Applying Reality Capture to Tenant Improvement Projects

A Digital Twin Consortium User Guide

2023-06-07

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1 INTRODUCTION

This user guide is a supplement to the white paper, *Reality Capture: A Digital Twin Foundation*. The industry user guides apply reality capture as it pertains to specific industries. This guide, for Tenant Improvement (TI) Projects, advises readers on how they can use reality capture within the interior of a building to modernize and improve the efficiency of their tenant improvement projects. Reality capture is seen as a critical component to the lifecycle of a digital twin and so TI projects can both benefit and contribute to the development of the digital twin.

2 REALITY CAPTURE PARAMETERS

As outlined in the white paper, reality capture can be defined in terms of time, scale and usage, which are identified as reality-capture parameters. It should also be mentioned that location is the first priority before scanning and consideration of the following parameters.

- Parameter 1: reality capture timing - a capture is a snapshot in time.
- Parameter 2: reality capture scale and accuracy.
- Parameter 3: reality capture intent or usage.

The following chart illustrates the use of devices in different (arbitrary) phases of the project. In each, the colors represent the use of a certain type of device. Figure 2-1 is a general rendition, without project type, tools and timing. It shows that you would use different devices (colors) based on the phase of the project and the frequency of how often you need data.

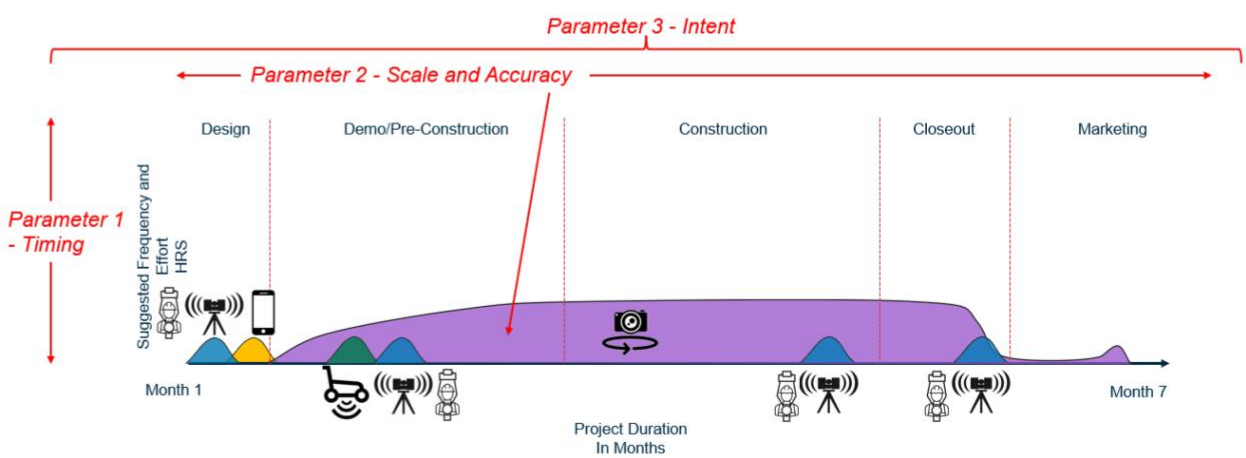


Figure 2-1*:* Timing, Scale, Intent.

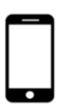
3 Reality Capture Devices Typically Used for Tenant Improvement

As originally presented in the first DTC Reality Capture white paper: *Reality Capture: A Digital Twin Foundation*, the icons below identify the scanning devices used for reality capture. These icons are used throughout this document and other DTC 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 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.

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.

Ground penetrating radar (GPR) creates an image map of underground, in-floor, and wall utilities and post tension cables with floor slabs. This can extend into devices used for scanning behind walls for rebar, piping, etc. These scans are considered non-destructive testing. Consider devices with RTK to capture real world coordinates.

4 TENANT IMPROVEMENT WORK STAGES

Design construction and operation can be defined as work stages. Design is the process of creating a plan or layout. Reality capture can contribute to that development through providing a clear picture of the existing conditions to stakeholders. Reality capture can drive better decisions on the layout, constraints and opportunities that will be constructed.

Construction is the process of building or assembling the product or structure according to the design plan. Reality capture can help prepare, verify and inform changes or opportunities ahead of ordering material and carrying out the actual building process. Reality capture can also communicate construction progress and act as a documentation tool.

Operations refers to the day-to-day tasks that are required to keep a building running smoothly. Reality capture can assist in providing historical documentation of conditions behind walls, above ceilings that can help teams with maintenance, repairs and monitoring to ensure that everything is functioning properly. It can also help provide data for making better decisions, necessary adjustments or changes to the building as needs change to optimize its performance.

The best-fit reality capture tools for each work stage are:

Design: terrestrial, mobile and handheld scanning can capture details quickly and efficiently that can be used for design development and communicating information to all stakeholders.

Pre-Construction: terrestrial, mobile and ground penetrating radar can inform the construction teams of potential issues in floors, floor leveling and flatness.

Construction: terrestrial, mobile and 360 cameras can capture details and changes on the site. This data can be used for Owner Architect Construction meetings to make decisions, analyze progress, compare built environment to design and serve to document conditions that will be hidden later.

Closeout: terrestrial and mobile can be used for capturing as-built conditions, shared with the design team for record drawing and model development and serve to document conditions that will be turned over to the owner.

5 STAKEHOLDERS

Tenant Improvement reality capture can benefit project stakeholders in many ways. First, by capturing every visible feature of the existing conditions that can be shared across the team as a visual communication tool. Cloud-based platforms, which are hardware agnostic and easily accessible, are an easy way to view, manipulate and share reality capture data. Second, the data analysis of scan data enables users to extract information like floor flatness and clashes detection to surface potential issues with proposed design. The following stakeholders or their third-party vendors may collect the data for viewing, consuming and distribution of the data.

Stakeholder Role	Data Use/Need	Recommended Data Collection Frequency
Owners (Tenant)	Baselining Existing Conditions, Operations and Capital Planning	Bi-Annually or when physical changes occur.
Owner (Core and Shell)	Baseline Existing and changing Conditions, Operations and Capital Planning	Bi-Annually or when physical changes occur.
Architect	Baseline Existing Conditions, Overlay to Design BIM Data (Scan to BIM) Record Model/Document Development	Project Start and End
Engineers	Baseline Existing Conditions, Overlay to Design BIM Data (Scan to BIM) Record Model/Document Development	Project Start and End in coordination with Architect
General Contractors	Baseline Existing Conditions, As-Built BIM Model Development	Project Start and End for As Built
GC Sub-Contractors	Baseline Existing Conditions, Overlay to Trade BIM Data	Project Start

Table 5-1: Roles and Responsibilities.

6 Control and Accuracy

Implementing control on any reality capture project is essential. It is the only way to orient and align data within a space and ensure that accuracy is maintained. A control point (shown in Figure 6-1) is a simple benchmark or point on the ground, a vertical face (i.e., wall, column), or any permanent structure whose horizontal and vertical location/position is known. Additional control points are then placed within line of sight of this point and used to locate captured data files accurately and precisely and spatially tie them together. This extends into referencing other data files like BIM, CAD and GIS.

Figure 6-1: Control Points.

There are several factors that can impact the control and accuracy of reality capture data, including the stability and quality of the devices, the precision of the scanning system and its ability to follow the desired scan path and the resolution and accuracy of the sensors or other data collection equipment used.

To achieve high levels of control and accuracy in laser scanning, it is important to use high-quality, reliable equipment and to carefully calibrate and maintain the scanning systems.

On both small and larger projects, where the compounding error of scan registrations over longer distances can become a problem, controls are used to mitigate this.

Items to consider prior to establishing control:

- Is there a facility-wide control network already existing? If so, it is imperative to tie new control points into that network to have spatial relativity and set the foundation for the digital twin?
- Will control be used for other purposes outside of the project in question? Consider use cases post construction in which tenants or operators could use this control information to orient themselves within the building (i.e., maintenance, navigation, etc.)
- Control points can vary in size, shape, location and type and are used to define coordinate reference within the point cloud.
    - Monuments - are typically on the floor or ground and fixed permanently.
    - Targets - typically temporarily taped to a wall.
    - Spheres - typically placed in the middle of a space.
    - QR Codes - Quick Response Codes hold information and can be read by digital devices.
    - April Tags - Similar to QR Codes, are useful for a wide variety of tasks including augmented reality, robotics and camera calibration.
    - Fiduciary Tags - Similar to QR codes that are used in navigation for robots.

7 COMPLIANCE AND SPECIFICATIONS

Since reality capture collects spatial data about objects and the interior environment there are special considerations for compliance and specifications to adhere to such as safety standards, privacy and the accuracy and precision of measurements.

- **Safety:** OSHA Regulation 1926.54 – laser scanners can generate high-powered lasers, so there are strict safety standards in place to protect operators and bystanders from accidental exposure to the eye. Laser scanners are classified based on their output power and beam divergence, with higher classes indicating a higher potential for hazardous exposure. Most laser scanners are low power, Class 1 and Class 2, and are considered safe for general use, while Class 4 lasers are considered potentially hazardous and require special precautions.

- **Privacy:** Particularly important when collecting and processing sensitive information, such as personal identification, locations and biometric data. Some scanners blur images on the device for privacy compliance. Other specifications used in reality capture include data encryption, data retention policies and access controls. As a general rule, one can reference *GDPR policies*. What country the data is located in may dictate specific corporate policies that will further define the considerations. The specific applicable policies and requirements should be documented before the capture of image-based data.

- **Environmental conditions:** Laser scanners are sensitive to environmental conditions, such as temperature and humidity. There are standards, guidelines and device manufacturer data sheets that specify the operating conditions in which a laser scanner can be used, to ensure reliable and accurate measurements.

- **Accuracy and precision:** Laser scanners are often used for high-precision measurement applications, such as surveying or inspection. There are standards, guidelines and in some cases, federal and state regulations that specify the required level of accuracy and precision for these types of applications. The level of accuracy and precision for the particular project should be defined in the project planning stages and mentioned in the contract specifications to assure quality of the data deliverable.

- **Data Quality:** Laser scanners generate large amounts of data, which must be processed and analyzed to extract useful information. There are standards and guidelines that specify the quality and format of the data that is collected and how it should be processed and analyzed.

- **Government Requirements:** Each Country, State and local jurisdiction may have specific requirements and guidance for laser scanning the data collected, distributed and retained.

Overall, compliance and specifications play a crucial role in reality capture, ensuring that personal privacy and data security are protected while still allowing for the collection and processing of necessary information needed for the project. Consider who owns the data, data retention policies and ownership for the verification of data.

8 Outputs and Deliverables

There are several outputs and deliverables that may be produced from a reality capture. These may include:

Point Cloud Data is the raw data collected from the device, typically a laser scanner, which consists of a set of 3D points in space. Deliverables specific to point clouds may include, but are not limited to:

.XYZ
.CSV
.LAS
.LAZ
.E57

3D Models are digital representations of the physical object or environment, created from the point cloud data. These models can be viewed and manipulated on a computer. Deliverables specific to 3D Models may include, but are not limited to:

.DWG
.RVT
.IFC
.FBX

3D Mesh Models are 3D models consisting of polygons converted from the laser scan point cloud. 3D meshes use reference points in X, Y and Z axes to define geometry. 3D Mesh models are much smaller in file size than the point cloud file. Deliverables specific to 3D Mesh Models may include, but are not limited to:

.OBJ
.FBX
.DXF

2D Drawings are flat representations of the scanned object or environment, which can include floor plans, elevations and cross-sections. Deliverables specific to 2D Drawings may include, but are not limited to:

.DWG
.IMG
.JPG
.BMP

Animated Flythroughs: These are virtual tours of the scanned environment, allowing users to navigate through the space in a virtual way.

Reports: These document the laser scanning process and may include information about the equipment used, the data collection process and any issues encountered during the project. Additionally, reports of built vs. design tolerances, punch list items and other items that would inform the Owner/GC of how the construction process was executed.

Digital Photos: These are the raw file (photos and 360 photo) data used in photogrammetry captured during the data collection process.

Cloud Tools: Services that exist for uploading and storing reality capture files are now available. This serves two purposes: (1) distribution of large datasets to stakeholders; and (2) processing into smaller files (creating mesh models).

Photogrammetry: The process of creating 3D models and maps from two-dimensional images by using the measurements of distance and angles between multiple images.

It is important to request scan data be delivered in native authoring software so that if needed, data can be saved into a different format in the future.

9 FUTURE USE CASES/TRENDS AND TECHNOLOGIES SUPPORTING DIGITAL TWINS

There are several technologies that are having a profound impact and that will have widespread adoption and continue to drive innovation, and efficiency in the creation of Digital Twins.

Computer Vision involves utilizing computer algorithms to interpret and analyze visual data from the world around them, such as images and videos. This technology is used in a wide range of applications, including autonomous vehicles, object recognition and equipment imaging.

For tenant improvements and similar projects with 3D reality capture datasets referenced in Section 8 above, teams have been utilizing computer vision algorithms to automate manual processes such as counting installed assets during commissioning phases of construction and/or quantifying existing assets before construction begins. This can be a typical value-add to be considered if regular site-walks are planned to occur with 3D reality capture scanning.

Edge Computing uses decentralized computing infrastructure where data processing and storage takes place closer to the devices and sensors (scanners) generating the data, rather than being sent to a centralized cloud server. This technology is useful in reducing latency, improving response times and saving bandwidth, especially in applications that require real-time data processing like reality capture to models or objection recognition.

This can be considered as a project requirement pending the standard data handling procedures of the country's agencies and/or the company. Referencing Section 7 above, given 3D reality capture can record personal and/or confidential information, 3D reality capture devices that include edge computing can be a mitigation method to best address data handling requirements such as those presented by data privacy requirements.

Thermal Photogrammetry: There are multiple types of photogrammetry depending on the types of images that are used. A primary type of photogrammetry used for existing buildings and tenant improvements is called thermal photogrammetry. It uses infrared images to create 3D models, showing the differences of heat on surfaces throughout a building.

This has typically been used as a non-destructive testing method to identify water intrusion, heat and energy loss, as well as concrete structural inspections. For tenant improvements, this can be used for existing conditions surveys as well as building energy performance analysis for pre-bid and due diligence use cases.

Deviation Analysis uses point cloud data for automated comparison of scans over time. Deviation analysis can effectively cut costs by quickly identifying errors. Users can prioritize issues based on magnitude of deviation, preventing errors in process and reducing rework. Deviation analysis can be used to compare actual progress to scheduled progress. Deviation analysis documents earned value on a line-item basis for easy comparison and integration for pay apps.

10 Relevant Standards

There are various standards that apply to reality capture of building interiors. These standards typically cover technical aspects such as accuracy, resolution and data quality, as well as how the data should be collected and processed. Some common standards for reality capture of buildings include:

- **ISO 19130-1:2014:** This standard specifies technical requirements for the collection and processing of 3D data for the general mapping of terrestrial and man-made features. It covers the accuracy, resolution and quality of the data, as well as the methods and equipment used to collect and process the data.
- **ASTM E57:** This standard specifies the technical requirements for the collection, documentation and exchange of 3D imaging data using 3D imaging lasers and related hardware. It covers the accuracy, resolution, and quality of the data, as well as the methods and equipment used to collect and process the data.
- **ASTM E1155-20:** This standard is a common method for measuring floor levelness and floor levelness (FF/FL) in buildings. It involves using a laser to measure the distance from the floor to a reference point, such as the ceiling or a wall. By scanning the entire floor area, it is possible to create a detailed map of the floor's levelness.

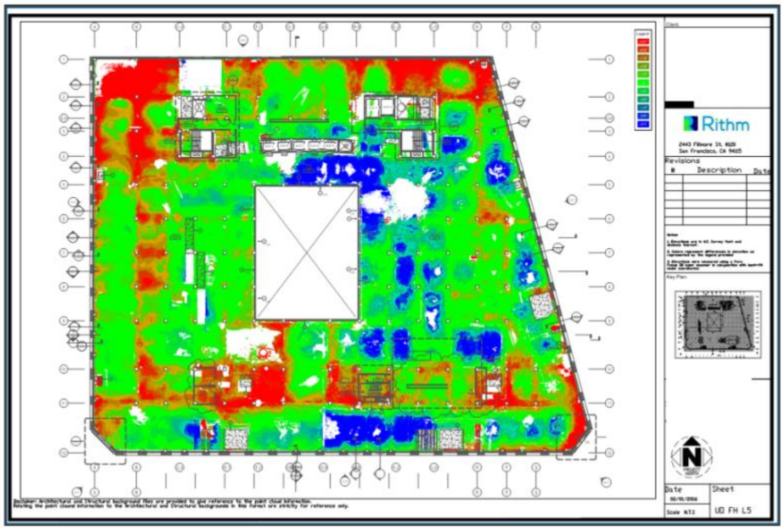


Figure 10-1: Floor Flatness Heatmap.

11 CONCLUSION

This user guide serves as a resource and practical companion for DTC and industry users seeking to better understand specific use cases within reality capture. We hope that this guide has provided you with the necessary guidance and insights to better implement reality capture for Digital Twins on Tenant Improvement projects. We appreciate your trust and dedication to the Digital Twin Consortium, and the AECO team. We remain committed to continuous learning through member experience and through ongoing updates and support to these guides.

Glossary

ASTM – American Society for Testing and Materials

FF/FL – Floor Flatness Floor Levelness is a visual report used to determine the flatness and levelness of a concrete floor.

GDPR - General Data Protection Regulation - is a Regulation in EU law on data protection and privacy in the EU and the European Economic Area.

ISO – International Organization for Standardization

OSHA – Occupational Safety and Health Administration.

RTK – Real-Time Kinematic, is a GPS correction technique that provides real time corrections to location data while the drone is capturing imagery.

Authors & Legal Notice

This document is a work product of the Digital Twin Consortium AECO Working Group, chaired by Chris Heger (OAC) and Salla Eckhardt (OAC), and the Reality Capture Tiger Team, chaired by John Niles (Gafcon Digital).

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