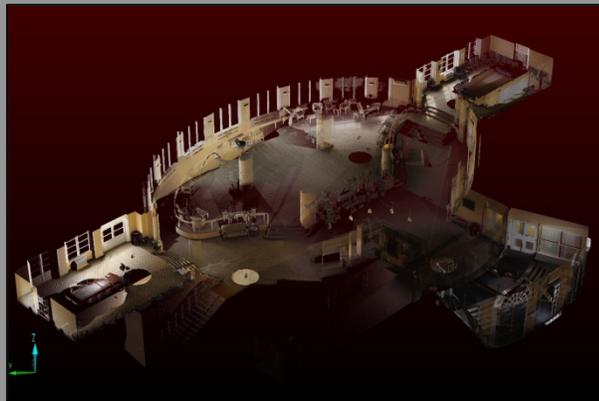
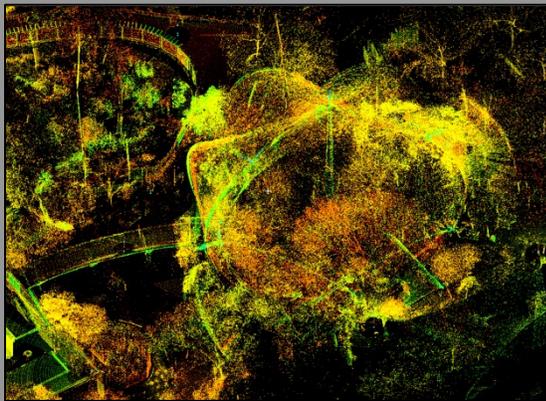


WHAT IS 3D DATA CAPTURE?

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Presented by



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INTRODUCTION

3D data capture is the process of gathering information from the real world, with x, y, and z coordinates, and making it digital. From there, it can be processed in a number of ways to create any number of end products: point clouds, 3D models, line drawings, fly through visualizations – really, the possibilities are endless.

This paper will discuss the many ways in which people capture 3D data, some of the reasons for doing so, and familiarize you with many of the terms used in the 3D data capture industry and community. (See “Glossary” at the end of this report.)

TYPES OF 3D DATA

GEOREFERENCED

Every location in the world can be described as an x, y, z point. It has a latitude (x), a longitude (y), and an elevation (z). Using a combination of GPS satellite technology and traditional survey techniques, any point can be established relatively quickly. If you start collecting data from a “known point” you can then know with relative certainty what the georeferenced position is of every point that you gather.

If your data is properly georeferenced, it can be combined with data collected anywhere in the world and it will be properly referenced together. You could take measurements and have them be accurate to whatever degree your collection technology is accurate.

NON-GEOREFERENCED

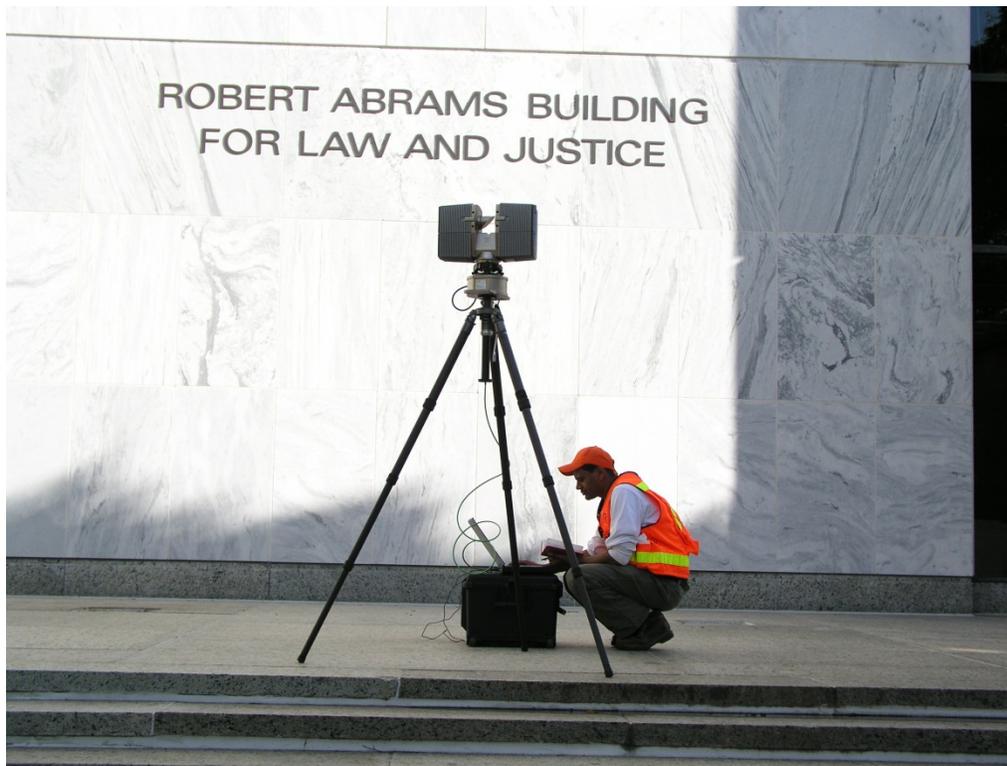
If you do not start from a known point, you can still collect 3D data, but the data you collect will only be referenced to itself. You can take measurements within the data, and they will be as accurate as your collection technology allows, but they will be only part of what in the industry is called a “pretty picture.”

There can be many uses for this kind of data – from reverse engineering to crime scene documentation – but it will have limited value if you are trying to combine that data with data collected at other times or in other locations.

METHODS OF COLLECTION

LASER SCANNING

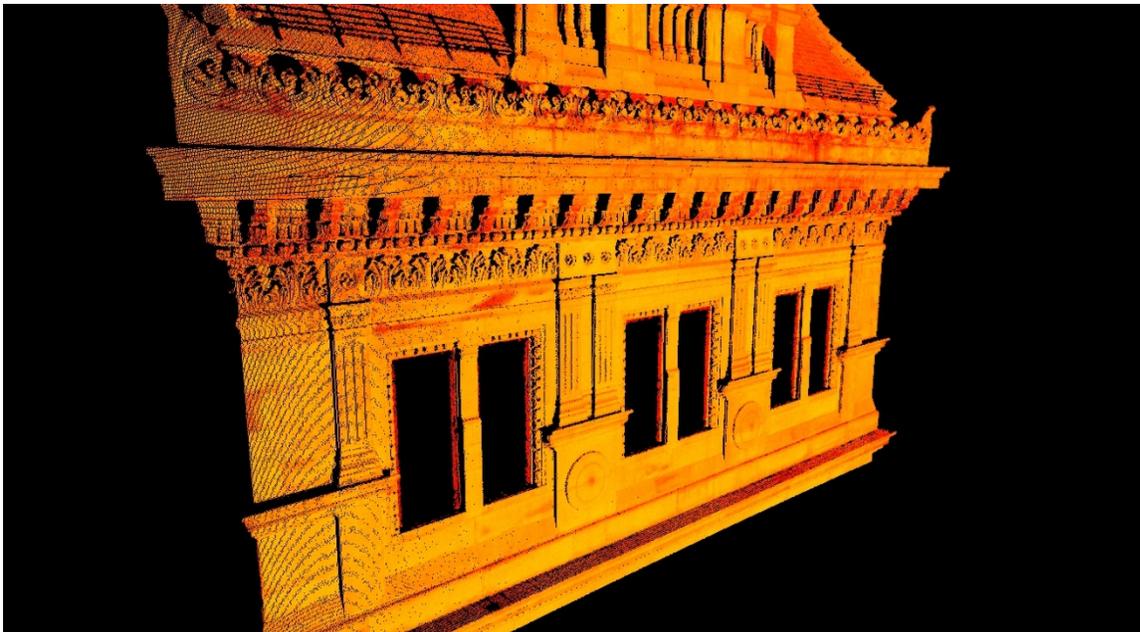
Laser scanning (or “lidar,” which stands for LIght Detection And Ranging, a specific type of laser scanning, but which is now often used as a catch-all term for laser scanning in general) is a broad term that encompasses a number of technologies that use lasers to determine the locations of 3D points. At its most basic, laser scanning emits laser pulses and then collects information about what happens to those laser pulses. That information is indexed into a computer file called a point cloud.



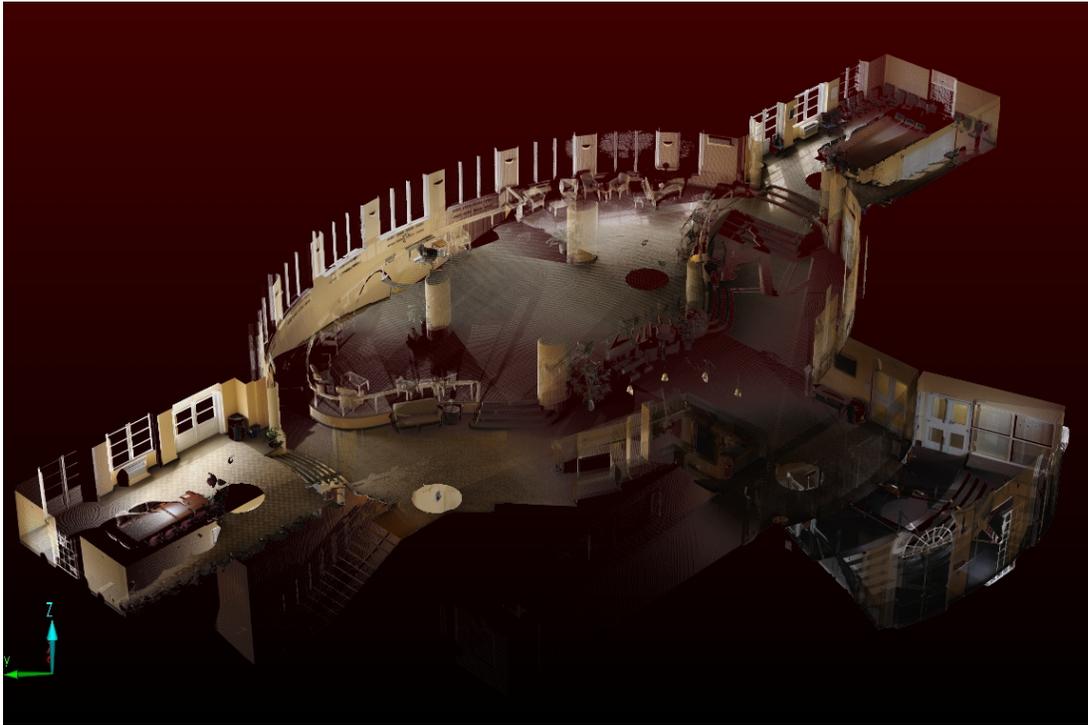
What a terrestrial laser scanner in the field looks like.

The more lasers that are emitted and collected, the denser your point cloud will be. Some point clouds can contain many billions of points and look as dense as a photograph. As you might imagine, however, the more points a point cloud contains, the larger the file size will be and the more difficult it will be to work with it.

In general, these types of lasers are harmless to whatever it is they're scanning, though some of the lasers may not be "eye safe."



An example of a point cloud generated by a terrestrial laser scanner, colored to show intensity



An example of a point cloud generated by a terrestrial laser scanner, colored with photographic data.

Types of Laser Scanning

Time of Flight (also known as “pulse based”)

As the name suggests, time-of-flight laser scanners emit laser pulses and then determine object location by measuring the amount of time it takes for that laser pulse to bounce off an object and return to the scanner.

Each manufacturer may have their own different “flavor” of time-of-flight scanning, in terms of how they receive the laser pulses and analyze the return.

FAQ

How does the laser pulse return to the scanner? If something is angled, shouldn't it just bounce off in another direction?

Answer: At the miniscule size of a laser pulse, nothing is actually flat. Everything is rough in some way or another and has at least a very small surface that is facing directly back to the scanner. At least some portion of the laser almost always returns to the scanner.

However, this is not the case with very shiny material, like water; even very dark objects will sometimes not bounce a laser back and are almost impossible to scan. This is often remedied by sprinkling some powder (such as baby powder) on the surface before scanning begins.

Pros: These scanners can measure things a great distance away.

Cons: They're relatively "slow." They can collect about 50,000 points a second.

Time of Flight (airborne)

Airborne collection of 3D data can often use something called waveform processing and echo digitization, which is a form of time-of-flight scanning. This type of ToF can get multiple returns from the same pulse of laser light, which allows you to get multiple readings from the same laser.

This is particularly useful if there are objects in the way of what you're trying to scan, such as trees blocking the surface of the Earth. In this way, it is possible to use software to remove all the returns that are clearly trees and vegetation and get smooth-earth point clouds, which are used for things like digital terrain models that are helpful in creating things like flood maps.

Phase-based

These scanners emit a continuous laser beam and the scanner can tell by the modulations of the phase of the laser the location of whatever the laser runs into.

Because the laser is essentially continuously gathering data, it can very quickly gather many points and therefore provide a great deal of data.

Pros: These scanners are very fast, gathering as much as one million points per second.

Cons: These scanners can only gather data out to about 80 meters at the most. Also, the amount of data they collect can create file sizes that are difficult to manage.

FAQ

What is “mobile laser scanning”?

Answer: Both time-of-flight scanners and phase-based scanners can be attached to vehicles, as part of a system that generally also includes a GPS device and an inertial navigation sensor, and used to scan large areas while driving. Phase-based scanners are more popular because they collect data more rapidly and you can therefore drive faster and cover the same area.

By integrating with the GPS and inertial navigation unit, the scanner can create a large continuous point cloud that’s georeferenced and registered to itself.

Mobile scanning systems have been strapped to boats, four-wheelers, helicopters, parachute planes – essentially anything that moves.

The accuracy of the data collected depends on the quality of the inertial navigation unit, the speed at which data is collected, and the quality of the software used to process the data.

Handheld/Close-range

A number of manufacturers make “close-range” or “hand-held” laser scanners, which are primarily used to capture objects about the size of a person, or smaller. However, these are increasing in utility and it is not uncommon now for someone to use a handheld laser scanner to scan something the size of a car or small airplane.

Some of these laser scanners require targets (essentially stickers) to be placed on the object ahead of time. Others do not require targets and use software to essentially match features to each other. Some of these close-range scanners can attain very high accuracy, well below 1mm. These products are also similar to other close-range scanning techniques like white light and structured light scanning (see below).



An example of a handheld laser scanner.

Many of these handheld laser scanners use a combination of camera and laser to create real time, scan-to-model workflow. The action of scanning is kind of like spray-painting a surface. You simply sweep the scanner along the surface of the object you'd like to ingest and the image appears on the computer screen.

Many of the close-range scanners use a rotating dolly. You place the object in the center of the scanner and the dolly rotates, allowing the laser to scan the entirety of the object. Others simply sweep a laser over the top of the object.

These scanners are often used in “reverse-engineering” applications, where there is a desire for a product to be manufactured but CAD drawings for the object don't exist. By scanning the object and creating a CAD model from the scan, it is possible to then manufacture the object.

PHOTOGRAMMETRY

Photogrammetry (also sometimes known as stereoscopy) is a science dating to the 1850s that determines distances using photographs to take measurements. In the last few years, great gains have been made in the algorithms that allow for measurements to be taken much faster, leading to software that can now create very large point clouds by ingesting thousands, even tens of thousands, of photographs.

Types of Photogrammetry

Take one measurement at a time, with targets

One type of photogrammetry software allows you to put out targets in a scene, take a number of overlapping photographs from a number of angles, ingest those photos, then manually identify which targets are the same in which photographs.

After doing those manual operations, the software is then able to tell you the distance between two points in 3D space. This type of software can be useful for creating diagrams of scenes, and is commonly used in the forensic marketplace and in the plant and process industry.

Ingest all the photos, create a point cloud

Some software packages are now able to automatically identify similar features from one photograph to another, and no longer need targets in the scene at all. With this software, you simply ingest as many photographs as you have, and the software spits back out either a point cloud or a mesh model.

This software is becoming relatively ubiquitous, and is even offered as a free app for smartphones. However, the quality of the models and point clouds produced varies widely.

The more sophisticated software can create point clouds and models that approach in accuracy that created by laser scanners. The less expensive software is more consumer-oriented, but is still being used at least experimentally by professionals who see possible applications for it.

FAQ

Is Photogrammetry going to replace laser scanning?

Answer: The answer to this question remains to be seen as both technologies are rapidly advancing. But the current consensus is that they are complementary technologies, each with their own pros and cons.

Laser scanning remains the more accurate technology, and the more predictable. You know pretty much what you're going to get when you gather your data. Photogrammetry offers some great benefits in cost, but is less reliable and more unpredictable in terms of accuracy and the end product.

One of the major drawbacks to photogrammetry is that it requires light. Without an illumination source, photographs just don't work. Further, dark areas within the field of vision will not be captured well. The technique works best in daylight and from an aerial source.

Laser scanning and other projected light solutions create their own illumination and don't require an exterior light source.

STRUCTURED LIGHT SCANNERS

Structured light scanners project a single line of light, or a pattern of light, onto an object, and then use a camera (or more than one) and software to measure how that light is distorted, which can then be used to create a point cloud or model.

Types of Structured Light Scanners

Static

The light source and the cameras are in fixed locations, while the object to be scanned is placed in the field of vision of the cameras and the light source. Sometimes the cameras and light sources are arrayed in a full 360-degree structure, allowing the entire object to be captured in 3D at once.

Things like full-body scanners are created this way.

Handheld

Like handheld laser scanners, handheld structured light scanners can be swept over an object - sometimes with targets attached, sometimes without – creating a point cloud or model as more of the object is covered with the light source.



An example of a handheld structured light scanner.

The Kinect is probably the best-known handheld structured light scanner. The Kinect uses projected dots of infrared light (outside of the visible spectrum) and an infrared camera to capture 3D data in real time and feed that back to the XBox video game system so that players can control video games with their body movements.

A commercial interface is now available from Microsoft that lets you use the Kinect as a 3D data capture device.

FAQ

The Kinect is so inexpensive. Is it going to replace “real” laser scanners?

Answer: At the moment, the Kinect is inexpensive because it is inferior technology. It cannot acquire the kind of resolution and accuracy that a professional data capture operation would usually require. However, the Kinect 2 is rumored to be released soon, and it is expected that there will be a large increase in resolution, which should deliver increased accuracy.

Already, there are handheld structured light scanners on the market that are based on the same Prime Sense technology that Microsoft licensed for the Kinect.

SONAR

While sonar, the process of using sound waves to establish position, has traditionally been a 2D technology, new advancements in technology have allowed manufacturers to create 3D sonar systems that are also capable of producing point clouds of underwater environments.

Types of Sonar

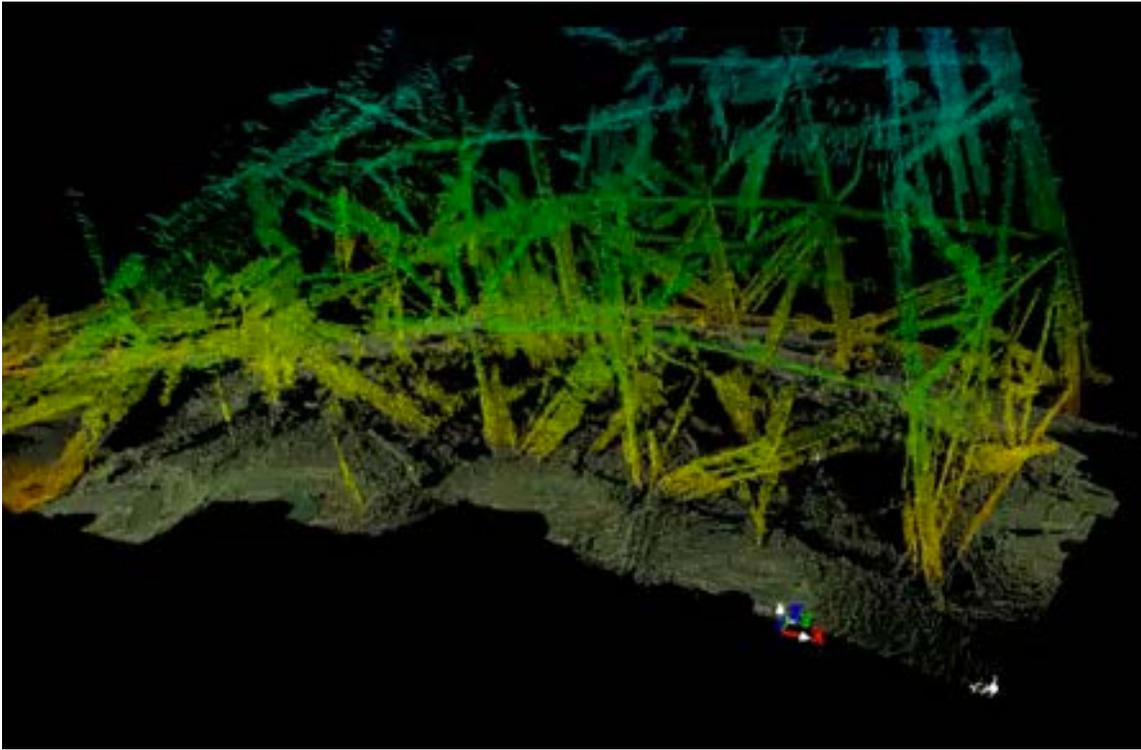
Single Beam

This is the “traditional” type of sonar, which can establish 3D position in a narrow path with a “ping” of sound. With enough measurements, maps can be created of underwater areas. It is equivalent to an underwater total station of sorts in that you’re gathering one point of data at a time.

Multi-Beam

A multi-beam sonar system can gather a point cloud of wide swaths of the bottom of a body of water, or, when tightly focused, can create very dense point clouds of underwater objects.

This technology can be used to map and model things like offshore drilling platforms, shipwrecks, dam tubes, and the like. Often, this technology replaces the need for a dive team to go underwater and take measurements by hand.



An example of a point cloud created with multi-beam sonar technology.

Robust Multi-Beam

It is possible by using a large number of sonar “beams” at a high rate of pings-per-second to create real-time 3D images of underwater objects. This is different from multi-beam sonar in that the images do not have to be post-processed in order for the 3D nature of the data to be realized.

The 3D imagery can be consumed like video, looking at underwater objects as they are moved around, for example, and not having to take a picture and then look at what you captured back in the office.

FAQ

Why wouldn't everyone just use robust multi-beam sonar all the time?

Answer: At the moment, it's incredibly expensive and there aren't very many systems in the world that can perform in that manner. Further, for most sonar applications, the technology is overkill. However, it's very helpful for positioning expensive objects underwater in low- or no-visibility situations.

GLOSSARY

The following definitions have been gathered from various sources, some of which have been listed. The definitions associated with the ASTM are further obtained from various standard documents developed by various standards development organizations. The ASTM provides more in-depth discussion of several terms that have not been disclosed here; please refer to Designation: E 2544 – 08b, "Standard Terminology for Three-Dimensional (3D) Imaging Systems" for more details

3D imaging system: A non-contact measurement instrument used to produce a 3D representation (for example, a point cloud) of an object or a site. (ASTM)

3D laser scanning: The process of collecting 3D coordinates of a given region of an object surface automatically and in a systematic pattern at a high rate (hundreds or thousands of points per second) achieving the results (i.e. 3D coordinates) in (near) real time.

Alignment: The process of aligning two objects in a common coordinate system. Commonly refers to aligning scan data.

As-built: Describes how a structure was actually constructed. The as-built condition of a structure may vary significantly from the design.

As-is: Describes the current status of the structure at present.

Azimuth: The angular distance measured along the horizon. Typically measured as the angular distance east from north.

Base station: In the context of external land surveying, a base station is a GPS receiver at an accurately-known fixed location which is used to derive correction information for nearby portable GPS receivers. This correction data allows propagation and other effects to be corrected out of the position data obtained by the mobile stations, which gives greatly increased location precision and accuracy over the results obtained by uncorrected GPS receivers.

Benchmark: A point of reference for a measurement.

Calibration: A set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards. (ASTM)

Clash detection: Detecting possible collision between as-is and proposed design.

Control (see survey control)

Cross section: The intersection of a 3-dimensional body with a plane.

Dimensional Control: A risk mitigation process that is applied to every project execution task that requires a dimensional accuracy.

DEM (Digital Elevation Model): Digital stored xyz-triples of a surface. It is necessary to mention always which surface is meant by using the DEM (for example DEM of the ground water surface, DEM of the Earth's surface).

DTM (Digital Terrain Model): Digital stored xyz-triples of the Earth's surface. Therefore, the DTM is one special case of the DEM (DTM = DEM of the Earth's surface).

Elevation: Angular distance measured from horizontal.

Error (of measurement): The result of a measurement minus a true value of the measurand (the particular quantity subject to measurement). (ASTM)

Field of View (FOV): The angular extent within which objects are measurable by a device such as an optical instrument without user intervention. (1) For a scanner that is based on a spherical coordinate system, the FOV can typically be given by two angles: horizontal (azimuth) angle and vertical (elevation) angle. (ASTM)

Fly-through: In virtual reality environments, fly through is movement of an object or model through a predefined path.

Georeferencing: Georeferencing is the process of aligning spatial data (layers that are shape files: polygons, points, etc.) to an image file such as an historical map, satellite image, or aerial photograph.

INS (Inertial Navigation System): A navigation system that uses a computer and motion sensors (accelerometers and gyroscopes) to continuously track the position, orientation, and velocity of an object without the need for external references.

Instrument origin: The point from which all instrument measurements are referenced, that is, origin of the instrument coordinate reference frame (0, 0, 0). (ASTM)

LiDAR (Light Detection and Ranging): A method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of pulsed laser light reflected from their surfaces.

Mesh: A polygonal subdivision of the surface of a geometric model; also referred to as polygon model or triangulated model.

Meshing: The process of creating a 3D surface from point clouds.

Phase-based: 3D laser scanners that produce measurements based on intensity modulated, continuous wave laser beams.

Photogrammetry: The process of taking precise measurements by using digital pictures and coded targets. For 3D scanning purposes, the coded targets and reference markers in the picture frame serve as references to align or register scan data.

Point cloud: Laser scan data from multiple scan stations in a defined volume space. [A] collection of data points in 3D space (frequently in the hundreds of thousands), for example as obtained using a 3D imaging system. (1) The distance between points is generally non-uniform and hence all three coordinates (Cartesian or spherical) for each point must be specifically encoded. (ASTM)

Point density: Number of points per unit. Usually the higher the point density is, the better representation of features.

Raw scan data: Any unprocessed data collected by a laser scanner. This might include different sources of error and peripheral data captured during the scanning survey.

Registration: The process of determining and applying to two or more datasets the transformations that locate each dataset in a common coordinate system so that the datasets are aligned relative to each other. (ASTM)

Scan: Refers to a single session of data collection at a single scan origin and scan orientation.

Segmentation: The process of separating and isolating groups of points from the laser scan.

Survey control: The point(s) of reference where all measurements for engineering and construction will be tied to.

TIN (Triangulated Irregular Network): Representation of a surface that is arranged in a network of non-overlapping triangles.

Time of flight: 3D laser scanners that calculate measurements based on the two-way travel time it takes for a laser beam pulse to detect a surface and return to the detector.

Uncertainty: The uncertainty is the quantity of how much a measurement is unknown compared to the actual feature.