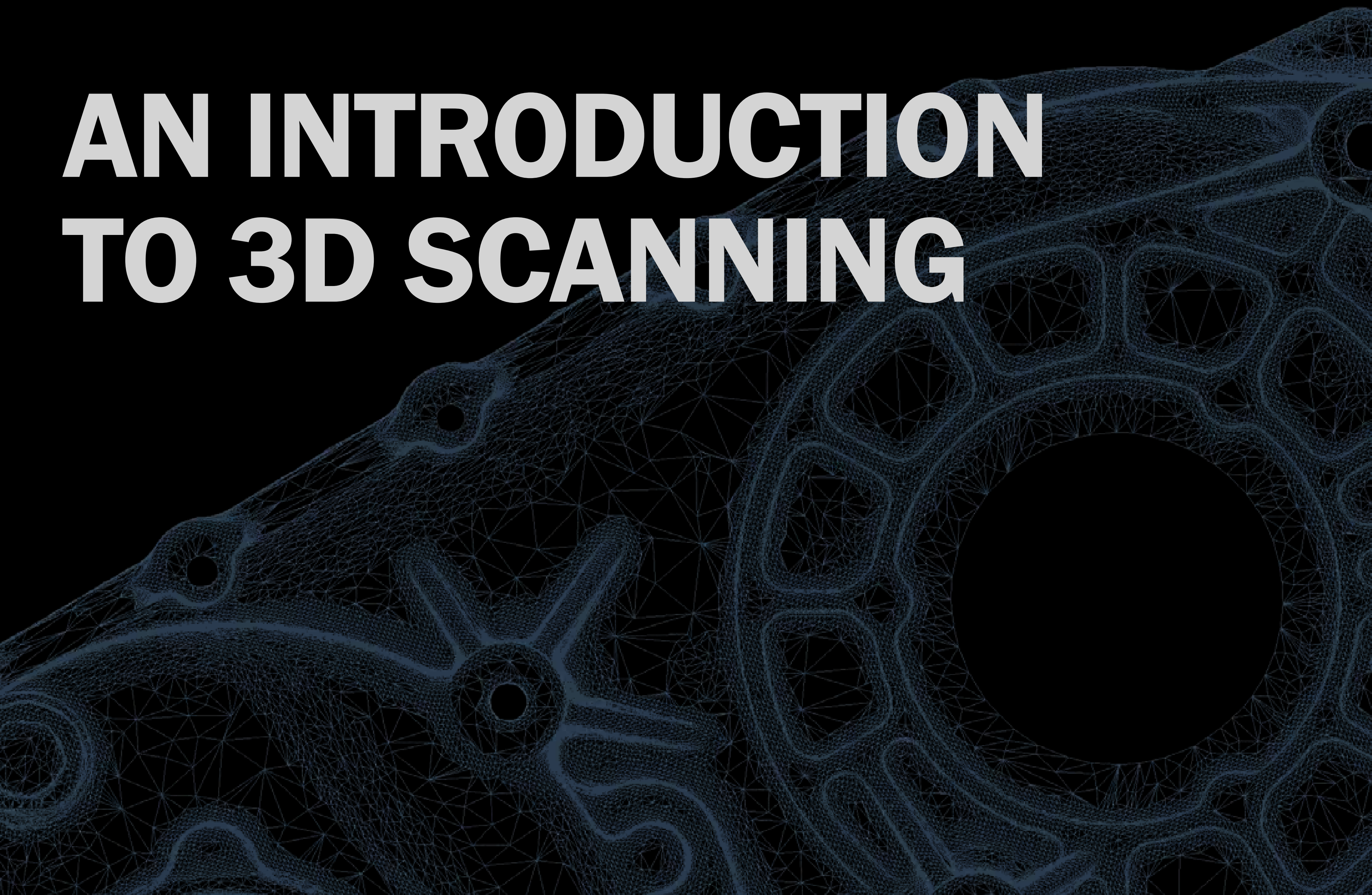
AN INTRODUCTION TO 3D SCANNING



Fast, furious and disruptive.

While the mainstream media continues its obsession with 3D printing, another quiet, perhaps more impactful, disruption is revolutionizing the way products are designed, engineered, manufactured, inspected and archived. It's 3D scanning – the act of capturing data from objects in the real world and bringing them into the digital pipeline.

ACCORDING TO THE NEW MARKET RESEARCH REPORT ON THE 3D SCANNER MARKET, THE MARKET IS EXPECTED TO GROW FROM

USD 4.13 BILLION

IN 2018 TO

USD 6.59 BILLION

BY 2025, AT A

CAGR OF 6.6%

BETWEEN 2019 AND 2025.

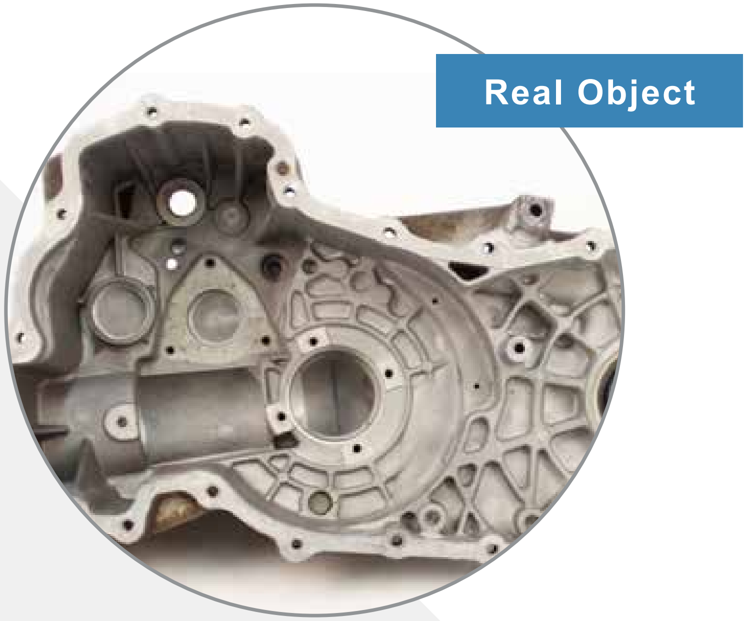
Source: marketsandmarkets.com

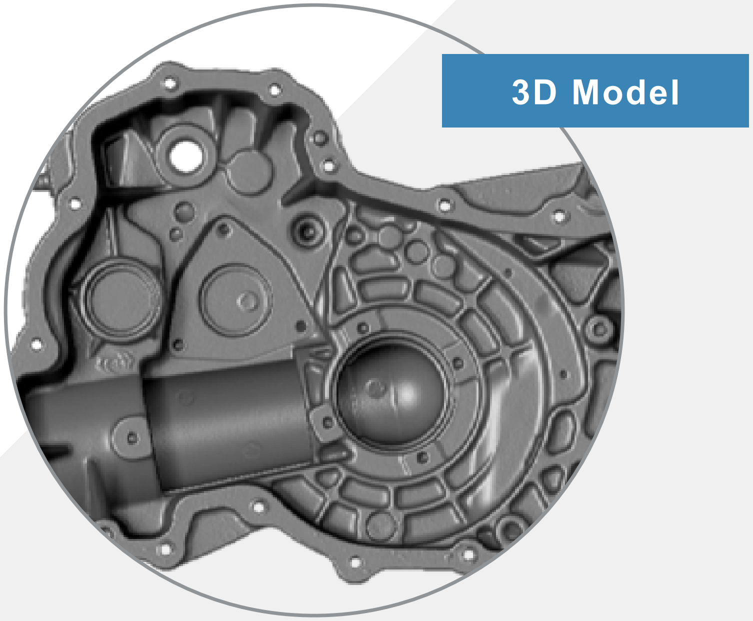
Portable 3D scanning is fueling the movement from the laboratory to the front lines of the factory and field, driven by the following key factors:

- Convenience and flexibility for a wide variety of applications, including every aspect of product lifecycle management (PLM)
- Simplicity and automation that spreads use beyond specialists into mainstream engineering
- Lower costs that broaden the market
- Greater accuracy, speed and reliability for mission-critical projects.

Bridging physical and digital worlds

3D scanners are tri-dimensional measurement devices used to capture real-world objects or environments so that they can be remodeled or analyzed in the digital world. The latest generation of 3D scanners do not require contact with the physical object being captured.

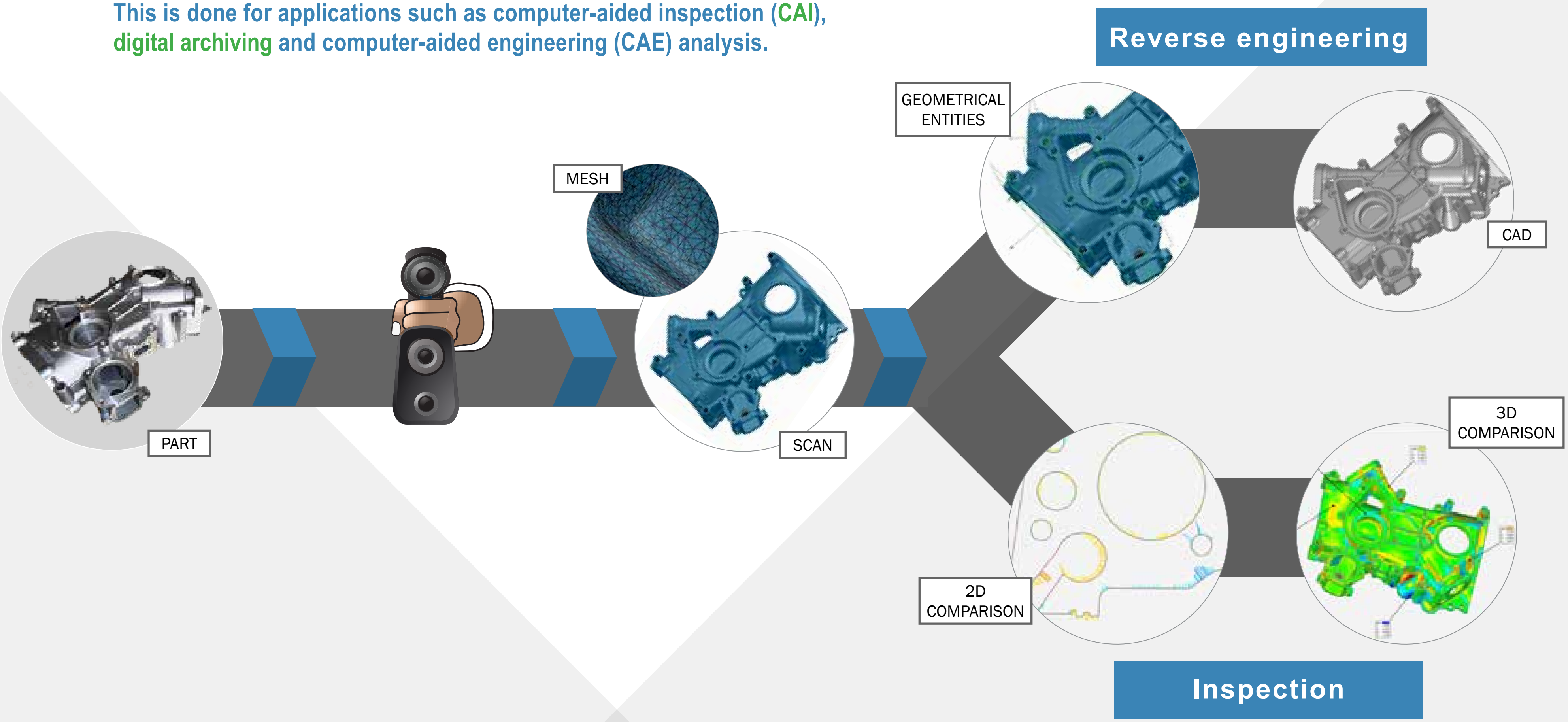




3D scanners can be used to get complete or partial 3D measurements of any physical object. The majority of these devices generate points or measures of extremely high density when compared to traditional "point-by-point" measurement devices.

OBJECTS ARE USUALLY SCANNED IN 3D FOR 2 PURPOSES:

1. Extracting dimensions to reconstruct a CAD reference file for reverse engineering or rapid prototyping.
2. Measuring the object itself for analysis and documentation.
   This is done for applications such as computer-aided inspection (CAI), digital archiving and computer-aided engineering (CAE) analysis.



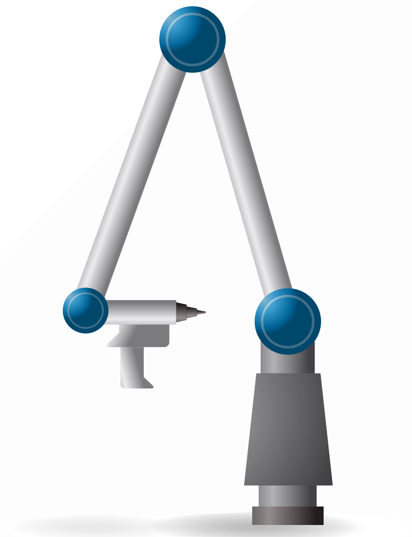
How 3D scanning works

There are two major categories of scanners based on the way they capture data:

WHITE-LIGHT AND STRUCTURED-LIGHT SYSTEMS

Take single snapshots or scans

SCAN ARMS AND PORTABLE HANDHELD SCANNERS

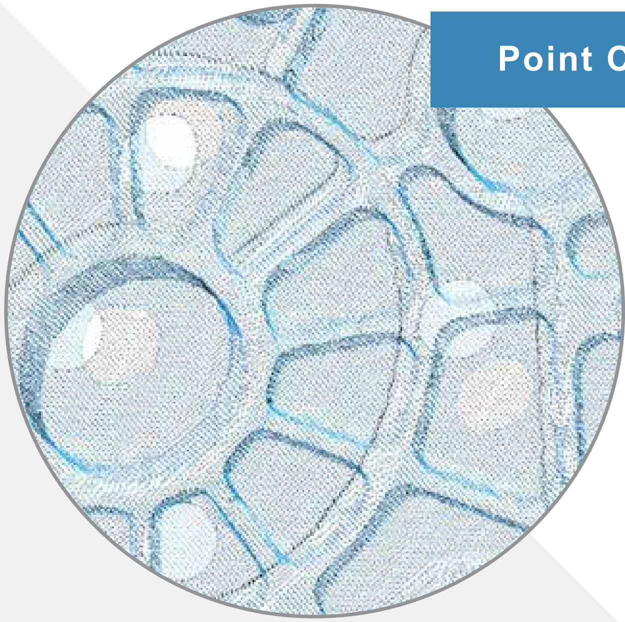


Capture multiple images continuously

How 3D scanning works

Scanning results are represented using free-form, unstructured three-dimensional data, usually in the form of a point cloud or a triangle mesh. Certain types of scanners also acquire color information for applications where this is important.

Images/scans are brought into a common reference system, where data is merged into a complete model. This process – called alignment or registration – can be performed during the scan itself or as a post-processing step.



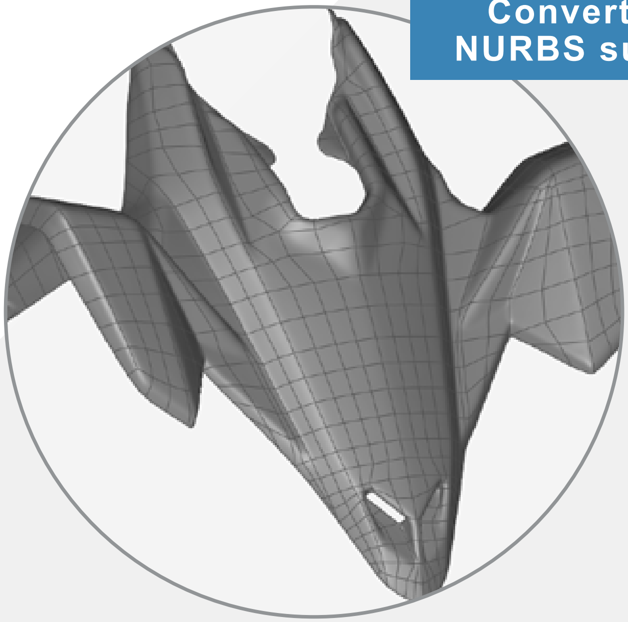
Point Cloud

Triangle mesh

How 3D scanning works

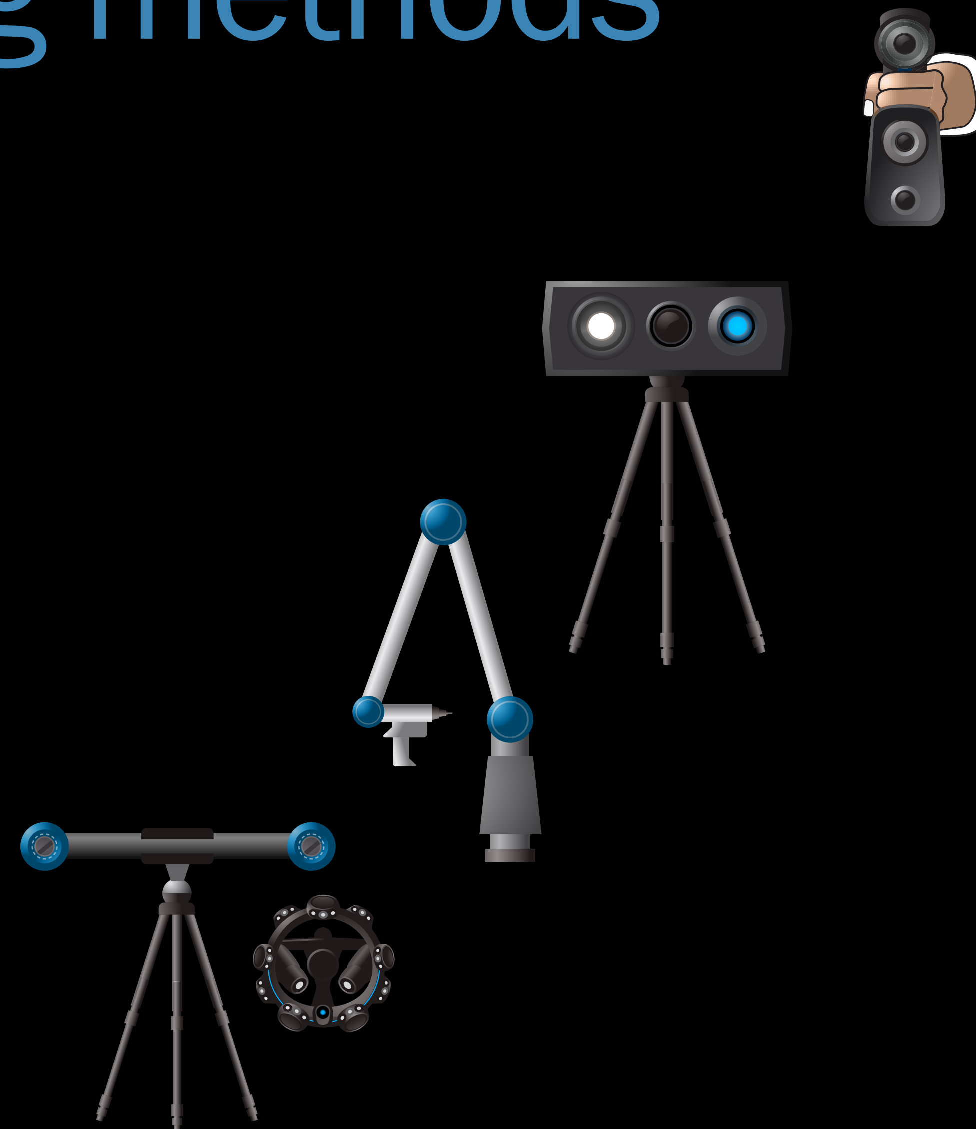
Computer software can be used to clean up the scan data, filling holes, correcting errors and improving data quality. The resulting triangle mesh is typically exported as an STL (STereoLithography or Standard Tessellation Language) file or converted to Non-Uniform Rational B-Spline (NURBS) surfaces for CAD modeling.

Triangle Mesh exportable in STL format



Converted to NURBS surfaces

3D scanning categories and positioning methods



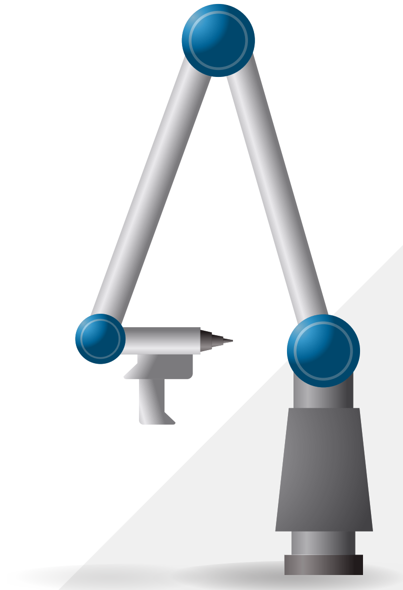
THE BENEFITS AND LIMITATIONS OF A 3D SCANNER ARE TYPICALLY DERIVED FROM ITS POSITIONING METHOD. THAT'S WHY IT IS VALUABLE TO TAKE A LOOK AT POSITIONING METHODS WITHIN THE DIFFERENT 3D SCANNER CATEGORIES.

The main 3D scanner categories:

- Measuring arms, portable CMM scanners
- Tracked 3D scanners
- Structured-light 3D scanners
- Portable 3D scanners

Measuring arms, portable CMM scanners

CMMs (coordinate measuring machines) and measuring arms can be equipped with either fixed-probe or touch-trigger probe heads. It is also possible to mount a 3D scanning head on a CMM.



POSITIONING METHOD: MECHANICAL ENCODERS

CMMs with portable arms are positioned using the mechanical encoders integrated in the arm.

Advantages

- Many different tools can be mounted on portable CMMs, making it possible to easily integrate scanning and probing in the same project.

Limitations

- Portable CMMs need to be fixed on a surface and use a physical link (arm) as their positioning method. This makes them prone to vibrations and other environmental constraints that can affect the performance and quality of the result. They also lack flexibility in terms of the locations in which they can be used and the shape of the objects they can scan.

Tracked 3D scanners

Optical tracking devices can track various types of measurement tools, including the positioning of a 3D scanner.

POSITIONING METHOD: EXTERNAL OPTICAL TRACKING DEVICE

These scanners use an external optical tracking device to establish positioning. They usually use markers (such as passive or active targets) that optically bind the tracking device to the scanner.

Advantages

- **Tracked 3D scanners provide very good accuracy and excellent precision throughout the measurement volume. Removing the need for a physical link between the scanner and the object being scanned provides freedom of movement.**

Limitations

- **The optical link that is a strength of this technology is also one of its limitations. The tracker must always have a clear and direct line of sight to the 3D scanner. Trackers often have a limited working volume. Extending the scanning parameters adds complexity to the process and can induce some additional uncertainty in the measurements. Finally, tracked 3D scanners are usually more expensive than solutions such as portable 3D scanners.**

Structured-light 3D scanners

These scanners project a pattern of light onto a part and process how the pattern is distorted when light hits the object. Either an LCD projector or a scanned or diffracted laser beam projects the light pattern. One or two (sometimes more) sensors record the projected pattern.

POSITIONING METHOD: OFFLINE TARGET POSITIONING AND GEOMETRY POSITIONING

The scanner can either rely solely on the part geometry to position the data or rely on positioning targets (small stickers provided with the system that can be placed directly on the part) to align 3D data.

If only one camera is used, the position of the projector in relation to the camera must be determined in advance; if two cameras are used, the stereoscopic pair must be calibrated in advance.

Advantages

- High-end structured light scanners generate very high-quality data. They typically deliver excellent resolution, which allows for the smallest features on an object to be captured in the results.

Limitations

- While white-light scanners can acquire large quantities of data in one scan, overall project speed is not always improved by this methodology. Multiple scans are required in most cases to cover all angles on more complex parts, which is very time consuming.

Portable 3D scanners

Many types of portable 3D scanners are available on the market today, principally using laser-line or white-light technologies.

Laser scanners project one or many laser lines on an object while white-light devices project a light and shade pattern. Both will analyze the resulting deformed projections to extract the 3D data.

POSITIONING METHOD: REAL-TIME SELF-POSITIONING THROUGH POSITIONING TARGETS, OBJECT'S NATURAL FEATURES/TEXTURES OR HYBRID

Handheld scanners rely on two cameras to create what is called stereoscopic vision. This enables the device to determine the scanner position in relation to specific points, which could be positioning targets, the object's natural features or textures. Some newer portable scanners use a mix of positioning types called hybrid positioning.

Advantages

- Portable 3D scanners can be transported with minimum effort and are often easier to use than other scanner types. They can combine multiple positioning methods, providing the accuracy of positioning targets with the flexibility of object features and texture positioning. The most advanced technologies can acquire more than half a million points per second and rebuild the 3D triangle mesh live during the scanning process.

Limitations

- Portable scanners use self-positioning on a more local area, which means that errors can stack up as the scanning volume grows. It is possible to circumvent this by using technologies such as photogrammetry and positioning targets to minimize errors, but these additional steps might increase setup time and limit the size of the objects or areas that can be scanned efficiently.

Speeding and enriching the PLM process

3D scanning has emerged as a critical tool in every step of the product lifecycle management (PLM) process. This is especially true of the new generation of truly portable, self-positioning scanners.

The ability of 3D scanning to bridge the gap between physical objects in the real world and the digital design environment has become extremely valuable in a wide range of industries that use PLM – aerospace, automotive, consumer products, manufacturing, and heavy industries among the principal ones.

These industries benefit from faster time to market, improved quality, reduced warehousing costs, and better understanding of product performance.

In the pages that follow, we'll explore the benefits of 3D scanning in four different stages of PLM:

- Concept
- Design
- Manufacturing
- Servicing

3D scanning in PLM: **concept**

3D scanning is used in the concept stage of PLM for a wide variety of processes, including determining requirements and specifications, concept design (including reverse engineering) and concept prototyping.

Concept

Requirements and specifications 〉 Concept design 〉 Concept prototyping

Requirements and specifications

- Competitive product analysis
- Measurement of product environment or connecting/Surrounding parts
- Measurement of existing parts for aftermarket or custom equipment

Concept design

- Clay model measurement/Reverse engineering
- Models and mock-ups measurement/Reverse engineering
- Styling and aesthetics

Concept prototyping

- Integration of prototype modifications into CAD file
- Form study, proof-of-concept prototypes
- Ergonomy prototypes

How can you design parts for automotive aftermarket without access to cad files?

Challenge

Countless car brands and models and no CAD file

Designing parts for the automotive aftermarket can be a challenge because of the multitude of car brands and models in circulation. Further complicating the situation, new models are launched each year. Thus, how can a part, such as an interior carpet, be designed to fit every type of car, model, and year available on the market? How can these parts be designed effectively when the CAD files for the car interior are rarely accessible? How can parts be designed successfully when measurements are taken on complex geometries and, therefore, traditional manual methods of measurement are too restrictive and do not lead to precise data?

Solution

Using portable 3D scanning technology to generate highly detailed CAD files

The solution for designing custom-made parts for each car model is a portable 3D scanner. The 3D scanning tool requires minimum setup, and it can be used to scan the inside of a vehicle quickly and directly at the car dealer. Moreover, it enables the automotive aftermarket part designer to design an accessory for any model, year, and brand of car. Finally, it enables the company to offer a complete catalog to its customers and to be at the forefront of the market with new accessories available as soon as a new car model is released.

Benefit

Faster, easier, and more efficient product development

With a portable 3D scanner, scan-to-CAD becomes a breeze, enabling product development to be faster, easier, and more efficient. It is faster because the product development is done correctly the first time. It is easier because the plug-and-play tool generates automatic STL surfaces and outputs mesh files directly. Finally, it is more efficient because the cost of product development is optimized and cheaper than traditional manual methods. Moreover, the design quality is superior because the scanning tool measures all the surfaces with more than half a million points per second for obtaining better product specifications and properties. Finally, the user who opted for a portable 3D scanner as a design tool was the first supplier to make such an offer to his customers, giving him a competitive advantage on the market.

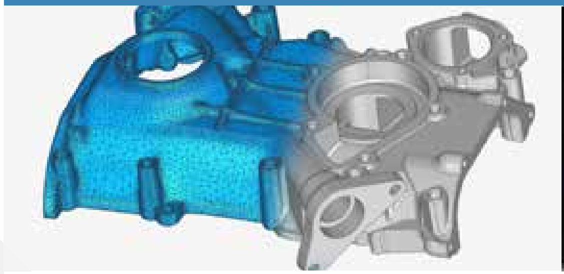
3D scanning in PLM: **design**

3D scanning is used in the design stage of PLM for computer-aided design (CAD); rapid prototyping; and testing, simulation and analysis (CFD, FEA).

Design

CAD design 〉 **Prototyping** 〉 **Testing, simulation and analysis**

CAD design

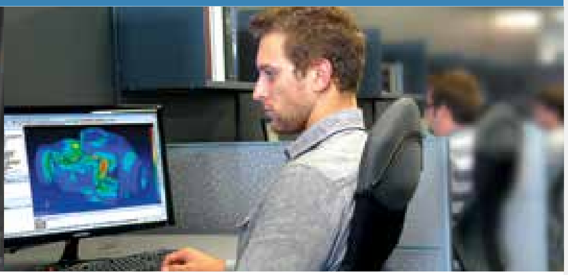


- 3D scan-to-CAD
- Reverse engineering (extracting design-intent)
- Packaging design

Prototyping

- Rapid prototyping/Manufacturing
- Integration of prototype modifications into CAD file
- Prototype inspection

Testing, simulation and analysis



- Finite element analysis (FEA)
- Interference analysis
- Deformation, geometry analysis

Rapid prototyping when accurately converting clay models into cad files

Challenge

Digitizing complex physical objects for prototypes

When designing a first prototype, it is wise to make a physical model first in order to hold it and try it. Indeed, the physical reality is often different from the CAD models. Thus, a first prototype will enable designers to make modifications to style lines and ensure a perfect design. In addition, it is interesting to look at what the market is already offering to ensure that the foreseen design is better than what the competition offers. However, what rapid prototyping phases need to be monitored or archived digitally? How should one take this information and bring it back to CAD software? How should complex physical objects be digitized? How should the proof of concept be made?

Solution

Clay models and 3D scanning

When designing complex shapes, the easiest approach is often to use clay models, which can be converted easily into 3D models. Designers and engineers have the flexibility and freedom to play with the prototypes until they achieve the perfect shape. 3D scanning can rapidly digitize complex shapes in high resolution for a fast and accurate conversion of the clay models into CAD files.

Benefit

Accelerate time-to-market for new products

3D scanning technology offers a versatile and user-friendly solution that yields accurate measurements quickly while eliminating the need for long measurement sessions and costly prototypes. The competition analysis is done quickly, the design of the part is done efficiently, and the modifications are integrated into the CAD model easily. Thus, a lot of time is saved, allowing designers to accelerate the time-to-market for their new products.

SCOTT Sports

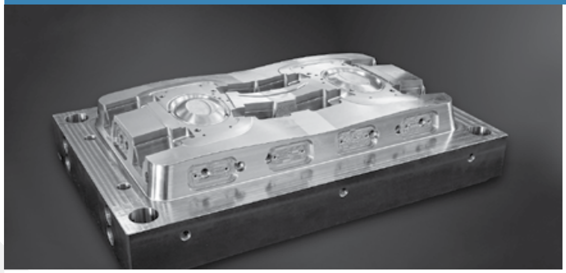
For Bertrand Didier, Chief Engineer in the Sports Division at SCOTT Sports SA, 3D scanning was the perfect solution for the development of high-performance headgear that meets both the industry's safety requirements and athletes' fit and comfort needs. Using Creaform's HandySCAN 3D, Didier's team was able to significantly reduce the design and production cycle time. The 3D scanner provided required assistance to facilitate the shape's integration and improve overall design efficiency, accelerating time-to-market. The size and portability of the scanner allowed SCOTT engineers and industrial designers to 3D model the helmet right in their offices, which also proved to be a significant time saver. Thus, HandySCAN 3D scanner helps designers accelerate time-to-market for their new products.

3D scanning in PLM: **manufacturing**

3D scanning is used in the manufacturing stage of PLM for applications such as tooling design, assembly and production, and quality control.

Manufacturing

Tooling design

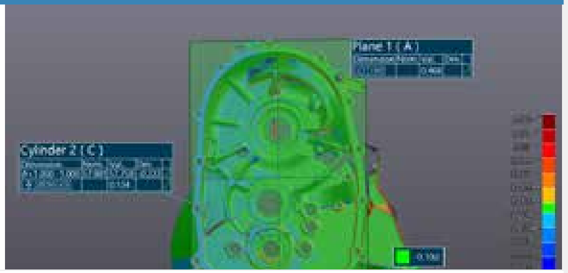


- Reverse engineering of dies, molds, fixtures, jigs and patterns
- Update of CAD file to reflect as-built tooling measurements
- Tooling validation/Inspection

Assembly/Production

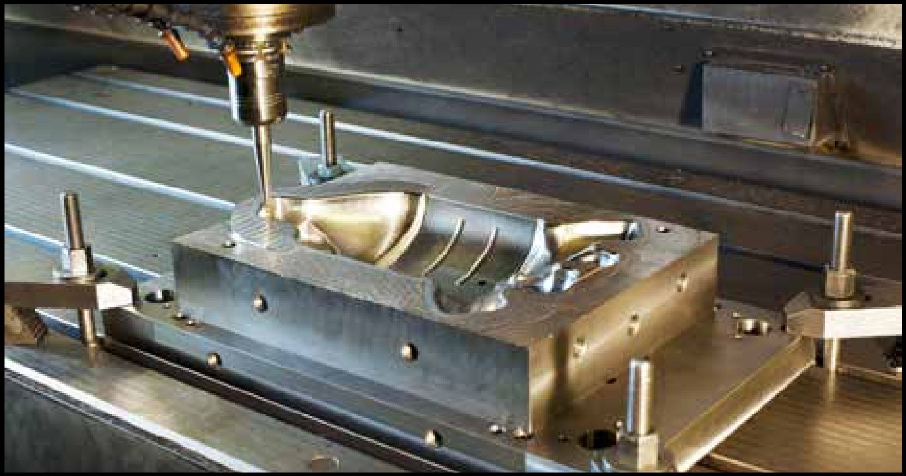
- Virtual assembly
- Tool/Robot path programming
- Part assessment before machining

Quality control



- First article inspection (FAI)
- Part-to-CAD inspection
- Supplier quality inspection

Accelerating the iterative process in tool design with intermediate quality checks



Challenge

Reducing the number of iterations when designing a tooling

When designing a tooling, an iterative process of quality control ensures that the part built from the mold, jig, or dye is built correctly and meets the technical requirements. The process involves producing a part, measuring it, analyzing deviations, and performing iterations on the tooling. This method, involving many iterations, can be lengthy, especially if the inspections are performed on a CMM. How can the number of iterations for tooling development be reduced? How can the inspection process be speed up? How can the PPAP and FAI be passed quickly in order to start production without delay?

Solution

Better and faster results with colormap

Opting for 3D scanning instead of touch probing will help accelerate the inspection process. Indeed, 3D scanning technology not only provides production process engineers with better and faster results, but it also offers the colormap, which gives a better visual overview of the part. This way, engineers can quickly adjust the tooling, produce a first part, and, thus, pass the first article inspection.

Benefit

CMM now accessible and number of iterations optimized

Quality controls made at each iteration with an alternative measuring tool reduce the bottlenecks at the CMM. Thus, the CMM is more available for important inspections with tight tolerances that require its high level of accuracy, such as the final acceptance or critical features. Choosing 3D scanning as an alternative solution to touch probing also optimizes the number of iterations in order to obtain the final tooling more quickly and more efficiently.

Developing, manufacturing, and inspecting a casting of superior quality in less time

Challenge
Inspecting 100% of the surface when producing a casting

When producing a casting, multiple changes are needed to correct elements of the manufacturing process and to produce the part precisely according to the specifications. How can one ensure that there is enough material before machining? How can the entire surface profiles—not just discrete points—be checked to make sure the part fits within the required tolerances? How can reliable data be obtained quickly to avoid unnecessarily extending the development time?

Solution
Better and faster results with colormap

Producing a casting for the aerospace industry requires not only an inspection of the critical dimensions and wall thicknesses, but also an overall view of the surface plans. In addition, the measurement technology must provide reliable and high-quality data quickly every time a part needs to be inspected. Unlike touch probing, 3D scanning provides an overall view of the inspected part and the surface profiles, and it indicates whether or not there is enough material before machining. In addition, all inspection data is provided quickly and without delay.

Benefit
Accurate casting inspections and impeccable quality control

With 3D scanning, the development time of a casting is shortened and the quality of the part produced is impeccable thanks to the ability of performing root cause analyses. High-quality information is quickly available. The time required for setup, scanning, and reporting is accelerated. The entire manufacturing process of a casting is improved to produce parts with tight tolerances.

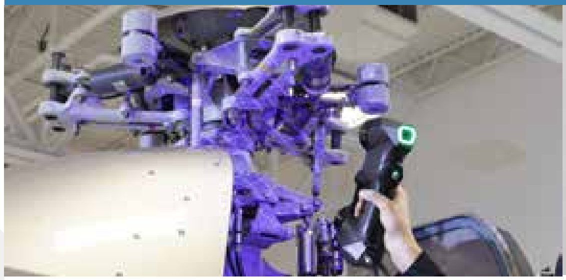
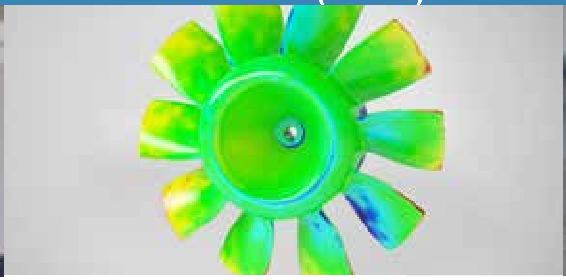
Alphacasting

"The team used the HandySCAN 3D to scan the entire casting very quickly. Having 100% of the surface and the inspection report was so vital for us to understanding the changes to be made and also to make sure there is enough material before machining. The quality of the scanned data enabled us to make better decisions and reduce development time", mentions Steven Kennerknecht, VP of Engineering at Alphacasting.

3D scanning in PLM: **servicing**

3D scanning is used in the servicing stage of PLM for applications such as documentation; maintenance, repair and overhaul (MRO); and replacement, recycling and restoration of parts.

Servicing

Documentation	Maintenance, repair and overhaul (MRO)	Replacement/Recycling
		
• As-built documentation of parts/Tooling • Marketing presentations, 3D training systems, serious gaming • Digital archiving	• Wear and tear analysis • Custom repairs/Modification • As-built documentation of parts/Tooling before maintenance	• Reverse engineering for developing replacement/Restoration parts • Planning of complex assemblies disassembly/Dismantling

Replacing headers on a main steam piping system at a power generating facility

Challenge

Design without CAD files, using only existing parts

Replacing headers on a main steam piping system at a power generating facility is challenging. Often, CAD models are no longer available. Therefore, engineers have to design the replacement parts by dealing only with the physical parts. Additionally, headers are often located in very confined, hardly accessible spaces. Then comes the alignment challenge: operators must align the manufactured spherical header with the requisite interface points within tight tolerances on site at the client's facility. How can these steam piping systems be maintained, how can replacement parts be built, and, finally, how can all of this be done within the allocated time and budget?

Solution

3D capture, 3D model, 2D drawing

The solution is to capture the spherical headers with a 3D scanner and create 3D models based on the captured information. Then, 2D manufacturing drawings are created and used to manufacture new headers. Once fabricated, the final product is scanned in order to generate a mesh, which is overlaid onto the initial 3D model to check the accuracy with which the headers have been manufactured and to ensure that they have been produced according to design.

Benefit

Perfect fit

With a portable 3D scanner, engineers can go on site and scan the different parts in order to obtain a global assessment of the existing plant. 3D scanning provides engineers with all of the information they need to optimize the design, as well as all of the dimensions they need to visualize the environment in which their design must fit. From the beginning, they know that the replacement parts will be manufactured precisely and will be consistent with the design. This way, they can be sure that, when reinstalled, the replacement part will be a perfect fit.

Babcock

"We decided to incorporate the Creaform handheld 3D scanner because of the convenience that its compact nature offers over conventional scanners. In previous trial runs conducted by the company, the HandySCAN 3D scanner had also demonstrated a high level of scan accuracy. This along with the quickness and ease of use made it an obvious option for use on this project", explains Chris Bosman, Engineering Department Drawing Office Manager at Babcock Ntuthuko Generation South Africa.

3D scanning beyond PLM

3D scanning is used in **digital reconstruction** to capture an actual object or environment – such as an historical artifact or a legacy product – and reproduce it as accurately as possible for digital archiving, re-creation or preservation.

3D scanning is used in **customized manufacturing** to enable nearly infinite variations on basic designs of existing consumer products, including toys, accessories and apparel.

Customization extends to capturing the human body for individualized medical devices and for fit-to-body design.

A full range of applications can be found in the Creaform website.

- Oil and Gas
- Health Care
- Education and Research
- Computer graphics/special effects
- Digital preservation
- Arts and architecture
- Virtual reality

Bringing new life to a 19th-century art form

Milwaukee School of Engineering's (MSOE) Rapid Prototyping (RP) Center modeled a time capsule from 3D scan data of an actual 19th-century Edgefield face jug. The time capsule was a central part of Face Jugs: Art and Ritual in 19th-Century South Carolina, an exhibition that originated at the Milwaukee Museum of Art.

The original face jug – about the size of a grapefruit – would normally be covered in a powder to reduce the reflectivity of the ceramic finish, but that could not be done with a fragile, valuable piece.

MSOE covered the face jug with a fine black net containing target dots that served as reference points for the 3D scanner. Geomagic software was used to upsize the scan model and create the compartments and other features of the time capsule.

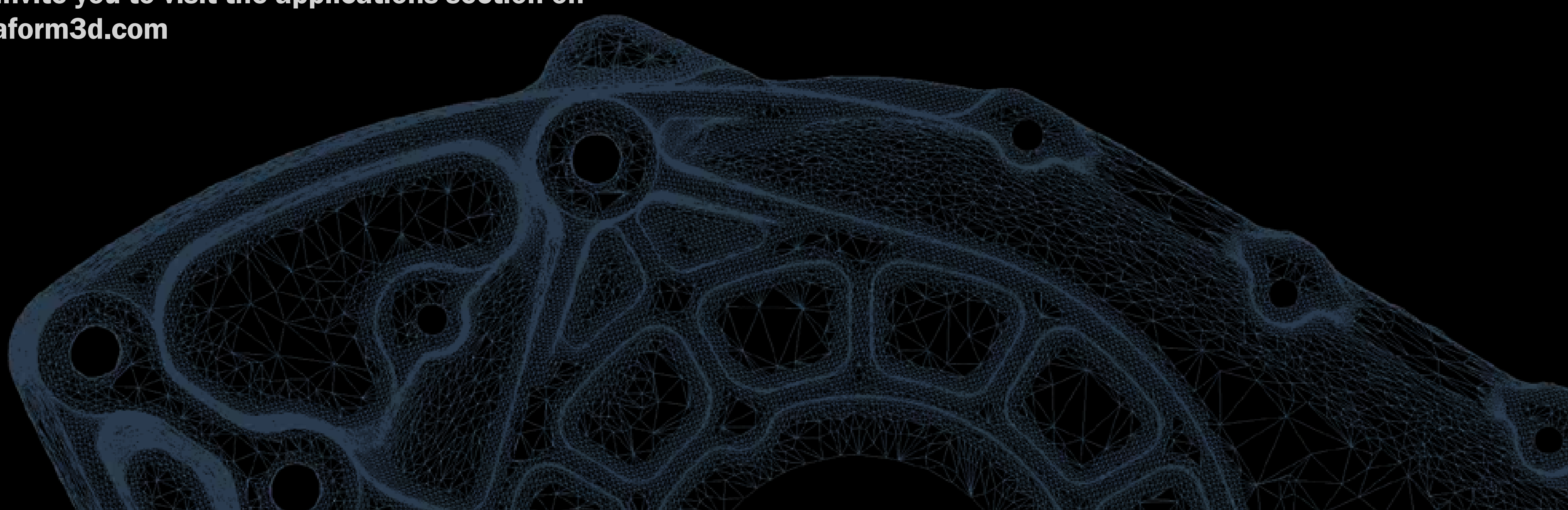
The final product was 3D printed and finished with electroplating.

A fast-developing discipline with a bright future

This e-book provided you with a high-level overview of 3D scanning and a glimpse into the multitude of new possibilities and applications it enables in a variety of disciplines.

Most of the key developments in 3D scanning have come about in less than a decade. Indeed,3D scanning is a fast-growing discipline with tremendous potential in the future.

To explore a broader range of 3D scanning topics, we invite you to visit the applications section on creaform3d.com



Glossary of 3D scanning terms

- **3D scanner** – A device that captures data on the shape and colors of a real-world environment for processing in the digital world, such as construction of 3D models.
- **Accuracy** – The accuracy of a mesh file is measured by the deviation between the actual part and the measured result. It depends on the specifications of the scanner used and on the quality of the set-up. In 3D scanning, accuracy differs from resolution (see below).
- **Alignment** – In 3D scanning, this refers to the act of bringing all the scans into a common reference system, where data is merged into a complete model. Also called registration.
- **CAD** – Computer-aided design; the act of creating a digital model for design, engineering and manufacturing. The models are based on various geometric entities such as triangles, lines and curved surfaces. Typical formats for CAD models are .stp and .igs.
- **CAE** – Computer-aided engineering; the act of digitally simulating performance of objects and assemblies. CAE encompasses simulations such as finite-element analysis (FEA) and computational fluid dynamics (CFD).
- **CFD** – Computational fluid dynamics; a digital process by which engineers can simulate how fluids such as air, water and gas behave within different design, engineering and natural environments.
- **CMM arm** – A coordinate measurement machine that uses a point or ball probe on an articulating arm, allowing users to collect individual 3D data points from a physical object.
- **CMM arm encoder** – An opto-electronic device that detects the incremental lines on a scale to determine positioning. An encoder is also known as a reader head.1
- **CNC milling** – Computer numerical control; computer-controlled milling machines that can create products along multiple axes for improved precision.
- **CAI** – Computer-aided inspection; the use of 3D scanning to compare an as-manufactured part to its CAD equivalent or ideal specifications for quality control, wear-and-tear assessment and other forms of analysis.

- **Customized manufacturing** – Using 3D scanning and complementary software to enable wide varieties of design choices at a reasonable cost. Sometimes called mass customization. Can also be used to describe the ability to customize medical and sports products – such as prostheses, athletic shoes and dental implants – for individual physiologies.

- **Digital archiving** – The ability to save models of physical objects in a digital environment, saving time and money.

- **Digital reconstruction** – The act of scanning a physical object in order to rebuild or renovate it close to its original state or at a different scale.

- **Dynamic referencing** – The ability of a scanner to ensure that the measuring device is continuously locked to the part by an optical link, providing greater accuracy in factory and field environments.

- **FEA** – Finite-element analysis; a digital process by which engineers can simulate how the structure of an object or assembly performs under different environmental stresses.

- **Normal** – In 3D space, a surface normal is the vector cross product of two (non-parallel) edges of a polygon.2

- **NURBS** – Non-uniform rational b-spline; a mathematical model used in computer graphics and CAD to generate curves and surfaces.

- **Optical CMM scanner** – A 3D scanner tracked by optical CMMs. Optical CMM cameras track passive or active reflectors affixed to the 3D scanner itself and to the part being scanned to dynamically reference them in 3D space.

- **Photogrammetry** – A methodology for extracting high-accuracy measurements from photos of an object or environment.

- **Product lifecycle management (PLM)** – The practice of monitoring and managing a product from inception to end of useful life.

- **Point cloud** – A set of data points within a coordinate system. In a three-dimensional coordinate system, these points are usually defined by XYZ coordinates, and are intended to represent the external surface of an object. Typical formats for point clouds are .txt, .igs and .ascii.

- **Rapid prototyping** – The process of quickly fabricating a model of a physical part or assembly using 3D STL or CAD data. 3D scanning is often the front end of the process and 3D printing the back end.

- **Reverse engineering** – The process of discovering the technological aspects of a device, object or system through analysis of its structure, function and operation. In 3D scanning, the reverse-engineering process involves measuring an object and then reconstructing it as a 3D model.

- **Resolution** – Defines the level of details visible in the scan data and measured in millimeters (mm). It can be compared to a screen resolution, which is defined by the number of pixels. A higher resolution increases the number of triangles in a mesh file.

- **Repeatability** – The variation in measurements taken by a single person or instrument on the same item under the same conditions.

- **Self-positioning 3D laser scanners** – Laser scanning systems that use retro-reflective targets as a reference. These scanners do not require external positioning systems because the position of the scanner in relation to the object being scanned is determined by triangulation between the scanner's two cameras and the patterns of the positioning targets. Data acquisition is in real time.

- **Self-positioning 3D white-light scanners** – The scanner obtains its position relative to the physical object by looking at the distortion of the white-light pattern on the scanned part. These scanners obtain their position on a continuous basis in real time as they move over the part.

- **STL** – Stands for stereolithography or standard tessellation language; a file format native to stereolithography CAD software created by 3D Systems Inc. and supported by many other software packages. STL files are used widely for rapid prototyping and computer-aided manufacturing.

- **Triangulation** – The process of determining the location of a point by measuring angles to it from known points at either end of a fixed baseline. The point can then be fixed as the third point of a triangle with one known side and two known angles.

- **Triangle mesh** – The output of self-positioning 3D scanners, this is a mesh from an optimized surface that takes into account measuring conditions and consistency. This is also referred to as a polygon model. Typical formats are .stl, .obj and .sat. An STL file can be used directly for applications such as rapid prototyping and computer-aided inspection or converted into NURBS surfaces for CAD.

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