Multi-parametric Performance Evaluation of Drone-based Surveying for Disaster Risk Management

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Abstract: Disaster situations, either natural or man-made, could be catastrophic as causes massive destruction of infrastructures or loss of human lives. First-responders should conduct quickly and efficiently to locate survivors; an operation that becomes difficult when the existing infrastructure and the conventional communication might collapse. Unmanned Aerial Vehicles have emerged as a reliable and cost-effective solution, which aids humans in performing such operations by implementing accurate geographical surveying. The proper combination of hardware and software components (for the design and implementation) has to be selected to produce appropriate results, both with respect to output quality and processing time. In this paper, photogrammetric approaches have been investigated in the terms of collection, processing and producing of dense clouds, orthophotos and digital elevation models considering the aforementioned aspects in disaster risk management missions. Thus, different datasets have been collected where the drone-based flight along with sensing parameters were jointly investigated, evaluating the total processing time and model quality. More specific, the following scenarios were investigated: (i) Selection and combination of the photogrammetric method parameters, (ii) Sensor altitude, and (iii) Area division into separated sectors. The decision about the processing software has be done after assessing the capabilities and the limitations of each solution, since this will affect time, quality and cost of the end result. Under this perspective, a commercial and non-commercial tools compared for the data analysis. Finally, the results of each tool were evaluated while the capabilities and limitations have been perceived.

1 INTRODUCTION

Disaster situations are catastrophic events that are important problems in all the areas of the world, both developed and developing. The problem arises from the extent of the disaster, which either can be natural (geophysical, hydrological, climatological or meteorological) or man-made, which causes massive destruction of infrastructures and loss of human lives. The first few hours following a disaster may be considered as the golden relief time to save the lives of several victims by providing emergency aid (Panda et al., 2019). During the disaster, the existing infrastructure and the conventional communication might collapse, meaning that the affected areas are disconnected without the ability to exchange information. Therefore, it becomes difficult from the first-responders to locate the survivors during the Search And Rescue (SAR) operation that have to conduct quickly and efficiently, and for the field teams to collect information, ranging from immediate metrics on the event itself, to more specific damage, need and recovery information (Kerle et al., 2014).

Nowadays, Unmanned Aerial Vehicles (UAVs) have emerged as a reliable and cost-effective solution, which aids humans in performing SAR operations, gathering early and continuous intelligence of a disaster site and monitoring variety of tasks such as planetary exploration, wireless related services for ground wireless devices, and many more (Al-Kaff et al., 2018; Akram et al., 2020; Kerle et al., 2014).

Drone-based surveying, introduces a multiplicity of additional factors that affect both accuracy and completion times (Kršák et al., 2016). With respect to flight planning, higher travelling speeds and higher altitudes reduces data collection times at the expense of lower sensing resolution (Yusoff et al., 2017). In addition, most positioning devices onboard drone platforms, are generally not able to provide location in-

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formation with accuracy more than ±5m. Real Time Kinematic (RTK) and Direct Real Time Kinematic (DRTK) technology could be deployed at the expense, however, of shorter fly times and travel distances (due mainly to the increasing weight and limited available transmit power). Nevertheless, drone-based surveying stems as a highly favorable approach for on-time surveying especially in disaster risk management operations as exemplified above. Many methods and sensors have been considered to date (Półka et al., 2018) and drone-based approaches have unlocked capabilities that could not be possible before; especially in hard to reach areas (Giordan et al., 2017; Ruzgienė et al., 2015).

UAV platforms, can offer sensing measurements at the low capital and operating cost. Among their benefits are: a) high portability, b) high ground resolution (Nex and Remondino, 2014), c) their ability to deploy easily, d) the ease of capturing images/ videos, e) the ability of drones to fly at arbitrary altitudes (Półka et al., 2018; Giordan et al., 2017) enables collection of data (images/ videos) of variable accuracy depending on the mission. Importantly, drone platforms are easily programmed to address varying requirements, and thus, easily adapt to the user needs (Yeong et al., 2015). Moreover, the high spatial and temporal resolution of onboard sensors and the ability to carry multiple such sensors like 3D sensors or near infrared sensors (Doulamis et al., 2017), enable significant uptake of this technology (Rao et al., 2016).

According the EU funded project INACHUS conclusions (INACHUS Project, 2019), first responders given the strong time pressure on their work, require some flexible solutions that is able to deliver timely data and with frequent update possibility. In addition, they need data that are easy to produce and quick to interpret also by non-remote sensing experts. All these, regard to low-cost and easily deployable and replicable solutions (Nex et al., 2019).

The aim of this work, is to investigate how flight planning parameters and image processing procedure can affect the total flight mission time of an a UAV participation in disaster management by providing situational awareness in less time. More specific, the following points were investigated:

1. Software tools performance using selected photogrammetric parameters.
2. How the model quality and processing time can be affected by flights on different altitudes.
3. How the division of the study area into sectors can affect the processing time.

The rest of the paper is organized as follows; Section 2 details the proposed methodology approach while Section 3 discuss the results obtained. Finally, concluding remarks us drawn and future research direction are highlighted in Section 4.

2 PROPOSED METHODOLOGY

A survey project, has to lead to the decision of how the 2 main steps such as flight planning and image processing, will be conducted. The needs and constrains of each survey mission rely on the considered parameter values from which any inaccuracy could result massive volume of collected data, increased processing time and geographical model estimation errors. A survey, can be considered holistically by processing the collected dataset in its unison to ensure quality. Moreover, when time is of essence then the various steps of the photogrammetry procedure can be designed and executed in a parallel fashion (Vacca et al., 2017; Xing et al., 2010). Under this perspective, the present methodological framework involves a coherence of several stages, aiming to investigate the latter fact and jointly consider flight planning parameters, along with the image processing procedure, in order to expedite the creation of the geographic model. More specific, this work investigates how the following cases/parameters can affect the total mission time and model quality:

1. Calculation of different photogrammetric method parameters using different software packages.
2. Flight altitude.
3. Area sectorization.

Figure 1, provides a schematic diagram of the proposed methodology architecture with the performed operational functions. *Level 1*, refers to flight planning where several parameters has to be taken into consideration such as selection of the appropriate sensor and platform. In addition, some parameters have to be defined regarding image overlapping percentage, flight altitude, area boundaries, etc. *Level 2*, refers to the image processing parameters that investigated and the photogrammetric products that derived, which includes: (i) Camera alignment resulting the tie points, (ii) Dense point cloud generation resulting the depth maps and dense cloud, (iii) 3D Model resulted through mesh and digital elevation model (DEM) products, and (iv) Orthophoto production to eliminate the effect of image perspective and correction of relief shifts caused by terrain conditions. In this level, the performance and sensitivity of both commercial and non-commercial solutions were also investigated. Precisely, the commercial Agisoft Metashape software and the non-commercial photogrammetric package of OpenDroneMap (ODM) were used, that have the ability to establish relative camera positions and use these positions to create accurate three-dimensional models of the ground surface. The models are textured by draping the aerial photographs over them to produce photo-realistic three-dimensional rendered outputs of the ground surface (Quartermaine et al., 2013). Finally, on *Level 3*, the results were extracted and grouped according the investigated cases.

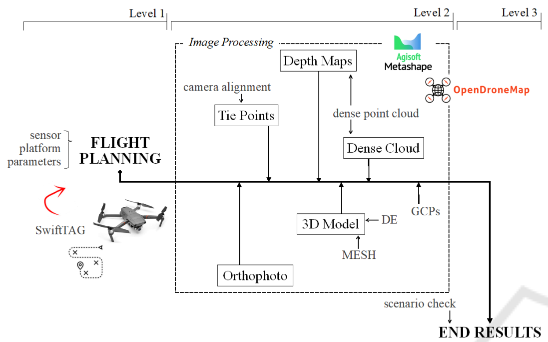

Figure 1: Proposed methodology architecture.

2.1 Implementation Aspects

In order to investigate all cases, 12 flights were conducted using the same UAV and camera parameters for all the flights. DJI Mavic 2 Enterprise was employed with an onboard sensor of 1/2.3” CMOS (complementary metal oxide semiconductor) and effective pixels 12M along with a lens of 82.6° field of view at 35mm and an aperture of f/2.8. Both the forward (p%) and the lateral (q%) overlap were fluctuated between 75-80%. The image location is planned to guarantee the results quality with almost the minimum overlap in each point of the surveyed area. Both position and acquisition order are optimized to minimize the number of acquired images and therefore, their acquisition time. The flight strip orientation is set parallel to the longer side of the surveyed area, as the image collection along the same strip is faster than across adjacent strips, minimizing the same time the number of of strips (Nex et al., 2019). The survey area was 220 m long and 170 m wide covering an area of 0.04 km^2 (Figure 2). Flight planning was completed using the SwiftTAG software that developed from KIOS CoE of the University of Cyprus and the UAV flight was autonomous allowing the automated generation of waypoints on the surveyed area. SwiftTAG software has been chosen, as an open-source solution which has the ability to be customized according the flight needs. The PC used for the analysis, has 6GB of RAM, an i5-7500 CPU core and an internal hard drive for 20TB.

A certain amount of points (field courts, poles

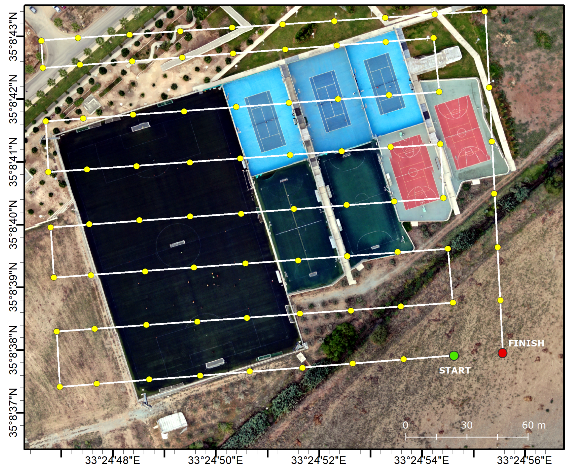

Figure 2: Flight plan of the surveyed area. The dots indicate the waypoints of the strips.

and building corners) clearly identified in the images where selected and measured by the method of RTK GPS survey and used as ground control points (GCPs) for georeferencing the data. Consequently, 55 targets were placed evenly throughout the entire area before the flight. The coordinates of the targets were determined using the Stonex S900 GNSS receiver. According to the manufacturer, the RTK performance of this receiver is 8 mm + 1 ppm RMS × the distance to next reference station horizontally and 15 mm + 1 ppm RMS × the distance to next reference station vertically. Figure 3, shows the location of the GCPs as distributed on study area.

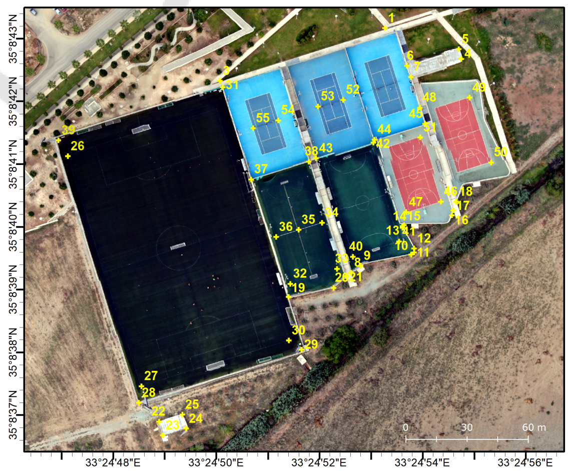

Figure 3: Spatial allocation of GCPs.

For each flight, specific settings and characteristics have been chosen comparing them in as similar conditions as possible, including weather conditions (under sunny, cloudless and breezeless weather conditions) and same flight speed (3 m/s). Flights

A-B refer to different area with the same altitude, where the datasets have been processed using both Agisoft Metashape from Agisoft LLC and ODM as photogrammetric packages. The total processing time and the sensitivity of each package was the primary performance indicator. Flights C-E were designed to investigate the impact of altitude on the processing time. The collected datasets from the respective flights captured images at 60 m, 90 m and 120 m height in the same area. Finally, flights F-L have been conducted to investigate the total processing time when a particular area of interest (AOI) is split into sectors. Specifically, flight F captured the full AOI, while flights G and H split the AOI into two equal sectors and flights I-L split the AOI into 4 equal sectors.

Table 1, summarizes all information about the collected 1.467 images (no oblique images were collected) along with their associated parameters.

Table 1: Collected data information.

	Parameter					
	Flight	**Image No**	**p%**	**q%**	**Alt/ (m)**	**Resolution**
Value	A	54	75	75	80	4Kx2K
	B	49	80	80	120	4Kx2K
	C	143	85	85	60	4Kx2K
	D	73	85	85	90	4Kx2K
	E	49	85	85	120	4Kx2K
	F	326	85	85	40	4Kx2K
	G	186	85	85	40	4Kx2K
	H	182	85	85	40	4Kx2K
	I	122	85	85	40	4Kx2K
	J	94	85	85	40	4Kx2K
	K	109	85	85	40	4Kx2K
	L	110	85	85	40	4Kx2K

3 EXPERIMENTAL RESULTS

3.1 Photogrammetric Parameters

Average time processing values have been extracted performing several repetitions on the collected dataset, using the same processing unit. Table 2, summarizes the results on each photogrammetric stage calculation, using both commercial and non-commercial software tools for 2 distinct datasets. As indicated in the table, ODM did not manage to complete all stages of the photogrammetric product in order to produce the orthophoto and this is the main reason for the significantly reduced execution time.

It has to be noted, that Agisoft Metashape offers 6 accuracy levels, from which the 3rd (medium accuracy) has been selected to account for the results produced by ODM. The batch processing option on the Agisoft Metashape environment, provided an automated processing operation, minimizing the user interaction.

Table 2: Processing time Vs Software package.

	Time (s)		
	Task	**Metashape**	**ODM**
Dataset A	Align	94,25	✓
	Dense Cloud	429,75	✓
	Mesh	3.333,00	Not Produced
	Texture	145,75	Not Produced
	Tiled Model	690,25	✓
	DEM	7,00	Not Produced
	Orthophoto	150,75	✓
	Total Time	**4.850,75**	**1.020,00**
Dataset B	Align	102,33	✓
	Dense Cloud	2.160,67	✓
	Mesh	4.591,00	Not Produced
	Texture	173,00	Not Produced
	Tiled Model	356,67	✓
	DEM	3,00	Not Produced
	Orthophoto	87,00	✓
	Total Time	**7.467,45**	**1.620,00**

Figure 4, presents the resulted 4 orthophotos using both software packages for the 2-dataset collection.

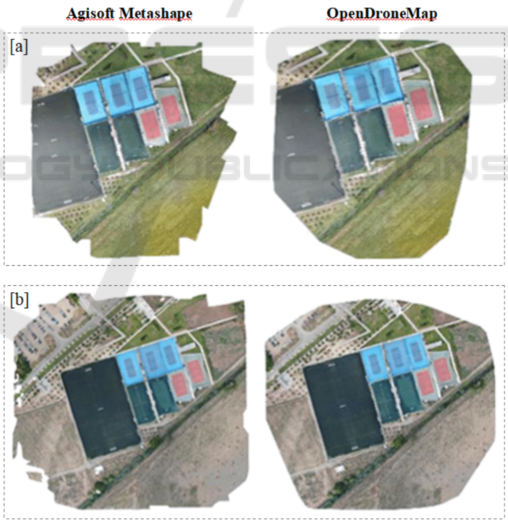

Figure 4: Orthophotos as created for both dataset packages [a] and [b].

The details of RMS errors for the GCPs and the resulted orthophotos for the 2-dataset collection, using both Agisodt Metashape and ODM software packages, are in Table 3.

3.2 Altitude Impact

In order to investigate the impact of altitude on the processing time, 3 flights were performed at 60 m,

Table 3: Measured errors between generated orthophotos and GCPs.

	Residual			
GCP	**Agisoft [a]**	**ODM [a]**	**Agisoft [b]**	**ODM [b]**
29	0,1043	0,1899	0,7338	0,1242
30	0,1599	0,1913	1,5234	0,3148
31	0,1215	0,1350	0,7276	0,2373
36	0,2722	0,0468	0,6699	0,0628
47	0,0518	0,1615	0,4124	0,0509
49	0,0829	0,4352	1,7566	0,0661
RMSE (m)	**0,1499**	**0,2268**	**1,0873**	**0,1740**

90 m and 120 m respectively. The UAV imagery have been processed using AgiSoft Metashape software package.

Table 4, summarizes the results on time processing for the production of each photogrammetric product for height-missions C to E. As is shown, altitude change, has a significant impact on the processing time, reducing from 17.325 s on a 60 m altitude towards to 7.521 s on a 120 m altitude.

Table 4: Processing time Vs Flying altitudes.

	Time (s)		
Task	**60 m**	**90 m**	**120 m**
Align	434,8	180,6	105,2
Dense Cloud	6.796,4	2.753,8	2.172,8
Mesh	8.593,2	4.647,2	4.570,0
Texture	435,6	239,4	174,0
Tiled Model	845,8	462,1	366,2
DEM	6,2	3,6	3,2
Orthophoto	212,8	150,2	129,8
Total Images	**143**	**73**	**49**
Total Time	**17.324,8**	**8.433,9**	**7.521,2**

Figure 5, presents the processing time for each examined parameter per altitude level. It is obvious that in high altitudes, where there are less images covering the AOI, the processing time reduces significantly. Dense and cloud mesh, stand out as the parameters with the major reduction on processing time when increasing the image capture altitude.

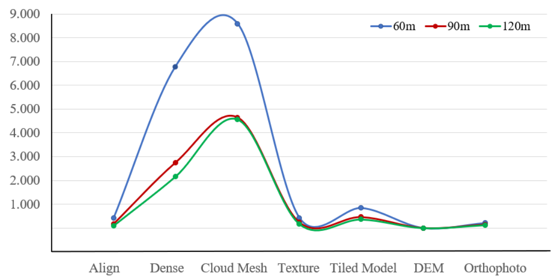

Figure 5: Processing time (sec) per altitude for each examined parameter.

Figure 6, presents a sample of the UAV imagery processing in Agisoft Metashape software environment, at 60 m flight altitude. The blue rectangles represent the collected images as distributed over the AOI, where the black axes refer to the platform position on capturing time as it is calculated with a ±5m GPS accuracy. In addition, a 3D model has been extracted of the AOI.

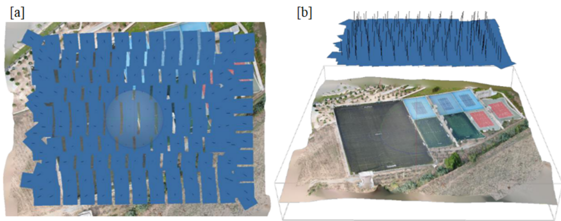

Figure 6: Image processing, where: (a) Distribution of images collected to cover the AOI, and (b) 3D model extraction of the AOI.

Figure 7, presents the resulted orthophotos per examined altitude flight and as fitted on the respect scene from Google satellite.

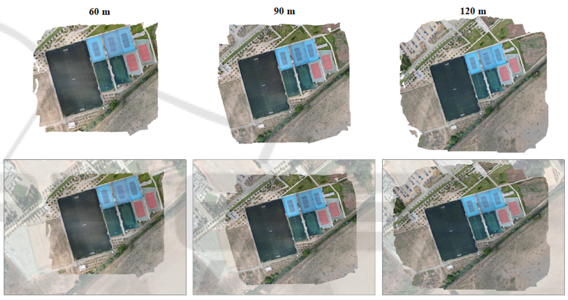

Figure 7: Resulted orthophotos for each altitude flight compared to the respect scene of Google satellite basemap.

Table 5, summarizes the total error values on GCPs for the resulted orthophotos per altitude.

Table 5: Measured errors between generated orthophotos per altitude and GCPs.

	Residual		
GCP	**60 m**	**90 m**	**120 m**
25	0,1584	0,3692	0,3690
26	0,0487	0,1606	0,4107
27	0,3064	0,1664	0,0839
30	0,1309	0,2409	0,1559
31	0,2011	0,1958	0,1453
36	0,1389	0,3060	0,3573
47	0,1988	0,2140	0,2961
49	0,1173	0,2759	0,1466
RMSE (m)	**0,1773**	**0,2504**	**0,2725**

3.3 AOI Coverage

The processing time of a selected AOI, proved to be significant depended with the respect covered area. Table 6, summarizes the processing time when area sectorization is applied in each overlap-mission. As it is shown, when the dataset covered the whole AOI, the total completion time was less than the total sum time of the subdivided areas 2a and 2b respectively. The same trend, is also observed on the next datasets where the AOI is divided into 4 sectors. The sum value of the total completion time of the last four datasets (4a-4d), has been approximately the same with the sum value of datasets 2a and 2b respectively. In the same way, this sum value is also close enough to total completion time of the dataset refereed to the whole AOI (a). Importantly though, smaller sectors enable parallelization in the execution and thus significantly slash processing time.

In Figure 8, the resulted orthophotos are illustrated, as derived from AOI sectorization, with the respect fitted scene from Google Satellite.

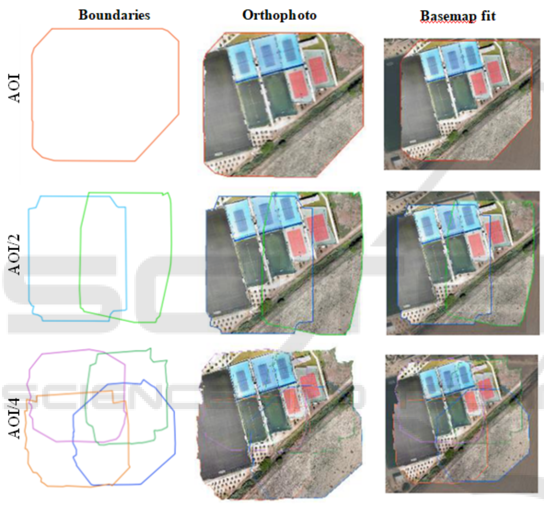

Figure 8: Resulted orthophotos for each flight with different AOI boundaries, compared to the respect scene of Google satellite basemap.

4 CONCLUSIONS

The proper combination of both hardware and software solutions is necessary to design and implement an accurate geographical survey. These components, are vital in the production of appropriate results in the terms of output quality and processing time, especially for disaster risk management. This paper, provides a very brief overview on how the total mission time and model quality can be affected during the processing of specific photogrammetric parameters. The investigated cases based on empirical findings from an extensive surveying campaign totaling 12 flights using various parameter settings (including altitude and coverage areas). In addition, a comparison of state-of-the-art commercial and non-commercial photogrammetric software was conducted to demonstrate the possible benefits in completion time from the use of different data processing algorithms.

The major findings of this work, can be summarized in some key points. First, the height of the flight plays significant role on time measurements and achieved accuracy. It is associated with the resulted orthophoto and the value of height should be calculated along with the focal length of the camera to meet the needed requirements. However, when there is a margin, a higher altitude could be considered for less flight mission and less processing time. Another key point is that the side and forward overlap of images is essential to acquire a higher accuracy which increases the time has to be spend for acquiring images and processing them in the software. However, smaller sectors enable parallel processing that significantly slash processing time. Finally, regarding the analysis software package, AgiSoft Metashape commercial software proved to be a reliable solution for data processing.

4.1 Future Recommendation

Given the importance of model accuracy when designing time-sensitive surveys, the following aspects should be taken into consideration for future work.

Use and test additional photogrammetric software in order to understand the limitations and capabilities of various algorithms employed. More commercial and non-commercial packages could be evaluated for their performance and their end results quality, in order to identify the best combination on processing time and model accuracy. Moreover, a further research is needed on how the quality of the orthophotos can be regulated to further improve the overall processing time. In addition, several parameters affecting the flight should be taken into consideration that might affect the survey overall measurements time and the output quality and accuracy. The drone size (mainly for its' vulnerability to weather conditions such as wind) and drone speed while taking photos should be investigated as well along with the influence of weather conditions and solar positioning during the UAV survey.

Another aspect that should take into consideration, is the use of Artificial Intelligence (AI) techniques to: (1) automate processes that require heavy manual operation; (2) improve performance of processes in terms of efficiency and robustness (Qin and Gruen, 2021).

Table 6: Processing time Vs Sectorized AOI.

	Time (s)						
Task	**AOI** (a)	**AOI/2** (2a)	**AOI/2** (2b)	**AOI/4** (4a)	**AOI/4** (4b)	**AOI/4** (4c)	**AOI/4** (4d)
Align	972,5	411,5	463,7	222,5	196,7	223,5	231,2
Dense Cloud	11.274,7	6.046,2	6.427,7	3.084,2	2.413,2	3.469,0	4.698,5
Mesh	17.100,0	10.809,2	10.185,0	4.682,7	3.416,7	4.740,5	5.887,2
Texture	710,0	414,7	405,5	275,0	21,0	255,2	256,5
Tiled Model	1.293,5	789,0	762,7	590,5	487,7	531,2	448,5
DEM	13,7	7,2	6,2	6,0	4,7	4,2	4,2
Orthophoto	649,7	434,5	429,7	168,0	141,0	182,2	212,5
Total Time	**30.014,25**	**18.912,5**	**18.680,7**	**9.029,7**	**6.875,2**	**9.406,0**	**11.738,7**
		↪	↩	↪			↩
		37.593,2			**37.049,6**		

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