise physical objects to collect data for personalised moulds, casts, sets, and so on.
- 3D Scanning converts the physical model into a digital 3D model, which can be further edited and analysed as per the requirement

➢ Reverse engineering

- Collecting information from pre-existing structures and reproducing them based on the information obtained is known as reverse engineering.
- Reverse engineering enables scan-to-CAD with the potential to produce templates and assemblies
- 3D scanning can search any material and then use CAD to modify its results in a simplified method for reverse engineering and fast prototyping

Applications of 3D Scanning in Archaeology

- **Designing of complex curved surfaces**

  - Different surfaces can be discovered by varying the sensitivity of the surface detection function of the scanner.
  - From every scan, automatic surfacing creates a solid model and for essential features like bosses, holes, and pockets, redrawing the features using the scan model as a guide is usually the quickest and most reliable choice
  - Customised and generic software enables the construction of sketch planes associated with flat surfaces on the scan and subtracts cross-sections from the scan mesh, which aids in matching the shape of the original piece

Applications of 3D Scanning in Archaeology

- **Conduct architectural surveys**
  - 3D scanning makes a beautiful proposal for conducting architectural surveys because of the potential to analyse structures in detail. 3D scans allow the user to use, view and change data completely for CAD with exact measurements
  - This technology can collect high-precision information promptly, reduces the efficiency and the time required to provide data for a customer
- **Customised digital replica**
  - 3D laser scanning means that customised digital replica is generated quickly and reliably from existing components designs
  - This technology is helpful for many uses, including reverse engineering, quality assurance and quality management, dimension analysis and monitoring
  - Distorted objects often yield inaccurate measurements; in such cases, 3D laser scanning is recommended

Applications of 3D Scanning in Archaeology

- **Prototyping**
- Combining 3D scanning and 3D printing technology enables the reproduction of actual objects without conventional plaster casting methods, which can be too intrusive in many cases for performing on fragile or fragile cultural heritage items
- 3D laser simulations may be used to teach people how they design or create various things correctly as a teaching medium in the educational field

Workflow of 3D Scanning

- **Preparation and Setup:**
  - Setup Configuration: Position and calibrate the 3D scanner with specific resolution parameters and defined scanning area.
  - Object Placement: Securely position the object within the scanner's field, ensuring stable conditions and optimal lighting

- **Data Acquisition:**
  - Scanning Process: Activate the 3D scanner (using laser triangulation, structured light, or photogrammetry) to capture surface data.
  - Data Collection: Accumulate data points to form a detailed point cloud representing the object's geometry.

Workflow of 3D Scanning

- **Data Processing:**
  - Point Cloud Generation: Process raw data to create a dense point cloud, aligning scans for a unified 3D model.
  - Mesh Generation: Use the point cloud to generate a mesh (vertices, edges, faces) defining precise surface topology.

- **Post-Processing and Refinement:**
  - Data Improvement: Refine mesh quality, smoothing surfaces and filling gaps as needed.
  - Detail Enhancement: Fine-tune digital models to preserve intricate features accurately.

Workflow of 3D Scanning

- **Output and Analysis:**
  - Output Formats: Export final 3D models in various formats such as STL, OBJ, XVl, Wavefront (OBJ), TXT, BMP, DXF, suitable for CAD systems and analysis tools.
  - Quality Assurance: Validate model accuracy against the original object or CAD references.

Workflow of 3D Scanning

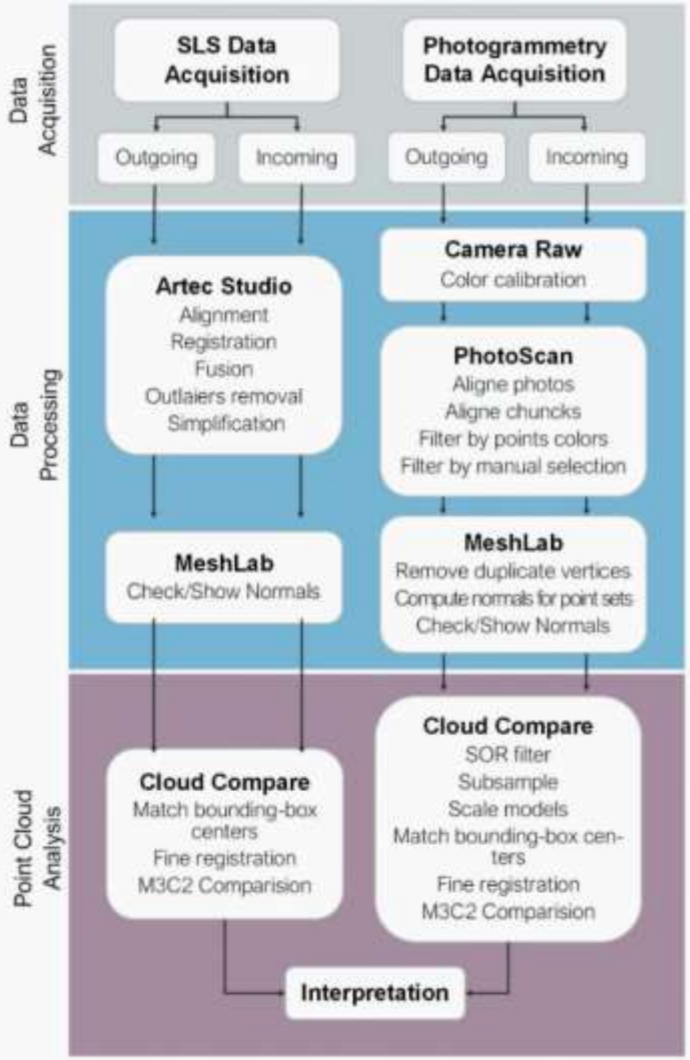


Figure 9: General workflow with the main steps from data acquisition to the damage control. Author: Alba Fuentes-Porto.

[source link : https://mok.scholasticahq.com/article/32524.pdf](https://mok.scholasticahq.com/article/32524.pdf)

Two-Phase Approach for 3D Laser Scanning of Archaeological Artifacts

- **Rotary Phase:**
- **Incremental Rotation**:
  - The artifact is mounted on a turntable and rotated incrementally.
- **Fixed Scanner Position**:
  - The 3D scanner remains stationary while capturing data from all sides of the rotating object.
- **Comprehensive Capture**:
  - Captures the overall form of the object, intricate details on curved surfaces, and hidden features revealed through rotation.

Two-Phase Approach for 3D Laser Scanning of Archaeological Artifacts

- **Plane Phase:**
- **Stable Platform**:
  - The artifact is placed securely on a stable platform.
- **Scanner Mobility**:
  - The scanner moves around the object in a systematic pattern, capturing data from various angles while remaining stationary itself.
- **Detail Focus**:
  - This phase emphasizes capturing details on flat or recessed areas, such as inscriptions or intricate patterns that might be obscured during rotation.

Two-Phase Approach for 3D Laser Scanning of Archaeological Artifacts

- **Combined Data Benefits:**
- **Detailed Analysis**:
  - Allows for minute analysis of the object without risking damage to the original artifact.
- **Collaborative Research**:
  - Facilitates the sharing of 3D models with colleagues worldwide, enhancing collaborative research efforts.
- **High-Fidelity Replicas**:
  - Enables the creation of precise replicas for educational purposes or exhibitions.
- **Digital Preservation**:
  - Preserves a digital record of the object, safeguarding against future damage or loss.

Case Studies

Fig – Roland Picza 3D laser Scanner Machine

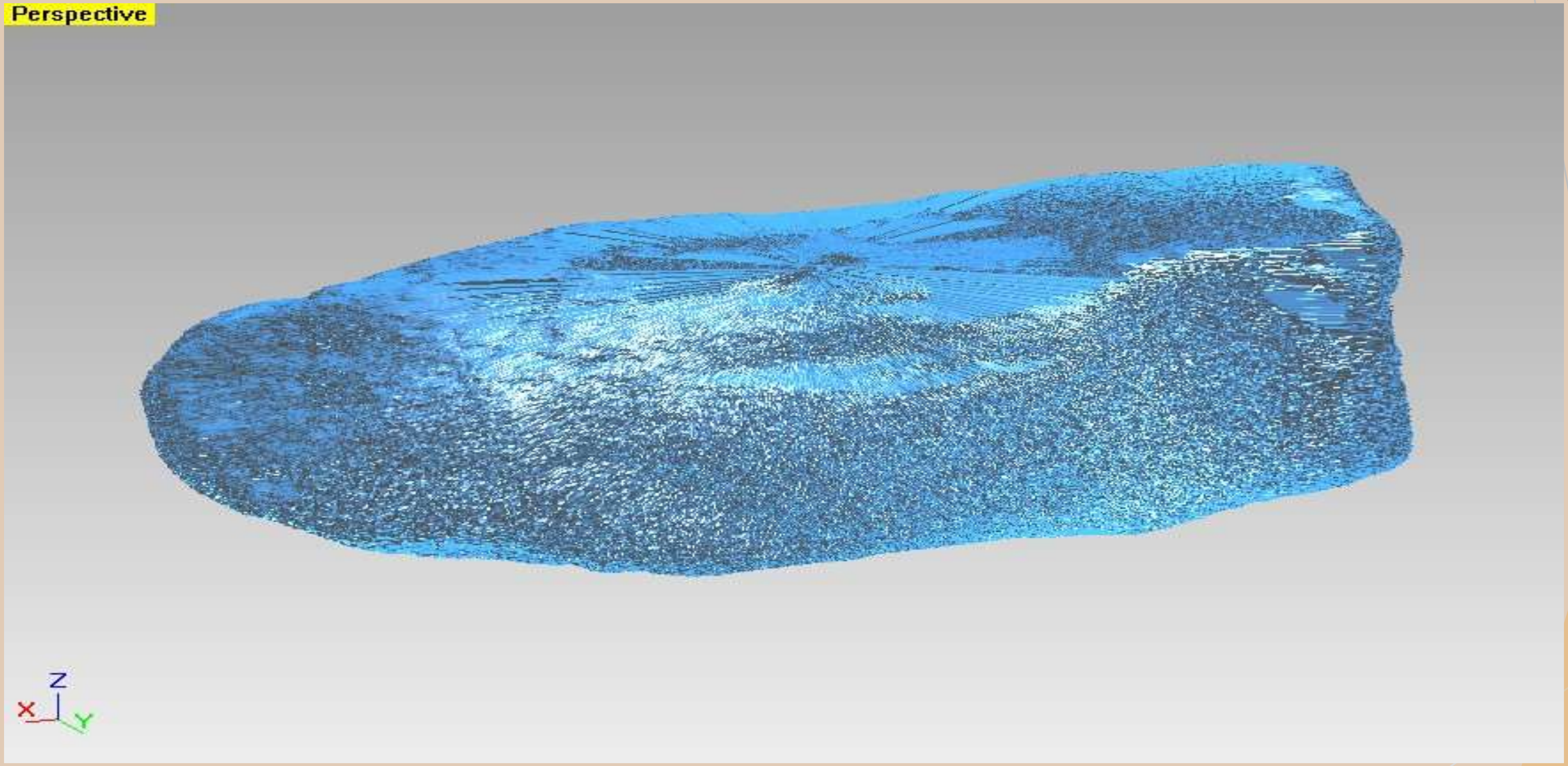
The is a Roland Picza 3D laser scanner machine available at IIT Guwahati. It is a device that uses a laser to scan a physical object and create a digital 3D model of it.

Case Studies

Fig – Roland Picza 3D laser Scanner Machine

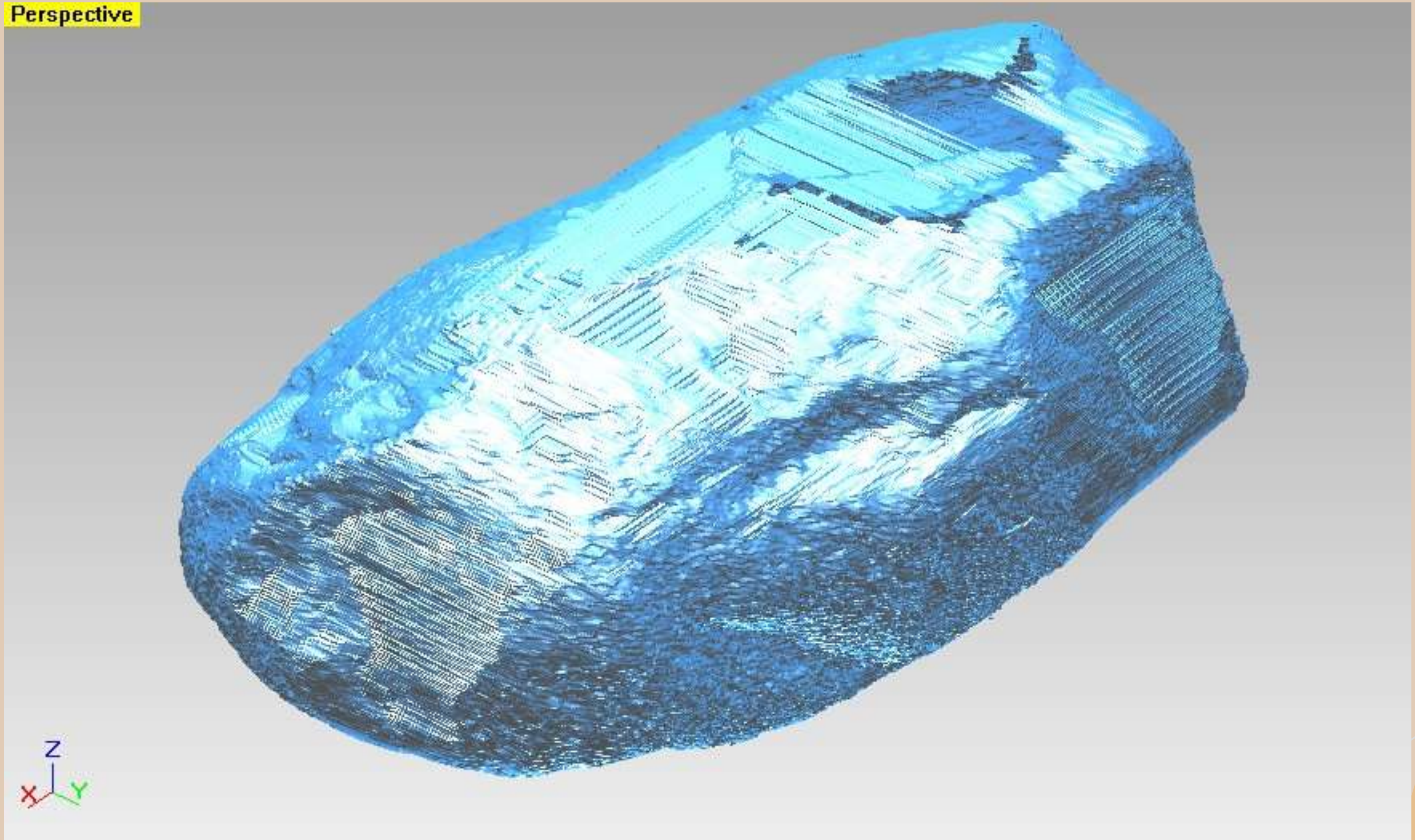
Here, we are trying to capture the stone's overall form, all the details on the curved surfaces, and all other features by 3d scanning of the stone using rotatory phase.

Some Pictures of the Scanned Object



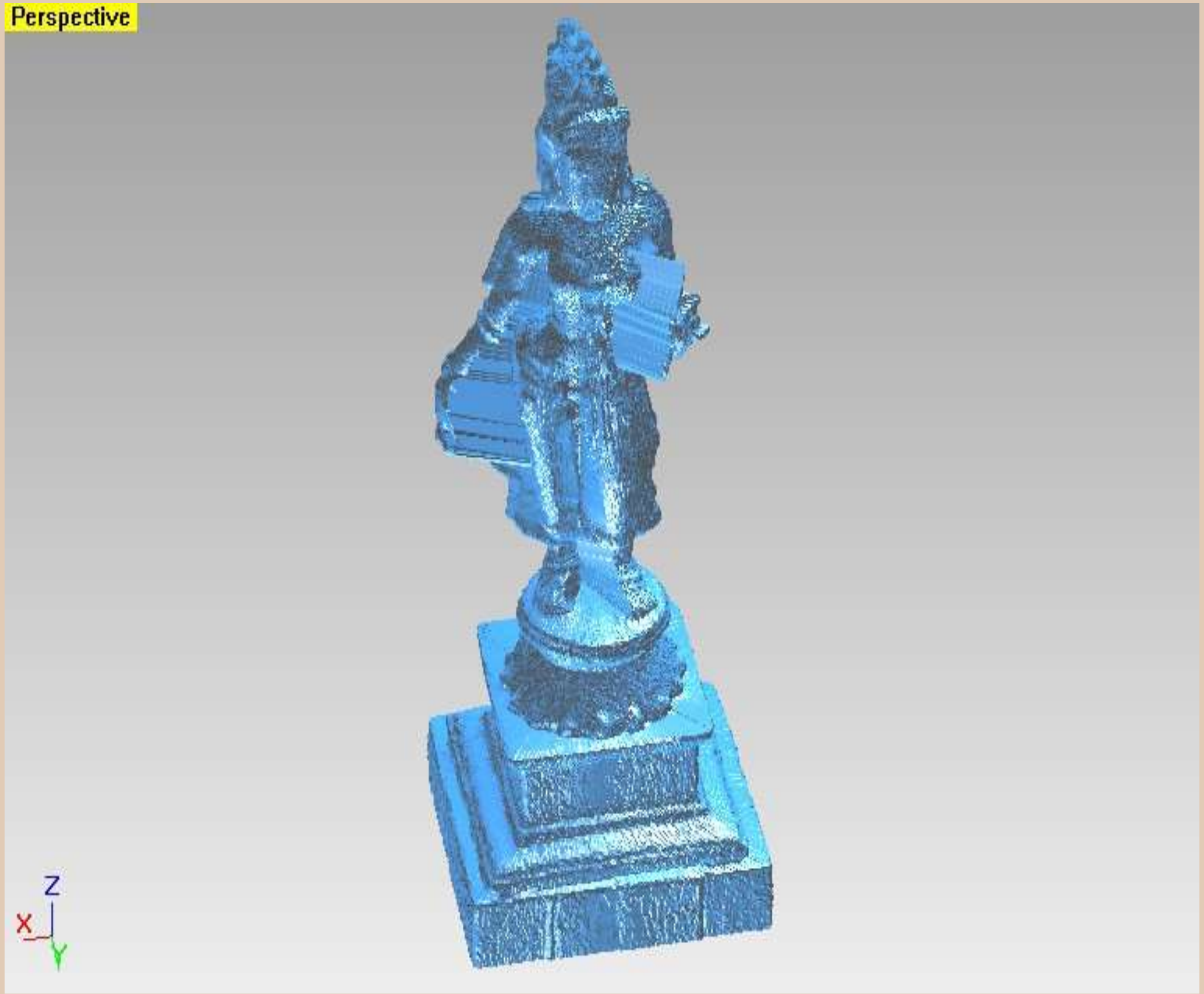
Rotary Phase

Some Pictures of the Scanned Object



Plane Phase

Some Pictures of the Scanned Object



Analysing model performance

- All model performances were evaluated using the unweighted macro F1 score35,36. The F1 score is the harmonic mean of the precision and recall. The models were evaluated by taking the unweighted average of all class specific F1 scores. This was chosen to avoid making the overall F1 score bias to the more numerous classes, as this would give a false confidence in the model performance.
- $precision = tp/(tp+fp)$
- $recall = tp/(tp+fn)$
- Where
- $tp = truepostives$
- $fp = falsepositives$
- $fn = falsenegatives$
- F1 therefore equals:
- $F1 = 2 * precision * recall/(precision + recall)$

Benefits of 3D Scanning in Archaeology

- **Limiting the destructive nature of excavating.**
  - The contribution of a digital model of an excavation, created with the combination of 3D and GIS applications, would be to re-bring to life the state of a stratum in a certain point.
  - Graphic and metric information of high accuracy and quality can be easily retrieved, various 2D plans, sections, ortho-photographs etc. can be extracted, whenever an issue arises or needs to be considered differently from before.
- **Placing excavation data into the bigger picture.**
  - 3D GIS applications contribute further to placing the data and finds of one excavation into the bigger picture of a site or even of a whole excavated culture.
  - The possibility to alter the transparency of digital layers allows a different understanding of spatial relationships

Benefits of 3D Scanning in Archaeology

- **Limiting "fragmentation" of archaeological remains.**
  - A digitally reconstructed and restored 3D model can be created for example, with the help of 3D scanning or photographing, along with CAD, 3D computer graphics and Virtual Reality (VR) software, for filling in the missing parts.
  - The significance of this contribution to research can be understood, when mentioning that the model is always readily available for accurate measurements and detailed view and study in a computer, far away from the site of discovery or a museum storeroom
- **Classifying archaeological finds.**
  - Classification or typology is one of the most essential works of archaeologists aiming to place their finds, based on one or more attributes, into a group with shared characteristics.
  - This task is very important, since it provides guidance for dating artefacts, it leads to conclusions about technology, decoration and other features and it also helps scholars to see patterns in society, economy, trade and other factors as well

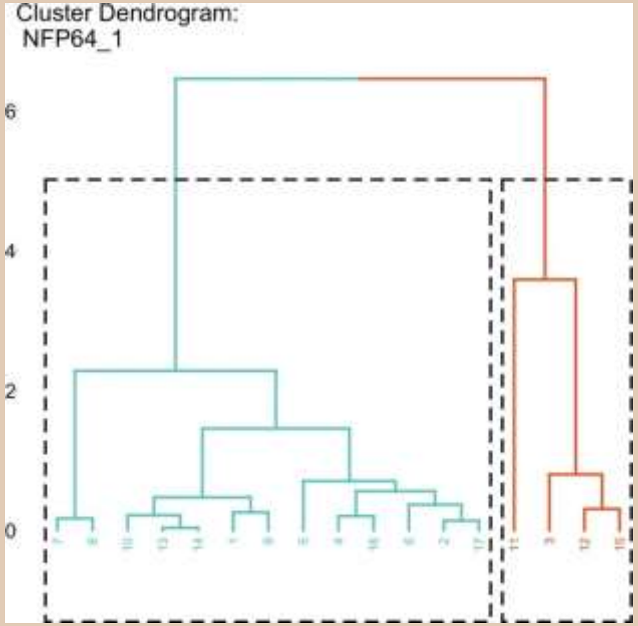
Benefits of 3D Scanning in Archaeology

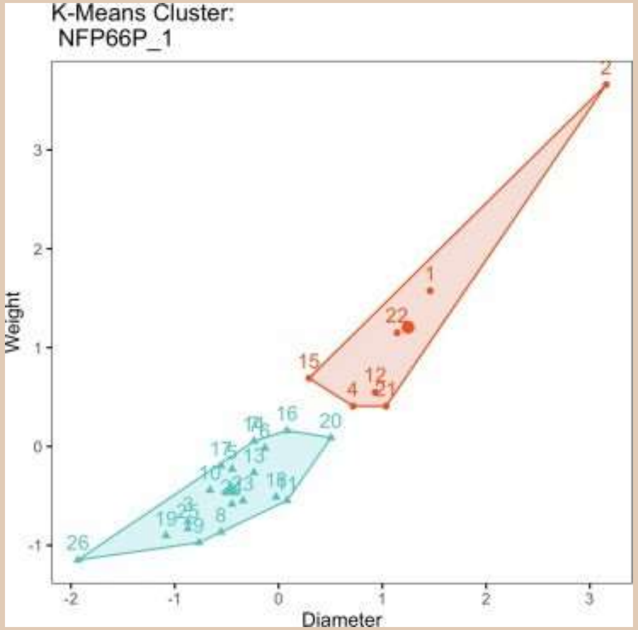
- **Limiting subjectivity and publication delays.**
  - The delays in publishing full excavation reports and presentations are a common problem in many countries and they can become even radical for the excavation’s and finds’ life cycle.
  - A complete and safely stored digital record of an archaeological dig and its finds can combine all the aforementioned technological solutions in a digital note book.
- **Enriching and extending archaeological research.**
  - Through quantification of the dig data, various conclusions can be deduced through statistical processing and the spatial span of finds.
  - An example that demonstrates this was created through a profound 3D digitization project, 3DICONS (Tsaouselis et al., 2015), conducted for providing 3D content for Europeana, the online collection of cultural heritage resources in Europe.

Unveiling the Power of Clustering

- Clustering in machine learning helps identify patterns and group objects based on their properties. For archaeological objects like stones, clustering can reveal insights into their usage by analyzing their dimensions, texture, age, and surface characteristics.
- **Procedure**
  - **Data Collection**
  - **Data Preprocessing**
  - **Assess Clustering Tendency**
  - **Choosing Clustering Algorithms**

Unveiling the Power of Clustering





source - Journal of Archaeological Science: Reports, Volume 45, October 2022, 103615.

Unveiling the Power of Clustering

- In machine learning, cluster analysis falls under unsupervised learning, which identifies patterns within unlabelled data. It groups data into clusters based on shared characteristics, making it ideal for exploring patterns in datasets like sphere diameters and weights.
- To perform cluster analysis on sphere data in R, the measurements were first standardized due to differing scales. A Hopkins statistic assessed clustering tendency, with values above 0.75 indicating significant clustering potential.
- Two main types of clustering algorithms were employed:
  - partitioning (e.g., K-means, Partitioning Around Medoids) and hierarchical.
  - The optimal clustering approach and number of clusters were determined based on these validation statistics, providing insights into the natural groupings and patterns within the sphere data.

Integration of 3D Scanning and Clustering

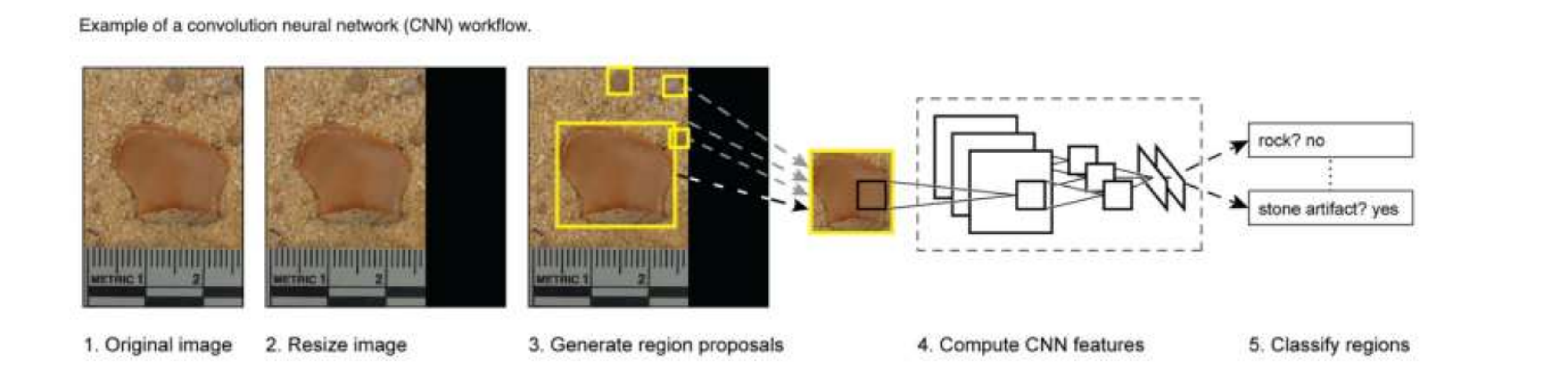


Fig - Machin learning for stone artifact identification: Distinguishing worked stone artifacts from natural clasts using deep neural networks
source link : https://doi.org/10.1371/journal.pone.0271582.g002

Challenges

- **Surface Properties and Reflections:** Archaeological artifacts often exhibit shiny or reflective surfaces that scatter light, leading to incomplete or inaccurate scans.
- **Complex Geometry and Occlusion:** The intricate shapes and multiple components of artifacts can cause occlusion, hindering the scanner's ability to capture all surface details.
- **Transparency Issues:** Artifacts like glass or translucent ceramics can be challenging to scan due to their transparency, which affects light reflection and data capture.

Challenges

- Resolution and Detail Preservation: Ensuring high-resolution scans to capture fine details is crucial, as lower resolutions may miss essential features necessary for accurate reconstruction.
- Post-Processing Requirements: Significant post-processing is often needed to fill gaps, smooth surfaces, and ensure the model's accuracy, adding complexity and time to the scanning process.
- Material Compatibility for 3D Printing: Considering the compatibility of scanned materials with 3D printing technologies is essential, as some materials or features may not translate well into physical replicas.

Overcoming the Challenges

- Equipment Selection: Choose a 3D scanner appropriate for the object's size, material, and complexity to balance resolution and accuracy.
- Environmental Control: Ensure consistent lighting and minimal reflections in the scanning environment to enhance detail and quality.
- Marker Utilization: Strategically place markers to aid in alignment and improve accuracy during scan processing.

Overcoming the Challenges

- Scan Parameter Adjustment: Optimize scanning settings based on the object's size and the required level of detail.
- Multi-Angle Capture: Scan objects from multiple viewpoints to ensure comprehensive coverage and accurate data capture.
- Post-Processing Techniques: Use advanced software for data stitching and processing to seamlessly merge scans, removing artifacts and ensuring a cohesive 3D model.

Summary of Findings

High-Quality Scans:

- ➢ The Blender scanner produced highly detailed and accurate digital models of various objects.
- ➢ Intricate geometries and fine details were captured effectively, ensuring the digital models closely resembled the physical objects.

Data Quality:

- ➢ The scanned data accurately represented the physical details and features of the objects.
- ➢ High-resolution scans allowed for thorough analysis and detailed inspection from multiple angles.

Summary of Findings

Challenges:

- Reflective and transparent surfaces posed significant difficulties during the scanning process.
- Variations in surface texture and material properties further complicated data capture.

Solutions:

- Applying a matte spray to reflective surfaces reduced glare and improved the quality of scanned data.
- Optimizing scanning angles and strategically positioning the scanner helped capture comprehensive data, minimizing blind spots and ensuring complete object coverage.

Limitations and Future Prospects

- In order to ensure a perfect model, scans are done from several angles, but complex geometry may still prove a challenge, like holes or threads always.
- Sometimes shining surfaces are not appropriately scanned.
- For this, some powder or spray is used around the shining surface, which takes extra cost.
- Another major limitation the initial cost of this technology is very high.
- Appropriate input parameters like temperature, humidity needs appropriate adjustment; otherwise, it affects the scanning accuracy.
- Appropriate software is a must, and there are issues of compatibility.

Limitations and Future Prospects

- In the future, 3D scanning will be used with precision material quantities.
- This technology will create more complex forms quickly and with lesser time and costs.
- Further, 3D printing technology uses newer materials and increased 3D print of assembled and parts.
- In the upcoming days, this will become useful in maintaining the working environment of manufacturing industries.

Conclusions

- 3D scanning is a fast and precise collection method for highly complex, physical objects with good surface details.
- 3D scanning is the method for collecting data, allowing scanning any object, regardless of material type, geometry or product size.
- The point cloud data created from the 3D Scan is used with the help of dedicated software to build a 3D CAD model of the product geometry and use a point cloud to improve product performance and design optimization.
- It enables detailed monitoring of the finishing and wear or surface cracking of structures to be compared.