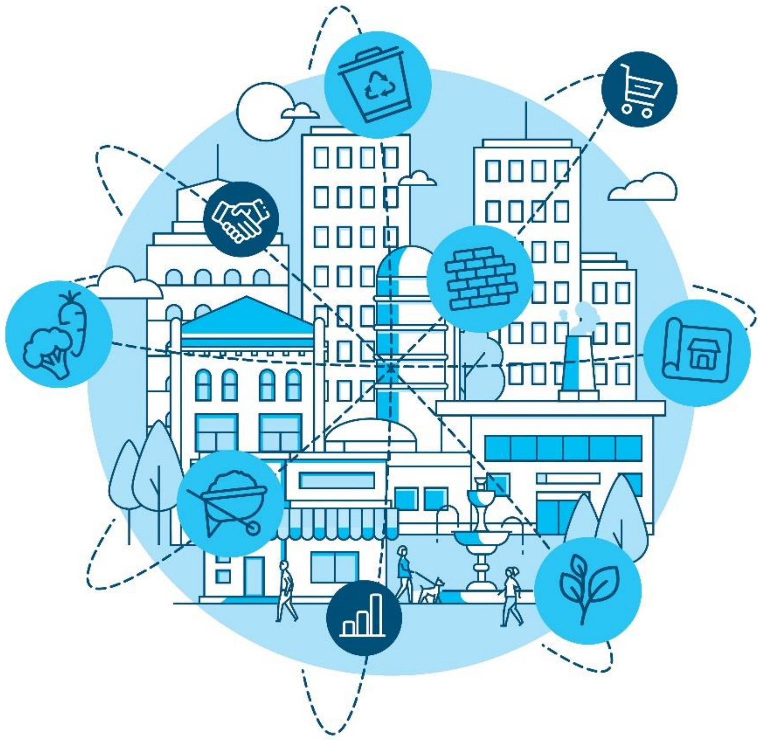
Tool 7) 3D modelling tool for tracking the flows of on-site CDW

Description of the tool

South-Eastern University of Applied Sciences (Xamk)



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Abstract	This description explains how the tool “3D modelling tool for tracking the flows of on-site CDW (Mikkeli)” is set up and how it is operated.
Keywords	CDW; material flow; demolition; renovation; handling CDW; flow tracking; 3D; data visualization; mapping; surveying; drone; drone-imaging
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1. Introduction

The CityLoops – Closing the loop for urban material flows – project solves the challenges of the circular economy. Better handling and possible reuse of construction and demolition waste (CDW) are in the focus in the CityLoops project. The project brings together several European cities to plan, develop and demonstrate tools and approaches for the CDW-issues. The CityLoops project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821033.

This document describes the 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 Kaakkois-Suomen ammattikorkeakoulu Oy – Xamk (South-Eastern Finland University of Applied Sciences), Mikkeli, Finland.

3D-modelling tool for tracking the flows of on-site CDW (*later:* 3D tool) is a technique for collecting amounts of construction and demolition waste materials during the actual demolition process. The 3D tool has a connection to another tool also developed in the CityLoops project: tool 8) "*Databank and digital market place for recovered materials*". The databank is about to work as storage for the collected data and calculation results. Furthermore, 3D tool as a whole or partly (i.e. some of its methods), could also be used for pre-demolition actions such as screening procedures and selective demolition. However, pre-demolition uses were not under the main study in the development of the 3D tool.

This document provides the description of the concept of the 3D tool. Topics covered are:

- Overview of the tool and how the tool was designed
- Technical backgrounds and similar methods on which the tool is based on
- Set-up i.e. the needed equipment and software of the tool and related regulations
- Operations model i.e. the procedure i.e. the process for running the tool.

The description mentions also different kinds of optional and/or additional and/or alternate possibilities and ways to implement above-mentioned topics when applicable. These are mostly situations where the 3D tool could be useful (as a whole or partly) and provide better results or work as an aid in other actions. However, these are mostly provided "as observed" during the designing and development process of the tool, i.e. not all of them are studied nor tested deeply. This means that further development may be possible or even needed.

2. Overview and backgrounds

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 of the use of 3D methods 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 the other changes of the site. The 3D tool was originally described in Annex 1 (European Commission 2019, 16) of the 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 in the demonstration sites. This will allow the documentation and modelling of material flows during the demonstrations, to help track and estimate of the quantities of different materials already on site. This data will be exported to the databank created during the project*."

The concept is actually a drone based 3D documentation and 3D monitoring process, which is done on the demolition site before and during the demolition actions. It is a combination and adaptation from two drone applications used already: drone based measurements in mining sector and monitoring construction sites of new-born buildings in architecture, engineering and construction (AEC) sector. Based on the studies done for the CityLoops project, a method of drone-based 3D imaging has not previously been used for mapping of demolition sites or to monitor the progress of the demolition in wider scale.

2.1. Image-based scanning

The method of using images and photogrammetry software is called image-based scanning. It produces accurate 3D point clouds, which can be used e.g. for measuring distances and volumes of targets. Point clouds could also be used for 3D visualizations and to produce maps and other GIS data about the target.

Practically any kinds of digital cameras could be used, as the accuracy is mostly depended on imaging distance per resolution, instead of the quality of the camera or the lens. In other words, the smaller the resolution is the closer the imaging should be done in order to gain the same accuracy as with higher resolution camera. As a part of the procedure, the imaging software calibrates the camera automatically i.e. it creates correction formulas for the lens error and for errors of the imaging sensor. However, using quality cameras and lenses better results can be achieved more surely.

Point clouds are made from the collection of digital photographs using photogrammetric range imaging technique Structure from Motion (SfM). In SfM technique a series of two-dimensional images are utilized to reconstruct the three-dimensional structure of a scene or an object. The method has often been reported to have approximately the same accuracy as traditional land surveying methods, such as laser scanning. The method needs a cluster of images (from dozens to thousands) where individual images have certain amount of overlap with each other. (E.g. Golparvar-Fard et. al. 2011.)

2.2. Similar applications

Similar methodology is used e.g. in the extractive industries i.e. the mining sector and in architecture, engineering and construction (AEC) as well in forestry. There is a plenty of studies about the applications. Also vendors of the photogrammetric software have published dedicated software packages and established dedicated internet resources and published dedicated whitepapers for these applications. The main goal is often to produce better and more information for the decision-making process using affordable methods.

In the mining sector, almost precise method is used for tracking and monitoring mine sites. For example, the layout of the mine facilities and infrastructure is optimized and stockpile sizes are measured. Many other uses of frequent 2D and 3D mapping have also been applied, including handling the safety of the site. (Pix4D SA 2021; SimActive Inc. 2021.)

The uses of the method in AEC industry sector are mainly focused on the new construction i.e. the making of new buildings. One application of the similar approach is described e.g. by Golparvar-Fard et. al. (2011) who were testing an accurate and rapid assessment of the as-built status of a construction site.

2.3. Additional techniques

Spectral imaging is a technology where photographs are taken partly or fully outside of normal visible wavelengths of light. Imaging is done by using special cameras i.e. multispectral (MS) or hyperspectral (HS) cameras. Spectral imaging makes it possible to gain information from the target that is impossible to notice otherwise. It is based on the fact that different materials reflect and absorbs light on different wavelengths that makes it possible to create reflectance models for materials (figure 1, Clark et al. 2001).

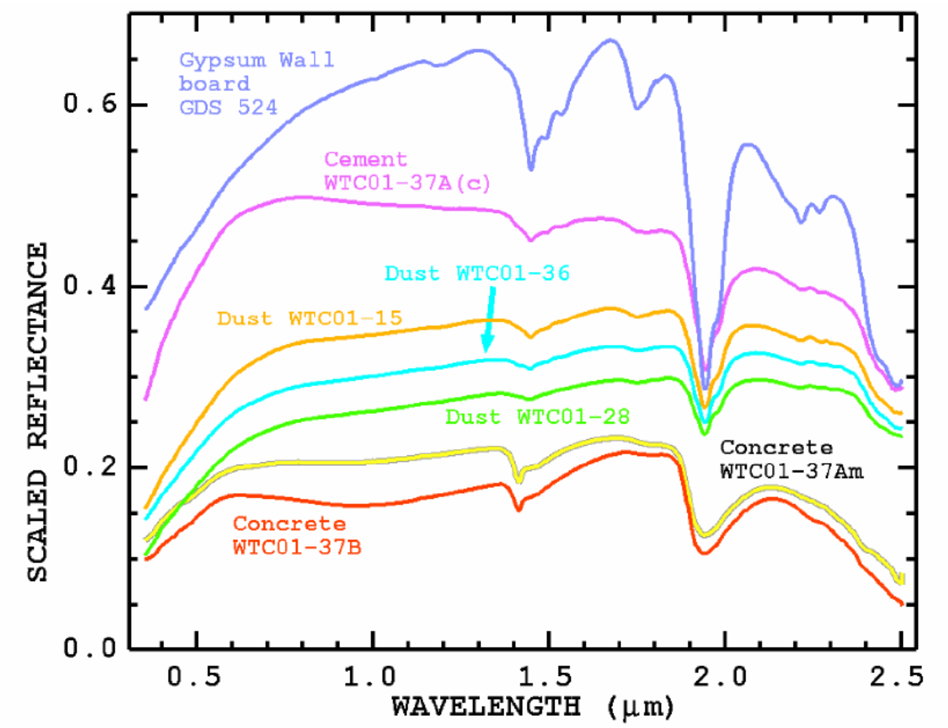

Figure 1 - An example of the spectral reflectance of some materials. (Clark et al. 2001.)

Adding spectral imaging to the image acquiring process, there is possibilities to aid or automatize the recognition of material types. It could also add the possibility to identify the quality and conditions of materials such as degradation and moisture. Spectral images could also provide information on connections of reusable components.

Spectral imaging has not been used in wider scale yet, due to e.g. less cost-efficient operations especially with HS cameras, which are very expensive and requires a bigger drone. MS cameras are more affordable and some of them could be mounted even on light drones, but their spectral range may not be suitable for all uses and it is not adjustable.

The use of multispectral imaging for more automatic recognition of material type, or for finding out the quality information of the material, needs more specific studies. The reflectance models for construction materials as well for demolished CDW should be determined under local lighting etc. conditions. There is some studies where spectral imaging has been used or investigated in relatively similar cases. As an example, the construction dust was tracked after the collapse of WTC buildings (Clark et al. 2001). Despite the limitations, the spectral imaging might be useful solution, especially if some kind of computer vision and artificial intelligence procedures could be applied.

2.4. Development of the tool

The background of tool was developed by gathering information about similar kinds of drone-based solutions, which are already in use e.g. in mining sector and on construction sites in AEC sector. Gathered information included scientific articles, journals, news, advertising materials and e.g. software manuals. The former studies and tests that had been done previously as well the other experiences in Xamk were also taken into account. Although a certain photogrammetric modelling software was in use at Xamk already, brief survey of possible alternatives was carried out.

Some additional or optional usage possibilities and technical methods were also noted and studied briefly (such as the use of multispectral imaging for more automatic recognition of material type or its quality). One addition was a brief test of taking 360° panoramic imaging of the interior of the buildings before the demolition.

Drone-imaging was practically tested in smaller scale by doing drone flights and data collection in similar kinds of sites with practically similar materials. Different types of materials and different fraction sizes were taken into account in imaging testing as much as possible. Also the starting situations of the forthcoming demonstration sites i.e. the situation before the demolition, were acquired using the same method as to be used during the actual demolition. As an addition, also some data was collected using multispectral cameras. Test phase was carried out by using Xamk-owned two DJI Phantom 4 quadcopters with their built-in cameras and two Mapir Survey 3 OCN and NGB multispectral cameras.

3D modelling i.e. production of point clouds were practically tested by using the aforementioned imaging data and a professional photogrammetry software. Several kinds of 3D quantity calculations were carried out. The used software were Pix4D Mapper and its cloud-based version Pix4Dcloud, to which there was former expertise in Xamk. As an addition, some amounts of possibly detachable materials were estimated based on the 3D model.

3. Set-up

The reported operations model i.e. the use of the same or similar workflow can be implemented in different conditions. The workflow can also be implemented fully or partly as needed, when only the necessary parts of the set-up are needed. Furthermore, it can be completed by using different hardware and/or software as well. In other words, there is no need for the use of exactly same hardware or software as mentioned on this document. The set-up is designed to have cost efficient and easy to use equipment, and it is aiming to rapid operations. However, by replacing some part of the set-up with its more capable equivalent or adding some new parts, even more or better results may be gained. As an addition to equipment, also the knowledge of the drone related regulations can be seen as a part of the set-up as they are essential for operations.

The set-up consist of:

1. Drone
2. Imaging device, which can be integrated with the drone or be separate
3. Software
4. Drone regulations.

3.1. Drone and imaging

Mid-class consumer grade drones with their **in-built cameras** are enough for producing very high accuracy results when they are operated in low altitudes such as 20–70 meters. From the perspective of demolition sites, only at larger sites some actual benefit could be gained by using higher altitudes and **bigger drones**. These high-end drones do not usually have built-in cameras. Instead of it, the camera is often chosen from the several choices from the manufacturer's catalogue or some normal high-end digital cameras can be applied to the system. The advantage of the use of bigger drone (and flying higher), would be to cover larger area in time, or to carry some special sensor, which is too heavy for a lighter drone or cannot be mounted on it. However, on urban areas and nearby airports, the use of higher altitudes may be prohibited or limited. In most cases, the needed solution can be accomplished using consumer-grade drone which can also be equipped with spectral imaging devices in some cases (image 2).

A map based **flight control and planning application** (or "mission planning" and "ground control") is recommended for the onsite flight operations. The software can be run on e.g. a **laptop computer, tablet, or smartphone**, which is connected to the control device of the drone. The use of the flight control application makes the piloting almost automatic and ensures that images became taken so that they can be used on photogrammetry software properly.

Costs: Mid-class consumer grade drone with normal but proper camera costs typically under 2000 Euros and bigger or more advanced drones 8000–30000 Euros. Spectral cameras cost from 250 Euros to few thousands of Euros. Hyperspectral devices can cost even tens of thousands of Euros. Flight control and planning applications may come from cost-free to hundreds of Euros. In addition, a computer or tablet is needed, rugged versions for the fieldwork are more expensive.

Original design of this tool is to use *DJI Phantom 4 Pro V2* quadcopter with its built-in camera or *DJI Phantom 4 original* equipped with *Mapir Survey 3 OCN* and *NGB* multispectral cameras. Those particular drones are also directly supported by the flight planning and control application *Pix4D Capture*, which was used on Apple iPad Air tablet. Also the used photogrammetry software suite *Pix4D Mapper* and its cloud-based version *Pix4Dcloud* supports images from DJI Phantom and Mapir Survey 3 directly that makes the whole very fluent.

Image 2 - A consumer grade quadcopter equipped with two multispectral cameras (image: Esa Hannus).

3.2. Photogrammetry software

There is different kinds of solutions for implementing the data manipulation process that is needed. Basically two things are needed: 1) a **capability to produce accurate 3D point clouds from drone-based photographs** and 2) a **capability to measure volumes etc. from the point clouds**. Additionally, some capabilities of GIS, CAD and mapping are needed too. Some of the needed capabilities may be offered in one or several software that the organization uses already.

The simplest way is to use a complete photogrammetry software suite, which includes point cloud measuring capabilities and enough GIS, CAD and mapping features. Many of photogrammetry software suites can provide different kinds of results on its own. Especially the always useful possibility to create an orthophoto (*actually*: an orthomosaic) from the bunch of images is usually an included feature. Some software suites can apply also cloud-based calculations and some are cloud-based-only applications. The advantages of cloud-based processing are that it frees the computer for other uses and high-end computers are not required. In addition, cloud-based solutions may offer possibilities for making some measuring etc. tasks via web-browser and sharing the results or even the calculation process via web-link as well.

As an alternative, a separate point cloud manipulation software with possible GIS, CAD and mapping features could be used together with the photogrammetry software. Alternatively, even separate software for every part in data manipulation process can be used.

Costs when using a single software solution are for example approximately 260 Euros per month or 6000 Euros as one-time payment. Costs may vary depending on the products and the used software solution. Also a powerful computer is needed if the used software is a desktop application.

Original design of this tool uses *Pix4D Mapper* photogrammetry suite on a desktop computer and its cloud-based version *Pix4Dcloud. Pix4D* has an own cost-free application for flight planning and control (*Pix4D Capture*), and it supports images from DJI Phantom drones and Mapir Survey 3 spectral cameras directly. Monthly or annual licences include both the desktop and cloud licenses.

3.3. Drone regulations

Despite the relatively small size, aerial drones are usually under international and/or national aviation regulations. The drone regulations are set for the sake of the air traffic safety, the public safety (persons and properties) and the privacy protection. The regulations may set limitations or prohibitions, which are derived e.g. from the weight of the drone, the distance from the airport and the population density on the site and its surroundings. In addition, the possibility for random people having the access to the area where the drone actions have influences is taken into account. For example, the maximum altitude may be set at the certain level, or additional safety inspections and documents may be required. Furthermore, drone actions are often completely prohibited over and nearby certain areas such as airports, military bases and prisons.

European Union has enacted the **EU drone regulation** (EU) 2019/947. It sets the rules and procedures for the operation of unmanned aircraft in EU countries. The act covers every operator and pilot and all types of drones in outdoor flights. The only two exceptions are: Using a drone without a camera weighing less than 250 g, or a drone that is officially a toy (CE marked according to the Toy Safety Act). The application of the EU drone regulation (EU) 2019/947 begun in Finland according to the transition periods of the regulation on 31 December 2020. (Traficom 2021.) National adaption dates of the EU drone regulation may vary but the actual content will be the same, possible with some minor national exceptions.

Because the drone activities are a sub-part of the general aviation, also the local aviation situation must be acknowledged at the moment of operation. The airspace in controlled by the local Air Traffic Service (ATS). Even though drone flights are usually done on relatively low altitudes, the use of the airspace can be limited or even prohibited, especially when other air traffic exists, or if the site is close to airport.

Certain skills of drone operator a.k.a pilot are needed too. Drone pilot must have experience to handle the equipment and knowledge of regulations and aviation legislation concerning to drone flying. Ongoing EU legislation process adds mandatory training for the drone pilots that is depend on the type (especially the weight) and the use of the drone. Depending on the national arrangements and regulations and the location of the operation site, some **costs** of registrations, airspace permissions, training of pilots, etc. may apply.

4. Operations model

The reported operations model i.e. the use of the same or similar workflow can be implemented in different conditions. The workflow can also be implemented fully or partly as needed, if it is otherwise applicable for the case and local conditions. If the main methods of the tool – making 3D models and measurements of the target site – are used before the demolition actions are taken place i.e. when the site is still untouched, it could also be taken as part of preliminary studies and preparations steps. The results i.e. 3D models, maps and photographs could be used for screening procedures, selective demolition, demolition planning, general site investigations and knowledge, as well for archiving the landscape, which is about to be vanished.

Practical operations of the tool could dived into three phases: 1) mapping and 3D modelling the demolition site before the demolition, 2) mapping and 3D modelling CDW on the demolition site during the demolition, and 3) creating calculations and extracting and storing the results. However, the main steps of the designed operations model are better described as follows:

1. **Preliminary studies and preparations**, may include steps 2-4 if used in preparations
2. **Flight planning**, may be done in step 1 and 3 partly
3. **Site operations**, repeated as often as the case needs
4. **Producing and storing the results**, repeated as often as the case needs.

4.1. Preliminary studies and preparations

In preliminary studies of the site, general investigations and knowledge of the target site is acquired. It includes e.g. discovering the size of the site and all other possible relevant information such as and floorplans, maps, etc. Normal photographs could be helpful and even

360° panoramic imaging (image 3) could be used for documenting both the interior and/or exteriors of the site. Well-collected material can reduce the needs for visiting the site and it can be useful for pre-demolition actions such as screening procedures and selective demolition. 360° images could also be used in 3D modelling phase in photogrammetry software.

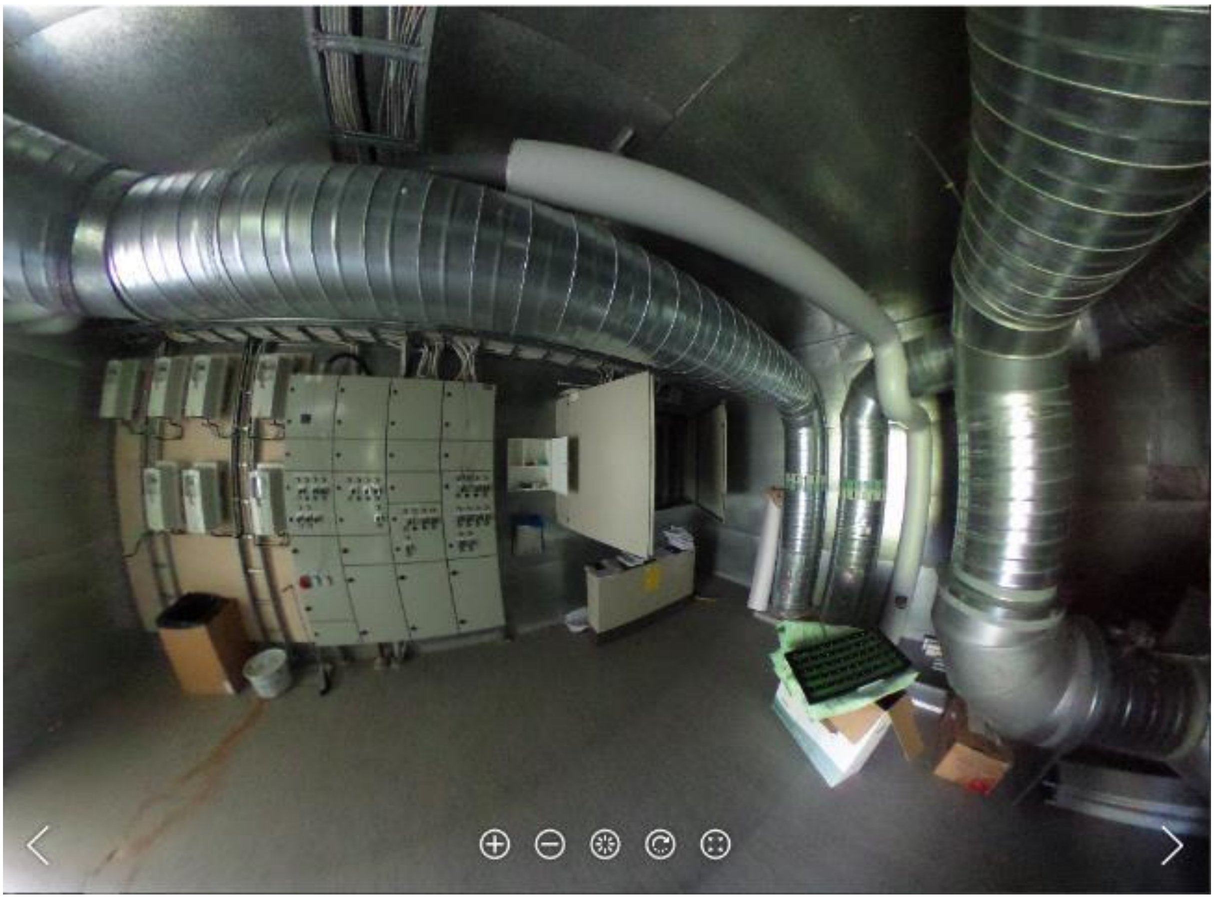

Image 3 - 360 degrees panoramic image in image viewer where the image can be zoomed and rotated freely (image: Esa Hannus).

One use of the 3D-tool is that it could also be used for producing more and updated information about the target site *before* the demolition. Implementing the mapping and 3D modelling of the demolition site before the demolition, the results could be used for preliminary study of the site and for preparation purposes such as demolition planning and safety planning of the site. In other words, information is gained by measuring objects, heights, distances, etc. and getting an updated maps and imaginary. A current 3D floor gets created too, to be used as a base in CDW 3D calculations later if needed.

If the operation results such as maps and orthophotos are needed precisely in some coordinate system, some (6…8) coordinates around the site are needed for establishing Ground Control Points (GCP) to be used in the calculating phase. Coordinates can often be obtained from the local authorities, or from the operator of the building, or they can be picked from some suitable map etc. (as in figure 4). The other option is to use a drone that is capable of surveying grade positioning. Of course, the use of the correct coordinate system must be acknowledged.

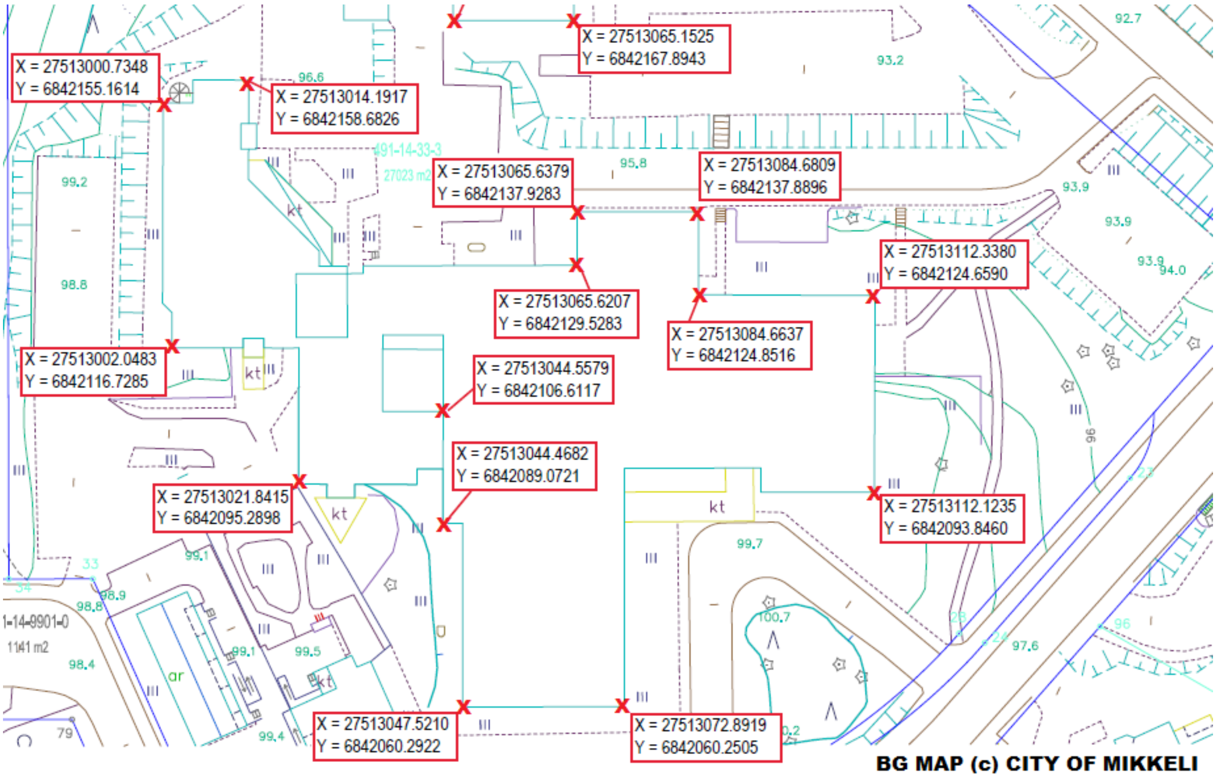

Figure 4 - Coordinates of building corners obtained from the map to be used for precise 3D mapping (figure: Esa Hannus, background map City of Mikkeli).

Preliminary studies and preparations includes figuring out what are the required qualifications for operating the drone at the target site. Possible stable aviation limitations of that location needs to be discovered. The aviation limitations together with the size of the site and the nature of the target are taken into account for figuring out the possible flight altitudes. If the flight altitude is too limited, it can make drone operations useless. The aforementioned issues may also affect to type of the drone and its equipment, as some regulations are related with the weight of the system. Drone operations can even be completely prohibited on that site.

Local authorities or other agents may provide services to make aviation awareness more fluent and easier to obtain. For example, in Finland, a private company Aviamaps Ltd provides a near real-time aviation map platform (figure 5) and easy-to-use flight planning tool for e.g. drone operations. Aviamaps shows information about the official aviation declarations, messages and spatial restrictions on an online map near real-time. The service can be used in general beforehand site investigations to find out what regulations stand for the operation site and as well for planning before every actual flight (as described later in chapter 4.2.). Aviamaps provides also a link to the official airspace reservation application of the national airspace manager and offers a possibility to give unofficial flight announcement for other users. (Aviamaps 2021.)

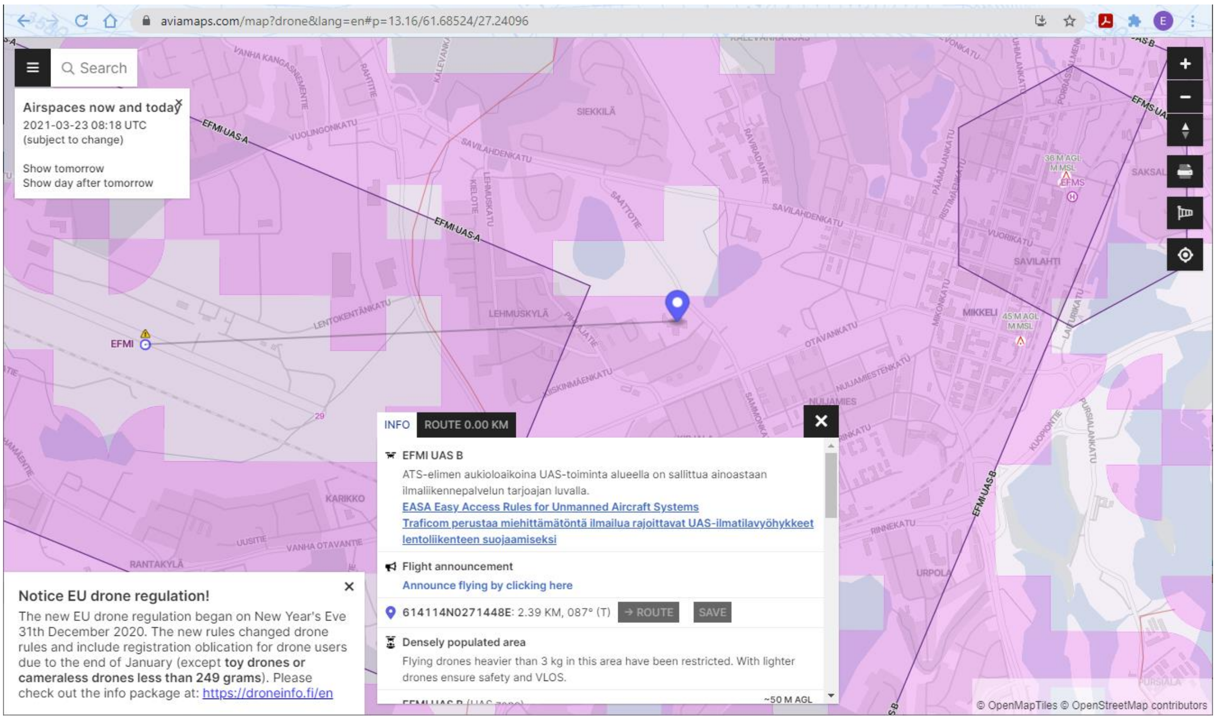

Figure 5 - An example of an aviation web-service for e.g. investigating regulations of drone operations on certain place: Finnish service Aviamaps. (Aviamaps 2021.)

As there is a need for repeating operations during the whole demolition process, owner of the demolished building and the demolition constructor should be contacted as soon as possible. Drone operations should take place so that all demolished material gets captured by drone imaging. This needs agreements and arrangements for the demolition process. However, this might not always be possible and not in every case the full commitment can be achieved because delays to the demolition are not acceptable e.g. for financial reasons. Also the safe movements at the site as well the drone safety issues must be taken into account.

4.2. Flight planning

Planning of flights must be carried out beforehand per site in general (as described in chapter 4.1) and before every single flight. Similarly, plans must be reviewed against conditions at the site just before every take off.

The regulations, or the nature of flight to be done, may require that the local Air Traffic Service must be contacted. Depending on the case, the drone flight may require beforehand given permission certain time before the date of the flight, or at least an announcement of the airspace usage at the time of the actual flight, or both. The aforementioned Aviamaps (in chapter 4.1.) or similar services (if available) could be very helpful, because they provide information near-real time and the aviation situation map is updated dynamically.

Planning just before the flight considers checking the current aviation situation, announcement of airspace use (if required) and general observations of condition and situation at the site. Weather conditions must also considered in the planning of the flight. Bad weather can prevent flight operations. Weather conditions may also disturb the quality of pictures. Bad imaging leads to less reliable information, or it may prevent achieving needed results.

The nature of the site and particular demolition process often requires and allows to use regular flights with similar flight paths. A map-based flight control and planning application can be used for planning onsite flight paths beforehand the actual operations. It can be done in the flight planning phase or even before as a part of the preliminary studies and preparations. In some cases, it is more convenient to do this kind of planning as office work. However, the flight path plan can be made or changed also in the field, and they must always be verified when on site.

In map-based planning application, the planning is typically done by 1) selecting an suitable flight model such as 3D mapping, 2) setting the flight altitude, and 3) drawing an rectangle or polygon representing the desired area on the map. After that, the planning application automatically calculates the proper locations for the needed images to be taken later on the flight mission. It also often has the appropriate settings for e.g. overlapping images, which could still be adjusted if needed. (Figure 6). The flight plan will be uploaded to the drone later, before the take-off.

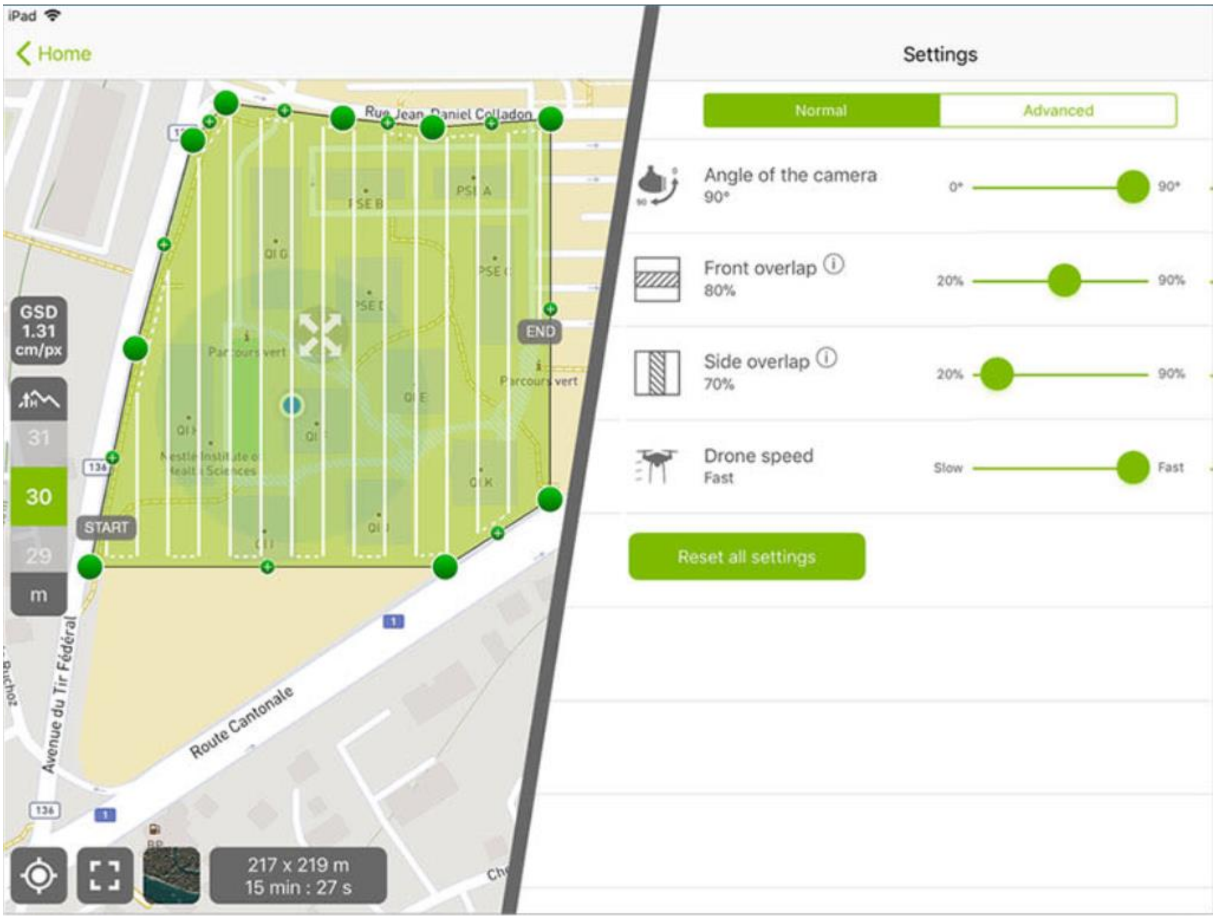

Figure 6 - Pix4D capture: An example of the flight planning mobile application. Map view and Settings view combined. (Pix4D 2021b.)

4.3. Site operations

Dozens or even several hundreds of photographs are captured systematically by a drone flight over the site, or over some individual CDW target object such as interchangeable container or a pile of concrete. The procedure i.e. the data collection round is repeated as often as the case needs. Organising and synchronizing on-site daily activities and timings with the operations of the demolition constructor needs to be set up properly in order to get all materials tracked. This procedure is repeated as often as the progression of demolition requires, i.e. it is continuous work.

Typical time spent onsite for one data collection round is less than 1 hour or even less. That time includes the needed flight time and preparations and post-flight work as well the unpacking and re-packing. For example, for the area of 2.3 hectares, the actual flight time is typically approximately 13 minutes. Time is short enough to be handled using only one battery with most of the drones. Consumer grade drones with standard cameras are quicker and easier to operate than more advanced drones or special cameras, so the time spent onsite may vary depending on the used equipment. As another example (figure 7), one 9 minutes long flight session at the altitude of 50 meters in a site sized as 3.53 hectares provided 194 overlapping images to be processed further.

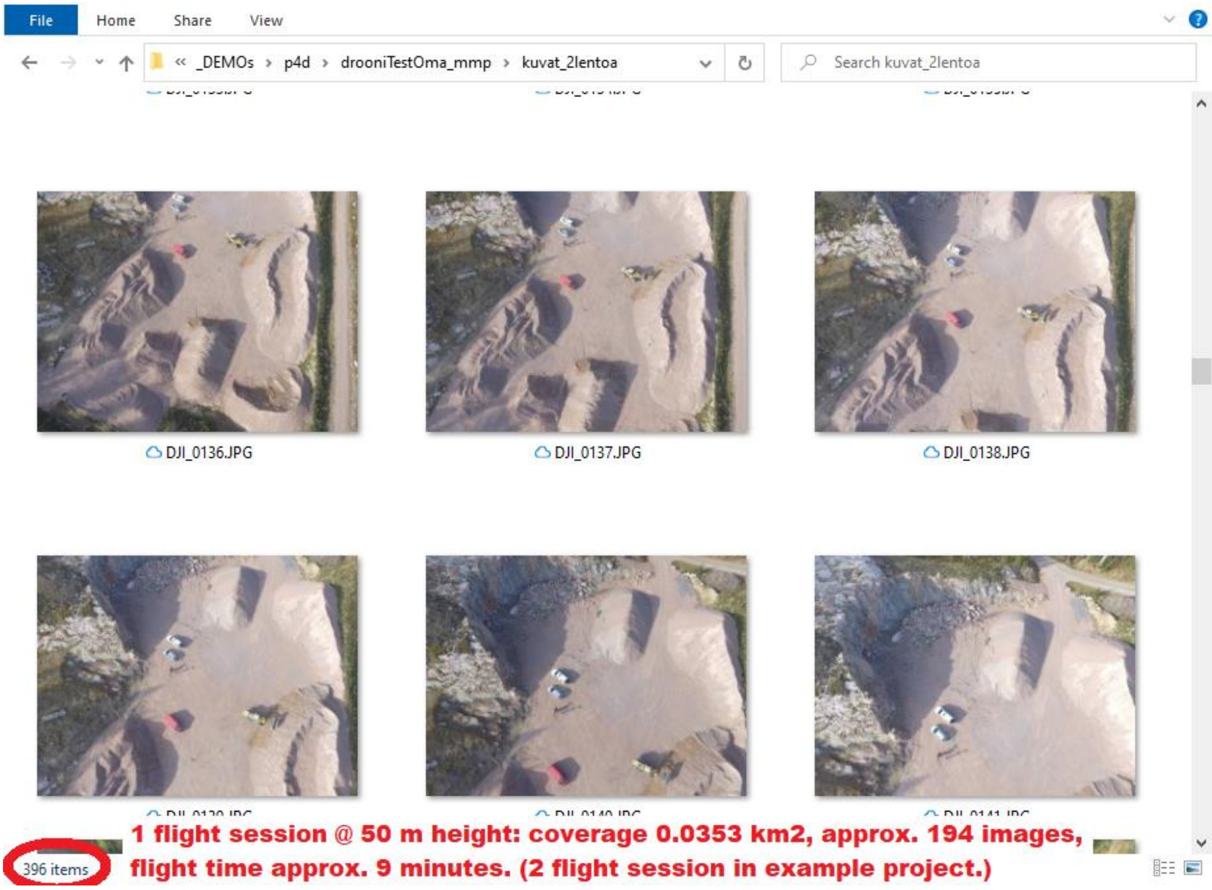

Figure 7 - An example of the results of an imaging project (figure: Esa Hannus).

At the site in the designed take-off place, the drone is unpacked and prepared for the flight mission. Preparations typically includes mounting propellers and batteries and establishing wireless connections between the drone and remote controller (RC). If the flight path was not planned already (as described in chapter 4.2), it needs to be done as well at this point. The flight plan is uploaded to the drone.

Drone piloting can happen automatically if a flight control application is used, or by manual steering. Even when using the flight control application, the pilot must always be ready to take the drone under manual control at any time needed. Fully automated flights are practically legally denied (with some exceptions and special permissions). The flight control application controls the taking of the images so, that they became taken at the planned locations automatically and will have the required overlap with each other.

4.4. Producing the results

In general, at least two tasks have to be completed: 1) **produce accurate 3D point cloud from drone-based photographs** and 2) **measure volumes etc. from the point clouds**. Additionally, some for GIS, CAD and mapping may also be done. This procedure is repeated after every data collection round done at the demolition site. Furthermore (as mentioned in chapter 4.1), different kinds of modelling and mappings and measures could also be done before the demolition in order to gain information about the site for e.g. planning purposes.

The results are produced by a software solution, which may vary (as described in chapter 3.2.). The following describes the matter, when using a complete photogrammetry software suite, which includes also point cloud measuring capabilities and enough GIS, CAD and mapping features. Image cluster is turned into accurate 3D & 2D data by using a image based modelling software. Results are: point clouds, maps, models, orthophotographs, etc. and measures that are produced from the 2D and 3D data. Additionally, fly-through videos etc. extra products may also be produced. Some software suites offer cloud-based processing and sharing, or cloud-based features can be used in combination with the desktop software.

Images are taken into the photogrammetry software and suitable calculation template is chosen. If needed, the area to be processed can be limited by fencing. Additionally, non-drone images could be used in modelling process too. This includes also 360° panoramic images (as seen in previous image 3). However, capturing and using panoramic images is time-consuming, so it is up to project needs are they actually worth of using.

If operation results, such as maps and orthophotos, are needed to be precisely in some coordinate system, some ground control points (GCP) with precise coordinates are added into the calculation project and GCPs are marked on some images (images 8 and 9). GCPs are not necessarily needed if the used drone was capable of surveying grade positioning. It takes typically approximately 5 to 15 minutes to move images from the drone into the software and establish the project. If GCPs are used, it causes some delay and the calculation process (described later) may need to be done in two parts - first the initialization, then setting up the GCPs and starting main processing.

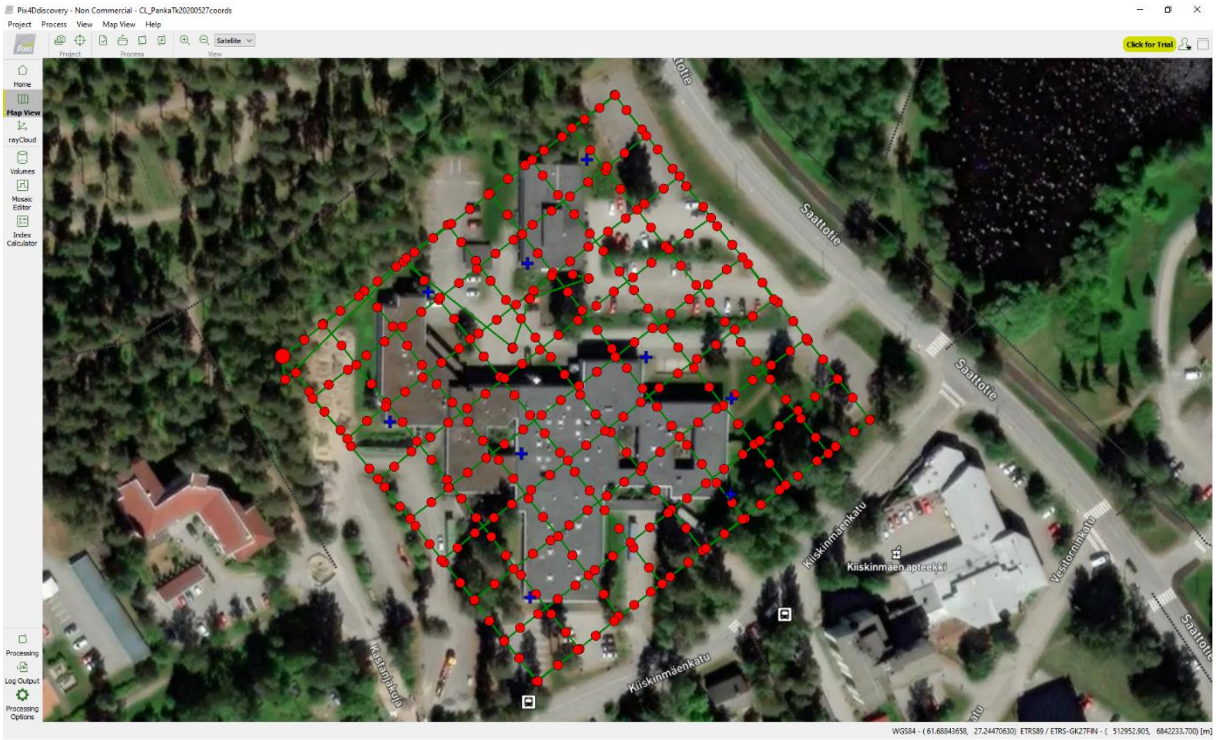

Image 8 - Places of images (red dots), GCPs (blue crosses) and flight path (green line) in a software view (image: Esa Hannus).

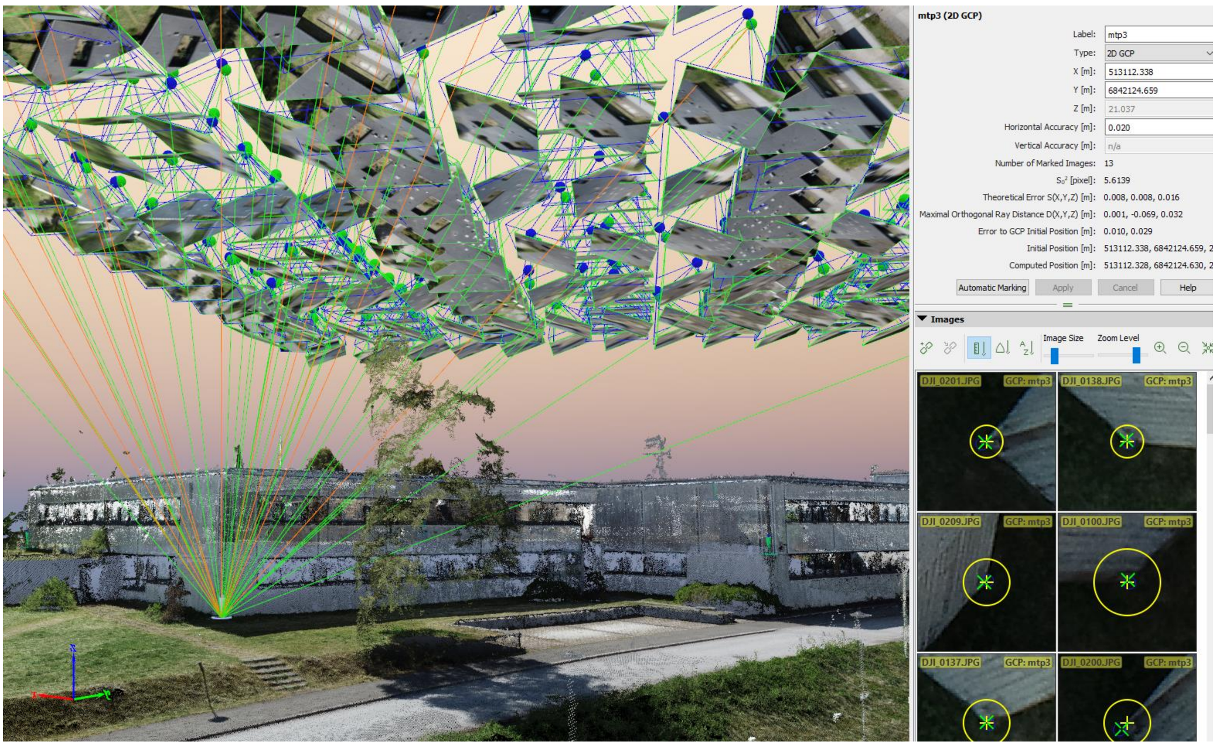

Image 9 - Point cloud, some camera places and marked GCP in software view (image: Esa Hannus).

The calculation process is automatic at level the user has set it (specified by the processing template). In most cases, fully automatic way is suitable, and it produces all the basic results (specified by the processing template) at once. However, the user can follow the status report and may interrupt the process, if some error or too bad quality shows up. The basic results are often an accurate 3D point cloud model (image 10), other 3D models and 2D orthomosaic image (image 11) of the site. Depending on the case, amount of images and the required results and the computing power as well, the process lasts from one hour to 12 hours. If the used photogrammetry solution offers cloud-based image processing, it may reduce the required time and frees the computer for other uses.

Image 10 - Precise photogrammetric point cloud of the site (image: Esa Hannus).

Image 11 - Orthomosaic of the site made from drone images (image: Esa Hannus),

After the accurate 3D point cloud model is created, it can be used for measuring distances and volumes of different kinds of targets, which appear in the point cloud. Measurements are done manually by pointing and drawing different kinds of measurement objects, such as lines and polygons into the point cloud. In some software solutions, more or less automatic tools are provided too. They are based on computer vision technologies and can provide automatic classification of points into several classes such as high vegetation, surface, buildings, man-made objects. However, some manual work is often needed for making results more accurate. Standard automatic classification tools might not be directly useful for recognizing different materials, but they can be helpful in measuring tasks and provide more informative view to collected data.

Recognition of materials could be emphasized by using spectral images (see also chapter 2.3). However, properly made reflectance models for different materials are needed, and ready-made complete solutions do not exist. The reflectance model must be created and inputted into a software before the processing. Practically this means typing in some calculation formulas (for certain indices).

Volume measurements provide so called cut and fill values of the fenced area (image 12). How the base is handled, can be adjusted in settings of the measurements, and also beforehand calculated or provided 3D base-models could be used as a reference. **Area** calculations could be used for example to measure the coverage of certain materials (image 13). Pointing out the desired area is done manually. Also different kinds of **other measures**, such as heights and distances and elevation profiles can be provided. Furthermore, textual markings and notes etc. can be added too. An example of these is seen in image 14, which also provides an example of web-browser-based interface of the point cloud application.

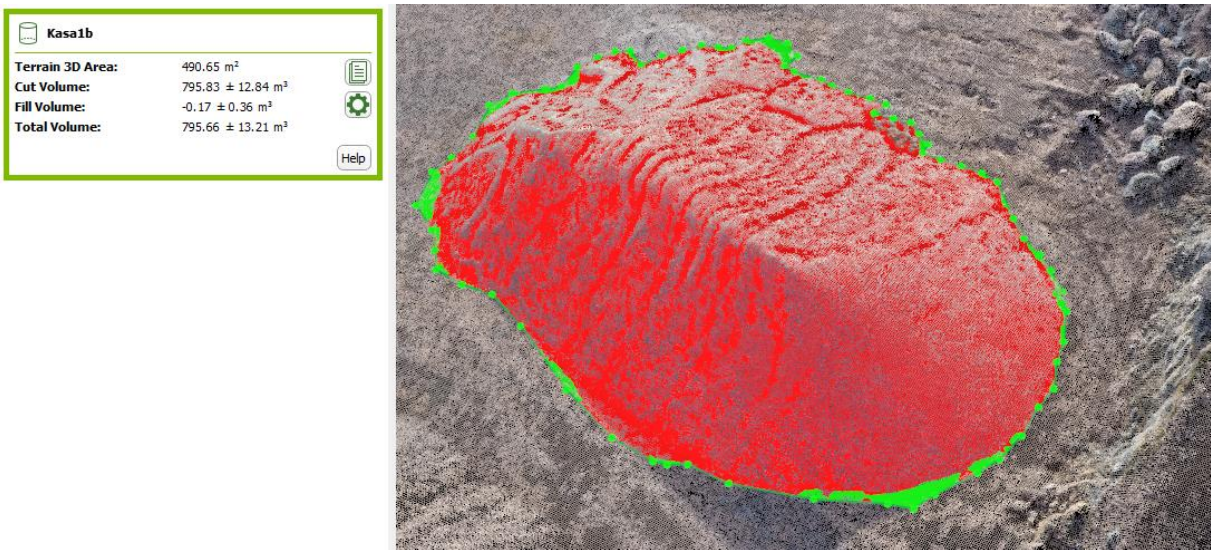

Image 12 - Volumetric measurement from the point cloud (image: Esa Hannus).

Image 13 - Calculating the amount of roofing felt from the point cloud. Note: coloured markings are hand-drawn and added for the sake of clearance. (Image: Esa Hannus.)

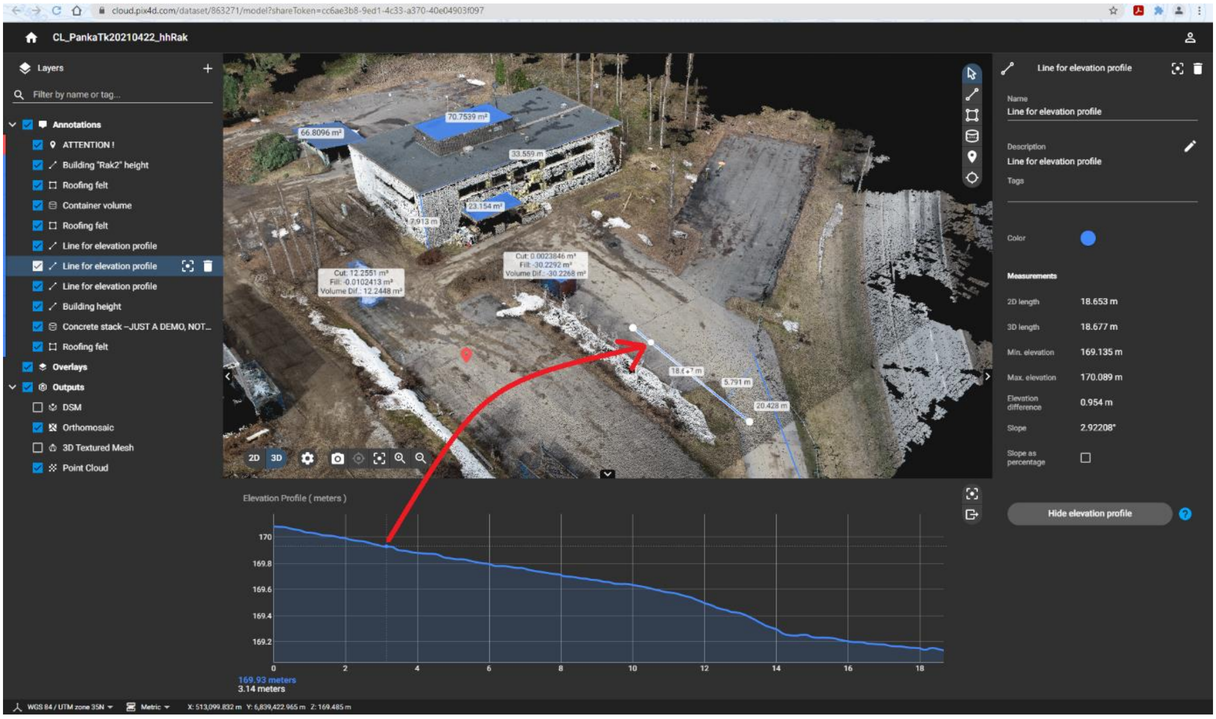

Image 14 - Different kinds of calculations (areas, lengths, heights, elevation profile) and one note marking done in a web-based, shareable point cloud platform. (Image: Esa Hannus.)

After all the results, including the measurements of the particular imaging session are completed, they should be stored. Also the ‘raw’ data (i.e. images) are good to be stored for possible later use and because of archiving reasons. Instead of local storage, raw data, models and measures could be taken into the databank from which the material lots could be further delivered to the marketplace. The databank and digital marketplace are developed in the CityLoops project as another tool.

5. Summary

The 3D imaging tool can provide amounts of construction and demolition waste materials during the actual demolition process by 3D measuring the quantities from the point cloud, which was created from drone-based images. In order to get all materials tracked, on-site daily activities during the demolition process must be organized and synchronized with the demolition constructor.

The tool has possible uses also in pre-demolition and selective demolition stages for e.g. estimating and measuring materials or counting building parts etc. while they are still in-place. This can be achieved if the site is imagined and modelled before the actual demolition. This also provides up-to-date 3D data, maps and orthophotographs to be used e.g. in the planning of the demolition. In addition, the gathered images are informative as-is i.e. they can be useful as a photography documentation.

The described operations model i.e. the use of the same or similar workflow can be implemented in different conditions. It can also be completed by using different kinds of hardware and/or software. The workflow can also be implemented fully or partly as needed and as it is applicable in particular situation or in current case. The original set-up is designed to have cost efficient and easy to use equipment, and it is aiming to rapid operations. Even more or better results are possible by e.g. using more capable hardware or software. In other words, the 3D imaging tool can be suited to different conditions and to different needs.

Despite the relatively small size and low flying altitude, aerial drones are under international and national aviation regulations. Drone operations may be limited or prohibited in certain areas because of several reasons. In addition, weather conditions have influences on the flying possibilities and on the quality of imaging.

The use of multispectral or hyperspectral imaging for more automatic recognition of material type, or for finding out the quality information of the material, needs more specific studies. The reflectance models for construction materials as well for demolished CDW should be determined under local lighting etc. conditions. Despite the limitations, this might be useful solution, especially if some kind of computer vision and artificial intelligence procedures could be applied to the process.

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CITYLOOPS

CityLoops is an EU-funded project focusing on construction and demolition waste (CDW), including soil, and organic waste (OW), 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 OW, 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 aspect of CityLoops are stakeholder engagement and circular procurement.

CityLoops runs from October 2019 until September 2023.

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