# GoPro forest: creating a digital forest twin

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## ABSTRACT

Terrestrial Structure from Motion photogrammetry images were used to create a digital 3D twin of several forest areas. The aim was to evaluate whether this method can calculate the existing biomass and stored carbon. Instead of an expensive laser scanning device, a GoPro camera was used. The project served to learn how to use the camera and software for digital data acquisition in forests. Using GoPro images, 3D twins were created and the forest stand was compared with conventional methods. An average value per square meter was calculated in four test areas and scaled up to one hectare. The results of the digital point clouds with Agisoft Metashape and ReCap Pro were compared with conventional images. Agisoft Metashape achieved an agreement of 82.5% and ReCap Pro 87.5%.

### GoPro Wald: Erstellung eines digitalen Waldzwillings

*ZUSAMMENFASSUNG*

*Mit terrestrischen Structure from Motion-Photogrammetrieaufnahmen wurde ein digitaler 3D-Zwilling mehrerer Waldbereiche erstellt. Ziel war zu evaluieren, ob diese Methode die vorhandene Biomasse und den gespeicherten Kohlenstoff berechnen kann. Anstatt eines teuren Laserscangeräts wurde eine GoPro-Kamera verwendet. Das Projekt diente dem Erlernen der Kamera- und Softwarehandhabung zur digitalen Datenerfassung in Wäldern. Mittels GoPro-Aufnahmen wurden 3D-Zwillinge erstellt und der Waldbestand mit herkömmlichen Methoden verglichen. In vier Testarealen wurde ein Mittelwert pro Quadratmeter berechnet und auf einen Hektar hochskaliert. Die Ergebnisse der digitalen Punktwolken mit Agisoft Metashape und ReCap Pro wurden mit konventionellen Aufnahmen verglichen. Agisoft Metashape erzielte eine Übereinstimmung von 82,5 % und ReCap Pro von 87,5 %.*


## INTRODUCTION

Measuring tree attributes for forest inventory traditionally utilizes calipers and measuring tapes, which is a time-consuming approach. State-of-the-art remote sensing methods offer an alternative to traditional approaches. Current remote sensing techniques include terrestrial laser scanning (TLS) and airborne laser scanning (ALS). While TLS and ALS are innovative, they are also expensive, especially for smaller areas. Recently, photogrammetric approaches have emerged as cost-effective alternatives, enabling high-resolution 3D data acquisition on forest structure without expensive ALS methods [1]. Photogrammetry reconstructs visible surfaces and provides ground information in vegetation-free areas. Terrestrial captures, or close-range photogrammetry, focus on trunk or individual tree reconstruction [1]. The structure-from-motion (SfM) approach relies solely on images without additional data like camera location or orientation, offering cost-effective 3D information acquisition from aerial and terrestrial sources [1]. SfM photogrammetry uses off-the-shelf cameras and software to create 3D models of trees, providing an efficient and cheap method for photogrammetric data acquisition. High image overlap and visibility in at least three images are key, requiring constant lighting and calm wind. The technique therefore offers a cost-effective way to acquire 3D remote sensing data from image sequences and allows non-experts to derive biophysical forest parameters from terrestrial SfM point clouds. It processes images from ground-based devices, poles, or UAVs. Analog tree inventories serve as controls but are time-intensive.

## METHODS

This work aimed to determine whether SfM could digitally capture tree attributes, such as diameter at breast height (DBH), with minimal effort and cost. A comparative analysis was conducted on four test plots using conventional and digital methods. The SfM method used a GoPro camera (GoPro, Inc., San Mateo, CA, USA) to capture images within a ten-meter radius test area. Each tree was precisely measured for biomass and location, with user-friendly software evaluated for digital biomass or $CO_2$ equivalent determination. Precise camera settings were consistently applied, considering environmental conditions like wind and light.

The photogrammetric process involved selecting test areas, conducting analog and digital inventories, analyzing images, and evaluating results. Test plots were captured in both analog and digital forms. Figure 1 shows the four test areas in Puch, Krastal, near Villach, forested with spruce trees. Each circular plot had a 10-meter radius with a corresponding area of 314.16 $m^2$. The process started with center selection, GPS determination, and marking of cardinal points.

Analog surveys of the four plots occurred on different dates in 2022: Weiterboden 1 on August 30, Weiterboden 2 on October 7, Krastalbach on October 8, and Steinsäge on October 9. Each plot required an average time investment of around three hours for two people. Measurements were taken clockwise from the plot center and included tree positions, number of trees, DBH, and tree height. In total, 55 trees were recorded, averaging 14 trees per plot, with an average DBH of 37 cm and an average tree height of 23 m.

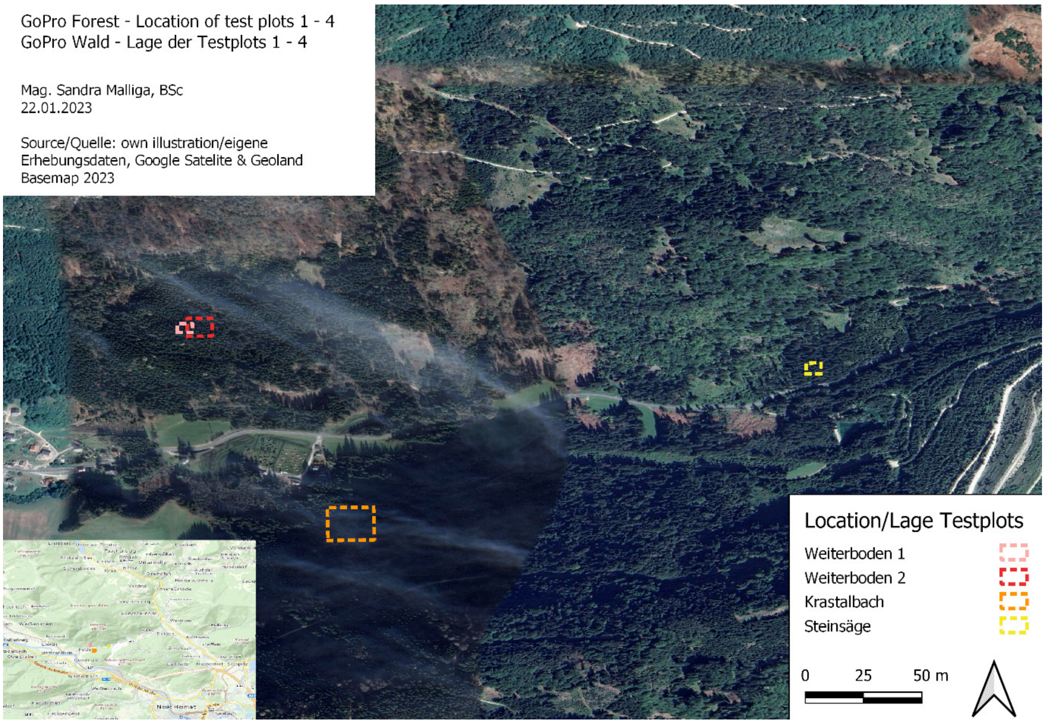


**Fig. 1**

**Figure 1:** Location of the four plots/ examination areas in Krastal, municipality of Weissenstein, cadastral municipality of Puch. Source: own figure

***Abbildung 1:*** *Lage der vier Plots/ Untersuchungsflächen im Krastal, Gemeinde Weissenstein, KG Puch Quelle: eigene Abbildung*

Diameters were measured with a caliper in two perpendicular directions following standard field inventory procedures. The average wood volume per plot, calculated using the Denzin formula, ranged from 18 $m^3$ to 21 $m^3$ (Table 1). This translates to approximately 18 to 21 tons of carbon sequestration per plot, assuming 1 $m^3$ of wood stores about 1,000 kg of $CO_2$.

Tab. 1

**Table 1:** Analog Survey Average Total Plot 1 to Plot 4.

***Tabelle 1:** Analoge Aufnahme Durchschnitt-Gesamt Plot 1 bis Plot 4.*

| Average number of trees per plot / Durchschnittliche Baumanzahl pro Plot | Diameter (cm)/ Durchmesser (cm) | Distance (m)/ Entfernung (m) | Height (m)/ Höhe (m) | Average biomass per plot, minimum (m3) / Durchschnittliche Biomasse pro Plot, minimale ($m^3$) | Average biomass per plot, maximum ($m^3$) / Durchschnittliche Biomasse pro Plot, maximale ($m^3$) |
|---|---|---|---|---|---|
| 14 | 36.69 | 6.72 | 23.46 | 17.98 | 20.88 |

The digital inventory used terrestrial SfM photogrammetry with a GoPro Hero 8 Black (12MP) camera on a gimbal, set to capture images every 0.5 seconds. Aperture sizes were adjusted based on lighting, and the focus was set to infinity. Laminated sheets with black-and-white circular patterns were attached to trees in Plot 1 to ensure a stable image network.

The photographic path for digital tree recording followed the method of Piermattei et al. [2]. The trajectory started with a stop-and-go sequence, covering a small circle from the plot center outward. Images were then taken along the plot's perimeter with the camera directed towards the center. The photographer moved within the plot along both axes, realigning the camera with the center, repeating the pattern as needed.

After the analog survey, digital analysis was performed on a private laptop using freeware CloudCompare (https://www.cloudcompare.org/) and 3D Forest (https://www.3dforest.eu/), along with trial versions of Metashape (Agisoft LLC, St. Petersburg, Russia) and ReCap Pro (Autodesk, Inc., San Francisco, CA, USA) (Figure 2). Analysis from 3D Forest was excluded due to crashes, and CloudCompare lacked user-friendliness, resulting in trees not being measured in digital models.

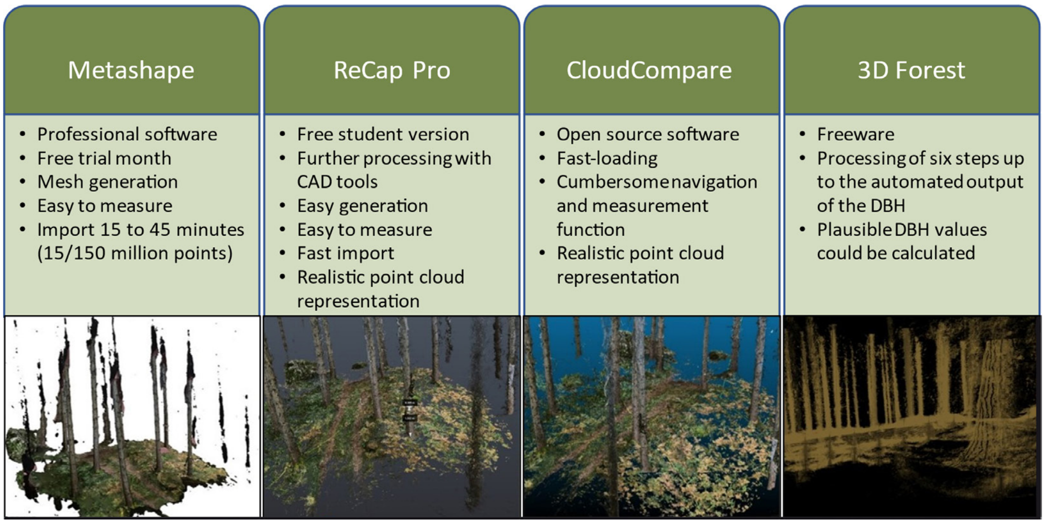


Fig. 1

**Figure 2:** Analysis of digital image material – Selection of digital software. Source: own figure

***Abbildung 2:** Analyse des digitalen Bildmaterials – Auswahl der digitalen Software. Quelle: eigene Abbildung*

Metashape, a professional photogrammetric tool, effectively processed images into high-quality spatial information. Upload times for LAS format data to generate point clouds ranged from 15 to 45 minutes. ReCap Pro converted photos into 3D models and allowed point cloud creation for use with other software or CAD tools. Tree measurements were conducted using a free student trial version. CloudCompare, an open-source software, processed 3D point clouds and triangular meshes but was impractical for measuring DBH. 3D Forest, a free software, processed point cloud files in six steps, including DBH calculation, but required additional time-consuming manual post-processing to achieve plausible outputs within the specified timeframe.

## RESULTS

In plot Weiterboden 1, the agreement between analog and digital measurements was about 87% using Metashape and 90% using ReCap Pro, with all trees clearly assigned. For plot Weiterboden 2, all 18 trees were unequivocally assigned, with an 86% agreement using Metashape and 93% using ReCap Pro. In plot Krastalbach, characterized by dense vegetation and large boulders, ReCap Pro achieved an 88% agreement for eleven trees, while Metashape averaged 81%. The challenging conditions made DBH determination difficult. In plot Steinsäge, which is steeply inclined to the south, ReCap Pro resulted in a 79% DBH agreement, and Metashape achieved 76% for eleven trees.

## DISCUSSION/CONCLUSION

In summary, forest measurements can be done through traditional, time-consuming field inventories or remote sensing techniques like SfM photogrammetry. Off-the-shelf cameras and drones can serve as cost-effective alternatives to expensive laser scanning for determining wood biomass or $CO_2$ equivalents of forest areas.

The extraction of 3D point clouds may not always be successful, as it is affected by lighting conditions, patterns of image capture, and the applicability of methods across different forest parcels [3].

With a well-planned photographic path and appropriate camera orientations, high-quality point clouds can be created, with acquisition times ranging from 30 minutes to 2 hours per forest plot [2].

User-friendly software is crucial, with ReCap Pro being particularly practical and easily combined with other Autodesk applications. Metashape is also useful but requires longer load times and is more complex. Combining image captures with tailored software offers a cost-effective alternative to laser scanning. SfM photogrammetry allows 3D modeling of trees and forest areas, depending on the visibility of the entire tree trunk. This method enables evaluation of tree parameters at the individual tree level and calculation of tree volume, increasing comparability. For generating the 3D forest model, besides precise modeling and georeferencing [4], a significant amount of relevant technical expertise, particularly when utilized by non-experts, is necessary to replace the standard forest survey with the SfM photogrammetry approach.

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