

Automatic calculation of volume changes in road construction

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ABSTRACT:

The construction industry is still one of the least digitized sectors in the world, and digitization in the road construction sector in particular is even more dire. To improve the efficiency of the sector, it is of utmost importance to automate construction monitoring tasks, i.e. progress, quality and quantity analyses. The goal of the presented framework is the automation of volume calculation in road construction, so the last branch, i.e. quantity analysis. This paper discusses volume calculations in road construction sites. These volume calculations will be done based on both as-design data and as-built data, where the former is modelled by considering the regulations formulated by the Agency of Roads and Traffic, Agentschap Wegen en Verkeer (AWV) of Flanders, and the latter is captured by using an RTK-UAV. The feasibility of the proposed workflow is examined using real test cases. As a result of the automation, the homogeneity of data across projects will increase and this forms the basis for further automation in road construction. By performing these checks on a regular basis at set intervals, one can obtain a clear overview of progress. In this way, possible delays or errors can be spotted quickly, resulting in higher quality and reduced failure costs.

1. INTRODUCTION

Nowadays, volume calculations and in general progress monitoring in road construction are still mostly conducted manually using Global Navigation Satellite System (GNSS) devices and traditional surveying techniques such as total station (TS) (Vick and Brilakis, 2016). This is very time-consuming so automation of this process is highly recommended. Additionally, this process is selective whereby a limited number of points are measured which is less accurate compared to aseleective methods such as terrestrial or aerial laser scanner or photogrammetry.

Consequently, an unselective method is needed to capture the data. This need supplemented by the needs for high accuracy and fast capture makes the ideal solution to use unmanned aerial vehicles (UAVs) to capture the entire site. There is a variety of sensors that can be placed on a UAV, but in this research a drone with an RGB-camera is used because it is low-cost and it is sufficient for this application, namely volume calculation, analogue to (Tucci et al., 2019). There are some situations where a RGB-camera cannot be used due to a lack of ambient lighting such as in tunnels, etc. but this but this exceeds the scope of this study (Siriba et al., 2015). In this research the data is captured with a Real Time Kinematic (RTK) UAV to automatically georeference the SfM outputs, so the need of ground control points (GCP's) is not necessary which saves a lot of time (Taddia et al., 2020).

There are two different ways to calculate volumes. On the one hand, the volume changes between two meshes, or other SfM output of the RTK drone. This method calculates the on-site change between two epochs. On the other hand, the volume changes between the captured mesh and the as-design model. This method allows the calculation of how much earthmoving still needs to be conducted and what is already done (Tucci et al., 2019). This is part of quantity analysis as well, but takes the first steps towards progress monitoring. As described above, meshes are used and not another SfM output. The reason why meshes and not point clouds are used is because of the classification of ground points, and only exporting those ground points, gaps can arise in the mesh data due to occlusions. These gaps in the meshes can be filled by interpolating the triangles around the missing data. For point clouds, this interpolation is much more difficult

to achieve so the use of meshes is appropriate. Occlusions are common problems in (road) construction sites, see Figure 1.

The algorithm will be tested on different testcases to demonstrate robustness, both methods, as-built vs as-built and as-built vs as-design, will be tested. In the case of the volume calculation between two different epochs, multiple testcases are used. There is a testcase in Mariakerke (Belgium), where the as-design model and one of the captured meshes are visible in figure 2. There is an other testcases for the volume calculation between two epochs, two meshes of two different epochs can be seen in figure 3, this testcase is situated in Gentbrugge. For the second method, the calculation between an as-built dataset and an as-design dataset, only one test case is used. In the case of the test case in Mariakerke, there is an as-design model that can be used, but in the other test case of Gentbrugge, there is a lack to an up-to-date as-design dataset. This ensures that only the Mariakerke dataset will be used to test the second method tre.

There are several problems for frequent application of this method in road construction at present. One problem is that currently the IFC-files are not often used, as presently there are nearly always 2D plans. Additionally, there are occasional some 2.5D plans that are required for GNSS-machines such as excavators. To calculate the effective volume changes compared to the as-design plan, the plans must be converted to 3D models. These models must be Agentschap Wegen en Verkeer (AWV) compatible, and certain design guidelines must be respected from other Flemish agencies. So such that in order to test the part of the algorithm, between a mesh and an as-design model, these 2D or 2.5D models need to be converted to AWV-compliant models. This was also done for one of the two test cases, i.e. that of Mariakerke, see Figure 2 (left).

The interchangeability of data among the wide variety of software applications used by all the stakeholders must be ensured to prevent the loss of information. The greatest benefits of BIM occur when all project stakeholders work together efficiently throughout the course of a project, from early design to completion, by exchanging structured data. In line with the most recent research on data exchange in the construction industry and the AWV- Object Type Library (AWV-OTL)



Figure 1: Problem of occlusions on construction sites. (a) Stock material and excavator seen from a georeference image. (b) The corresponding gaps in the point cloud. (c) The filled gaps in the mesh.

initiative, this research project explores how to implement a BIM environment between stakeholders using Linked Data for the asset management phase (i.e. AWW), i.e. during the design and construction phase of a road infrastructure project (Rasmussen et al., 2018). As a result, stakeholders are able to define, link, exchange and validate content of datasets between otherwise largely disconnected software environments. Resulting in a need for structured data to both ensure automation and implement of Linked Data based on the OTL.

The rest of this paper will consist first of a review of the literature on related research. Second, the methodology of volume calculation applied in this study is discussed. Third, experiments are discussed, showing why certain choices were made and where to pay attention to when applying this algorithm. Finally, a conclusion will be discussed complemented by future work.



Figure 2: The IFC-file from the test-site (left) the mesh from the test-site (right) (Mariakerke)



Figure 3: The mesh of epoch 1 (left) and the mesh of epoch 2 (right) in (Gentbrugge)

2. RELATED WORK

This section will review various issues discussed in literature in order to come up with our own method used in this paper. Data acquisition will be discussed as will data processing. In addition, there is a literature review of working with different data such as 2-, 2.5- and 3D-data. Finally, there is looked at how volume calculations are done in other studies.

The first thing that is checked is how the data is captured. As mentioned above, there are several manners to capture the desired data to start applying volume calculations, here only aselective methods will be discussed because select methods are outdated (Vick and Brilakis, 2016). In the work of (Son et al., 2020), they compare a Terrestrial Laser Scanner (TLS) point cloud with an UAV-based photogrammetric point cloud. The conclusion from the study is that UAV photogrammetry is the fastest method for accurate volume determination, a combination of TLS and UAV does provide a more accurate result, but increases the capture time. Because for this application the accuracy of the photogrammetric method is sufficient, only the photogrammetric method will be used and the TLS will not be combined to capture the site. Price-quality-wise, the go-to UAV is a multi-propeller drone, the advantages for this type being: robustness, high manoeuvrability and a low acquisition and maintenance cost, (Li et al., 2019).

The data that will be worked with for the volume calculations are RGB-images captured by the RTK-UAV. Before volumes can be calculated with this data, several steps have to be done in order to get a georeferenced SfM output. The first step of this processing of data is to georeference all the data. Since this research is working with an RTK-UAV, no Ground Control Points (GCP's) are needed as mentioned in (Ajayi et al., 2020) (Siebert and Teizer, 2014). GCP's can be used, but the increase in quality is negligible, (Julge et al., 2019). The next step is to process these RGB-images to georeferenced output, i.e. point clouds, meshes, etc. , these end products are the same in different researches just the processing software is different. The last step in the processing of the data is the classification of points. In order to get a correct volume displacement only ground points can be taken into account. This process is also called ground-filtering which classifies the points in two classes, ground point and non-ground points, (Jiménez-Jiménez et al., 2021).

The ultimate goal is to work with 3D as-design data, but temporally, 2.5D as-design data, needed for the use of GNSS-excavators for example see figure 4, can be used. When working with 2.5D data, some steps need to be taken to obtain 3D from this 2.5D data. In addition, 2D as-design data will have to be converted manually to calculate the theoretical volume changes. This can then also be modelled AWW compliant, which is ideal for subsequent progress monitoring steps. Planes are drawn through the various contour lines so that the 2.5D data becomes 3D. There are various algorithms that can be used for this purpose, such as algorithms like the deterministic and the geostatistical one, (Khalil, 2015). The difference between these two interpolation techniques is that the deterministic is based on measured points or mathematical formulae where the geostatistical one is based on statistics. The latter is more suitable for advanced models, according to (Khalil, 2015). The study by (Yue et al., 2010) describe similar methods. Their study also proposes another method, high-accuracy surface modelling (HASM). The difference between all these methods is how one is going to assign a certain weight to a point, where the weight determines how much influence a point has on the surface to be formed.



Figure 4: The 2.5D data from Gentbrugge needed for the GNSS-excavator.

The last part of the literature review is about the volume calculation itself, different methods can be found in literature. The study of (Tucci et al., 2019) presents three different ways to determine volumes, these are: "cross-section", "horizontal section" and "prism between two surfaces". These methods correspond to those discussed by (Labant et al., 2015). In the research by (Napoles and Berber, 2018), there are three other methods, in their work they use: "the contours method", "grids method" and "Triangulated Irregular Network (TIN) method", the latter is similar to the "prism between two surfaces method" from the study (Tucci et al., 2019). The article by (Julge et al., 2019) lists the following three methods: "grid-based method", the "triangular prism method" and the "cross-sectional method". In the "grid based method", points are created from a uniform grid. These points are then projected along the z-axis on the second surface. The distance between the corresponding projected points is determined. The volume is then determined by taking the average distance between the points and multiplying this by the ground surface, the horizontal area of the element. It is a fast method but not the most accurate (Benedek et al., 2018). A similar method to the "grid based method" is the "volume of spot height method", discussed in the article by (Siriba et al., 2015). Three methods will be discussed, i.e. the "TIN method" or "prism between two surfaces method", the "grid method" and finally the "section method". The volume following the prism between two surfaces is calculated by connecting the upper surface to the lower surface connecting by prisms. To do this, both surfaces must be a TIN surface. The volume is then calculated by starting to calculate the volume of each prism separately and taking the sum of these. In the "grid method", a surface is divided into a uniform grid, these points are projected along the z-axis onto the second surface. The distance between the two points is determined and multiplied by the size of the grid. The total volume is then the sum of all grid cells. And finally the "section method", the last method has two analogue versions, i.e. "cross-section", "horizontal section". Both methods use flat cuts that in most cases are taken at a fixed distance from each other. In the "horizontal section method", these sections are horizontal where those in the "cross-section method" are vertical. The volume between two successive cuts is obtained by taking the average area of the two sections. This average area is then multiplied by the distance between the two cuts. The total volume is the sum of all the sections. The conclusion from all these different methods, and their pros and cons, is that the grid method will be used for the volume calculation in this study.

3. METHODOLOGY

The process of the volume calculations exists of **four steps**. There is **(1)** the pre-processing of the as-design data, **(2)** the pre-processing of the as-built data, the UAV-data, **(3)** the analysis between two datasets, i.e. as-built and as-design datasets, and **(4)** the reporting of the volume calculations.

(1) The pre-processing on the as-design data side is limited, if an IFC file is available then it can simply be loaded in the algorithm as in Mariakerke see figure 2. When there is a 2.5D model as in Gentbrugge, see figure 4, this data will be converted to a 3D model. This will be done by connecting the contour lines with planes as can be seen in figure 5, for all the contour lines.

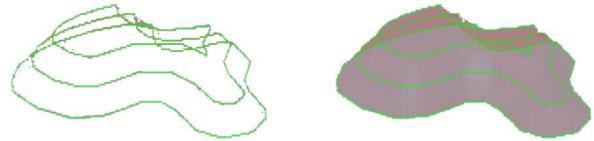


Figure 5: Converting contourlines into a 3D file for further volume calculations.

(2) The RGB-images from the RTK-UAV are processed with a photogrammetric software, in this case Agisoft Metashape (Agisoft Metashape version 1.5, 2019) in different georeferenced outputs. The output that is needed for the volume calculation is the mesh model with only the classified ground points as described before. This step is also included in the used software from Agisoft Metashape.

(3) There are two different analyses this algorithm can perform. This is, on the one hand, the analysis between two different epochs, i.e. two meshes. And on the other hand the analysis between an epoch and an as-design model, this calculation has similarities, yet is slightly different to the first one.

The first step is to create an uniform 2D grid based on the axis aligned bounding box of one of the meshes, see figure 6 (left), as discussed in the related work. Since these points will be projected onto the as-design and as-built data, it is convenient to put the grid above all the data, that way the points can be projected in one direction, i.e. downwards. For the second method, the method of as-design vs as-built, another grid is needed below the data to detect the bottom of the BIM model, this will be clarified later in the text, see figure 6 (right). The distances between the points of the grid in both x and y are determined by the resolution r , this resolution is important to later calculate the volume per grid cell.

The second step is to create rays that start at each point of the grid. These rays hit the mesh and gives the distance between the point and the grid. So each point of the grid gets two distances, one to each mesh from respectively the first and second epoch. When a ray doesn't hit a mesh there will be no value. This returns two depth maps, one for the first epoch and one for the second epoch. The way this works with the as-design data is that both a depth map from the top is created as well as one from the bottom, that way one knows the thickness of all layers of the road for each point, because both grids, bottom and top, have the same x and y coordinates and a fixed difference in z coordinates. This is important for the calculation between the as-design en as-built.

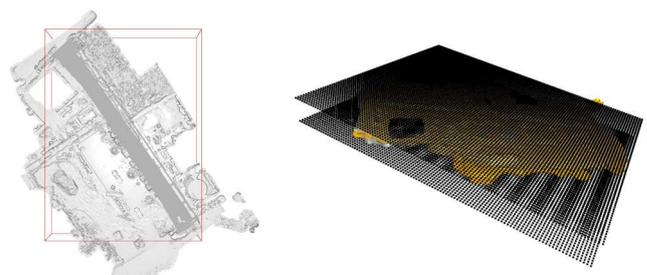


Figure 6: The axis-aligned bounding box of the mesh of one epoch (left) and the grids on top of and under the data (right).

For the volume calculation between the two epochs a third depth map is created where the second depth map is subtracted from the first depth map resulting in one depth map where a negative value is a cut value and a positive value in a fill value. Because these depth maps give distances, d , this must be multiplied with the surface of the grid, r^2 . The total volume is the sum of the volumes per grid cell, equation 1, see figure 7.

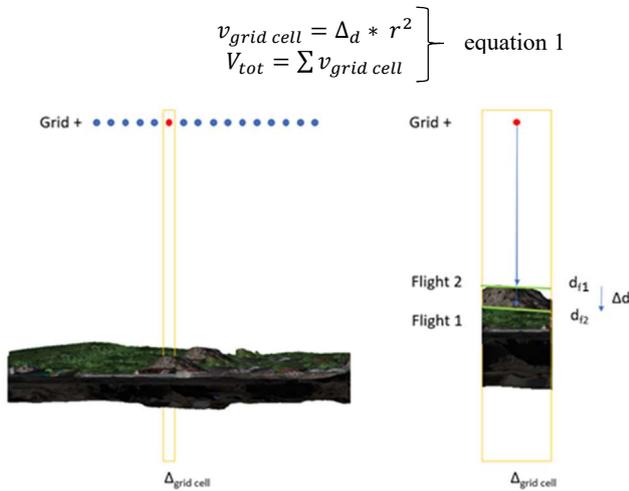


Figure 7: Visualisation of the volume calculation methodology between two epochs.

For the volume calculation between an as-design model and an as-built model the calculation is a bit different. There are three possibilities and each possibility has another method for calculating the volume changes, see equation 3. The first option is that the as-built mesh is beneath the as-design model, so there is more soil removed than there should be, see figure 8 (left). The second option is that the as-built mesh is between the top and the bottom of the as-design model, see figure 8 (middle). And the third and last option is that the as-built mesh is above the top of the as-design model, so there is less soil removed, or more soil filled than should be, see figure 8 (right).

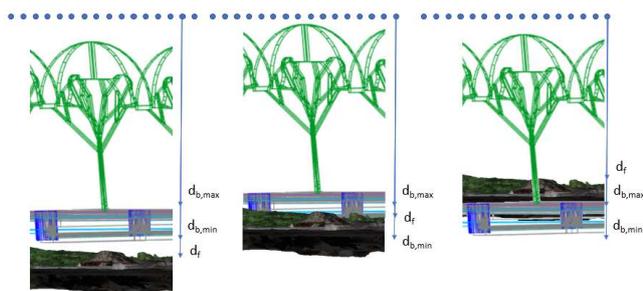


Figure 8: The three options for as-built vs as-design, the as-built is beneath the as-design (left), the as-built is between the top and bottom of the as-design (middle) and the as-built is above the as-design model (right).

These three options gives us the following equation 2 for the distance that needs to be used for the volume calculation. Where $d_{b,max}$ is the distance from the grid to the top of the BIM, $d_{b,min}$ is the distance from the grid to the bottom of the BIM and d_f is the distance to the flight mesh.

$$d(x, y) \begin{cases} 0, & \text{if } d_f \geq d_{b,min} \\ (d_{b,max} - d_{b,min}), & \text{if } d_f \leq d_{b,max} \\ (d_f - d_{b,min}), & \text{else} \end{cases} \text{ equation 2}$$

The reason that there is a grid on the bottom of the scene is to determine the $d_{b,min}$, because the used method only returns the first hit so the bottom of the BIM-model needs to be found from beneath the model. So the $d_{b,min}$ can be found with the following equation 3. Where h_{grid+} is the height of the top grid, h_{gri} is the height of the bottom grid and d_{b-} is the distance from the bottom grid to the bottom of the BIM, see figure 9.

$$d_{b,min} = h_{gri} - h_{grid+} - d_{b-} \text{ equation 3}$$

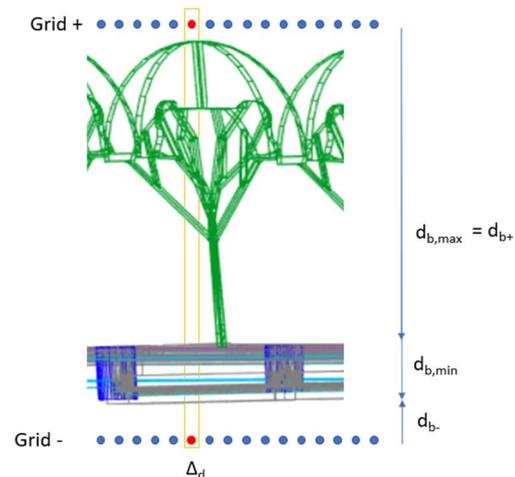


Figure 9: The calculation of $d_{b,min}$ for the calculation of the volume in the second method.

Analogue to the volume calculation of the two epochs these distances needs to be multiplied with the squared resolution, r^2 , (Eq. 1). The sum of all these $v_{grid\ cells}$ gives the V , (Eq. 2). An advantage of using this BIM model with multiple objects is that a volume can also be viewed per object. Thus, the boundaries of the object can be determined using oriented bounding boxes and these coordinates can be used to view parts of the different depth maps. Working with sections of depth maps also means that the full depth map does not always have to be loaded when there are calculations which makes calculations much faster.

(4) The reporting of the calculations is two-sided, on the one hand the values from the volume calculation are displayed whereby a negative volume calculation is an excavation and a positive volume is a raising of the soil, see figure 10. On the other hand a coloured point cloud is generated where red is excavation and green is raising. These values are gradually coloured to visualize where more is changed. There is also a buffer coloured grey where nothing has changed, see figure 11. The edges of the point cloud are darkly coloured, this because of a poor photogrammetric reconstruction due to little data, this results in false data at the edges. Besides these two methods, there is also an option to express the volume changes in percentages compared to the as-design data this way one knows how far one is in the displacements of soil. This falls partly under volume calculation, but can also be seen as progress monitoring as it reflects progress more than an effective volume by unit.

The soil that is filled in this project between flight 101-0366 and 101-0367 is 335.62 m³.
The soil that is cut in this project between flight 101-0366 and 101-0367 is -54.28 m³.
The absolute volume change between flight 101-0366 and 101-0367 is 281.34 m³.

Figure 10: The volume calculation displayed with a fill, cut and a total calculation in numbers.

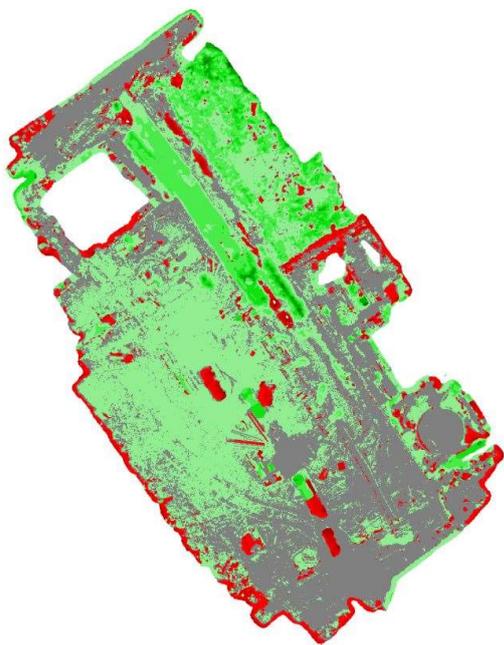


Figure 11: The coloured point cloud where green is a fill of soil and red is a cut of soil, the grey colour visualise no changes.

4. EXPERIMENTS

Experiments were conducted in addition to the literature review to arrive at the final methodology of this study on volume calculation using UAV photogrammetry. This to find a robust and fast way to achieve this. For example, there are experiments on using point clouds or meshes. Another experiment is an experiment on the resolution r in the grid. And experiments on the influence of occlusions on the volume calculation are done.

The first experiment done is the experiment on using meshes or point clouds for the algorithm. Both possibilities come as output from the RGB images obtained by the photogrammetric process, so pros and cons of both outputs have to be considered in order to choose one.

When working with point clouds, two types of problems occur, i.e.: (1) the as-design data is not a point cloud so a conversion is needed from either IFC to point cloud or from 2.5D contour lines to point cloud. (2) there are gaps present in the point cloud of the as-built model coming from the classification in the pre-processing of the as-built data. An example of such an opening is shown in Figure 12.

When meshes are used, some problems are overcome, e.g. the gaps created by classification are taken care of by interpolating the triangles in the mesh, see figure 13. In addition, meshes also come as output from photogrammetric processing and IFC files contain already meshes. The 2.5D data can also be converted to meshes quite smoothly. An additional advantage is that raycasting is only possible on meshes. All this makes meshes preferable to point clouds.



Figure 12: The gaps in point clouds because of the classification (left), the influence of these gaps on volume calculation (right).



Figure 13: The gaps of the point cloud (left) are filled in the mesh (right) by interpolating the triangles over the gaps.

The second experiment is to look at the ideal r off the grid to obtain correct and yet still rapid results. Since the visualisation in colour does increase rapidly with the number of points, this experiment will only take into account the visualisation in numbers, in the future we can look at making the colouring more efficient.

To arrive at the volume, there are some resolution-dependent steps in the process. Step 1, the rays are created (grid and direction of raycasting) for both the upper and lower grid. Step 2, the depth maps are created. Step 3, these depth maps are then subtracted from each other and, step 4, the depth map is multiplied by the resolution squared. Finally, step 5, these calculated volumes are split into cut and fill and this then gives the final result. The time to process these steps and a total of time is given in Table 1 for the test site in Mariakerke for a mesh with 597.197 faces.

Table 1: Time necessary to process the algorithm for different grid cell sizes for a mesh with 597.197 faces .

	1 m	0.1 m	0.01 m
Step 1	0.1 s	0.3 s	42.9 s
Step 2	0.3 s	0.3 s	12.1 s
Step 3	0.1 s	0.1 s	0.3 s
Step 4	0.1 s	0.1 s	0.4 s
Step 5	0.1 s	2.9 s	4 m 32.8 s
Total Steps	0.7 s	3.7 s	5 m 28.5s

It can be seen in table 1 that there is little difference in process time between a grid cell size of 1 m or of 0.1 m. Because the accuracy of the volume calculation cannot be done on the entire site of Mariakerke, due to the fact that the edges have a large influence. These edges are not accurately created due to the poor photogrammetric process on places with little data, see edges figure 11. The volume calculations are done on part of the site, here in Gentbrugge, see figure 14.

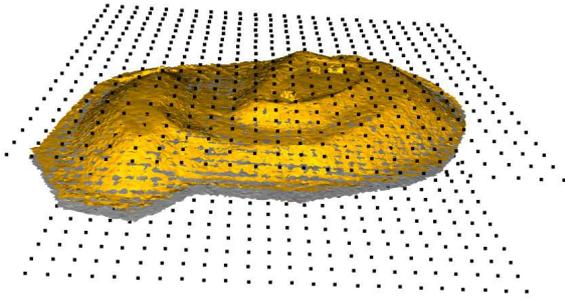


Figure 14: Section of two meshes in Gregorius to test the influence of grid cell size to accuracy, here the grid size is 1m.

In table 2 the results of the volume calculations on a part of the testcase in Gentbrugge is shown for different grid cell sizes, compared with a commercial software, i.e. civil 3D. All values are similar to each other, and for this application, the accuracy of all three sizes of grid cells is sufficient. However, the 0.1m cell will be chosen because it has almost the same calculation time as the 1m cell. In this case, the grid cell size of 0.1m deviates slightly more from the external commercial software than the grid cell size of 1m, but both fall within the 3% tolerance, here 0.19% and even 0.15% respectively. So both give a correct volume in this case, though a smaller grid cell size will be chosen for other calculations as it will generate more correct results especially with more erratic situations.

Table 2: Volume of the section of Gentbrugge testcase with the different grid cell sizes, compared to Civil 3D.

	1 m	0.1 m	0.01 m	Civil 3D
V+	413.42 m ³	412.04 m ³	412.22 m ³	412.82 m ³
V-	0 m ³	0 m ³	0 m ³	0 m ³
V Total	413.42 m ³	412.04 m ³	412.22 m ³	412.82 m ³

A third experiment is to look at influencing factors on the processing of the data resulting in the volume calculation. For instance, both water and vegetation give influence on the volume calculations, other occlusions will be tested too.

Points that are part of the vegetation can be filtered using the classification present in the Metashape software itself. The problem is with low vegetation that the software either cannot detect or causes errors. For example, tall grass causes errors on the calculation because the software classifies these points as ground points, besides if they have been classified as vegetation, there are no ground points, resulting in gaps. In other situations, i.e. high vegetation or machinery, the classification works just fine.

Since vegetation, certainly grass, does not disappear between epochs, no tests can be done on its influence on the volume calculation. In contrast, this can be done with the presence of water. Water has about the same influence as vegetation because the photogrammetric software does not create the soil but the surface of the water. In the test case of Mariakerke, between two different epochs there is respectively the presence and absence of water this does allow to investigate the influence of water. The influence of the water in the data is tested by performing volume calculations between the as-built data with water, and the as-built data without water. This volume calculation is done in the data from Mariakerke for three elements, see figure 15. Here it is important that the area whose volume is calculated no earthworks have been carried out between the two datasets and any possible volume difference comes only from the presence of water. Table 3 shows the volume calculation where the entire area consists of

water in one dataset and completely without water in the other dataset. The volume difference is limited by 0.03m³ per m² on average. It can be stated that water has an influence on the volume calculation depending on the depth. With large objects the influence is negligible, with smaller objects it can be of a large impact.



Figure 15: Part of the test site in Mariakerke with a water accumulation for three objects.

Table 3: The influence of water in the volume calculation.

	Surface	V _{water}	V _{nowater}	Difference	Difference/m ²
1	17.20 m ²	27.81 m ³	28.26 m ³	-0.45 m ³	-0.03 m ³ /m ²
2	26.38 m ²	17.82 m ³	18.53 m ³	-0.71 m ³	-0.03 m ³ /m ²
3	35.31 m ²	36.08 m ³	36.84 m ³	-0.77 m ³	-0.02 m ³ /m ²

The influence of material and tools in the data is investigated by calculating the volume difference between two as-built datasets, one with material and one without. The data used for this purpose comes from Mariakerke, in this case, in addition to the actual site zone there is a concrete slab on which tools are placed in several datasets and also a dataset on which the concrete is completely empty. An area, the size of the material or machinery, is cut out each time to test the algorithm as best as possible, then a volume calculation between an area with and without the machinery is done. In table 4 three times the calculation for a truck and two times an excavator is shown. The presence of materials and tools greatly affects the calculated volume. For a volume calculation of a large area, this influence will be limited. For a smaller area, the influence will be very large in percentage terms and will ensure that no correct result can be obtained. Parameters, i.e. maximum angle, maximum distance, can be changed in Agisoft Metashape in order to improve the classification of ground points, this can revolve in false positives, so these parameters have to be controlled and are different from test case to test case.

Table 4: The influence of material and machinery on the volume calculations.

Element	Surface	V _{difference}	Difference/m ²
Truck 1	13.00 m ²	2.32 m ³	0.18 m ³ /m ²
Truck 2	13.00 m ²	1.27 m ³	0.10 m ³ /m ²
Truck 3	13.00 m ²	3.22 m ³	0.25 m ³ /m ²
Excavator 1	13.00 m ²	0.91 m ³	0.07 m ³ /m ²
Excavator 2	13.00 m ²	2.37 m ³	0.18 m ³ /m ²

All these factors create an impact on the final volume calculation at the test site. At large test sites, these results are often negligible, but one must be aware that certain occlusions affect the final volume calculation. Ideally, these calculations should be done without occlusions, but conclusions can also be drawn with them although one should be aware of any discrepancies.

5. CONCLUSION

The basic principle of the algorithm works and produces accurate results, yet there are some limitations on the algorithm. Sufficient elaborated as-design data needs to be available, ideally an IFC file conforming to AWV. Another limitation is the inaccuracy of the result in case of occlusion by machinery, but also by water or vegetation in the data, this means that for the calculated volume, account must always be taken of possible errors due to the presence of this occlusion. The result must therefore always be looked at carefully, especially for datasets with a lot of occlusion. It is best to always ensure that there is as little occlusion in the data as possible. The algorithm has two methods by which it can work, on the one hand the as-built vs as-built data and on the other hand the as-built vs as-design data. In the first case, only one grid is needed and then only one formula is possible, namely, equation 2. The volume is the difference in distance times the resolution squared. In the second case, there is a need for two grids and there are three possibilities for calculating the volume, equation 3. Analogous to the first method, the volume in the second method is also the difference in distance times the resolution squared. Here, the difference in distance depends on where the as-built data is relative to the as-design data. The consequence of the second method is that a step between volume change and part of progress monitoring is already partly in place, as volumes can be calculated relative to what was originally planned.

From this research come some additional research questions that can be looked at in future works. Vegetation has an influence on the calculated result, future work can investigate what exactly the influence of this is for different types of vegetation and in what way vegetation can be handled in the algorithm. Also for occlusion, further research could reveal whether there is a fixed pattern in the error this produces in the volume calculation and how this can then be taken into account in the algorithm. In addition, the ideal parameters for ground points classification could be investigated. If a correlation can be found between the error per type of occlusion, this error can automatically be taken into account in the volume calculation. In this way, the algorithm is more robust and more applicable in practice. In addition, future work may also look at improving the colouring algorithm for visualising volume changes so that the influence of grid size is less. Currently, the algorithm works, but when the datasets become larger, this may cause longer computation times. The advantage is that this visualisation is not a must for calculating volumes, it does add value for stakeholders to see where exactly the changes occur.

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