




DEMONSTRATION RESULTS

3D modelling tool for tracking the flows of
on-site CDW

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Sciences (Xamk), Mikkeli



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Abstract	Demonstration results from the 3D modelling tool for tracking the flows of on-site CDW in Mikkeli.
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1. Introduction

Better handling and possible reuse of construction and demolition waste (CDW) are the focus of the "CityLoops - Closing the loop for urban material flows" -project. Several European cities are involved in the project to develop and demonstrate tools that can be used to handle CDW-issues more efficiently. The CityLoops project began on October 1, 2019 and will end on September 30, 2023. The project is coordinated by the German ICLEI - Local Government for Sustainability and receives funding from the internationally sought-after EU Horizon 2020 research and innovation programme (Grant Agreement No. 821033).

This document describes the demonstration results from tool number 7: "3D modelling tool for tracking the flows of on-site CDW" of the CityLoops project. The tool has been developed by the project partner South-Eastern Finland University of Applied Sciences (Xamk), Mikkeli, Finland.

2. Overview of the tool

The 3D modelling tool for tracking the flows of on-site CDW is an operations model in which a camera drone and a photogrammetry software are used for modelling and monitoring demolition sites in 3D. The aim is to produce calculations of buildings and material quantities, which can be stored into a databank. Using repetitive scans of the same site, the movement of different materials can be tracked, as well as other changes to the site. The 3D tool was originally described in Annex 1 (European Commission 2019, 16) of Grant Agreement Number 821033 — CityLoops as follows:

"3D modelling tool for tracking the flows of on-site CDW: A model for drone imaging, already piloted in the mining sector, will be developed, adapted for use on demolition sites to track material flows, and then tested on the demonstration sites. This will allow the documentation and modelling of material flows during the demonstrations, to help track and estimate the quantities of different materials already on site. This data will be exported to the databank created during the project."

The 3D modelling tool uses a method called photogrammetry. Photogrammetry consists of capturing images to recreate a survey area. These images are processed and stitched together using software to create geo-referenced and measurable 3D models, as well as 2D maps. The tool was developed and preliminarily tested during the preparation phase of the project. More information on the tool can be found on the CityLoops website:

- [3D Modelling Tool Factsheet](#)
- [3D TOOL FOR FLOW-TRACKING CDW – description of the tool](#)

3. Monitoring sites

Drone monitoring was performed at three demolition sites in the Mikkeli area in 2021-2022. CDW demonstration action in Mikkeli included the demolition of two buildings: the Pankalampi Health Centre and Tuukkala Hospital. In addition, the tool was tested at the Pellosniemi replication site, where residential buildings were demolished. Volume measurements of material piles were also made in the soil material storage area in Häyrylä, Mikkeli. The volume of the pile was measured with a tachymeter as well as a drone, and the accuracy of the results were compared. Multispectral imaging was also tested in the Metsäsairila sorting and recycling centre area.

3.1. Pankalampi Health Centre

The external demolition phase of the former dental clinic of the Pankalampi Health Centre (Pankalammen Alatalo) was monitored in more detail. The building was built in 1979 and had a basement and two above-ground floors. The structure of the building was made of concrete columns and beams, and its walls and intermediate floors were made of concrete elements. The floor area of the building was 1496 m² and the volume 5490 m³. (Ramboll Oy 2020a). The Pankalampi Health Centre is shown in Figure 1.



Figure 1. Pankalampi Health Centre during demolition. (Picture: Juha Vihavainen)

The demolition of the Pankalampi Health Centre began in March 2021 and ended in August 2021. Drone monitoring was carried out in the health centre area during this time.

3.2. Tuukkala Hospital

The former Tuukkala Hospital, Part A of which was built in 1960 and the newer Part B in the 1970s, was originally built as a mental hospital and was later used until 2005 as a health centre and forward use. In 2005, the hospital was closed. After the closure, the hospital was partially leased until the early 2010s. Since then, the building has been empty. Figure 2 shows the Tuukkala Hospital.



Figure 2. Tuukkala Hospital during demolition. (Picture: Juha Vihavainen)

Part A of the building had five floors, and Part B had four floors. Both parts had a reinforced concrete structure, and their exterior walls were covered with bricks. The foundations were underground footprints. (Ramboll Oy 2020b)

The demolition of the Tuukkala Hospital began in May 2021 and ended in August 2021. Drone monitoring was carried out in the hospital area during this time.

3.3. Pellosniemi residential buildings

In winter of 2022, drone monitoring was also carried out at the demolition site in Pellosniemi. The site consisted of four apartment buildings built in the 1970s, owned by Mikalo Ltd. rental housing company. The buildings had a precast concrete structure, and the exterior walls were covered with bricks. The buildings had two floors and a basement. No contaminants were found in the building during the contaminant survey. The external demolition began in February 2022 and was completed in June 2022. Figure 3 shows the demolition site at the beginning of the external demolition.



Figure 3. Pellosniemi residential buildings during demolition. (Picture: Juha Vihavainen)

3.4. Häyrylä soil material storage site

Volume measurements were also made in the soil material storage site in Häyrylä, Mikkeli on 12.5.2022. The Häyrylä site is in a sparsely populated area along the main road 62, about five kilometres from the centre of Mikkeli in the direction of Puumala. The Häyrylä site is an operational soil and rock material storage area owned by the state-owned forestry company (fin. Metsähallitus). The aim of the volume measurements was to measure the material pile by traditional methods, such as using a tachymeter, as well as a drone and a photogrammetry software. The results from both methods were compared.

3.5. Metsäsairila sorting and recycling centre area

The project also explored the suitability of a multispectral camera for material identification. Multispectral imaging was done in the Metsäsairila sorting and recycling centre area on 5.7.2022 and 2.9.2022. The subject of the imaging was an area where construction waste, such as concrete, bricks and other waste such as plastic and wood, was unloaded (Figure 4.).

The aim of the multispectral imaging was to see how CDW materials behave in multispectral imagery and to determine if it is possible to easily identify different materials with the Micasense RedEdge-MX camera. Figure 4 shows the unloading area from the side.



Figure 4. CDW unloading area in Metsäsairila sorting and recycling centre area. (Picture: Juha Vihavainen)

4. Drone monitoring and methods

Drone monitoring was carried out at the Tuukkala, Pankalampi and Pellosniemi demolition sites during 2021-2022. The aim was to perform the imaging 1-2 times a week during the demolition phase, but due to a case caused by coronavirus, there was a break in monitoring at the Pankalampi demolition site during June 2021. Monthly monitoring amounts are shown in Table 1. During 2021, monitoring was done at the Tuukkala demolition site 10 times, in Pankalampi 24 times, and in 2022, during the Pellosniemi replication, monitoring was done nine times.

Table 1. Amounts of collected datasets at the Pankalampi and Tuukkala demolition sites.

Month (2021)	Tuukkala	Pankalampi
March	0	3
April	0	7
May	2	8
June	6	4
July	1	1
August	1	1

Table 2 shows the monthly monitoring amounts at the Pellosniemi demolition site. The monitoring in Pellosniemi was done approximately once a week.

Table 2. Amounts of collected datasets at the Pellosniemi demolition site.

Month (2022)	Pellosniemi
February	1
March	4
April	4

The datasets were taken from the Pankalampi and Pellosniemi demolition sites at a height of 45 metres, and the Tuukkala demolition site at a height of 50 metres. At the Pankalampi demolition site, the focus was on the dental building, but after its demolition, the buildings of the entire health centre were photographed. On average, one dataset contains around 80-140 images.

4.1. Data capture in demolition sites

Datasets were taken with the Phantom 4 Pro V2.0 drone and the camera built into the drone (Figure 5). Due to its low weight (1,38 kg), flying Phantom drones is easier from a legal standpoint compared to drones capable of carrying larger payloads. Flying a drone over 2 kilogrammes in a densely populated area requires a special permit. The drone features a camera with mechanical shutter, which minimises rolling shutter effect. Rolling shutter effect

can reduce accuracy in calculating measurements in photogrammetry software, or even completely prevent the creation of a point cloud model.



Figure 5. Drone used for data collection, Phantom 4 Pro V2.0. (Image: Juha Vihavainen)

The data capturing process of the demolition sites demonstrated in the project takes an average of less than an hour, which includes arrival at the site, inspecting the area, putting the drone in flight, data capturing and landing the drone.

4.2. Automatic flights

To ensure sufficient overlap between images, a map-based, flight-planning application called Pix4DCapture was used. Flights are planned by determining the flight path, marking the flight area on the map and determining the desired flight altitude. The software calculates the number of images and the duration of the flight. For this demonstration the focus was on buildings and calculating volumes from the point cloud, so the flight path was selected as "Double Grid Mission". Double grid is recommended for 3D models, since double grid captures more detail for vertical features from all angles in the flight area. The flight area visualisation is demonstrated in Figure 6.

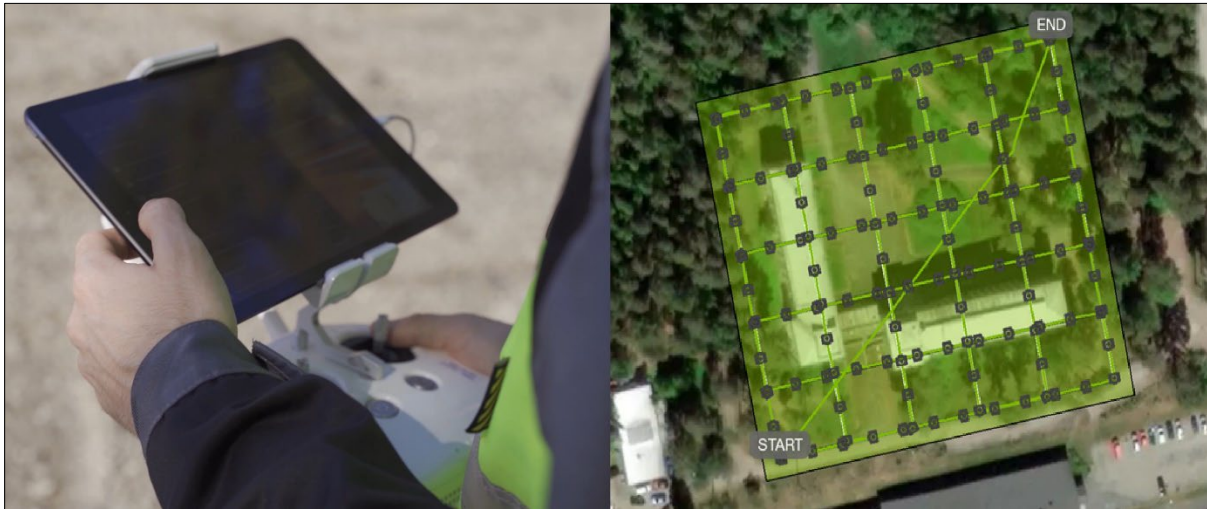


Figure 6. Flight route planned in Pix4DCapture. The application is used on a tablet. (Picture: Juha Vihavainen)

Pix4DCapture communicates with the drone, so automatic flights are possible. In the software, the user can specify an appropriate overlap for the images, so the image processing software can combine the images into orthomosaics and point cloud models for further processing. Data capturing is possible on any flight-planning software, as long as there is the possibility to determine overlap for the images.

4.3. Data processing in PIX4DMapper

After capturing datasets, the images were processed with commercial photogrammetry software called PIX4DMapper. Pix4D S.A. develops a suite of software products that use photogrammetry and computer vision algorithms to transform DSLR, RGB, thermal and multispectral images into 3D maps and 3D models. PIX4DMapper can output a variety of data, such as the following:

- **Point clouds:** Collections of individual points plotted in 3D space. Each point contains several measurements, including its coordinates along the X, Y and Z -axes, and additional data, such as a colour value and luminance value, which determines how bright the point is. (Doggett s.a.)
- **3D textured meshes:** The point cloud itself can be seen as a 3D model, but often the point data is converted into a polygon mesh because most 3D software programs (for

example SketchFab) work with polygons. Polygon meshes are used to digitally reconstruct the surfaces of objects, using point cloud data as reference. (Doggett s.a.)

- **Digital Terrain Models:** A topographic model of the Earth's surface. Vegetation, buildings, and other cultural features are removed automatically, leaving just the underlying terrain. (Pix4D²)
- **Digital Surface Models:** A topographic model including cultural features and vegetation. Digital surface model represents the Earth's surface only in open areas, while in other regions the model follows the forest canopy and the roofs of buildings. (Oksanen s.a.)
- **Reflectance maps:** The reflectance maps contain the reflectance values of each pixel after calibration from reflectance panels and image metadata. Used in multispectral applications. Reflectance is the ratio of the radiation striking a surface to the radiation reflected off it. (Shippert 2013).
- **Orthomosaics:** Large image with high detail and resolution made by combining many smaller images from the flight, including distortion corrections and colour balancing for a visually pleasing result. (ArcGIS).

The images are captured according to the image acquisition plan; different types of terrains or objects require different approaches to the processing. In this demonstration, the main focus is on buildings and volume calculations, so a detailed point cloud and digital surface model is important. The software reads camera parameters, GPS information and other parameters from the images EXIF data. In this case, the datasets were mainly set in the ETRS89 / TM35FIN coordinate system, which is Finland's official coordinate system. The user interface in PIX4DMapper is shown in figure 7.

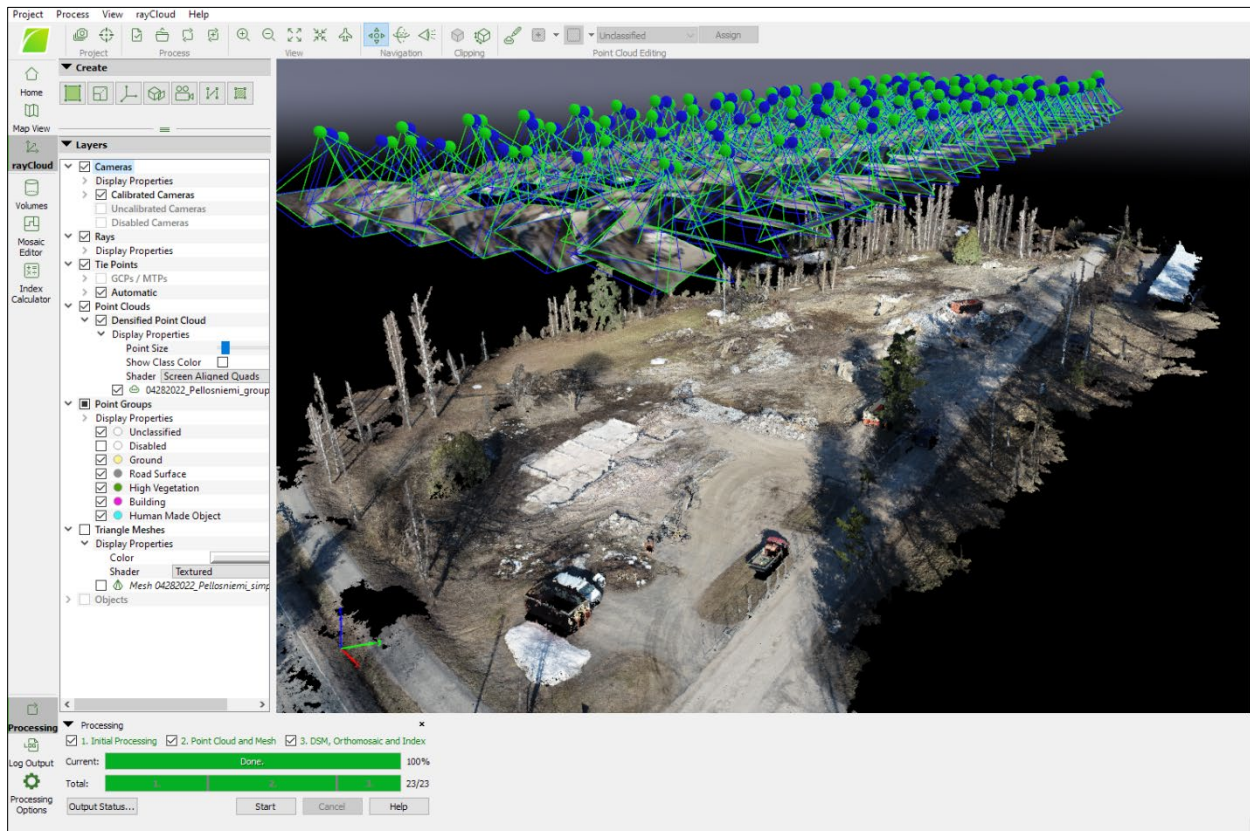


Figure 7. PIX4DMapper user interface showing 3D point cloud processed from drone imaging data.

Data processing can be done using ready-made templates; for example, there is a ready-made template for built environment, which includes buildings, trees and land terrain. This requires setting minimum file locations for the project and images, after which processing can begin. On average, about 80-140 photos were taken per project at the project sites (Tuukkala and Pankalampi). It took about 2 hours for the computer to process one project (80-140 photos), after which the 3D model was complete. However, the processing time is completely dependent on the processing power of the computer and the size of the datasets.

4.4. Volumetric measurements

Volumetric measurements are made in the PIX4DMapper software. Making volume measurements requires that the software has successfully calculated a point cloud of the imaged area. The volume measurements are made from a point cloud model.

In PIX4DMapper, volumetric calculations are made under the menu "Volumes" (Figure 8). In case of a material pile, the volume is determined by first clicking the left mouse button on the point cloud to mark the points on the bottom surface of the volume. With each click, a base

point is created, and this forms the bottom surface of the specified volume. A click with the right mouse button and the volume base will close. After selecting "Compute", "Total Volume" indicates the measured volume in cubic meters.

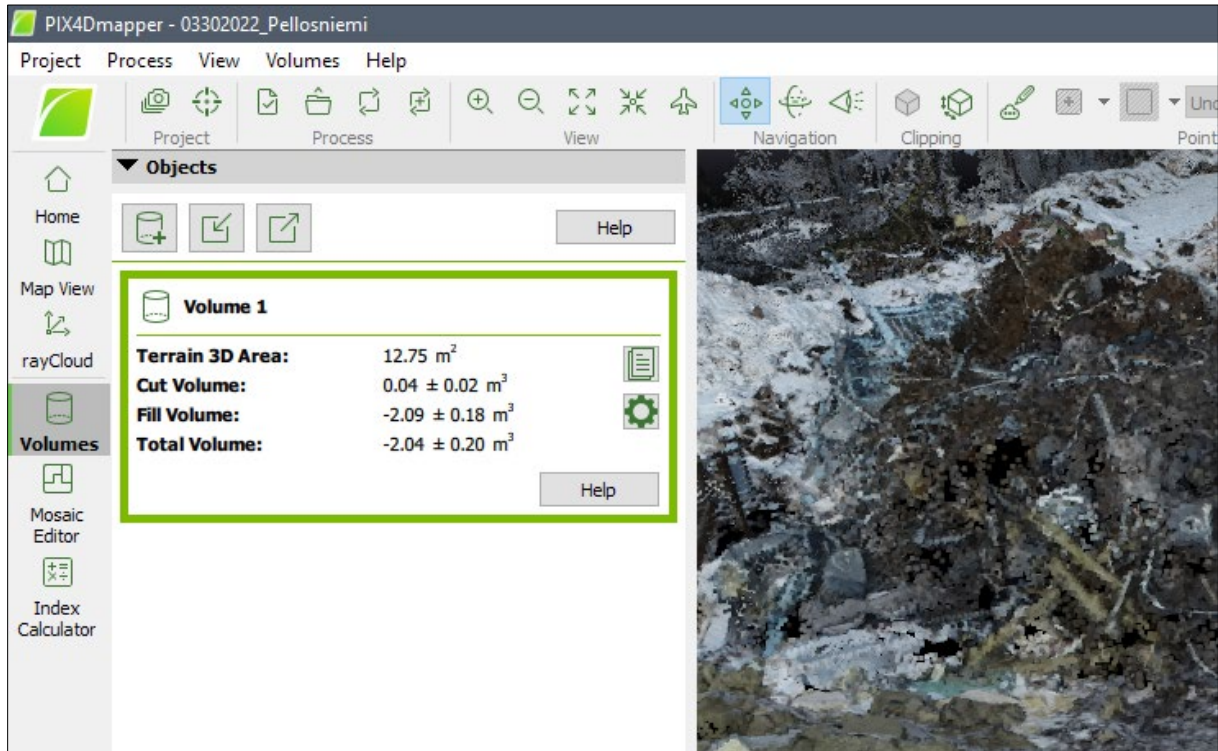


Figure 8. "Volumes"- menu in PIX4DMapper.

After computing the volume, different kinds of information can be seen:

- Terrain 3D Area: The base surface area (m²).
- Cut Volume: The calculated volume above the base surface area (m³). Volume is measured between the base surface area and DSM (Digital Surface Model).
- Fill Volume: The calculated volume below the base surface area (m³).
- Total Volume: Cut volume + Fill volume (m³).

Volume data from the software can be exported in numerical form or in an ESRI shapefile for further processing. PIX4DMapper also estimates error for the volumes: The average error for the height of each 3D point is 1,5 times the GSD (Ground Sampling Distance). As each cell of the volume base has a width and a length equal to the GSD, the error on the X and Y direction is estimated to be 0. (PIX4D¹).

In the Häyrylä soil material storage site, the volume of the material pile was measured at the site with both a drone and a tachymeter. The volumetric measurements with a tachymeter were performed by local earthwork company Maanrakennus Talpa Ltd. The results from both methods were compared. Figure 9 shows the material pile to be measured and the tachymeter equipment in the Häyrylä soil material storage site.



Figure 9. Volume measurements from a material pile. Tuomas Kellman from Maanrakennus Talpa Oy is making volume measurements with a tachymeter. (Picture: Juha Vihavainen)

4.5. Multispectral imaging

In spectral imaging, different materials reflect and absorb light on different wavelengths; that makes it possible to identify materials on certain wavelengths. Spectral imaging devices with a drone can be roughly divided into two categories: multispectral and hyperspectral cameras. The main difference between multispectral and hyperspectral is the number of bands and how narrow the bands are. Multispectral imagery generally refers to 3 to 10 bands, with descriptive band names assigned to each band. Hyperspectral imagery consists of much narrower bands (10-20 nm) with possibly hundreds or thousands of bands.

Multispectral sensors are generally very cost-effective and often optimized for vegetation analysis in precision agriculture use. Multispectral cameras are also used for medical and industrial applications. (JAI A/S). Hyperspectral sensors produce more detailed spectral data, but with that comes issue related to increased sensor and image costs, data volumes and data-processing costs, and a high demand to maintain operations.

The multispectral imaging was done in the Metsäsairila sorting and recycling centre area on 5.7.2022 and 2.9.2022. The subject of the imaging was an area where construction waste, such as concrete, bricks and other waste, such as plastic and wood, was unloaded (Figure 10). The flight altitude was 35 metres.



Figure 10. True colour orthomosaic image taken from Metsäsairila sorting and recycling centre area.

The imaging was done with a DJI Matrice 300 RTK drone and a Micasense RedEdge-MX multispectral camera (Figure 11). The drone can carry separate payloads, and it can power the multispectral camera during flight. The drone's controller has a built-in software (DJI Pilot) where the data of the multispectral camera was entered, such as sensor size, focal length and sensor resolution. Then a suitable overlap between images was set, after which the software calculated the flight path from the selected area based on the entered data.



Figure 11. DJI Matrice 300 RTK drone with Micasense RedEdge-MX multispectral camera.

The multispectral camera was set to start to take pictures as soon as the flight altitude exceeds 30 metres and stop when the flight altitude drops below 30 metres; this is done using the camera's built-in GPS. The camera recorded images every second during the flight.

Before the flight, a picture of the calibration reflectance panel was taken, which is a white balance card giving the reflectance properties of the card across the spectrum of light captured by the camera, on all five captured bands. Figure 12 shows the calibration panel captured with a multispectral camera.



Figure 12. Picture of a calibration reflectance panel, taken with RedEdge-MX multispectral camera.

Images from the reflectance panel were used to later calibrate the dataset to the lightning conditions of the flight, and to convert images from raw pixel values and radiance to reflectance. Reflectance is the ratio of the amount of light leaving a target to the amount of light striking the target. Reflectance is a property of the material being observed, and it has no units. Radiance depends on the illumination (both its intensity and direction), the orientation and position of the target and the path of the light through the atmosphere. With effort, many of the atmospheric effects and the solar illumination can be compensated for in remote sensing data. (Terrill 1994).

The Micasense RedEdge-MX captures five different spectral bands simultaneously, which are presented in Table 3. The camera is highly optimised for precision agriculture use; the spectral bands enable the output of common vegetation analysis, such as NDVI (Normalised Difference Vegetation Index), NDRE (Normalised Difference Red Edge Index) and advanced vegetation index layers.

Table 3. Micasense RedEdge-MX spectral bands and bandwidths. (Micasense)

Band name	Centre wavelength (nm)	Bandwidth (nm)
Blue	475	32
Green	560	27
Red	668	14
Red Edge	717	12
Near IR	842	57

Raw data from the camera was processed with Pix4DMapper software, where reflectance maps were produced from the images. The reflectance maps were imported into QGIS, which is a free and open-source geographic information system (GIS) application. Spectral signatures were extracted using a Semi-Auto Classification (SCP) plugin. The plugin allows for the supervised classification of remote sensing images, providing tools for the download, the preprocessing and postprocessing of images. (Congedo 2021).

Since the data was spread over five reflectance layers (Red, Green, Blue, NIR, RedEdge), a virtual reflectance raster was built with an SCP plugin, which will hold all the reflectance data from the five bands. Building a virtual raster is a way to organise all the layers for easier visualisation. After all the bands were set correctly in the SCP plugin, the virtual raster was built. Figure 13 shows the SCP plugin's interface with all the reflectance layers configured in the plugin.

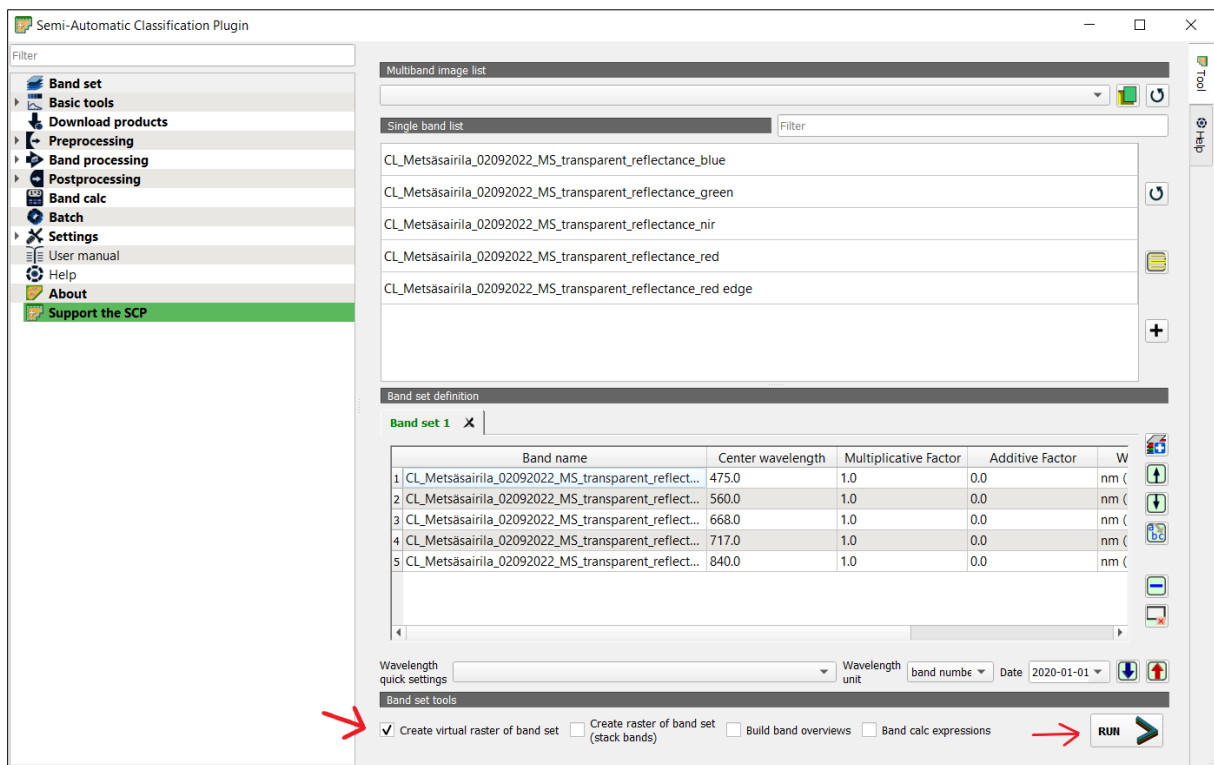


Figure 13. SCP plugin interface, showing all the multispectral cameras' reflectance maps configured.

The virtual raster is built by selecting "Create virtual raster of dataset", and then "Run". In the "Band set" window (Figure 13), all the reflectance maps processed in PIX4DMapper can be seen with the centre wavelength of each layer configured. Figure 14 shows the QGIS interface with reflectance map. The bands are configured in the layer styling menu, so the image can be viewed close to true colour, for easier visualisation.

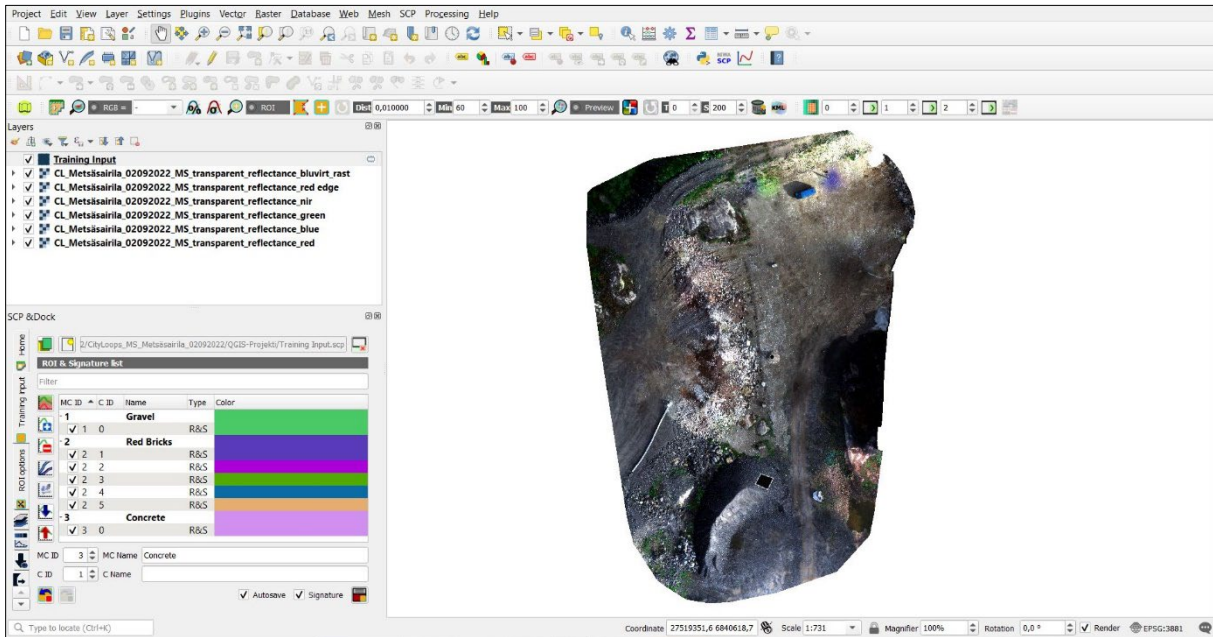


Figure 14. QGIS interface with reflectance maps, visualised for true colour.

Different materials (concrete, bricks, gravel, rock, vegetation) were tagged in the image raster, and the materials were classified by drawing ROI polygons around the materials. Figure 15 shows an example of a gravel pile with a ROI polygon drawn in it.

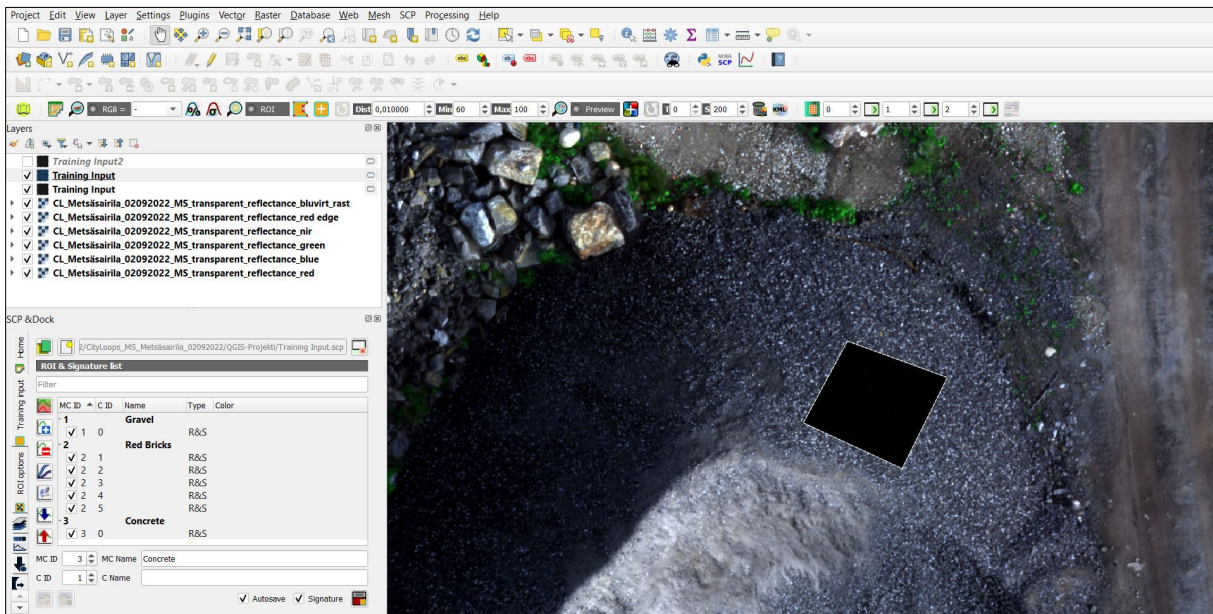


Figure 15. ROI polygon in the gravel pile.

After the polygons were placed in the image for different materials, they were added to the training input. Then the reflectance signatures of each material were visualised using the SCP plugins "Add signatures to the spectral signature plot"- function.

5. Results

5.1. Volumetric measurements

5.1.1. Häyrylä storage site

In the Häyrylä storage site, the volume of the material pile was measured with both a drone and a tachymeter. The result of the measurement was cubic volumes of the material pile, which are shown in Table 4.

Table 4. Comparison between tachymeter and drone imaging data.

Tachymeter (m ³)	Drone imaging (m ³)
888,6	890,8

Based on the result, pile volume measurements performed by using a drone and photogrammetry software are comparable to traditional methods such as tachymeter. Exact capturing and processing times for both methods were not measured, but the on-site data capturing process with a drone was significantly faster. Figure 16 shows the material pile measured.

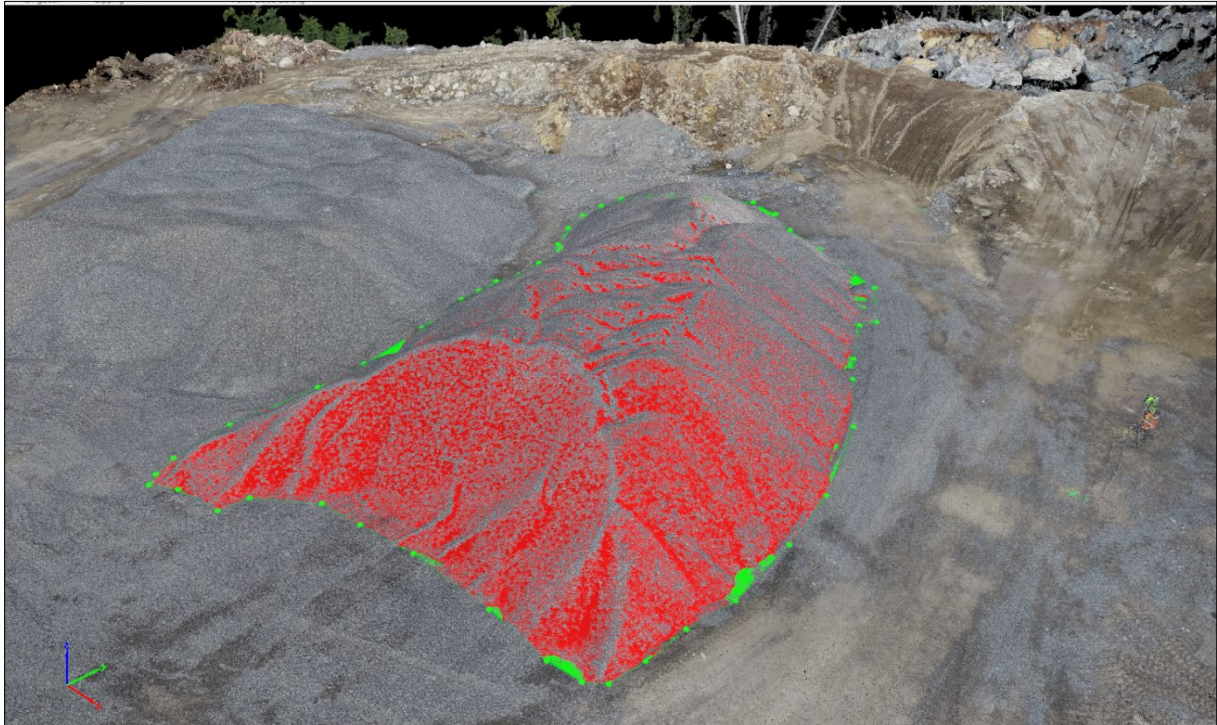


Figure 16. Material pile which was photographed using a drone and a tachymeter.

The difference between relative accuracy and absolute accuracy is important. For many applications the accuracy of where objects are in relation to one another (relative accuracy) is most important. When the objects' true positions on Earth are an important factor in the equation, a surveying process that provides absolute accuracy (tachymeter) is necessary. For calculating volumes of material piles, relative accuracy is what is needed, so a drone is suitable tool for that purpose. For projects that need an absolute accuracy of under 2 cm, a tachymeter is recommended. Drones consistently achieve 5 cm accuracy, and depending on the payloads and flight parameters, up to ~1cm accuracy. (Murison 2021).

5.1.2. Demolition sites

Many dimensional calculations can be performed with a point cloud model made from a demolition site, e.g., volumes, areas and lengths. Volume measurements can be made from demountable containers or material piles located at the demolition site. In Pankalampi and Tuukkala, the material was mostly transferred directly to the pallets. At the Pellosniemi replication site, the demolition material was first collected on piles, after which it was transferred to demountable containers for transport. Figure 17 shows volume calculation from an insulation wool pile at the Pellosniemi demolition site.

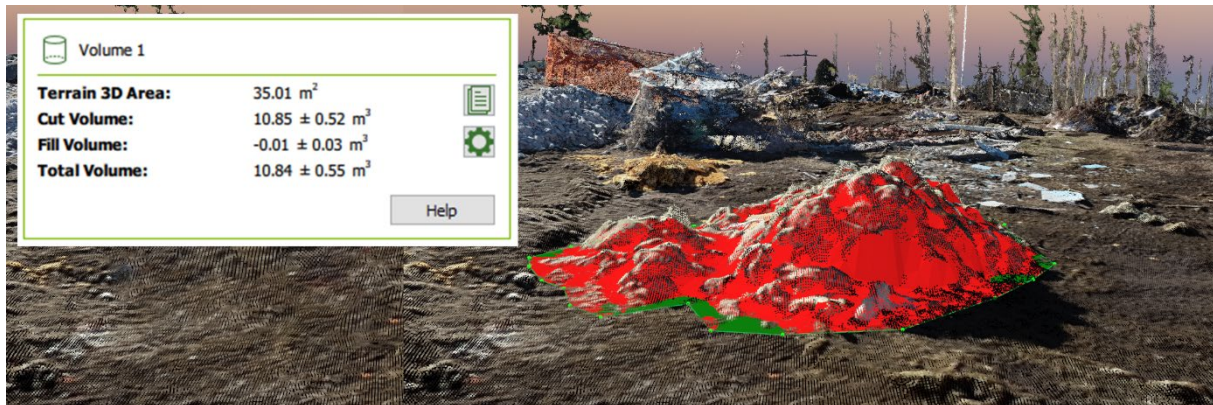


Figure 17. Volume calculation from a material pile.

Figure 18 shows volume calculations from a demountable container filled with wood waste. The green plane represents the base surface area that is drawn manually on the container, and the red area represents the empty area in the container that the program automatically "fills" and calculates the fill volume.

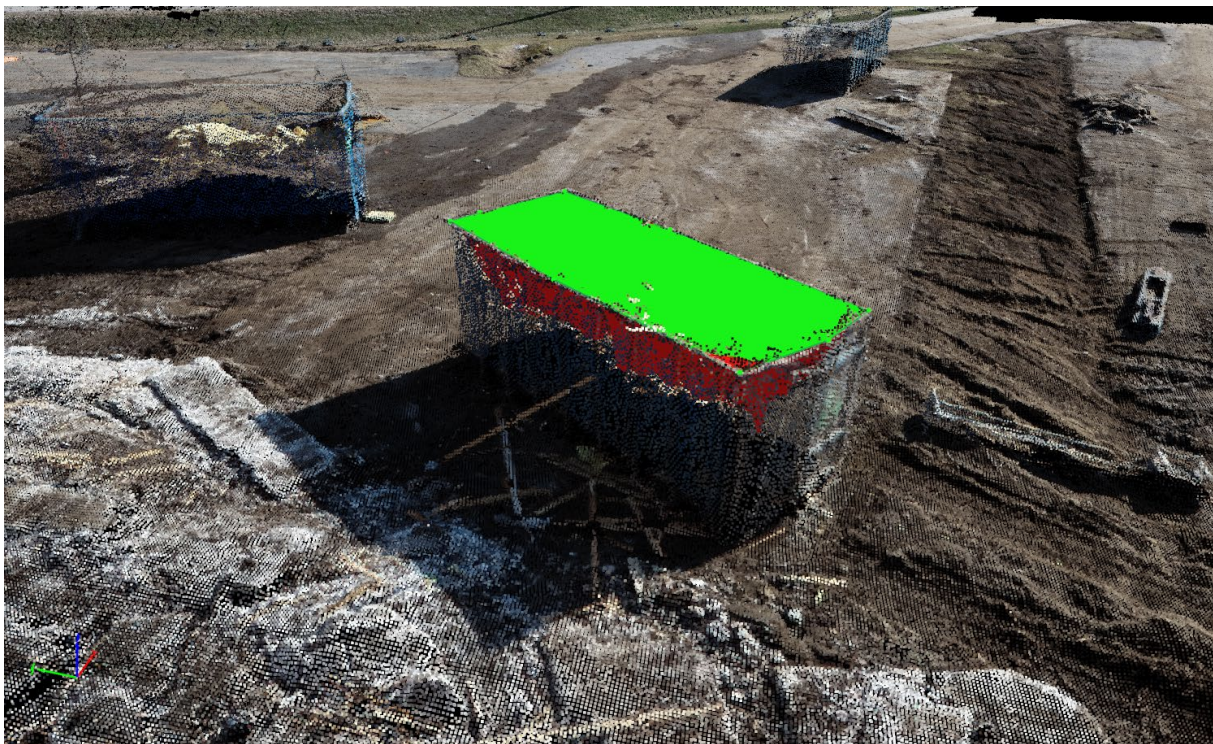


Figure 18. Volume calculations from a demountable container.

Once the empty volume of the container is known, the volume can be calculated by subtracting the filled area from the total volume of the empty container. In this example, the cubic volume will be calculated as follows:

$$30 m^3 - 10,54 m^3 = 19,46 m^3$$

The volume of the material pile is determined by drawing a plane around the pile, after which the software calculates the volume by filling the area above in the point cloud. Figure 19 shows a pile of concrete beams before and after volume calculations. When the material pile is not in a consistent shape, the automatic fill can introduce elevated inaccuracy in the results. In Figure 14, red fill areas represent the empty space between the concrete beams. That is not useful information; this needs to be taken into consideration when measuring material piles.



Figure 19. Volume calculations from a pile of concrete beams.

Monitoring was carried out from the demolition sites on average once a week, making it impossible to monitor all materials leaving the site. Important consideration in measuring material piles at a demolition site is the organisation of the monitoring process with site operators. In the case of the Mikkeli demonstrations, material was constantly being transported out of the demolition site to the sorting and recycling centre area, and not all materials could be traced without the drone operator being constantly on site. One option could be that the material would be collected somewhere on site, from which they will all be removed only at the end of the day after photographing.

5.2. Material detection using multispectral imaging

The spectral signatures of gravel, red bricks, concrete, rock and vegetation were calculated in QGIS from reflectance maps made in PIX4DMapper. Figure 19 shows that healthy vegetation absorbs red light and reflects light in the near infrared region: common vegetation indices (e.g., NDVI) are based on this phenomenon. The vertical dashed lines in the plot describe the wavelengths recorded by the Micasense RedEdge-MX multispectral camera.

CDW materials do not have the same effect as vegetation at the recorded wavelengths. CDW materials spectral signatures are flatter, and each CDW materials reflectance value is similar. This makes it difficult to identify CDW materials from the Micasense RedEdge-MX camera, because the ratios of different wavelengths are small, and the reflectance deviation between pixels are high. Figure 20 and Table 5 show that, in the case of vegetation, the ratios of different wavelengths are high, and their reflectance deviation between pixels are relatively smaller. For example, in the case of using vegetation indices, the ratios produced by the index formula can be coloured using a lookup table, which makes it easier to identify the vegetation in the picture.

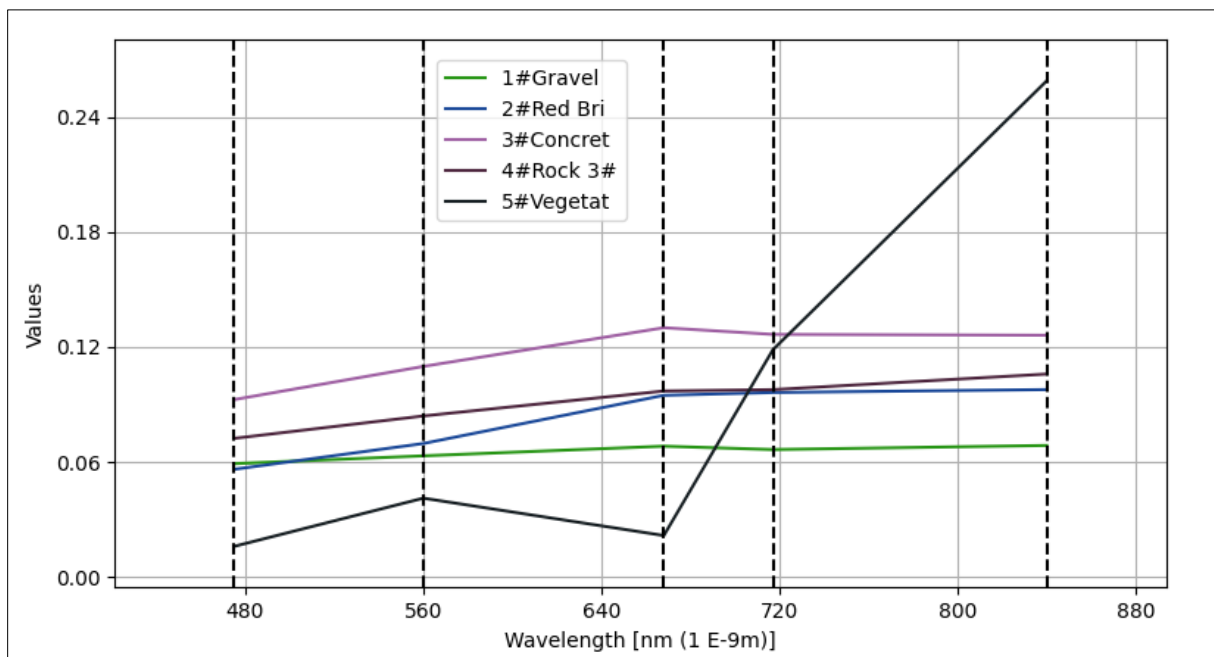


Figure 20. Spectral signatures of different materials in Metsäsairila.

Table 5 shows the reflectance values for different materials, as well as their standard deviation between pixels. The deviation values are high on CDW materials when compared to the reflectance values.

Table 5. Reflectance values recorded on different materials and their standard deviation.

Gravel					
Wavelength [nm]	475	560	668	717	842
Reflectance values	0.05912	0.06318	0.06822	0.06645	0.0686
Standard deviation	0.01401	0.01582	0.01779	0.0171	0.01728
Red bricks					
Wavelength [nm]	475	560	668	717	842
Reflectance values	0.05616	0.06961	0.09474	0.09622	0.09774
Standard deviation	0.02417	0.02823	0.0347	0.03356	0.03172
Concrete					
Wavelength [nm]	475	560	668	717	842
Reflectance values	0.09251	0.10982	0.13	0.12653	0.12607
Standard deviation	0.03934	0.04739	0.05535	0.05316	0.05008
Rock					
Wavelength [nm]	475	560	668	717	842
Reflectance values	0.07229	0.08398	0.09699	0.0977	0.10584
Standard deviation	0.01869	0.02095	0.02393	0.02327	0.0228
Vegetation					
Wavelength [nm]	475	560	668	717	842
Reflectance values	0.01596	0.04111	0.02162	0.11853	0.25878
Standard deviation	0.0069	0.01551	0.008	0.03535	0.06347

Some studies can be found from literature, where imaging technology has been used to identify CDW materials. Figure 21, for example, shows measurements of different materials made with the spectrally enhanced Ladar equipment at a 500-1500 nm range (Chhabra ym, 2015). The spectral signature of roof tiles, bricks and soil is flatter compared to the spectral signature of vegetation.

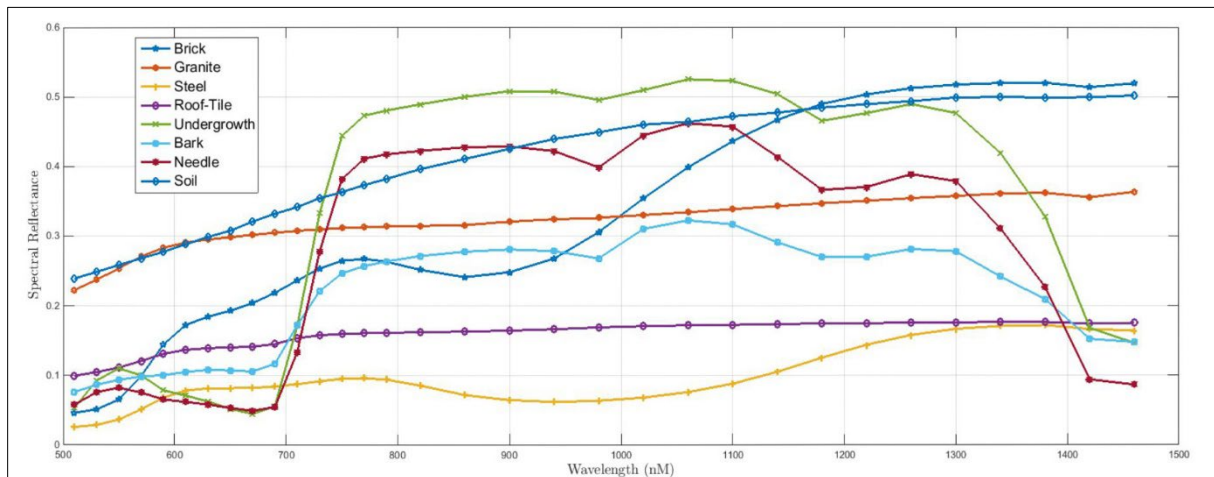


Figure 21. Spectral signatures of different materials at 500-1500 nm range. (Chhabra ym, 2015).

An ideal case would be that the background of the material to be identified was some other material with a different spectral response; then the ratios between different wavelengths could be compared with each other more reliably.

6. Review of the tool

The use of a drone to monitor demolition waste flows can be a cost-effective alternative in evaluating the amounts of material flows. In the case of Mikkeli demonstrations, all the CDW materials were transported to the Metsäsairila sorting and recycling centre area, where material flows as masses were detected at the weighting station. However, in some cases, material volumes, instead of masses, can be more useful for planning the reuse or utilisation of materials. In addition, if the CDW materials are reused on-site or transported to another construction site for re-use, using a drone and a 3D-modelling tool to estimate the amount of materials is a good option because of its speed and relative accuracy.

Collecting data from demolition sites, and the length of processing, depends entirely on the size of the demolition site, the number of images taken, the camera(s) used and the processing power of the computer. In this project, the imaging at the demolition sites lasted one hour on average, which includes arriving at the demolition site, getting the drone ready for flight, determining the flight path, surveying the automatic flight and packing the drone. The processing time for 80-140 Phantom 4 Pro V2.0 drone images was two hours on average, of which 20 minutes was configuring the PIX4DMapper software to work on the images. For the rest of those two hours, the computer processed the project on its own. The time spent on

measurements depends on the amount of measurements needed to be made. On average, it takes approx. 20 minutes to one hour to take measurements from a processed 3D model from a demolition site which contains 5-15 material piles. When estimating the time taken for the whole process, the formation of an individual routine for doing the process must be also considered.

In this project, a Phantom 4 Pro V2.0 drone was used, which costs around 1600 euros. It is also possible to do the project with cheaper drones (around 1000 euros), for example DJI Mavic Air series. SD memory cards add around 50-100 euros to the cost. The largest expense comes from the PIX4DMapper program, which costs approx. 4000 euros for the desktop version. It is also possible to get the PIX4DMapper desktop version subscription-based, which costs approx. 250 euros per month, or cloud-based (Pix4DCloud), which costs around 140 euros per month and removes the need for a processing computer completely. The drawback in the cloud-based Pix4DCloud is that there are limits for the number of images (2500 images/month) and projects (20 projects/month) processed and stored in the Pix4D servers.

The computer for processing small projects (under 100 images at 14 MP) can be any modern machine. However, it must be considered that the processing time increases with a low-power machine, and it is difficult to do anything else with the same machine while the project is being processed. Pix4D recommends 8 GB of RAM and 10 GB free space in HDD for medium-sized projects (between 100 and 500 images at 14 MP). (Pix4D³).

Exact image acquisition and processing times for volume measurements were not measured, but the on-site data-capturing process with a drone was significantly faster compared to a tachymeter. The tachymeter provides absolute accuracy; when the objects' true positions on Earth are an important factor in the equation, a monitoring process that provides absolute accuracy is necessary. As a general rule, projects that require accuracy to within 2 cm will need to be augmented by traditional methods, such as a tachymeter. Drones consistently achieve 5 cm accuracy, which is suitable for calculating, e.g., volumes from material piles in a demolition site. (Murison 2021). If the only purpose is to determine relative dimensional calculations about the materials, then the drone is well suited for the purpose.

The challenges for using drones are the ever-tightening EU legislation on UAS operations and the organization of data collection with site personnel. Nearby airports and outsiders significantly restrict drone flights. Currently, drone A2 certificate allows to fly at least 30 m horizontally away from outside people, but in some places, this too can be difficult to accomplish. It is also necessary to determine who are the people involved in drone flights and who are outsiders; no drone may be flown near or over by people not involved in drone operations. Usually the demolition site is gated, so the site can be considered as a closed area.

Commercial multispectral cameras such as Micasense Rededge-MX are optimized for studying vegetation: the wavelengths recorded by the cameras are chosen so that they respond well to changes in reflectance that describe the health of the vegetation. Based on tests, it is not feasible to use commercial multispectral cameras designed for vegetation analysis for CDW material identification due to the materials spectral response. A suitable tool

for CDW material identification could be a hyperspectral camera, which records significantly more different wavelengths and thus obtains more detailed data. However, the amounts of data produced by hyperspectral cameras are very large and laborious to process. The spectral responses of different lighting conditions, flight altitude and their effects on CDW materials spectral response with hyperspectral cameras should also be studied more.

During the project, it was noticed that some contractors use drones to document and monitor the progress of the demolition site. Aerial photos, videos and 3D models provide a very comprehensive and clear picture of the progress of the demolition site. Aerial imaging and 3D modelling of the building to be demolished before the start of the demolition work can also facilitate the planning of the demolition work and provide indicative information on the amount of materials and other dimensions on-site. This data can be useful e.g., in pre-demolition audit. Volumetric measurements based on 3D imaging can be a useful tool for e.g. contractors, building owners and designers, especially in the future, when the reuse of building parts and materials is expected to increase.

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CITYLOOPS

CityLoops is an EU-funded project focusing on construction and demolition waste (CDW), including soil, and bio-waste, where seven European cities are piloting solutions to be more circular.

Høje-Taastrup and Roskilde (Denmark), Mikkeli (Finland), Apeldoorn (the Netherlands), Bodø (Norway), Porto (Portugal) and Seville (Spain) are the seven cities implementing a series of demonstration actions on CDW and soil, and bio-waste, and developing and testing over 30 new tools and processes.

Alongside these, a sector-wide circularity assessment and an urban circularity assessment are to be carried out in each of the cities. The former, to optimise the demonstration activities, whereas the latter to enable cities to effectively integrate circularity into planning and decision making. Another two key aspects of CityLoops are stakeholder engagement and circular procurement.

CityLoops started in October 2019 and will run until September 2023.



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