

## 3D scanner technology in the reverse engineering of complex mechanical components: A literature review

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*Received:* 06 February 2026; *Revised:* 10 April 2026; *Accepted:* 16 April 2026

<https://doi.org/10.58712/jerel.v5i1.213>

**Abstract:** This study addresses the challenges involved in the reverse engineering of complex mechanical components, where conventional manual measurement methods often produce geometric deviations that negatively affect the reliability of advanced engineering analyses. A descriptive literature review was conducted to evaluate the role of 3D scanning technology in overcoming these limitations. The study compares various data acquisition methods, including laser scanning, structured light scanning, and photogrammetry, while also analysing how the level of geometric accuracy influences finite element simulation results and structural analysis outcomes. The review found that 3D scanning significantly improves geometric fidelity compared with traditional techniques, thereby enhancing the validity of numerical simulations. However, the review also identified that the quality of the final model is highly dependent on the selected scanning technology, surface conditions, and advanced reconstruction processes such as point cloud registration and mesh generation. The findings indicate that although 3D scanning offers superior precision, geometric deviations may still occur and influence structural parameters. This study concludes that the integration of 3D scanning into reverse engineering workflows requires systematic validation to ensure not only visual accuracy but also functional reliability in engineering applications. Furthermore, this review highlights a critical research gap, suggesting that future studies should place greater emphasis on the direct correlation between geometric accuracy and engineering simulation outcomes.

**Keywords:** 3D scanning; geometric accuracy; modal analysis; reverse engineering

### 1. Introduction

Reverse engineering has been widely recognized as a crucial approach for reconstructing digital models of physical mechanical components, particularly in high-value industrial sectors such as aerospace, automotive, energy, and maritime manufacturing, where technical documentation or original CAD models are often unavailable (Debnath et al., 2025). With the advancement of Industry 4.0 and 5.0, 3D scanning technology has gained increasing attention due to its ability to accelerate processes including rapid prototyping, remanufacturing, quality inspection, and the development of digital twins for real-time performance simulation (Onyia et al., 2025). This growth is further supported by the expanding global 3D metrology market, which is projected to increase from USD 10.6 billion in 2022 to USD 15.9 billion by 2027, with reverse engineering serving as one of the primary driving forces behind this expansion. Accordingly, this literature review aims to examine recent developments in 3D scanning technology, including hardware systems, reconstruction algorithms, and accuracy evaluation methods during the 2022–2026 period. In addition, the review seeks to identify the role of emerging technologies, such as artificial intelligence and additive manufacturing, in addressing challenges associated with geometric complexity and measurement limitations in mechanical components.

Several studies have demonstrated that 3D scanning technology is capable of generating highly detailed geometric representations in the form of point clouds Point Cloud ([Nazim et al., 2025](#)), thereby enabling more accurate model reconstruction processes compared with conventional measurement methods ([Vodilka et al., 2025](#)). Nevertheless, geometric deviations occurring during the reverse engineering process affect not only the visual quality of the model but also directly influence engineering analysis results. In advanced engineering analyses based on the finite element method Finite Element Method, even minor variations in geometric dimensions can significantly affect critical structural parameters such as mass distribution and structural stiffness ([Lengvarský et al., 2025](#)). Therefore, geometric accuracy in the reverse engineering process is a critical factor in determining the reliability of engineering analysis outcomes.

Most existing studies primarily focus on the stages of data acquisition and geometric reconstruction alone, while investigations that directly correlate geometric accuracy with its impact on engineering analysis results remain limited. In fact, understanding the extent to which improvements in geometric accuracy achieved through 3D scanning technology can significantly influence the reliability of analysis outcomes is critically important. Therefore, this literature review aims to:

1. To examine the development of 3D scanning technology in reverse engineering processes for addressing challenges related to geometric complexity and measurement limitations in mechanical components.
2. To compare the influence of different data acquisition methods, particularly between conventional manual measurement techniques and 3D scanning-based methods, on the accuracy of geometric representation.
3. To analyse how the level of accuracy and quality of geometric models generated through reverse engineering affect the reliability of engineering analysis results and numerical simulations.

## 2. Literature review methodology

The methodology employed in this study is a descriptive literature review, aimed at examining, understanding, and developing a theoretical foundation based on relevant scientific sources ([Barry et al., 2022](#)). Unlike a systematic literature review, this approach does not follow a strictly predefined protocol. Instead, it focuses on the collection, evaluation, and synthesis of existing theories and previous studies that support the research topic, particularly in the areas of reverse engineering, 3D scanning technology, and structural dynamic analysis.

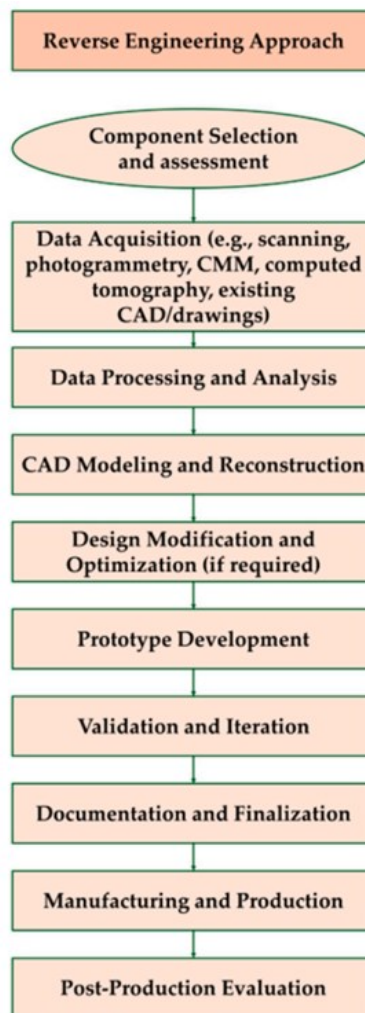
During the literature collection process, the authors conducted a direct selection based on topic relevance, specifically focusing on articles discussing:

1. Reverse engineering processes for mechanical components
2. The application of 3D scanning technology in geometric data acquisition
3. Digital model reconstruction from Point Cloud data
4. The influence of geometric accuracy on engineering analysis, particularly the Finite Element Method

The selected literature was then analysed qualitatively by comparing the concepts, methods, and findings presented in each study. This approach was intended to develop a comprehensive understanding of the relationship between geometric data acquisition processes and the accuracy of engineering analysis results.

### 3. Reverse engineering

Reverse engineering is an engineering approach used to retrieve design information from a physical component with the objective of reconstructing its digital model without relying on original technical data such as engineering drawings or CAD models (Verykokou & Ioannidis, 2023). In the context of mechanical components, this approach becomes particularly crucial, especially in cases involving legacy components, where technical documentation is either unavailable or no longer relevant. Technically, reverse engineering is not merely a process of “copying shapes,” but rather an integrated process involving data acquisition, geometric modelling, and engineering validation (Abdalla et al., 2026). This process generally consists of four main stages: geometric data acquisition, data processing, CAD model reconstruction, and model evaluation and validation. Each stage contributes directly to the quality of the final model produced.



**Figure 1.** Reverse engineering process (Debnath et al., 2025)

### 4. 3D scanning technologies

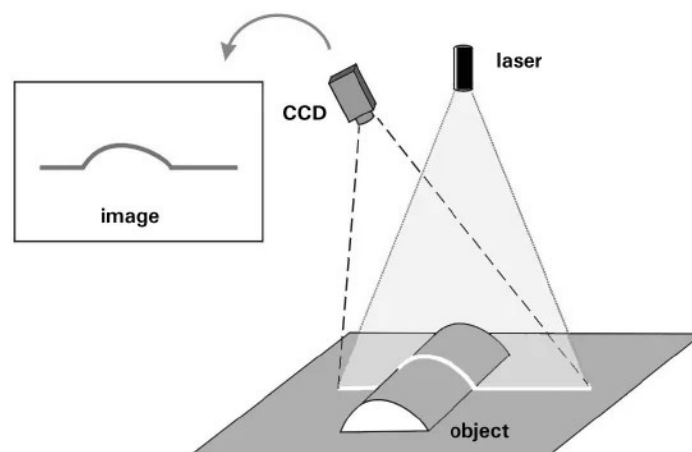
3D scanning technology is a geometric data acquisition method used to generate accurate and comprehensive three-dimensional digital representations of physical objects. This technology operates by capturing the coordinates of points on an object’s surface within a three-dimensional space, which are subsequently represented as a Point Cloud to serve as the basis for digital model reconstruction.

Unlike conventional measurement methods, which are discrete in nature and rely on specific measurement points, 3D scanning is capable of continuously generating large volumes of data. Each point within the point cloud contains coordinate information ( $x, y, z$ ), thereby enabling a more detailed geometric representation that closely resembles the actual condition of the object ([Verykokou & Ioannidis, 2023](#)). This capability represents a major advantage in handling mechanical components with complex and irregular geometries.

The operating principle of 3D scanning is generally based on the projection of energy in the form of laser light or structured light onto the surface of an object, which is then reflected back to the sensor ([Cuesta et al., 2022](#)). Based on the reflection angle and signal travel time, the system calculates the position of each point on the object's surface. This process enables rapid geometric data acquisition with a high level of accuracy, depending on the sensor resolution and the scanning method employed. In general, 3D scanning technology can be classified into several main types, namely:

a. Laser scanning

Laser scanning is a three-dimensional data acquisition technology that operates by projecting a laser beam onto an object's surface to measure distance based on the principle of light reflection. The system determines the position of points on the object's surface through either signal travel time analysis (time-of-flight) or triangulation methods, thereby generating a collection of coordinate data in the form of a Point Cloud. This technology is widely recognized for its high level of accuracy and its ability to capture complex geometric details, making it extensively applied in Reverse Engineering, dimensional inspection, precision manufacturing, and quality analysis ([Meana et al., 2024](#)). The primary advantage of laser scanning lies in its capability to generate high-resolution data; however, its performance may be affected by surface conditions such as high reflectivity or material transparency ([Fontana et al., 2003](#)).

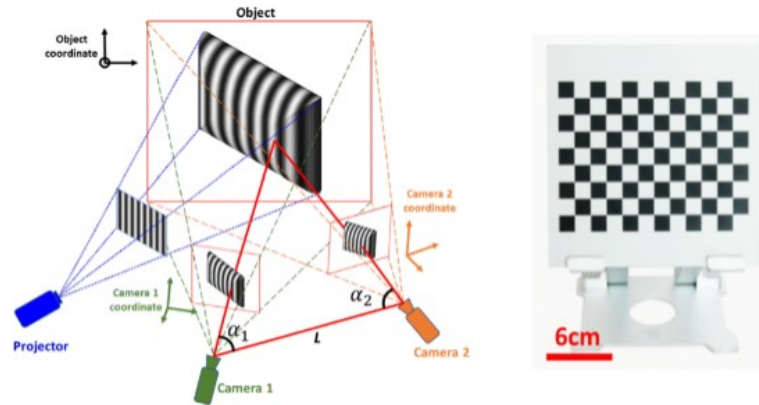


**Figure 2.** Laser scanning system ([Fontana et al., 2003](#))

b. Structured light scanning

Structured light scanning is a three-dimensional scanning technology that operates by projecting specific light patterns, such as lines or grids, onto the surface of an object. A camera or sensor then captures the deformation of these light patterns caused by the object's surface geometry, which is subsequently analysed using the triangulation principle to determine the coordinates of points within three-dimensional space ([X. Zhang et al., 2025](#)). This technology offers advantages

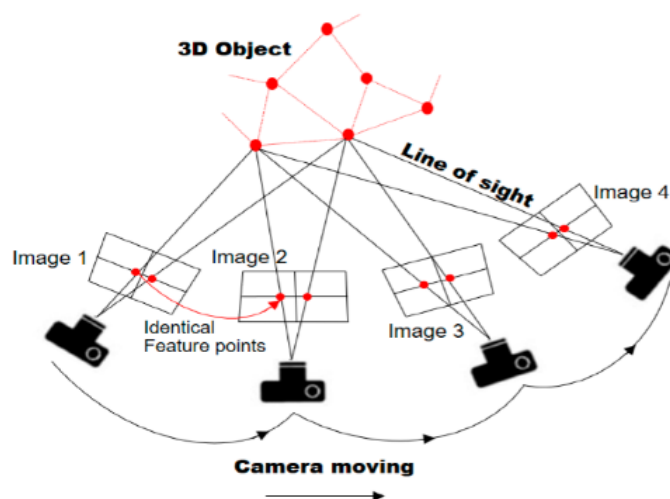
in terms of high-speed data acquisition and the ability to accurately capture surface details, making it widely applied in Reverse Engineering for small- to medium-scale components, quality inspection, and the digitization of complex objects (Wang et al., 2021). Nevertheless, the accuracy of the scanning results can be influenced by environmental lighting conditions and the optical characteristics of the object's surface.



**Figure 3.** Structured light scanning system (Wang et al., 2021)

### c. Photogrammetry

Photogrammetry is a three-dimensional model reconstruction method that utilizes a collection of two-dimensional images captured from multiple viewpoints (Benrabah et al., 2023). The system identifies corresponding points between images to calculate the spatial positions of the object and construct a three-dimensional geometric representation. Unlike laser scanning and structured light scanning, photogrammetry does not require active sensors, as it relies heavily on image quality, lighting conditions, surface texture, and image-processing algorithms. This technology is relatively more flexible and cost-effective, making it widely used for large-object documentation, mapping, and geometric shape reconstruction. However, its level of accuracy is generally lower than that of active scanning technologies, particularly when applied to objects with homogeneous textures or under suboptimal lighting conditions (Nazim et al., 2025).



**Figure 4.** Photogrammetry working principle (Benrabah et al., 2023)

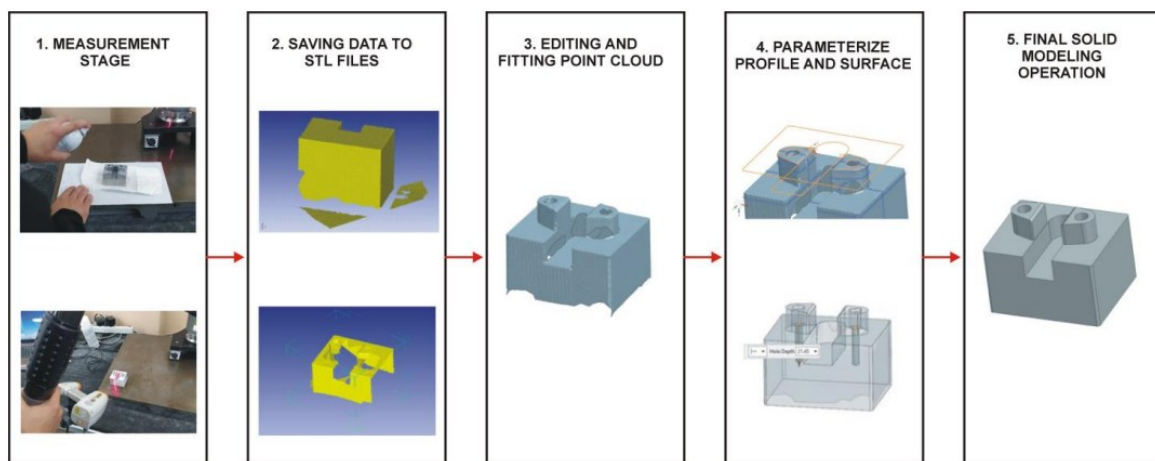
Each technology possesses distinct characteristics in terms of accuracy, resolution, acquisition speed, and sensitivity to object surface conditions. Therefore, the selection of an appropriate scanning technology must be aligned with the specific application requirements, particularly in the Reverse Engineering of mechanical components. The primary output of the scanning process is Point Cloud data, which is subsequently processed through several stages, including filtering to remove noise, registration to merge multiple scan results, mesh surface generation, and conversion into a CAD model. These stages demonstrate that the quality of the final model is determined not only by the scanning hardware but also by the data processing procedures applied afterward (Turek et al., 2025).

The primary advantage of 3D scanning technology lies in its ability to capture complex geometries in a non-destructive manner with a high level of accuracy within a relatively short period of time (Debnath et al., 2025). This capability makes it highly relevant for applications in Reverse Engineering, particularly for components that are difficult to measure manually, such as impellers, turbines, and other components with complex curved geometries. Nevertheless, this technology also has several limitations, including sensitivity to reflective or transparent surfaces, the potential occurrence of noise in scanning data, and high computational requirements during the model reconstruction process (Freni et al., 2026). In addition, errors occurring during either the data acquisition or data processing stages may lead to geometric deviations that affect the accuracy of the digital model.

## 5. 3D scanning process

### 5.1 Reverse engineering from 3D scan data

The reverse engineering process based on 3D scanning data represents a critical stage in transforming the physical representation of an object into a digital model that can be utilized for engineering analysis. Unlike conventional approaches, this process involves a series of complex data-processing stages, ranging from data acquisition to the generation of a CAD model ready for analysis.



**Figure 5.** Reverse engineering process from scan data (Turek et al., 2024)

In general, the reverse engineering process based on scan data consists of several main stages, namely data acquisition, Point Cloud processing, mesh surface generation, CAD model reconstruction, and model validation (Abdalla et al., 2026). Each stage plays an important role in determining the quality of the final model produced:

- a. The first stage is data acquisition using 3D scanning technology, which produces raw data in the form of a Point Cloud. This data consists of a collection of three-dimensional coordinate points representing the object's surface. The quality of the data at this stage is

- highly influenced by the type of scanner, the device resolution, and the environmental conditions during the scanning process ([Nazim et al., 2025](#)).
- b. The next stage involves point cloud processing, which includes filtering to remove noise, outlier removal, and registration to combine multiple scan results obtained from different viewpoints ([Ghorbani & Khameneifar, 2025](#)). This stage is highly critical because raw scanning data generally still contains imperfections that may affect the reconstruction results.
  - c. After the point cloud data has been refined, the process proceeds to the mesh surface generation stage, in which the points within the point cloud are connected to form polygonal surfaces, typically triangles. This process produces a mesh model that more accurately represents the object's geometry; however, it is still not fully suitable for engineering analysis because it does not yet possess a parametric structure similar to a CAD model ([Chlost & Bazan, 2025](#)).
  - d. The following stage is CAD model reconstruction, in which the mesh model is converted into a feature-based geometric model. This process may be performed either manually or semi-automatically, depending on the geometric complexity and the software utilized. At this stage, geometric simplifications or approximations frequently occur, which may potentially cause deviations between the reconstructed model and the original object ([Turek et al., 2024](#)).
  - e. The final stage is model validation, which aims to evaluate the degree of conformity between the reconstructed model and the original data or physical object. This validation is generally performed by comparing geometric deviations or by using specific parameters such as surface error ([Wakjira et al., 2024](#)). This stage is particularly important because it determines whether the resulting model is suitable for further analysis.

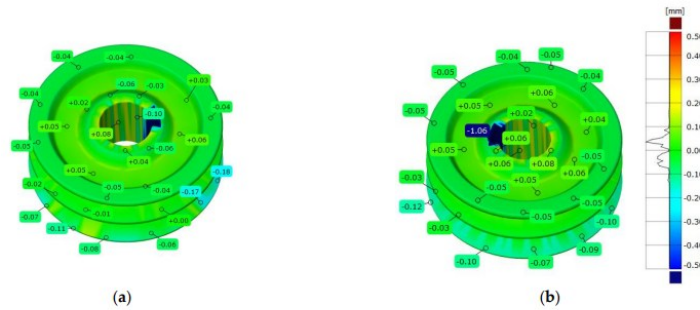
In practice, each stage of the Reverse Engineering process has the potential to generate cumulative errors. Noise in the initial data, registration errors, and model simplifications may lead to significant geometric deviations ([Wakjira et al., 2024](#)). These deviations directly affect engineering analysis results, particularly analyses that are highly sensitive to geometric variations. Within the context of this study, the reverse engineering process based on scan data becomes a key stage in generating geometric models that will be compared with models obtained through manual measurement methods ([Jang et al., 2022](#)). Differences in data-processing and model reconstruction stages will consequently influence the quality of the resulting geometry.

## 5.2 Geometric accuracy evaluation and model validation

At the data acquisition stage, the method employed plays a crucial role in determining the level of accuracy of the geometric representation. Conventional methods, such as manual measurement, have limitations in capturing complex geometries, particularly for components with irregular three-dimensional characteristics, such as pulleys ([Turek et al., 2024](#)). This condition often necessitates geometric assumptions during the modelling process, which may potentially result in dimensional deviations. An example of the deviation observed in a 3D pulley model is shown in Figure 6.

Geometric deviations occurring during the Reverse Engineering process affect not only the visual aspects of the model but also directly influence engineering analysis results. In analyses based on the Finite Element Method, even minor changes in dimensions such as thickness, radius, and curvature can affect mass distribution and structural stiffness ([Lengvarský et al., 2025](#)). Therefore, geometric accuracy in the reverse engineering process becomes a critical factor in determining the reliability of engineering analysis outcomes. Along with the advancement of digital technology, Reverse Engineering has experienced significant improvements through the integration of 3D scanning

technology. This approach enables more detailed and objective geometric data acquisition, thereby reducing dependence on subjective assumptions during the modelling process. As a result, the generated digital models become more representative of the actual condition of the component (Vodilka et al., 2025). Within the context of this study, reverse engineering serves as the primary foundation for comparing two approaches to geometric representation, namely conventional manual measurement methods and 3D scanning-based methods.



**Figure 5.** Three-dimensional deviation map representing CAD modeling errors for a pulley model: (a) top view; (b) bottom view.

**Table 1.** Statistical parameters representing CAD modeling errors for the pulley model.

Parameters	Pulley Model
Maximum deviation [mm]	0.278
Minimum deviation [mm]	-1.203
Range [mm]	1.481
Mean deviation [mm]	-0.002
Standard deviation [mm]	0.031

### Figure 6. Pulley model deviation results (Turek et al., 2024)

Accuracy evaluation and model validation constitute critical stages in the Reverse Engineering process based on 3D scanning, aiming to ensure that the reconstructed geometric model possesses a high level of conformity with the original object. This stage is particularly important because the quality of the geometric model directly affects the reliability of the engineering analysis results performed afterward (Turek et al., 2026). In the context of reverse engineering, accuracy refers to the degree of similarity between the reconstructed digital model and the actual geometry of the physical object. In practice, this accuracy is influenced by various factors, including scanner resolution, the quality of Point Cloud data, filtering processes, and the reconstruction methods employed. Errors occurring at each of these stages may lead to cumulative geometric deviations.

One of the methods commonly used in accuracy evaluation is geometric deviation analysis, which involves comparing the reconstructed model with reference data, such as the original CAD model, manual measurement results, or other scan data. The comparison results are typically visualized in the form of a colour map deviation, illustrating the distribution of dimensional differences across the entire object surface. In addition, accuracy evaluation can also be performed quantitatively using statistical parameters such as maximum deviation, average deviation, and root mean square error Root Mean Square Error (RMSE) (Wakjira et al., 2024). These parameters provide numerical representations of the level of geometric error present, thereby serving as indicators of model quality.

In the context of engineering applications, model validation is not limited solely to geometric conformity but must also consider its influence on engineering analysis results. A model with minor geometric deviations does not necessarily produce identical analysis outcomes, particularly in analyses that are highly sensitive to dimensional variations. Small changes in geometric parameters such as thickness, diameter, and curvature can affect mass distribution and structural stiffness (Lengvarský et

al., 2025). Therefore, model validation should be conducted not only from a geometric perspective but also functionally through the comparison of analysis results.

Several studies have shown that models generated through 3D scanning with a high level of accuracy tend to produce analysis results that more closely represent actual conditions compared with models developed based on manual measurements (Turek et al., 2025). Nevertheless, non-optimal reconstruction processes, such as excessive smoothing or meshing errors, may reduce model accuracy and lead to deviations in the analysis results. In this study, accuracy evaluation was conducted by comparing the Reverse Engineering model generated through 3D scanning-based methods with the model obtained from manual measurements. This comparison was performed both in terms of geometry and the resulting Finite Element Method (FEM) analysis outcomes, thereby enabling the assessment of how differences in data acquisition methods influence the reliability of the analysis results (Kandiyil et al., 2025). Accordingly, accuracy evaluation and model validation serve not only as verification stages but also as the foundation for determining the quality of models used in engineering analysis.

## 6. Analysis and synthesis of the literature

The classification of studies represents an important stage in a literature review for grouping previous research based on the approaches, methods, and research focuses employed (Debnath et al., 2025). Through classification, researchers can identify dominant research patterns, differences in the approaches applied, and the direction of technological development in the fields of Reverse Engineering and 3D Scanning. Based on the results of the literature review conducted, studies related to reverse engineering and 3D scanning technology for mechanical components can be classified into several main categories, namely according to data acquisition methods, model reconstruction approaches, and engineering analysis objectives.

### 6.1 Classification according to data acquisition methods

Research in this field is generally divided into two main approaches (Konecki et al., 2024), namely:

- a. Conventional measurement methods (manual measurement)
- b. 3D scanning-based methods

Studies employing conventional methods generally rely on measuring instruments such as callipers and micrometres to obtain geometric dimensions. This approach tends to be relatively simple; however, it has limitations in capturing complex geometries and often produces deviations due to modelling assumptions. In contrast, studies based on 3D scanning utilize technologies such as laser scanning and structured light scanning to acquire geometric data in the form of highly detailed Point Cloud data. Previous studies have shown that this approach is capable of improving the accuracy of geometric representation, particularly for components with complex shapes.

### 6.2 Classification according to model reconstruction processes

Based on the digital model reconstruction process, studies can be categorized into:

- a. Direct modelling approach

The CAD model is created directly from measurement results or Point Cloud data through manual interpretation.

b. Point cloud processing-based approach

This approach involves several stages, including filtering, registration, meshing, and surface reconstruction before the data is converted into a CAD model ([Barsanti et al., 2022](#)).

c. Automation and AI-based approach

This approach utilizes Machine Learning algorithms or optimization techniques to improve reconstruction accuracy ([Y. Liu et al., 2024](#)).

Recent studies indicate that the use of more advanced data-processing algorithms can improve the quality of reconstructed models, particularly in reducing noise and enhancing surface precision.

### 6.3 Classification according to research objectives

From the perspective of research objectives, studies in this field can be categorized into:

a. Geometry reconstruction

This category focuses on generating accurate CAD models from physical objects.

b. Accuracy evaluation

This category involves comparing scanning results with other methods or reference data.

c. Engineering analysis applications

This category utilizes models generated through Reverse Engineering for analyses such as Finite Element Method (FEM), stress analysis, and modal analysis ([Catbas et al., 2023](#)).

Interestingly, most studies still focus primarily on the stages of geometric reconstruction and accuracy evaluation, while the direct integration of reverse-engineered models into engineering analysis remains relatively limited.

### 6.4 Classification according to object complexity

Studies can also be distinguished based on the type of object being analysed, namely:

a. Simple geometry

Components with basic shapes that are relatively easy to measure.

b. Complex geometry

Components with freeform curves and high-detail features, such as impellers, turbines, and blades ([Chlost & Bazan, 2025](#)).

Studies have shown that the level of geometric complexity significantly influences the methods employed as well as the degree of difficulty involved in the reconstruction and validation processes.

Based on this classification, it can be concluded that current research trends indicate a transition from conventional methods toward the use of 3D scanning technology integrated with digital data processing (Abdalla et al., 2026). Nevertheless, most existing studies still focus primarily on the aspects of data acquisition and geometric reconstruction, while investigations directly linking geometric accuracy with engineering analysis results remain limited. This condition indicates significant opportunities for further research aimed at examining the influence of reverse-engineered model quality on the reliability of numerical analysis results.

**Table 1.** Classification of existing studies on reverse engineering and 3D scanning technologies

Reference	Data acquisition method	Model reconstruction process	Research objective	Object complexity	
(Konecki et al., 2024)	Conventional (caliper, Vernier) vs Optical	Direct modeling	Accuracy evaluation	Complex (non-standard gears)	
(Alsoufi et al., 2025)	Conventional (DVC) vs automated CMM	Direct modeling	Accuracy evaluation	Simple (CNC components)	
(Turek et al., 2025)	Contact & Optical (scanning)	Point processing	Cloud processing	Accuracy evaluation + Geometric RE	Complex (turbine blades, helical gears)
(Nazim et al., 2025)	Photogrammetry vs Structured Light	Point processing	cloud processing	Geometric RE + accuracy evaluation	Simple–Medium (industrial robots)
(Cuesta et al., 2022)	3D Scanning (4 triangulation sensors)	Point processing	cloud processing	Accuracy evaluation	Simple (GD&T artifacts)
(Ghorbani & Khameneifar, 2025)	3D Scanning (laser)	Point processing (denoising)	cloud processing	Geometric RE	Complex (aero-engine blades)
(Q. Liu et al., 2024)	3D Scanning → point cloud	AI/ML-based (Point2CAD)		Geometric RE	Complex (freeform CAD)
(Barsanti et al., 2022)	3D Scanning (terrestrial LiDAR)	Point cloud → NURBS → FEA		Engineering analysis (FEA, stress analysis)	Complex (heritage buildings)
(Catbas et al., 2023)	3D Scanning (laser)	Point cloud → FEA model		Engineering analysis (modal analysis, natural frequencies)	Complex (pedestrian bridges)
(Lengvarský et al., 2025)	3D Scanning + EMA	Point cloud → FEM updating		Engineering analysis (modal analysis)	Simple (axisymmetric steel pipes)
(Abdalla et al., 2026)	3D Scanning (optical/laser/XCT)	Point cloud → mesh → CAD → FEA		Geometric RE + engineering analysis	Complex (metal components)
(Freni et al., 2026)	3D Scanning (various surface conditions)	Point processing	cloud processing	Accuracy evaluation	Medium (shipyard components)

## 7. Comparison of 3D scanning technologies

The development of 3D scanning technology has led to the emergence of various geometric data acquisition methods with different characteristics in terms of accuracy, resolution, speed, and data-processing complexity. Therefore, the selection of an appropriate scanning technology becomes a critical factor in the Reverse Engineering process, particularly when the reconstructed models are intended for engineering analyses that are sensitive to geometric variations (Cuesta et al., 2022). In general, the 3D scanning technologies most commonly used in research can be classified into three main types, namely laser scanning, structured light scanning, and photogrammetry (X. Zhang et al., 2025). These three technologies differ fundamentally in both their operating principles and technical performance.

In terms of accuracy, laser scanning technology generally offers the highest level of precision compared with other methods. This is due to the use of laser beams capable of measuring distances accurately through triangulation or time-of-flight methods. Structured light scanning also provides high accuracy, particularly for small- to medium-sized objects; however, its performance can be influenced by environmental lighting conditions (Meana et al., 2024). Meanwhile, photogrammetry tends to exhibit lower accuracy because it relies heavily on image quality and algorithm-based reconstruction processes. In terms of resolution and surface detail, structured light scanning offers advantages in capturing fine surface features, as it utilizes light patterns capable of representing surface deformations in detail. Laser scanning is also capable of producing high-resolution data; however, in some cases, it is more focused on distance accuracy rather than texture detail. Photogrammetry, although flexible, often faces limitations in capturing details on homogeneous or low-texture surfaces (Z. Zhang et al., 2025).

From the perspective of data acquisition speed, structured light scanning is generally superior because it can capture surface areas rapidly through the projection of light patterns. Laser scanning tends to be slower, as the scanning process is performed point by point or line by line. Meanwhile, photogrammetry requires additional time for image acquisition from multiple viewpoints as well as relatively more complex data processing (X. Zhang et al., 2025). In terms of flexibility and cost, photogrammetry is considered a more economical option because it only requires a digital camera without expensive specialized equipment. In contrast, laser scanning and structured light scanning require dedicated hardware with relatively high investment costs, but they offer more consistent and accurate results (Nazim et al., 2025).

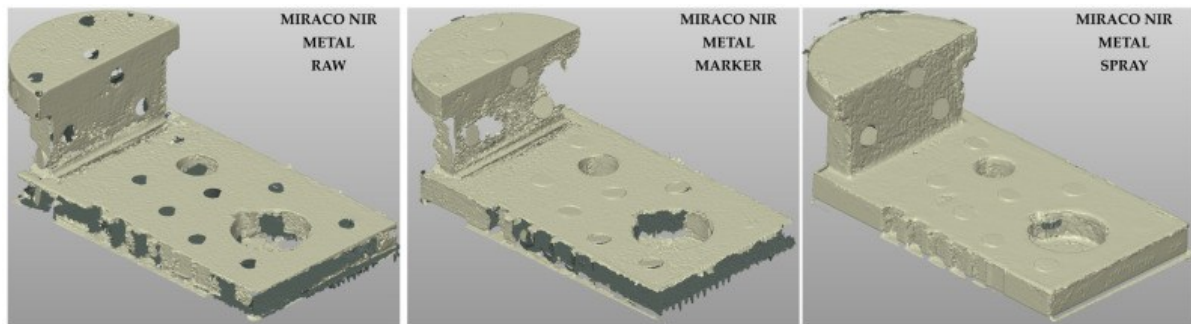
In addition, from the perspective of technical limitations, each technology possesses specific drawbacks that must be considered. Laser scanning and structured light scanning have limitations in handling reflective or transparent surfaces, which may cause data distortion. Photogrammetry is highly dependent on lighting conditions and surface texture, causing its results to vary depending on the surrounding environment (Lakovaki et al., 2026). In the context of Reverse Engineering for mechanical components, particularly objects with complex geometries such as impellers, the selection of scanning technology should consider a balance between accuracy and the ability to capture surface details. Technologies with higher accuracy are capable of producing more representative geometric models, which ultimately improves the reliability of engineering analysis results (Debnath et al., 2025). Furthermore, differences in the quality of scanning data directly affect both the model reconstruction process and numerical analysis results. Models with high geometric deviations may lead to variations in mass distribution and structural stiffness (Catbas et al., 2023). Therefore, the evaluation of scanning technologies becomes an essential step in ensuring the quality of the data used in the analysis process.

**Table 2.** Comparison of 3D scanning technologies

Technology	Accuracy	Resolution	Speed	Cost	Limitations
Laser Scanning	Very high	High	Moderate	High	Sensitive to reflective surfaces
Structured Light Scanning	High	Very high	Fast	High	Sensitive to lighting conditions
Photogrammetry	Moderate	Moderate	Slow (processing)	Low	Dependent on surface texture

## 8. Challenges and limitations of current technologies

Although 3D scanning technology has experienced significant advancements and has been widely applied in Reverse Engineering processes, various challenges and limitations still affect the quality of the generated geometric data. These limitations are related not only to the technical aspects of the scanning devices but also to data acquisition, data processing, and their implications for engineering analysis (Turek et al., 2026). One of the primary challenges in the application of 3D scanning technology is its sensitivity to object surface conditions. Reflective, transparent, or dark-colored surfaces may interfere with the sensor reading process, resulting in inaccurate Point Cloud data or even loss of information in certain areas (Turek et al., 2024). This condition often requires additional treatments such as surface coating, which in some cases may affect the original dimensions of the object.



**Figure 7.** Effect of reflective surface conditions on point cloud quality in the 3D scanning process of ship components (Freni et al., 2026)

In addition, the presence of noise and outliers in Point Cloud data represents a common issue in 3D scanning processes. Scanning results often contain points that do not accurately represent the object surface due to environmental disturbances, sensor limitations, or errors during the data acquisition process. Although filtering procedures can reduce noise, excessive filtering may lead to the loss of important geometric details. Another challenge lies in the data registration and alignment process. In many cases, objects must be scanned from multiple viewpoints to obtain complete geometric coverage. The process of merging data acquired from different positions may introduce alignment errors, which can subsequently result in distortions in the overall geometry of the reconstructed model (Wakjira et al., 2024).

At more advanced stages, the mesh reconstruction process and conversion into CAD models also present several limitations. Mesh models generated from Point Cloud data do not always exhibit optimal quality, particularly in regions with incomplete data coverage. In addition, the conversion process into CAD models frequently involves geometric simplification, which may result in deviations from the original object geometry (Catbas et al., 2023). From a computational perspective, processing

scanning data requires substantial computational resources, especially for high-resolution datasets. This condition may become a constraint in the model reconstruction process, both in terms of processing time and hardware requirements.

Furthermore, one challenge that is often overlooked is the dependence on operator expertise and process parameters. Scanning parameter settings, such as resolution, distance, scanning angle, and data-processing techniques, significantly influence the quality of the final results. Variations in these settings may produce models with different levels of accuracy, even when the same scanning device is used. In the context of engineering applications, these limitations have direct implications for the reliability of analysis results. Geometric deviations generated during the scanning and reconstruction processes may affect mass distribution and structural stiffness ([Lengvarský et al., 2025](#)). Therefore, understanding the limitations of the technology is essential in evaluating Reverse Engineering results.

Nevertheless, continuous advancements in technology and data-processing methods are being developed to overcome these limitations, including the implementation of more adaptive filtering algorithms, more accurate registration techniques, and the integration of artificial intelligence into the model reconstruction process. Therefore, although 3D scanning technology offers significant advantages in geometric data acquisition, its application still requires a comprehensive understanding of the existing challenges and limitations to ensure that the generated models can be reliably utilized in engineering analysis ([Mhadgut et al., 2025](#)).

## 9. Research gaps and future research opportunities

Based on the results of the literature analysis and synthesis presented in the previous sections, it can be identified that research in the field of Reverse Engineering based on 3D scanning technology has experienced significant development, particularly in the areas of geometric data acquisition and digital model reconstruction. Various studies have demonstrated that the application of 3D scanning technology is capable of improving the accuracy of geometric representation compared with conventional measurement methods ([Debnath et al., 2025](#)). Nevertheless, most existing studies still focus primarily on the early stages of the reverse engineering process, namely data acquisition and geometric model reconstruction. Many studies emphasize improvements in Point Cloud quality, filtering methods, as well as mesh generation and CAD conversion techniques, without thoroughly investigating the implications of geometric quality on engineering analysis results ([Y. Liu et al., 2024](#)).

Furthermore, studies addressing model accuracy evaluation are generally limited to geometric comparisons, such as dimensional deviations or surface errors. This approach does not fully represent the reliability of the model within the context of engineering applications, as it does not consider how these geometric deviations influence numerical analysis results ([Turek et al., 2025](#)). A significant research gap lies in the limited integration between geometric accuracy evaluation and engineering analysis, particularly in analyses that are highly sensitive to dimensional variations ([Catbas et al., 2023](#)). Although several studies have applied models generated through 3D scanning in simulations based on the Finite Element Method, investigations that systematically compare the influence of data acquisition methods on analysis results remain relatively limited.

In addition, there are still limited studies that directly compare models obtained through manual measurement methods with models generated through 3D scanning within the context of engineering analysis ([Kandiyil et al., 2025](#)). In fact, such comparisons are important for understanding the extent to which improvements in geometric accuracy can significantly influence analysis results.

Based on the identified research gaps, several research opportunities can be further explored, including:

- a. The development of evaluation methods that consider not only geometric accuracy but also functional validation through engineering analysis results.
- b. Comparative studies between various data acquisition methods and their influence on numerical simulation results.
- c. The more systematic integration of Reverse Engineering processes with analyses based on the Finite Element Method.
- d. The development of approaches capable of minimizing geometric deviations at each stage of the model reconstruction process.

Within the context of this study, the primary focus is directed toward a comparative analysis between models obtained through manual measurement methods and models generated through Reverse Engineering based on 3D scanning technology. Accordingly, this study is expected to address the existing research gap, particularly in establishing the relationship between geometric accuracy and the reliability of engineering analysis results.

The results of the literature review and analysis conducted in this study indicate that the geometric accuracy of models generated through Reverse Engineering has a significant influence on the reliability of engineering analysis results. Therefore, the engineering implications of this study are not limited solely to methodological aspects but also directly affect the practices of design, analysis, and maintenance of mechanical components ([Abdalla et al., 2026](#)). In the context of product design and engineering, the application of 3D scanning technology in reverse engineering processes enables the acquisition of geometric models that are more accurate and more representative of the actual condition of the component. This capability is particularly important in redesign or component modification processes, where geometric inaccuracies may lead to functional incompatibility or reduced system performance ([Vodilka et al., 2025](#)).

In simulation-based engineering analyses, such as Finite Element Method, the quality of the geometric model becomes a determining factor in producing valid simulation results. Models with high geometric deviations may generate inaccurate mass distribution and structural stiffness characteristics. Therefore, the use of highly accurate 3D scanning data can improve the reliability of simulation results and reduce the risk of misinterpretation ([Lengvarský et al., 2025](#)). In the fields of manufacturing and quality control, 3D scanning technology can be utilized for dimensional inspection and product verification in a faster and more precise manner. Comparisons between design models and manufactured products can be performed digitally using deviation analysis, thereby enabling more effective detection of defects or deviations compared with conventional methods ([Freni et al., 2026](#)).

Furthermore, in the context of maintenance and component reconstruction, particularly for components lacking technical documentation (legacy parts), Reverse Engineering based on 3D scanning provides a practical solution for regenerating digital models that can be utilized in component repair or replacement processes. This capability is highly relevant in industries that depend on the operational continuity of equipment ([Debnath et al., 2025](#)). Nevertheless, the engineering implications of applying this technology also require a thorough understanding of process limitations, such as the potential occurrence of noise, reconstruction errors, and the necessity of model validation before the models are used in analysis. Without adequate validation procedures, the use of scanned models may instead lead to inaccurate engineering decisions ([Turek et al., 2025](#)).

Therefore, this study emphasizes that the integration of 3D scanning technology, Reverse Engineering processes, and engineering analysis must be conducted in a systematic and controlled manner. This approach not only improves the accuracy of geometric models but also ensures that the resulting analysis outcomes can be reliably utilized in engineering decision-making processes.

## 10. Conclusion

Based on the results of the literature review and analysis conducted in this study, it can be concluded that the Reverse Engineering process based on 3D scanning technology plays a significant role in producing geometric models with higher accuracy compared with conventional measurement methods. The resulting level of geometric accuracy has been shown to be a key factor influencing the reliability of engineering analysis results. The comparison between manual measurement methods and 3D scanning-based approaches demonstrates that the limitations of conventional methods may lead to greater geometric deviations. In contrast, the use of data obtained through 3D scanning is capable of providing geometric representations that more closely resemble the actual condition of the object, thereby improving the reliability of simulation results.

Nevertheless, the review results also indicate that model quality is determined not only by the scanning technology employed but also by the data-processing and model reconstruction procedures applied. Factors such as noise in Point Cloud data, registration errors, and simplifications during the conversion process into CAD models may affect the final level of geometric accuracy achieved. From an application perspective, the integration of 3D scanning technology into Reverse Engineering processes has substantial potential to support engineering activities, including component redesign, simulation-based analysis, as well as inspection and maintenance. Nevertheless, the application of this technology must be accompanied by adequate validation procedures to ensure that the resulting models are truly representative and can be reliably utilized in engineering decision-making processes. Based on these findings, it is recommended that future studies should not focus solely on improving data acquisition quality but should also develop evaluation methods capable of directly correlating geometric accuracy with engineering analysis results. Such an approach is important to ensure that reverse-engineered models are not only visually accurate but also functionally valid within the context of engineering applications.

### Author's declaration

### Author contribution

**Afferli Seftian:** Conceptualization, Methodology, Investigation (Literature Search and Selection), Data Curation, Formal Analysis, and Writing – Original Draft. **Delima Yanti Sari:** Conceptualization, Methodology, Validation, Writing – Review & Editing, and Supervision. **Rifelino:** Validation, Writing – Review & Editing, and Supervision. **Zainal Abadi:** Validation, Writing – Review & Editing, and Supervision.

### Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### Data availability

Not applicable, as this study did not generate or analyse any new data.

## Acknowledgements

The authors would like to express their sincere gratitude to the lecturers of the Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, for their guidance and support during the completion of this literature review study.

## Conflict of interest

The authors declare that there are no conflicts of interest related to this research or the publication of this article.

## Ethical clearance

Not applicable.

## AI statements

The translation process in this article was assisted by ChatGPT, while grammar checking and language refinement were performed using Grammarly to improve readability and linguistic quality. The authors manually reviewed the accuracy, correctness, and contextual appropriateness of the generated content to ensure its consistency with the topic and scope of this study. No AI-generated sentences, tables, or figures were directly included in this article. The authors take full responsibility for the entire content of this article.

## Publisher's and Journal's Note

Researcher and Lecturer Society as the publisher, and the editor of Journal of Engineering Researcher and Lecturer state that there is no conflict of interest towards this article publication.

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