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3D Data Acquisition - 1

Lecture Notes

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Version

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Learning outcomes

At the end of this lecture, the learner is expected to be able to

- Explain 3D geospatial data acquisition technologies
- Describe the ways of using data acquired with different sensors (UAVs, ALS, TLS, Tacheometry)

Expected competences when entering the lecture

- No specific pre-requisites required.

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Summary

The lecture explains 3D geospatial data acquisition surveying technologies: tacheometry and photogrammetry.

Expected Workload

24 slides with course learning content, 2 hours

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Revision History:

Revision	Date	Author(s)	Status	Description
0.1	2023-09-09	V. Cetl, D. Markovinović	Draft	Table of content
0.2	2023-09-20	S. Šamanović	Draft	Photogrammetry included
0.5	2023-11-16	V. Cetl	Draft	First complete version
1.0	2024-01-15	V. Cetl	Final	Final after revision

Contents

Introduction

There are different surveying methods for 3D Data Acquisition surveying methods. The most used are: Tacheometry, Photogrammetry and 3D Laser Scanners.

3D Data Acquisition – 1 Lecture notes cover Tacheometry and Photogrammetry.

Tacheometry

Tacheometric surveying is one of the methods of angular surveying in which electronic tacheometer or total station (Figure 1) is used to determine both the horizontal and vertical distance between two points.

Figure 1. Tacheometer (Total Station)

Tacheometry is the process of measuring horizontal angle, vertical angle and slope distance in order to calculate three dimensional polar coordinates of an object describing point's position through angle and distances (Figure 2).

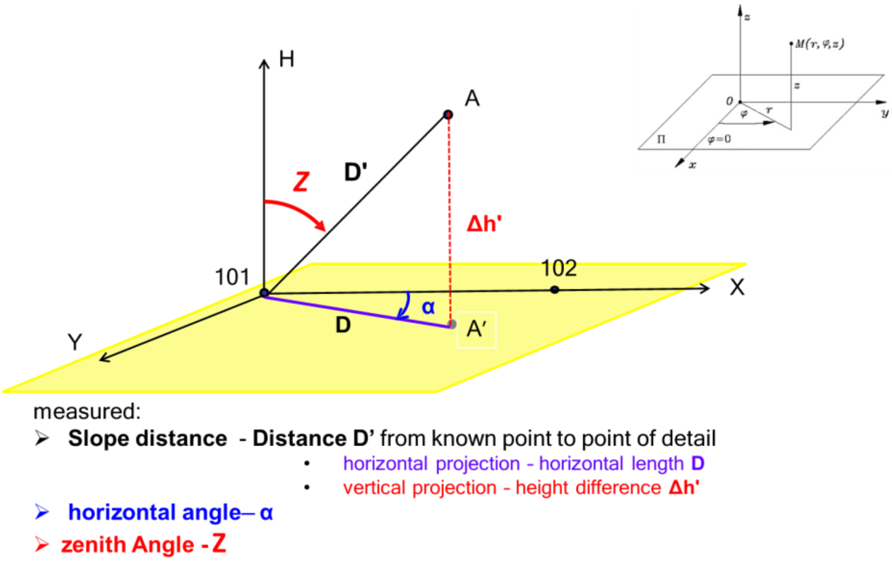

Figure 2. Tacheometry

Tacheometric surveys are usually performed to measure the 3D location of points on the landscape and buildings (Figure 3) to produce contour and detail plans for further work, or to produce coordinates for area and volume calculations.

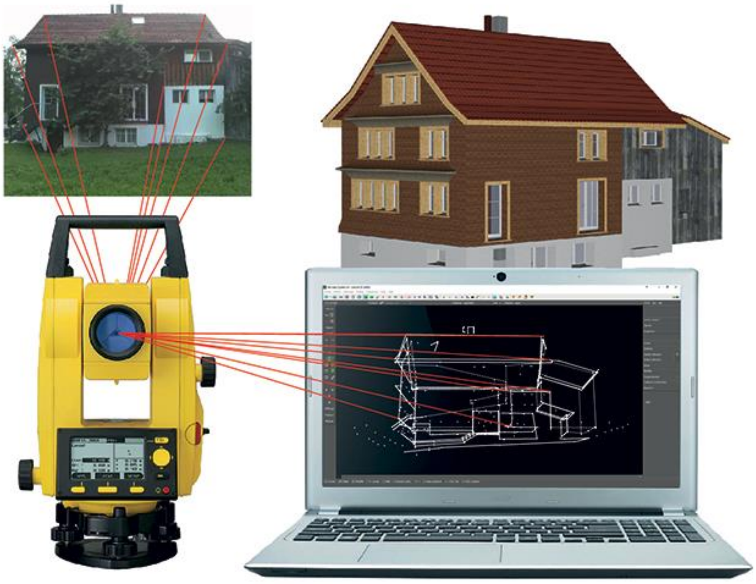

Figure 3. Tacheometric survey application

Tacheometry in BIM is used for stake out of buildings before construction work and also for As-built survey (Figure 4).

Figure 4. Staking out with tachymeter and As-built survey

Photogrammetry

Photogrammetry is widely recognized as a prominent field within Applied Computer Sciences. It actively collaborates with adjacent disciplines, as visually represented in Figure 5

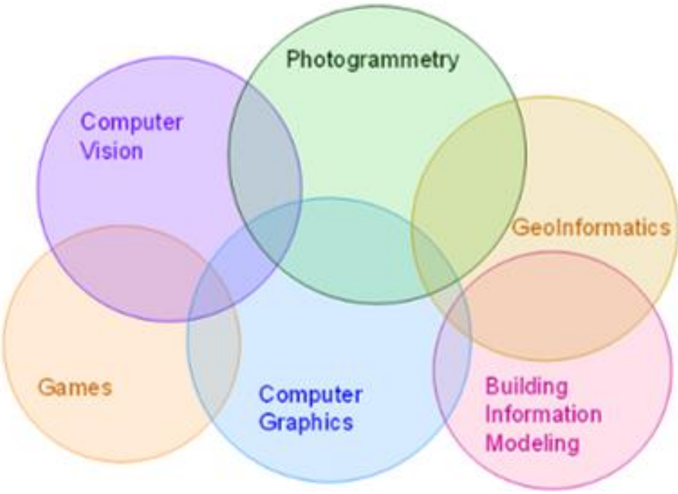

Figure 5. Photogrammetry and other disciplines

Photogrammetry is classified into two types Aerial Photogrammetry and Terrestrial Photogrammetry. Aerial and Terrestrial photogrammetry are used for mapping and measurement related issues. Aerial is far range and terrestrial is close range photogrammetry.

The first step is to take a picture of the object or terrain with different angles and positions. These images should have an overlap to ensure that the same object or feature appears in multiple images. After that, characteristic points or features are identified in the images. These points are used to align the images to create the 3D geometry and calculate the 3D coordinates of the characteristic points using pairs of images in which these points appear. After the 3D coordinates are calculated, point clouds are created that represent the 3D spatial distribution of points on the surface of the object or terrain. The point clouds can be used to create a 3D model of the object's surface. We use the original images to add colours and details to the 3D model (texturing), making it more visually appealing and realistic. Ultimately, the 3D model can be visualized on a computer or in a virtual environment. It can also be analysed, measured and used for various purposes, such as design, cultural heritage preservation, games and scientific research.

Aerial photogrammetry:

- involves capturing photographs from an elevated position
- using aircraft or drones
- used for large-scale mapping, surveying, and monitoring applications

- land surveying, urban planning, environmental monitoring, and agriculture
- cost-effective and efficient way to capture large-scale 3D data over extensive areas

During aerial photogrammetry, the sensor mounted on the aircraft collects many high-resolution photographs of an area from the air. These photos overlap in a certain percentage, and when overlapping, care should be taken to ensure that a certain detail of the area of interest is visible on multiple shots. The result of such imaging technique is a 3D reconstruction of the target area/object. Such a model contains information about terrain height, texture, shape and colour of each recorded point. Based on the overlap between the images, it is possible to obtain an orthophoto - a two-dimensional aerial image and a DMR - a 3D representation of the area. By combining orthophoto and DMR, a 3D model of the required area is created.

Close-range photogrammetry/terrestrial photogrammetry

- refers to situations where the camera is relatively close to the subject being captured
- commonly used for small- to medium-sized objects or scenes
- used in controlled environments
- suitable for applications requiring detailed measurements and accurate 3D models
- archaeology, cultural heritage documentation, product design, forensics, reverse engineering, virtual reality

Terrestrial photogrammetry plays an important role in the preservation of cultural heritage objects. The advantage of such photogrammetry is the possibility of carrying out measurements inside the objects themselves (e.g., rooms of buildings). Unlike aerial photogrammetry, where the final products are made based on aerial photographs obtained, in terrestrial photogrammetry photographic images are collected with a measuring camera at the level of the earth's surface (Figure 6). Terrestrial photogrammetry also finds its application in measuring, i.e., determining the dynamic displacements of objects.

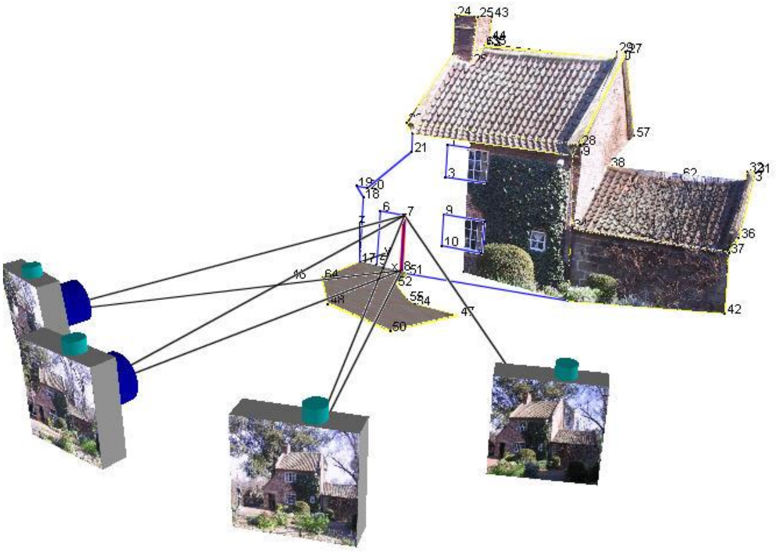

Figure 6. Terrestrial Photogrammetry

Close-range photogrammetry is a technique used to create accurate 3D models or measurements of objects and scenes using photographs taken from a relatively short distance. It has a wide range of applications across various fields, including architecture and construction, cultural Heritage preservation, archaeology, forensic investigation, industrial design and manufacturing, virtual reality and gaming, medicine and healthcare, film and animation.

Figure 7 shows comparison of aerial surveying with a manned aircraft or using UAV in **Aerial photogrammetry**.

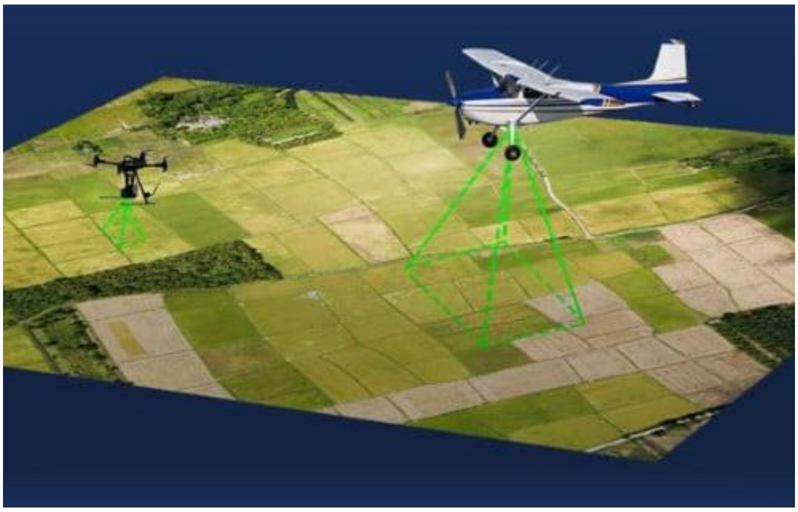

Figure 7. Aerial surveying with a manned aircraft or using UAV

The decision on whether to employ manned aircraft, unmanned aerial vehicles (UAVs), or a combination of both depends on various factors. The significant advancements in unmanned aerial vehicles (UAVs) have greatly expanded the options for surveying, photography, measurement, and mapping across different terrains compared to traditional aircraft. This innovation has also led to increased efficiency and cost savings for organizations of all sizes. The choice between the two is a key consideration in surveying projects, as organizations weigh whether to replace manned aircraft with UAVs.

In some cases, one platform may be the superior choice or the only viable option, but more often than not, both types of aerial platforms complement each other. Manned aircraft excel at rapidly covering extensive areas and carrying heavy sensors due to their extended endurance. On the other hand, UAVs are better in areas where manned aircraft cannot safely operate, such as near buildings or cell phone towers. UAVs are the first choice for locations where manned aircraft cannot fly at all, including narrow streets, beneath bridges, or within enclosed stadiums. They are also the best solution for conducting repetitive surveys of smaller areas, such as monitoring construction site progress.

The selection between manned aircraft and UAVs hinges on the specific project requirements, and often, a strategic combination of both platforms proves to be the most effective approach.

A standard image-based aerial survey involves the essential steps of flight planning and, if necessary, the measurement of Ground Control Points (GCPs) for accurate geo-referencing. Following data acquisition, the images can serve multiple purposes, including image stitching and mosaicking, or they can be utilized as inputs for the photogrammetric process. In the latter case, the initial stages involve camera calibration and image triangulation to facilitate the generation of either a Digital Surface Model (DSM) or a Digital Terrain Model (DTM). These resultant products can then be employed for various applications, such as producing ortho-images, conducting 3D modelling tasks, or extracting additional information. The general workflow is depicted in the figure, with input parameters highlighted in green and individual workflow steps detailed in yellow (Figure 8).

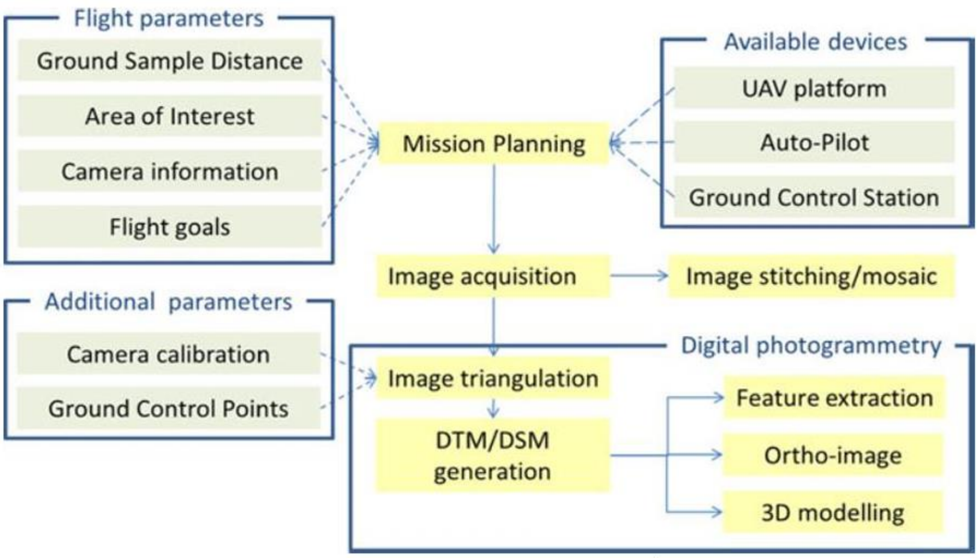

Figure 8. Aerial photogrammetry workflow

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Typically, the mission, encompassing both flight planning (Figure 9) and data acquisition, is meticulously prepared within a dedicated software environment. This process initiates with a thorough understanding of the area of interest (AOI), the desired Ground Sample Distance (GSD), or footprint, as well as the intrinsic specifications of the onboard digital camera. The choice of image scale and camera focal length typically remains fixed to determine the mission's optimal flying altitude. The camera's perspective centers are precisely calculated by establishing both longitudinal and transversal overlap percentages, such as the commonly used 80%-60% configuration. It's worth noting that these parameters can vary significantly depending on the specific objectives of the flight. For missions aimed at generating intricate 3D models, higher overlaps and lower-altitude flights are favoured to attain finer GSDs. Conversely, expedited flights designed for emergency surveys and management necessitate wider coverage in a matter of minutes, albeit at a lower resolution.

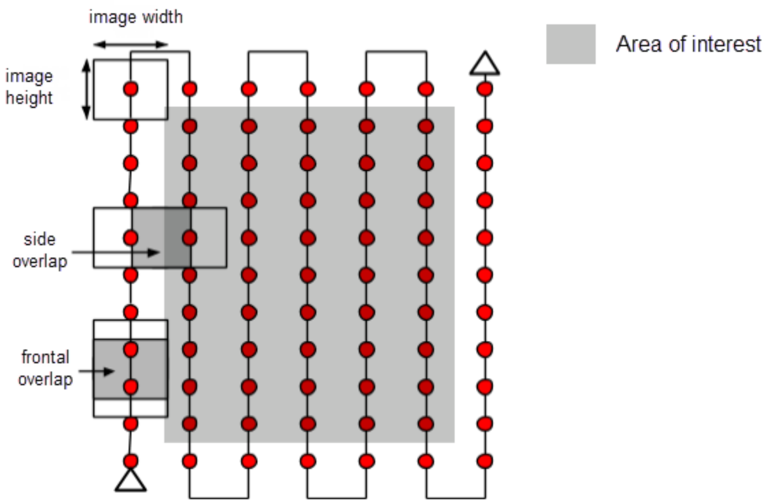

Figure 9. Flight plan

The project contains a flight plan and a layout plan for orientation points. The project defines the planned differences due to height differences of the terrain and a transverse overlap that must ensure a stereoscopic connection between adjacent arrays.

The construction of an orthophoto or mosaic requires that the images have a certain overlap. Overlapping images is nothing more than when photographs in different geographic positions have a common point. Therefore, through photography geometry concepts, it is possible to perform calculations to generate the mosaic with greater precision. Among the types of overlap, we have lateral overlap and longitudinal overlap, as shown in the Figure 10.

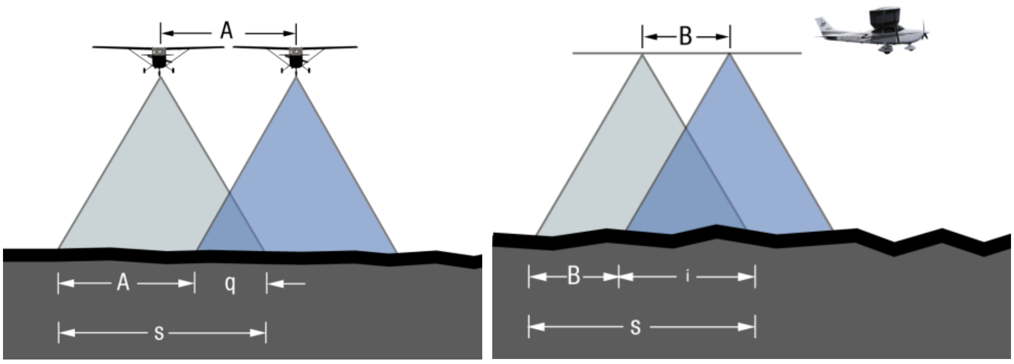

Figure 10. Image overlap

Aerotriangulation is a work process performed with photogrammetric hardware and software, the goal of which is to obtain equalized coordinates of the basic setpoints and connection points and external orientation elements for each individual shot, based on which stereopairs can be formed for photogrammetric measurement or a digital orthophoto can be created.

Sensors

Devices used to capture images or data from the scene being observed play a crucial role in photogrammetry and remote sensing. These devices are often mounted on various platforms, such as satellites, aircraft, drones (UAVs), or ground-based vehicles, to capture imagery or data for subsequent analysis and modelling.

One significant advancement in modern remote sensing and photogrammetry is the ability to use multiple sensors on a single platform. This approach allows for the collection of diverse data types simultaneously, enhancing the richness of information gathered. For example, a single aerial or satellite platform may carry sensors for capturing visible imagery, infrared data, LiDAR (Light Detection and Ranging) data, and more. This multi-sensor approach enables comprehensive analysis and modelling of the observed area, as it provides data from different parts of the electromagnetic spectrum and various sensor modalities.

Sensors are often divided into active and passive sensors, each of which plays a key role in different applications and scientific disciplines.

Passive sensors are devices that record electromagnetic radiation emitted or reflected by bodies and objects, without using their own light or signal sources. This type of sensor plays a key role in scientific research, technology and everyday applications.

Active sensors emit their own signals or light towards the target and record the feedback. They are independent of the natural light source and can provide more precise information in certain situations.

Examples of passive sensors are:

- GNSS (Global Navigation Satellite System) - uses satellite signals to determine geographic location and precise time.
- Infrared (IR) sensors - detect infrared radiation emitted by the body and objects based on their temperature. They are used in thermodynamic and meteorological measurements and in night vision.
- Visible spectrum sensors - detect light in the visible spectrum of electromagnetic radiation. These sensors are widely used in photography, video surveillance and various optical devices.
- Multi-/Hyper-Spectral Sensors - use passive radiation that the body reflects or emits in a much wider range of the electromagnetic spectrum than visible light. This enables more detailed analyses of the material and the environment. Applications include agriculture, mineral exploration and remote sensing.

Example of active sensors are:

- LiDAR (Light Detection and Ranging) - sends laser pulses towards the surface and measures the time it takes for the reflected light signal to return. LiDAR is used to create high-precision digital terrain models and for 3D scanning.

- SAR (Synthetic Aperture Radar) - uses microwave radiation to image the Earth's surface. SAR is useful in all weather conditions and allows observation of the surface even through clouds and at night.

3D Models (Products)

A Digital Elevation Model (DEM) is a digital representation of the Earth's terrain surface. It's a 3D dataset that describes the elevation or height of the Earth's surface at various points across a specific area. DEMs are used in various applications, including topographic mapping, land-use planning, hydrology, and environmental modelling. A digital model always represents some kind of surface. Depending on what is included in it from the Earth's surface, we distinguish between DTM and DSM. We can say that the primary difference between a Digital Terrain Model (DTM) and a Digital Surface Model (DSM) lies in the information they represent and how they are created.

Digital Terrain Model (DTM) represents the bare Earth's surface, excluding any vegetation, buildings, or other above-ground features. It includes the terrain's topography, such as mountains, valleys, hills, and the ground elevation variations. DTMs are often used in applications like land surveying, civil engineering, hydrology, and terrain analysis. To create a DTM, all above-ground features, like buildings and vegetation, are digitally removed or "flattened" from the data, leaving only the underlying terrain.

Digital Surface Model (DSM) represents the Earth's surface as it appears with all surface features, including natural and man-made structures like buildings, trees, and other objects. It includes both the terrain's topography and any above-ground features on the surface. DSMs are useful for applications like urban planning, 3D modelling, vegetation analysis, and flood modelling, as they capture the full surface complexity. Creating a DSM typically involves retaining all elevation data points, including those representing buildings, vegetation, and other above-ground features

Both DTMs and DSMs provide elevation information, but DTMs focus solely on the ground's topography, excluding above-ground features, whereas DSMs capture the entire surface, including terrain and all objects on it. The choice between using a DTM or a DSM depends on the specific application and whether you need to analyse the natural terrain or consider all surface features.

Orthophotos and true orthophotos are types of aerial or satellite imagery used in mapping and geospatial applications. Orthophoto mosaic is one of the most popular products of modern photogrammetry. It is a product that explicitly shows ground terrain and constructed buildings.

The main difference between orthophotos and true orthophotos lies in the treatment of above-ground features. Orthophotos correct geometric distortions but include above-ground objects, while true orthophotos eliminate above-ground features, providing a more accurate representation of the bare Earth's surface.

3D point cloud is a set of data points in a 3D coordinate system. Each point represents a single spatial measurement on the object's surface, coordinate of objects. Taken together, a point cloud represents the entire external surface of an object.

3D point cloud is composed of millions of points at the correct X, Y, and Z coordinates with greyscale or colour information assigned. This form of Reality Capture represents the precise condition of a building or space and works best with modelling software such as Autodesk Revit. Point clouds are produced by photogrammetry or 3D laser scanners, which measure the physical dimensions of the visible surfaces of buildings and objects around them.

In contrast to the 3D point cloud data, a Building Information Model (BIM), provides a digital representation of the actual building. This is known as a "digital twin". Elements in the 3D model have sizes and properties that can be scheduled and counted, and database information can be attached for tracking specifications, cost analysis, energy efficiency, maintenance and repair, and much more. This 3D model becomes a shared resource for information about a facility and it forms a reliable basis for decisions during its life cycle, from as early as the project's conception to its demolition.

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