Reality Capture: A Digital Twin Foundation

A Digital Twin Consortium White Paper

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"A lack of transparency results in distrust and a deep sense of insecurity."

- Dali Lama

This paper introduces the fundamentals of reality capture as a critical component to the lifecycle of a digital twin. Reality-capture technology embodies a set of devices and processes that collect conditions of a physical object or space. When implemented and managed correctly, these tools accurately and efficiently create digital duplicates of physical things, such as small objects, rooms, buildings or planetary landscapes. The essence of reality capture is to provide insight and awareness through the faithful and transparent representation of real-world conditions.

The reader should expect to take away an understanding of reality-capture devices, their applications, and knowledge of key industries where reality capture has specific considerations.

1 THE FOUNDATIONS OF REALITY CAPTURE

Reality-capture technology has rapidly evolved in the past two decades. In 2000, reality capture, then called laser scanning, comprised large bulky equipment costing more than US$100,000. Fast-forward 20 years and simple scans can be created on a phone or commercial camera that cost less than US$1,000. While scanning is more affordable and more accessible, the results are highly dependent on the hardware and software, requiring the expertise of the operator to navigate both. If well executed, laser scans help to resolve issues and make decisions. That said, the industry is in a state of accelerated change.

So, why is reality capture data not more fully embraced? There are several reasons:

- Not using the right reality-capture devices for the right use case is prone to failure.
- Laser scan files are large, making them difficult to process and share.
- Current software to process laser scans requires extensive training.
- Laser scans and point clouds are not easily viewed or navigated without special hardware and software.
- The workflows are not well documented nor easily understood.
- Capturing scans and assembling them into useable data is time sensitive. Once a project is underway, construction activities are fast moving, making it difficult to intercept.
- Interpretation of a point cloud requires technical expertise.
- The automation required to extract meaningful information is challenging.

To embrace reality capture more fully, we must overcome these obstacles by education in time, scale and intent (use).

2 Reality Capture Definitions

First, we must define some key terminology so that we can understand them and see how they fit into the broader context of the devices and processes.

Reality capture is the entire domain of devices and processes used to capture existing conditions of a given subject. Here, we limit it to refer to physical objects and spaces.

Laser scanning is the process of generating accurate measurements with a laser beam. Laser-scan files can be combined to create a point cloud.

*Point cloud*s combine several laser-scan files to depict existing conditions of a space or objects. They take the form of a constellation of points in 3D-space, outlining the geometry of the scanned structure. Commonly, the form cloud is colored for additional context. It can be imported into design software, eliminating the need to measure and model in traditional ways.

Range is the distance a scanning device can send and receive a signal.

Capture frequency is the number of times that a reality capture task repeats itself in a given time frame, for example, drone capture performed weekly.

Device fidelity is the degree of accuracy that the capture device replicates the object digitally.

Digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.

- Digital twin systems transform business by accelerating holistic understanding, optimal decision-making and effective action.
- Digital twins use real-time and historical data to represent the past and present and simulate predicted futures.

Maturity model, as described in the Digital Twin Consortium whitepaper "*Infrastructure Digital Twins Monitoring: A Model for Measuring Progress*," looks at the main participants in the overall digital lifecycle and how they interact in the evolving world of digital twins and the role reality capture plays. It defines the respective roles and responsibility of owners, architects, general contractors and trade partners, and of vendors, government, standards organizations, authorities having jurisdiction, and society.

This process evolution is reflected in the maturity model, as shown in *Figure 2-1*.

Dinosaur (laggard): Active and passive resistance to digital twins. Little or no digitization in legacy projects.

Average: Passive observers of digital twins. Siloed professions are first to digitize. In the Architecture, Engineering, Construction and Operations (AECO) industry, the effort to digitize is often driven by architects automating the production of drawings or general contractors using models to coordinate and eliminate clashes in the field.

Leader: Active observers of digital twins. Siloed professions realize that there is mutual benefit in sharing, and this is often done without owner involvement.

Evangelist: Active prototypes of digital twins. The owners see the benefit and start to define the sharing of data between point solutions, often providing the technology platforms. This integration spreads across all phases controlled by the owner internally.

Pioneer: Active adoption of digital twins in an entire organization. Eventually, the integration encompasses the complete supply chain.

Figure 2-1. Maturity model.

The Pioneer maturity level does not end the process. Change agents and industry innovators continue to evolve and adapt their processes to create new levels of digital twin maturity.

Digital thread: a mechanism for associating information across multiple dimensions of the virtual project, which relies on stable and consistent real-world data.

- A digital thread is populated with data flowing from upstream or previous time phases in the digital lifecycle. For example, a digital twin focusing on operational use cases would need to be populated with data from the planning, design, procurement and construction phases.
- The digital thread communicates with other systems within the same phase of the digital lifecycle.
- It also passes data to downstream systems that require the data in a later phase of the digital lifecycle.

3 Common Reality Capture Misconceptions

There are a few misconceptions with reality capture, especially in the AECO industry, including:

1. Reality capture captures everything in a space: false.
   - Devices are only line of sight.
   - Devices have a range and specific use.
2. Reality capture devices can see through walls and ceilings: false.
   - Devices are only line of sight.
3. Always choose the highest frequency and fidelity of reality capture available: false.

- Getting a higher resolution image may not add value for your needs. Your use case determines the fidelity.
- A higher fidelity requires greater processing and therefore more time and energy to process.
- Cost is a consideration.

4. Reality capture is the same as BIM: false.
   - Reality capture does not identify objects, such as doors, walls and furniture.
   - A higher level of analysis is required for Object Context Recognition (OCR).
5. Laser scanning doesn't require a strategy or training: false.
   - Some reality-capture devices are complicated and require specialized training.
   - Effective use requires planning and training.
6. Photogrammetry from reality capture automatically becomes a BIM model: false.
   - There are applications available that help convert laser scans into BIM, but it is not automatic and not without training.
7. The best time to use reality capture is during construction: false.
   - Reality capture encompasses many different technologies that can be used at different stages throughout the entire building lifecycle.
8. Only large projects with huge budgets use reality capture: false.
   - Reality capture technologies come in various price points and are not only for billion-dollar projects.

4 Reality Capture Devices

Figure 4-1 illustrates the mosaic of data that is the digital twin.

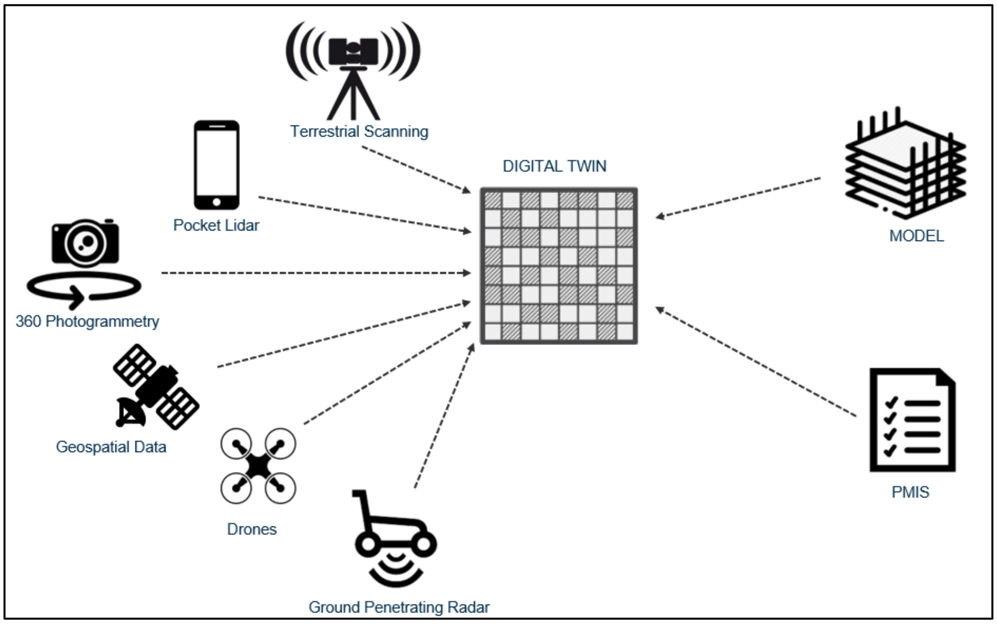


Figure 4-1: Devices and data contributing to the digital twin.

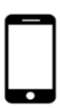
The icons below identify the scanning devices used for reality capture. These icons will be used throughout this document and further guides associated with reality capture:

Terrestrial scanning is the foundation for most reality capture projects, large and small. Terrestrial scanning comprises many different devices with varying ranges and features. With the scanning device on a tripod, this modality provides the highest accuracy of all reality data types ('survey-grade', i.e., below 5mm). The panoramic image generated by those devices is also used for machine learning and AI.

Mobile outdoor lidar scanning is the foundation for scanning large linear or horizontal infrastructure (roads, highways, railways, large pieces of land). They are meant to capture at driving or flying speed from a device mounted on a car or an aircraft. Accuracy is typically within a few centimeters.

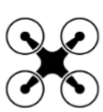
Mobile indoor lidar scanning is halfway between terrestrial scanning and mobile outdoor lidar scanning, these devices are mounted in a backpack or are handheld. They allow the fast scanning of job sites at walking speed with centimeter accuracy. They also provide a set of panoramic images if the devices are equipped with RGB sensors.

Structured light scanning is based on sensors projecting a pattern in the infrared spectrum (such as the Microsoft Kinect sensor), those devices mounted on a tripod capture high-quality 360-degree images together with 3D information. Range of scanning and accuracy are limited. Initially meant to create 3D virtual tours for real estate, they can be used in various confined industrial spaces as well.



Pocket lidar is a relatively new offering that uses sensors within the smartphone range (below five meters), density and accuracy are limited, making it an alternative to other laser scanners for small spaces (i.e., telephone and communication closets, electrical rooms or small objects.)

360-degree cameras and apps are used for documenting project progress repeatedly. This offering has become popular for teams unable to visit the construction site during the COVID-19 pandemic. 360-degree (or panoramic) images can be captured via still images or as a continuous video. This content can also be used for machine learning and AI.



Drones use a variety of reality capture sensors. Most low-cost drones have high-quality RGB sensors, which static images are then used to create the 3D data in a process call *photogrammetry*. More capable drones can sustain heavier payloads and can be equipped with thermal sensors or lidar devices.

Geospatial data captures geospatial data, capturing large swaths of land at high photographic resolution.

Ground penetrating radar (GPR) creates an image map of underground or in-floor utilities.

Cloud data-hosting and cloud-based software-as-a-service enables processing of large files, sharing and visualization of point cloud data. Advances on these platforms such as object context recognition, artificial intelligence (AI), machine learning (ML) and asset tagging will compete or replace traditional BIM models in the future.

5 Reality Capture in Parameters

"A good photograph is knowing where to stand."

- Ansel Adams

Reality capture in this paper is limited by the definitions of physical spaces. If we understand reality capture in terms of time, scale and usage intent then stakeholders can more fully plan and implement reality capture projects successfully.

The goal of reality capture is collaboration. If complex project details can be captured and shared to all project stakeholders, then time and money are saved. The more complex the project is, the more important it is for issues to be identified early, based on real data from the field.

To aid in managing the complexity, we have identified three reality-capture parameters.

5.1 Parameter 1: Reality Capture Timing

A capture is a snapshot in time, so timing should be considered carefully. Considerations include:

- when to begin and stop capturing,
- capture frequency (minimum and maximum),
- dynamic capture frequency (adjust the number of captures),
- adjusting capture scope and detail deliberately to control costs and
- set target capture frequencies based on:
  - resources,
  - capacity and
  - demand.

5.2 Parameter 2: Reality Capture Scale and Accuracy

Your use case will dictate the accuracy needed for your reality data and the frequency of scanning and surveying, from which you will be able to decide which capturing device should be used and how much you need to invest. Not all scanning or surveying devices are meant for similar goals and there is no such thing as 'one size fits all' when it comes to reality capture.

Whether your goal is to:

- document a construction site for progress tracking repeatedly,
- create a virtual tour for marketing purposes,
- scan large horizontal infrastructure such as roads or highways,
- perform some QA/QC for your building construction or
- create an accurate digital twin of your factories or plants, you will need to select the right equipment to fulfill your requirements.

Here is a brief summary of some common reality-capture criteria to be considered for scanning as-built static spaces:

- Terrestrial laser scanning will give the survey-grade accuracy needed for all types of QA/QC workflows and the most trustful source of point cloud data for various scan-to-BIM or scan-to-digital twin workflows in indoor and outdoor spaces.
  - Speed of scanning is around 100 scan positions (also called setups or vantage points) per surveyor per day on average.
  - Range of scanning can vary from a few tens of meters to a few hundred meters.
  - On top of the reality-capture session, you will need to add the processing time for registration (i.e., the alignment of all scan positions in the same coordinate system) and the time to upload the data to the data center eventually.
  - Acquiring a terrestrial laser scanner may be found as expensive if you don't have too many jobs that require reality capture. In which case, outsourcing the 3D scanning to a local service company is the way to go.
- Mobile indoor lidar scanning is a faster option to getting 3D spatial data of large indoor spaces such as a factory.
  - Scanning at walking speed, you will scan faster than with terrestrial laser scanners, but at the expense of data accuracy and range.
  - Some processing time is also needed to run the Simultaneous Localization and Mapping (SLAM) technology before being able to access or upload the data, a similar process to the registration of static scans.

  - You will need to invest a similar amount than for a terrestrial laser scanner (around US$40k to US$80k) or outsource to a local service company.

- Mobile outdoor lidar scanning or drone scanning are the two ways to capture large outdoor sites or city-scale projects. Whether you will use an active lidar technology or passive photos depends on the use case:

  - Lidar will be used to get accurate Digital Terrain Models (DTM) since the laser beam can capture the ground through the tree leaves. Since such mobile lidar devices are very expensive to acquire and run, outsourcing to a specialized scanning service company is the way to go to get your data.

  - Photos can be captured with a simple low-cost drone, from which you will easily get a photo-realistic 3D space and accurate orthographic views of your job site and its surrounding context. Stitching the photos to get such 2D and 3D data requires running photogrammetry algorithms on your desktop or in the data center, which usually takes a few hours. Drone scanning is therefore meant for frequent outdoor scanning like those needed at each stage of the building construction. Buying a drone is cheap (less than US$3k) and getting a 'drone pilot' license by passing the FAA exam (in the USA) is easily accessible now. There are restrictions to flying a drone in some areas though, but everything is very well documented, and those restrictions are usually embedded in the flight setup app.

- Cameras capturing 360 panoramic images cost under US$1k and easy to use. They allow capturing large sites at walking speed daily. But since there is no 'active' sensor, you cannot expect accurate or dense 3D data from such devices. They are meant for 'visual' analysis, monitoring and comparisons.

Reality capture devices should be considered carefully then. There are many variables for consideration and have cost implications. These include:

- size of the project,
- frequency of capture, level of detail vs speed to capture,
- capabilities of technology: range, and speed to capture data,
- adjusting capture level of detail (high resolution vs low resolution),
- setting acceptable levels of accuracy,
- resources trained and qualified to operate capture devices and capacity for capture team to scan and deliver data or
- availability of a reality-capture servicing company able to perform the job and deliver the data to you.

5.3 PARAMETER 3: REALITY CAPTURE INTENT

Reality-capture intent is different across different industries. Each industry has its use cases that will drive the different hardware and software selections. It will also drive different capture frequencies and accuracy requirements. For instance, a surveyor that is building a bridge may require a scanner with a range of thousands of feet, whereas an electrical designer surveying an electrical room may only need a scanner with a range of a few feet. A weekly capture for mid-construction clash detection to help engineers head off issues prior to pouring foundation or installing duct work.

The following two charts illustrate the use of tools in different (arbitrary) phases of the project. In each, the colors represent the use of a certain type of tool. *Figure 5-1* is a general rendition, without project type, tools and timing. It shows that you would use different tools (colors) based on the phase of the project and the frequency of how often you need data.

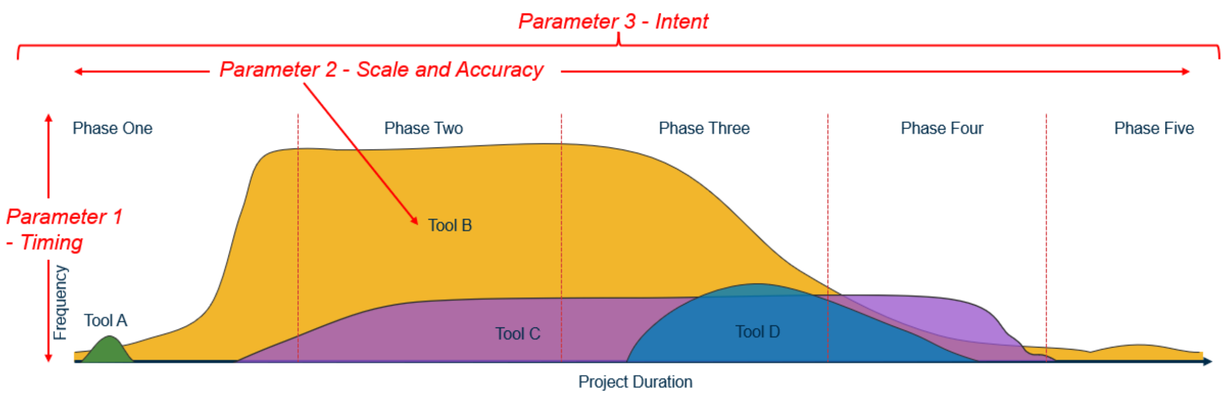


Figure 5-1: Timing, Scale, Intent.

Figure 5-2 overlays the different reality capture tools that would likely be used throughout a new construction project. During site development, ground penetrating radar (GPR) creates an image map of underground or in-floor utilities. Throughout the entire project, drones can track progress from overhead, providing images to help with the eventual marketing of the building.

Virtual walkthroughs are made easier with 360-degree cameras during all stages of construction. As the building is closed in and fit-out takes place, the 360-degree cameras and applications along with terrestrial scanning offer progress tracking and can set the foundation for artificial intelligence and machine learning used during close out and operations.

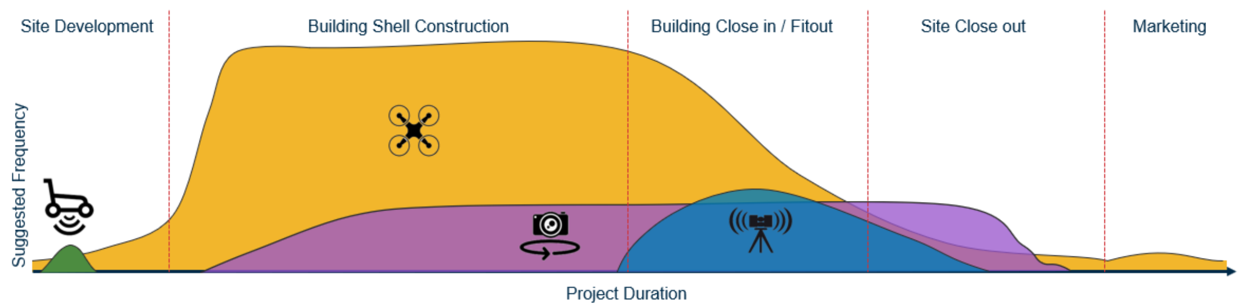


Figure 5-2: Typical reality capture use case.

Understanding the project requirements, which match to timing and frequency, will inform the team in terms of technologies, cost and final deliverable goals.

6 Reality Capture Industry Guide

Incorporating reality capture into workflows should be done per industry sector and specific use cases. Here are some industry-specific guides:

Real estate and construction: Construction is one of the least digitized industries. Laser scanning can be used to capture existing conditions, changing conditions and baseline digital twin in facilities management.

Infrastructure: Laser scanning can be used to capture existing conditions and for inspections, documenting changing conditions and condition assessments.

Cities: Useful for understanding a site in the context of its surroundings, documenting envelope conditions and a basis for simulations.

Accident forensics: Captured data can be used to document and analyze crime scenes or to determine the root cause of an accident.

Aerospace & defense: Capturing parts, components and structures that may fatigue and fail over time.

Mining and energy: Capture of existing conditions of stockpiles, spoils, tunnels and site conditions for documenting changes, measuring and future work planning.

Manufacturing and logistics: Existing building conditions for planning of new manufacturing lines and equipment in an existing plant. Safety and familiarization training.

Medical: Measurement of the human body and use for surgeries and prosthetics.

Planetary and geospatial: Capture of ground terrain on Earth and other planets. Data can include thermal imaging and chemical composition.

Cultural heritage and history: Preservation and reconstruction of historic objects and sites.

As shown above, many industries can benefit from reality capture to support the development of the digital twin.

7 Reality Capture Maturity Model

How might a maturity model inform the overall adoption of devices? See *Figure 7-1*.

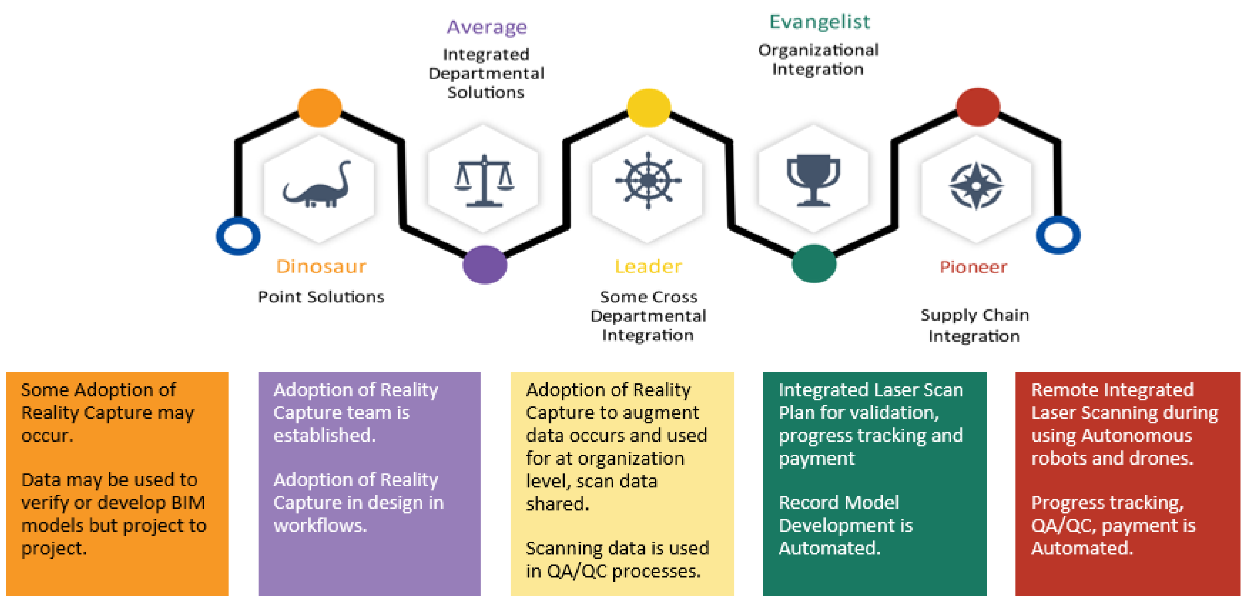


Figure 7-1: Reality capture maturity model.

8 Other Considerations

The industry is in a state of accelerated change. There are other considerations that should be evaluated before implementing any reality capture project or program. These include:

- People:
  - stakeholders,
  - roles and responsibilities,
  - training and upskilling and

  - user needs.
- Automation technologies:
  - AI,
  - robotic for automated capture and
  - machine learning.
- Evolving methodologies:
  - new or enhanced features,
  - automated workflows and
  - usability of data.

9 The Path Forward

It is important to restate that the industry is in a state of accelerated change. Reality capture can be more easily adopted by engaging a technical subject-matter-expert that can develop a specialized plan for reality capture that is tailored to a specific industry use case.

Authors & Legal Notice

This document is a work product of the Digital Twin Consortium's Architecture, Engineering, Construction & Operations (AECO) Working Group, co-chaired by Salla Eckhardt (Microsoft) and John Turner (Gafcon Digital).

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