UNMANNED AERIAL VEHICLES BASED 3D CITY MODELING DATA COLLECTION, PROCESSING AND ANALYSIS THE CASE OF YAVUZ SINAN NEIGHBORHOOD

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ABSTRACT: In recent decades, Unmanned Aerial Vehicles (UAVs) have shifted from being exclusively used for military purposes to playing a role in civilian applications, with small drones becoming available for purchase in markets. Simultaneously, 3D city models (3DCMs) have taken a significant place in various fields of research, especially after the rise of computer graphics and improved storage abilities. High number of publications and their Compound Annual Growth Rate (CAGR) were observed in both 3DCM and UAV research separately, while limited publications were found when searching for topics involving both 3DCM and UAV. The main motivation behind this research is to integrate UAV technologies into 3D city modeling. Data, including aerial and oblique imagery, were collected in the Yavuz Sinan neighborhood, located in the historical peninsula of Fatih province in Istanbul. Multiple UAV flights were performed using the DJI Phantom 4 drone and its built-in high-resolution camera, with flight settings based on previous photogrammetry research. The imagery was processed using key-points matching techniques, and the resulting data were integrated into the 3D modeling platform as input. Produced maps were recognized to have higher resolution and accuracy when compared with satellite imagery. The Digital Terrain Model (DTM) was produced from a high-density classified point cloud dataset, with all points classified as vegetation, buildings, or man-made features being removed to create the DTM. The resulting mesh model, relying on both high-resolution aerial and oblique imagery, provides textured building roofs, elevations, as well as vegetation and terrain information. However, the derived buildings' footprints had limitations due to the fact that the buildings are side-attached, leading to the manual editing of polygons to split them into separate buildings of different heights. The generated building masses were represented by least solid polygons, allowing for urban simulation. Finally, in an attempt to examine the analysis ability of

UAV-based 3DCM, a pedestrian wind comfort analysis was performed. The simulation relied on Computational Fluid Dynamics (CFD) for 32 wind directions, with wind data obtained from the nearest weather station. The Lawson wind comfort criterion was used to assess the pedestrian wind comfort at a height of 1.6 meters from the ground. The study concludes with recommendations for maximizing the power of integrating UAVs as data collection tools for 3DCM to overcome data limitations. Lastly, the study provides general guidance for the workflow, highlighting the sections that can benefit future research likely to follow the same approach.
KEYWORDS: Unmanned Aerial Vehicles, 3D city models, pedestrian wind comfort analysis, Drone, Yavuz Sinan neighbourhood.

INTRODUCTION

In the first of October 2019, UAVs' trends according to SCOPUS and Web of Science database were observed throughout different publications in order to examine the importance of UAVs in different fields (Web-1, Web-2). A total number of 56,567 document were found according to SCOPUS academic bibliographic database. On the other hand, a total number of 31,682 document were observed when searching for the same terms in the Web of Science database. Significant rise in the number of publications was observed in the last decade, a number of 114 publications detected in SCOPUS database in 1995, rising to its peak in 2018 with a total of 8711 publications, Figure 1. And a total number of 61 publications according to Web of Science database, reaching its peak at the same year with 5795 publications in 2018. The total number of publications in both SCOPUS and WoS reached 9504 in the last year 2019. The result shows a significant interest and trend for different terms of the UAVs as observed from both academic databases.

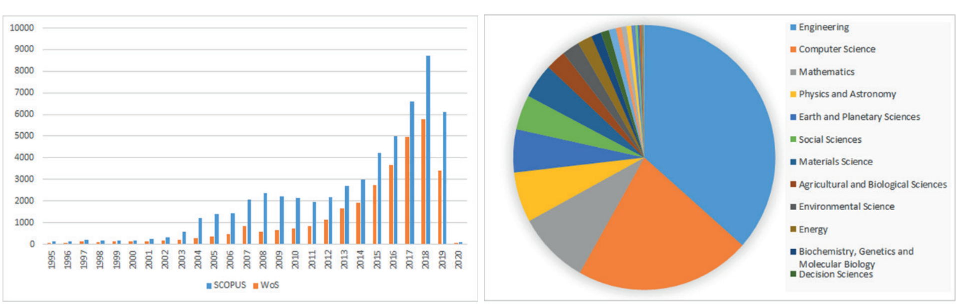


Figure 1. UAV Publications by year according to SCOPUS and WoS Databases (Web-1, Web-2) (Date: October 2019) (left), UAV Publications by subject area according to SCOPUS Databases (Web-2) (Date: October 2019) (right).

When viewing the records according to different subject area, a total of 37834 publications were published in engineering subject area according to SCOPUS, which resembles 67% of the total number of publications, 22425 publications were under the computer science subject area, Figure 1. For both social and environmental sciences, 4407 and 2255 publications were observed respectively, whereas there is a need to be awareness with the power of UAVs, which can be used widely in the academic social and environmental research studies.

It is worth mentioning that United States and China are the leading countries for the UAVs publications in both SCOPUS and WoS database, with a total number of 24372 and 16521 respectively in both databases. Followed by German, England and South Korea, Italy which are competing in the third forth, and fifth sixth places. Turkey lies in the seventeenth and fifteenth rank according to number of publications in SCOPUS and WoS respectively, with a total number of 1140 publications in both databases, representing about 1.3% of total publications.

In Turkey, analysis was done according to SCOPUS database for a total of 653 publications and 5551 citations when searching for the same term, the highest affiliation observed was 91 documents for Istanbul Technical University (ITU), followed by Middle East Technical University (METU) and Turkish Air Force academy with 79 and 59 publications respectively. Both number of publications and citation reached its peak in year 2018, with 100 documents published and 1177 citation. According to WoS for total of 487 documents and 3779 citations, again Istanbul Technical University (ITU) leads the rank with 73 documents, followed by Turkish Air Force and Turkish Air Force academy with same number of 62 publications. The peak for both publications and citation go back to 2018 again, with 75 document and 840 citation, Figure 2.

Figure 2. UAV Publications in Turkey by year (Right), UAV citations for Turkish publications by year (Left) (Web-1, Web-2) (Date: October 2019).

In the second half of November 2019, 3D virtual city trends according to SCOPUS (Web-2) and Web of Science (Web-1) database were observed throughout different publications in order to examine the trend of 3D virtual cities' various terms with regard to different subject areas. A total number of 13,634 document were found according to SCOPUS academic bibliographic database. On the other hand, a total number of 35,894 document were observed when searching for the same terms in the Web of Science database. Significant rise in the number of publications was observed since 1995, a number of 31 publications detected in SCOPUS database in 1995, rising to its peak in 2018 with a total of 1470 publications (Figure 3). And a total number of 165 publications according to Web of Science database in 1995, reaching its peak at the same year with 3874 publications in 2018. The total number of publications in both SCOPUS and WoS reached 4062 in the last year 2019. The result shows a significant interest and trend for different terms regarding 3D virtual cities from both academic databases.

When viewing the records according to different subject area, a total of 5497 publications were published in computer science subject area according to SCOPUS, which resembles 22% of the total number of publications, 4023 publications were under the engineering subject area (Figure 3). For both social and environmental sciences, 3778 and 1762 publications were observed respectively, resembling 22% of the total publication regarding the academic social and environmental research studies.

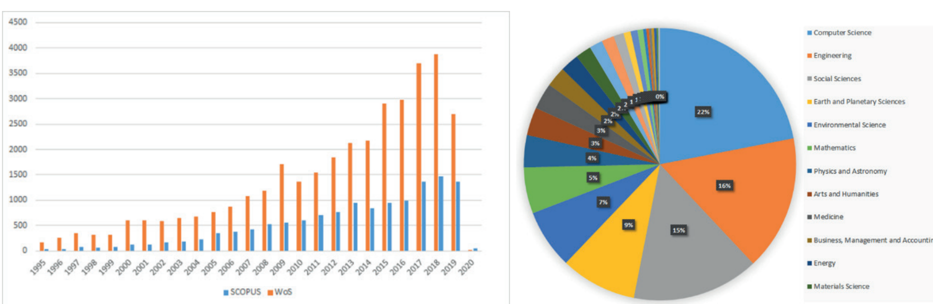


Figure 3. 3D Virtual City Global Publications by Year according to SCOPUS and WoS Database (Web-1, Web-2) (Date: November 2019) (left). 3D Virtual City Publications by subject area according to SCOPUS Database (Web-2) (Date: November 2019) (right).

Worth mentioning that United States and China are the leading countries for the 3D virtual city publications in both SCOPUS and WoS database, with a total number of 12,705 and 9,993 respectively in both databases. Followed by German, England and Italy in SCOPUS, and Mexico, Japan, and Canada in WoS database. Turkey lies in the sixteenth and twenty seventh rank according to number of publications in SCOPUS and WoS respectively, with a total number of 547 publications in both databases, representing about 0.11% of total publications.

In Turkey, analysis was done according to SCOPUS database for a total of 227 publications and 1452 citation when searching for the same term, the highest affiliation observed was 27 documents for Istanbul Technical University (ITU), followed by Ankara University and Middle East Technical University (METU) with 17 and 17 publications respectively. Comparatively, according to WoS for total of 320 documents and 6,003 citation, Middle East Technical University (METU) leads the rank with 38 documents, followed by Istanbul Technical University (ITU) with a total number of 32 publications. Number of publications for both databases reached its peak in year 2017, with total of 70 document published, whereas citation reached its peak in 2019 according to SCOPUS with 323 citations, and in 2018 according to WoS with 1390 citation (Figure 4).

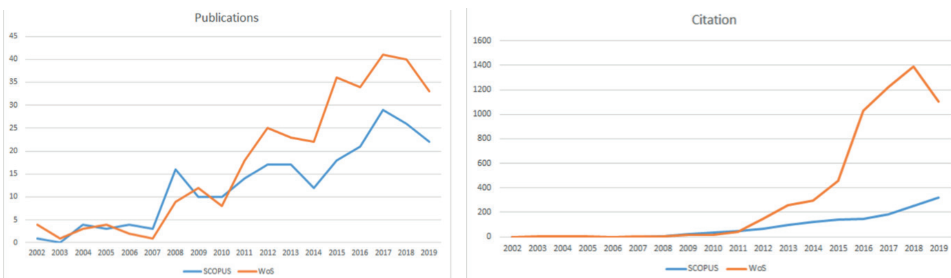


Figure 4. 3D Virtual City Publications in Turkey by year according to SCOPUS and WoS Database (Web-1, Web-2) (Date: November 2019).

Similarly, by examining the trend of both 3D virtual city and UAV together, a total number of 182 publications were found when examining SCOPUS database (Web-2). For 182 publications found, a total of 903 citation were detected, highest publication number goes back to 2017, while highest citation detected was in 2019 (Figure 5). Publications covered various subject areas, 30% of publications were found under computer science, followed by engineering and social sciences with 17% and 13% respectively. Both social science and environmental science subjects involved 18% of the total publications (Figure 5). Again, China and USA were the leading countries of the publications, with 27 and 25 publications respectively, followed by Italy, German and France. Turkey took the seventh rank with seven publications, representing 3.8% of the total publications. In Turkey, the seven publications detected were cited 174 times, the highest citation with 133 cite were for Pehlivanoglu (2012). Highest affiliation were Istanbul Technical University (ITU) and Hacettepe University with two publications each. WoS were not included in the integration due to imprecision of the data results when searching for the same terms.

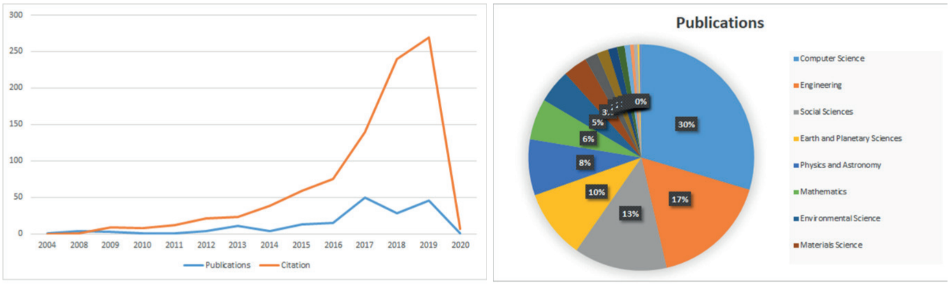


Figure 5. 3D Virtual City and UAV Publications and Citations by year (Web-2) (Date: November 2019). 3D Virtual City and UAV Publications by Subject Area (Web-2) (Date: October 2019).

Table 1 bellow concludes SCOPUS and WoS database results with regard to 3D virtual city, UAV, and the combination of both terms. Cumulative annual growth rate (CAGR) between 2008 and 2018 were calculated (Eq. 1) to show the high trend of both terms, while the shortage of publications with regard to their integration. Although the CAGR in the global publications regarding the integration of 3D virtual city and UAV is increasing, but it is not the case in Turkey, which covers almost 19.2% of the global citation.

$$CAGR = (SP/PP) \wedge (1/(n-1)) -1 \quad (1)$$

Comparison Point		3D Virtual City		UAV		3D City and UAV	
		Global	Turkey	Global	Turkey	Global	Turkey
Total Publications	SCOPUS	13,634	227	56,567	653	182	7
	WoS	35,894	320	31,682	487	NA	NA
CAGR 2008-2018	SCOPUS	12%	6%	16%	56%	**24%**	**0%**
	WoS	14%	18%	29%	64%	NA	NA
Total Citation	SCOPUS	NA	1,452	NA	5,551	**903**	**174**
	WoS	NA	6,003	NA	3,779	NA	NA

Table 1. SCOPUS and WoS database results: 3D virtual city, UAV, and the combination of both terms, CAGR.

In Turkey, seven studies were detected in Turkey with both UAV and 3D virtual city key words included. The highest citation was for Pehlivanoglu (2012) followed by Koyuncu and Inalhan (2008), both articles focus on the flight path planning algorithms. Uysal et al. (2013) used photographs generated from UAV with attached Canon camera to it as a reference for a manually modeled a historical mosque, which can be used for cultural heritage documentations. Anbaroğlu (2017) examined the potentials of using UAV for logistic and cargo delivery purposes in urban environment. Yalçin et al. (2017) used UAV to scan Istanbul Technical University campus, generating 3D point cloud dataset, which by segmentation algorithms can be used to generate 3D model robustly, to perform urban solar analysis map. Yürür et al. (2017) proposed an approach of 3D geological site reconstruction using UAV based high resolution imageries, the study aims at transferring these maps for the future generations as a documentation for their geological heritage. Erenoglu et al. (2017) compared UAV surveying abilities with the traditional terrestrial surveying methods, high accuracy results of UAV based model was detected, with -0.0055 meters average error, which shows the high accuracy and reliability of the generated outputs from UAV survey.

STUDY AREA

Istanbul is the most popular city in Turkey, it is considered to be Turkey's touristic, cultural and historical capital. Istanbul is located in north east of turkey (Figure 6). It connects the Asian and European sides of the country through three bridges, the city is popular with the major urban waterway known as golden horn, which separates the historical and the modern part of the city. Fatih district is the capital district hosting provincial authorities' buildings, the district is surrounded by the golden horn from a side, the Marmara Sea, and the old city walls, which is known as the historical peninsula of Fatih (Figure 6). Fatih district contains a total number of 57 neighbourhood, including Yavuz Sinan neighbourhood, the case study of the thesis.

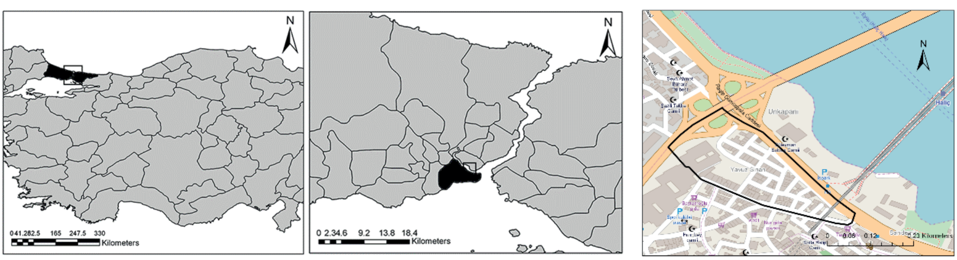


Figure 6. Location of Istanbul in Turkey's Map (Left), Location of Fatih District in Istanbul's Map (Middle), Yavuz Sinan Neighbourhood Map (Right).

Yavuz Sinan neighbourhood is located in the historical peninsula side of the golden horn, between two bridges that connect the historical peninsula with the other side of the golden horn, the first bridge for both vehicles and pedestrians is Ataturk bridge, and the second bridge for metro and pedestrians is golden horn (Halic) bridge (Figure 6). Yavuz Sinan neighbourhood has an area of 0.051 square kilometre, with a total of 252 population, the maximum building heights of the neighbourhood is about 15 m. the neighbourhood includes 1 commercial building, 3 mosques, residential houses with commercial shops or restaurants in ground floor, and hotels. For the data collection, multiple drone flights were done to capture all the buildings from top and sides, in two separate days, flights were performed, the following section briefly discuss the UAV regulations in Istanbul, Turkey. Then procedures of data collection will be clarified.

Istanbul UAV Regulations - Directorate General of Civil Aviation (IHA)

Before going through the data collection section, it is important to highlight Istanbul's regulation with regard to UAV, Directorate General of Civil Aviation (Web-3) is the responsible institution for civil UAV registration, air traffic service, and flight operations. Terms used in UAV regulation section will be discussed with accordance to Istanbul case depending on the regulations provided by the institution (Web-4). (A) Applicability: Weight classification in Turkey are four classes (Table 2). IHA-0 and IHA-1 vehicles must be registered to the DGCA internet-based registration system before performing any flights. DGCA should be informed before performing trial flights with the scope of research and development of UAVs (Web-4).

Personal License	Weight
IHA-0	Less than 500 gr
IHA-1	500 gr to less than 25 kg
IHA-2	25 kg to less than 150 kg
IHA-3	150 kg and more

Table 2. IHA license Classes by weight (Web-4)

(B) Technical requirement: Regarding the technical requirements, regulations provided by the Directorate General of Civil Aviation institution (Web-3) in both categories of IHA-0 and IHA-1 regulates the presence of product catalogue, production year, manufacturer country, criminal record for the owner, conformity of standards provided by the manufacturer, and invoice with GTIP code. These procedures ensure the technical safety of the UAV, so as to be applicable for flights in Turkey. Technical specifications provided in Turkey's civil aviation law (Web-4) includes emergency landing option, battery monitor, etc. specifications are assigned to various UAV categories specified in the table 3.1. It is highly recommended in the pre-flight process to carefully follow the instructions (Web-4) provided by the government for the public and self-safety, hiring a professional UAV pilot is recommended in the first flight.(C) Operation Limitations: Turkish authority defined sensitive and secured zones where UAV are either not allowed, or allowed with certain restrictions (like altitude), these restrictions and zones are then assigned to the manufacturer company's flight planning smart device applications. The Geo zone map (no-fly zone) (Web-5, Web-6) of Istanbul (Figure 7) shows zones assigned to airports, prisons, and local administrative areas. Highly detailed maps can include densely populated areas, whereas different types of restriction zones can be assigned. Fly Safe Geo Zone Map (Figure 7) provides also different restriction maps for various UAV products of DJI company. It is usually highly recommended to check the map before the choice of the case area in the pre-flight process. (D) Administrative Procedures: Following the instructions and achieving the requirements of UAV in some countries are not enough, administrative permissions are also required in case of Turkey. Several permissions including safety declarations and usage permission from the Information Technologies and Communication Authority should also be included, informing the authority by the date, number and frequencies of the flights (for civil traffic control purposes). The administrative procedures and permissions in most cases are considered as an obstruction to the usage of UAV, as it hardly can be obtained. (E) Human Resource Requirements: Qualification of the operator mainly dependable on the category of the UAV in table 2. It is illegal to perform any flight unless the operator had training and knowledge, operator with no UAV license convenient to the weight category may expose the operator to legal liability. To overcome such issue, a professional licensed operator was hired to perform this study's surveying flights. The operator in our case didn't have a pre-knowledge with the mapping applications and processes, but was aware of the emergency landings, battery endurance, and most importantly, the regulations assigned by the local government, which affected even the case study choice.

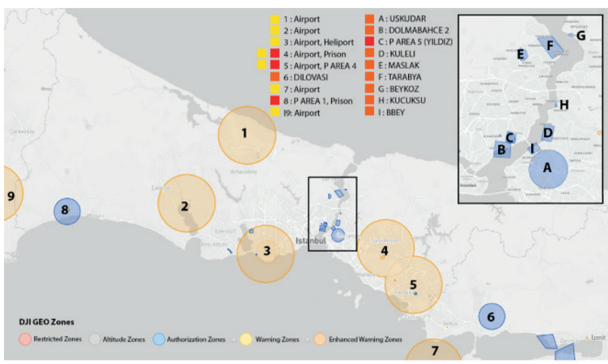


Figure 7. GEO Zone Map Istanbul (Web-5, Web-6).

DATA COLLECTION

In order to cover the whole area of the neighbourhood and its surrounding, multiple flights designed using PIX4D mobile application, including both aerial and oblique photos, the drone used in the imagery process was DJI Phantom 4. The choice of the drone depended on several aspects, firstly is its ability to capture high resolution 4k images, the images' size produced by the drone is 4000*3000 pixels, with 72 dpi resolution, all photos produced has geo-referencing according to the built-in GPS, with latitude, longitude and altitude measurements, the camera has gimbal that stabilize the image for less blurriness during the drone's motion and has the ability to capture different camera angle (oblique, aerial). Secondly, the DJI platform is compatible with different data processing tools like PIX4D mapper, Reality Capture, and Drone Deploy, along with its compatibility with the flight planning tools of the same platforms. Thirdly, the weight of the DJI Phantom 4 is 1380 grams, making the pilot license falls in the least license category according to the Turkish

Civil Aviation Law (Web-3). Lastly, the battery of the drone lasts for about 20 minutes, including the take-off and landing, giving about 15 minutes single flight maximum duration. As for mentioning, the used drone in this thesis was rented with daily fees including license holder operator, the fees are included in the cost section bellow.

As mentioned, several flights were performed in a duration of two days. Details of these flights are as following, (1) Flight Day One: Dates 4th of October 2019, the images were taken between 2:53 pm and 3:44 pm, the total number of the images taken were 137 images, the basepoint of the operator was on the golden horn walkway, two aerial flight and two grid oblique flights (Figure 8). In the aerial flight, drone altitude was set to be 80 meter above ground, camera angle set to be 90 degree (perpendicular to ground), front and side overlap of 70%, grid were aligned with the street pattern in the first flight (about 4 min duration), and perpendicular to it in the second flight (about 5 min duration), 42 image were captured in both directions. In the oblique flights, double grid mission was performed, drone altitude was set to be 80 meters, camera angle was set to be 60 degrees not looking at grid centre (camera face along the grid lines), with front and side overlap of 60%, with a total duration of about 12 min, 96 images were captured.

Images captured in this day were considered to be a trial, to examine the and better understand the whole process, images were processed in multiple programs, the general observations were that numerous buildings' elevations were not captured, due to the narrow street grid of the neighbourhood, the orhtomosaic map produced was of 19352 pixels width and 12398 pixels height and 96 dpi resolution. the first processing time in PIX4D desktop took about 4 hours, in PIX4D and Drone Deploy platforms, just took the images uploading time, the resulted mesh had some distortions in the buildings' elevations. As mentioned, the problem was that number of buildings' elevations were not captured due to the narrow street grid, this resulted in the second flight day.

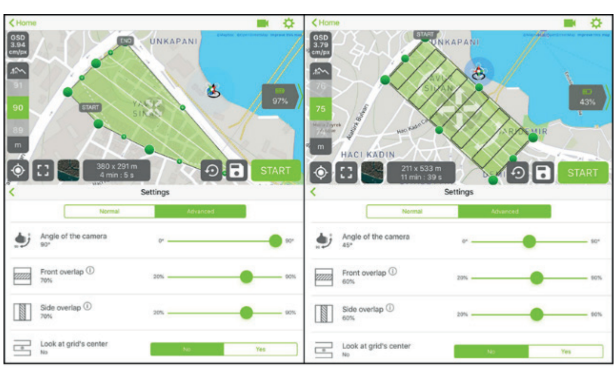


Figure 8. Flight 1 plan and settings (Pix4D App), Aerial flight (left), oblique flight (right).

(2) Flight Day Two: Dates 15th of October 2019, the images were taken between 2:41 pm and 4:31 pm, the total number of images taken were 807 images, since there isn't distortion in the orthomosaic map, only oblique photos were taken, whereas all georeferenced images can be combined in the processing, the basepoint of the operator was on building roof top terrace (Figure 9), enabling the operator to trace the drone and perform wider radius away from the controller. A total number of five oblique flights were performed, drone altitude was set to be 55 meters, in order to capture all buildings' elevations, front and side overlaps were increased to be 90% and 70% respectively, the camera angle was set to be 60 degrees not looking at grid centre (camera face along the grid lines).

Figure 9. Flight 2 plan and settings (Pix4D App), oblique flights (left), Circular path flight (upper right), oblique flight settings (lower right).

By increasing the front overlap, the drone captured more photos along its motion, lowering its speed when compared to previous flights, and by increasing the side overlap, the drone had to travel longer distance to cover the given mission area. By the first day mission's settings, we could cover the whole area by one flight, but by applying the second day mission's setting, there was a need to split the scanning into three overlapping sections. Double grid mission was performed in each section with the given mission settings applied, each planned to be about 12-minute duration and grids were aligned with street's pattern. Followed by two circular missions to capture the external building's walls which appeared to be distorted in the previous mesh model, angle between images were set to be 5 degrees in the first flight, and 10 degrees in the second, depending on the available drone battery. The resulting georeferenced images were added to the aerial images produced previously, creating a dataset of 944 georeferenced aerial and oblique images that were used in the processing.

Other datasets used in the generation of the 3D neighbourhood model were the neighbourhood base map, the file format used is DXF file, where the buildings' footprint was filtered, georeferenced, flattened, and put on top of orthomosaic map to examine its compatibility. Streets' data base used in the production of the three-dimensional model is produced from OpenStreetMap data base (Web-7), buildings of open street map data base were not used to conduct the 3d due to its incompatibility with the orthomosaic map.

DJI Phantom 4 was used as mentioned in data collection section, the controller was connected to a smart device having the mission planning application and connected to the internet. For the processing and 3d model implementation, portable gaming computer device aside to different cloud platforms that uses workstations to process data, the used device is Lenovo Ideapad Y700, with the following specifications: CPU: 2.6GHz Intel Core i7-6700HQ (quad-core, 6MB cache, up to 3.5GHz with Turbo Boost), Graphics: Nvidia GeForce GTX 960M (4GB DDR5 VRAM), Intel HD Graphics 530, RAM: 16GB DDR4 2133MHz and Storage: 128 GB SSD, 1TB HDD (5,400 RPM).

The software used in the study are divided into 4 categories, data collection software and applications, data processing software and platforms, 3D model implementation software, and presentation software, see Figure 10.

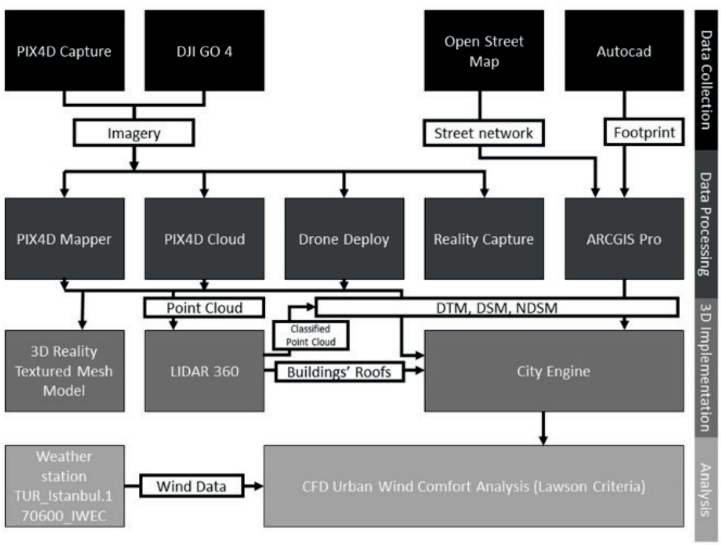


Figure 10. Work Flow according to Software Used.

Data collection software and applications

- PIX4D Capture: Mission planning and control application used to capture drone imagery with precise overlap, the application is totally free and can be used through smart devices
- DJI GO4: application designed by the manufacturer of the DJI Phantom 4, and it is used to track the drone while being on mission, it views life streaming of the drone camera, providing details about the altitude and precise location on map.

- AutoCAD 2020: 2D data provided were modified, flattened, and filtered. In order to be used as building footprints.
- Open Street Map: the open-source platform was used to provide the model with city model elements like streets, buildings footprints were incompatible with the real situation thus were ignored.
- ARCGIS Pro: the software provides different file formats, allowed the overlapping of the DWG buildings footprints and the orthomosaic map, beside the geo-referencing of the DWG file on the map.
- 3.3.2 Data processing software and platforms
- PIX4D Mapper: photogrammetry software used for imagery allocation and the production of point cloud data, used for generation of multiple datasets used in the study beside the data quality report
- PIX4D Pro Cloud: images were uploaded to the cloud to control the precision of the data produced by the software.
- Drone Deploy Dashboard: images were uploaded to the dashboard, to be processed, and to provide variable datasets used for the study.
- 3D Survey: software used for the classification of the point cloud data set for buildings' roofs, to be used as building heights reference in the 3d model generation.
- ARCGIS Pro: software used to transfer the DWG footprints to polygons, as to be used in the model generation. Different geo-referenced datasets were viewed to control their accuracy.

3D Model Implementation software

- City Engine: different 2D datasets and 3D maps used in the study were integrated to create the final 3D model of the neighbourhood.
- CityGRID: software used in the model texturing according to the aerial and oblique image dataset.

Presentation Software

- Adobe Photoshop CC 2019: imagery and maps refining and editing software.
- ARCGIS Pro: Software used for the presentation of maps included in the study, providing scale bar, map legend, and north arrow.
- Reality Capture: drone produced imagery were reprocessed, and point cloud data were produced, the software doesn't provide data export unless having a paid license, thus was just used for point cloud presentation.
- Cesium Ion: platform used for the final product visualization.

Cost Overview

The reliability of UAV as a surveying depends on the precision of the data and the cost effectiveness of such surveying tool, so it is crucial to highlight and discuss various processes performed in this study. The table below clarify the processes regarding this study giving the cost of each step in the processes. Since costs are time and location dependable, it is important to consider both the date and the case study (including the total area covered) before proceeding into this section. All prices given in table 3.2 are in US dollars. Steps applied in this study, additions and alternatives are provided reviewing a full cost review for both research and commercial purposes.

Worth mentioning, free versions of commercial applications and software and dashboards in most cases doesn't provide a full availability of processing; whereas limited editions are provided as a trial version. The study relied mainly on the open-source software, but difficulties with regard to the open-source application setup (as in case of CGAL) and processing (as in case of Open-FOAM analysis and photogrammetry software) were detected. The open-source software in many cases were found not user friendly, depending on script language and coding pre-knowledge. Unlike commercial software open-source software lacks video and document tutorials. As mentioned with regard to data collection, hiring a professional licensed operator with daily rent was found more cost effective than purchasing the UAV, battery, smart device, and licensing expenses, which can be less effective in case of commercial dependent surveying.

Process	Step	Product	Cost	Alternatives	Cost
Data Collection	Surveying	DJI Phantom 4 Pro	2,900	DJI Phantom 4 Pro Daily Renting with Licensed Operator	Around 185
		DJI Phantom 4 Pro 2 Batteries	450		
		Smart Device	300		
		License	See ()		
	Surveying Applications	Drone Deploy	0	PIX4D Capture	0
	GCP	3D GPS	133	University Laboratory	0
Data Processing	Personal Computer	Lenovo	1000	University Laboratory	0
	2D Software	AutoCAD	500	Student Version	0
	Spatial data processing	ARCGIS	800	University Laboratory	0
	Photogrammetry processing	Pix4D	520 per month	Limited free trial	0
		Drone Deploy	399 per month	Free Trial 1 month	0
	Point Cloud Processing	LIDAR 360	0	CGAL Classifier	0
	Building Footprint Generation	ARCGIS	800	University Laboratory	0
	Mesh Generation	MeshLab	0		
	Mesh Processing	Blender	0		
3D Implementation	3D City Modeling	CityEngine		Free Trial 1 month	0
	Data Driven Method	CGAL	0	Building Reconstruction	NA
Analysis	Pedestrian Comfort Analysis	Simulation Hub	500 monthly	Free Trial for 1 Analysis	0
	CFD Analysis	Open-Foam	0		
Presentation	Image Editing – Maps Presentations	Adobe Photoshop	239	University Laboratory	0

Table 3. Cost Overview.

DATA PROCESSING

In this section, data quality will be reviewed according to the software reports, then various processing for various produced 2D and 3D data will be explained and clarified, as to be an input for the 3DCM.

Data Quality Report

Observations found from the first flight data quality report for the neighbourhood and its surrounding (0.212 km2 according to the report), total processing time was 19m:41 s, median of 37493 key points per image were detected, 126 out of 137 images calibrated (91%). Generated points' density was 8,291,377 points, with an average density of 59.75 per cubic meter, Figure 11 shows the reported data results. As mentioned, the generated mesh and point cloud data were lacking parts of building details, due to the street width and the low front overlap in the flight settings, also distortion can be observed in the generated 3D mesh model. The orthomosaic map was satisfying but the DSM generated had the same distortion problem as the mesh model, see Figure 12, as the DSM depends on the point cloud data. It was concluded that the oblique flight settings need modifications, in order to capture all buildings' elevations, for more precise DSM and 3d mesh model.

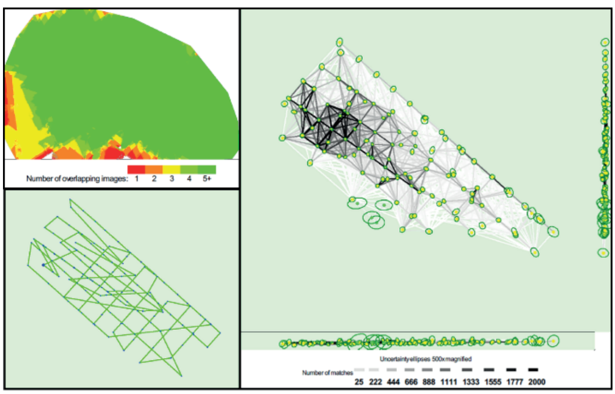


Figure 11. Data Quality Report for flight 1, images overlap map (upper left), initial images' position (lower left), links between matches (right).

Figure 12. Buildings' distortion in the mesh of flight 1 (up), DSM distortion for flight 1 (down).

Accordingly, by increasing the front overlap of the flight settings (as mentioned in flight day two in the data collection section), the area covered was 0.257 km2, representing the neighbourhood and its surrounding, total processing time was 02 h:27 m:16 s, median of 35909 key points per image were detected, 921 out of 944 images calibrated (97%). Generated points' density was 29,588,885 points, with an average density of 89.19 per meter, Figure 13 shows the reported data results. The resulted data were satisfying with regards to both 2D and 3D datasets created, thus can be used after several processing as an input for 3DCM generation and implementation, the following section shows a separate explanation and clarification of these various datasets. Figure 14 shows the resulted mesh of processing the second flight data.

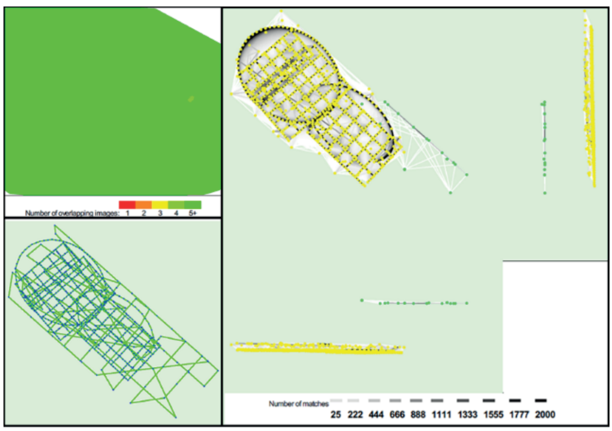


Figure 13. Data Quality Report for flight 2, images overlap map (upper left), initial images' position (lower left), links between matches (right).

Figure 14. Buildings' mesh of flight 2

Orthomosaic map

The raster map produced through merging geo-located aerial imagery produced by the UAV for the study area was observed to be 33041*25255 pixels width and height respectively, 96 dpi resolution vertically and horizontally, RGB photometric interpretation, 625 MB size, and 35 mm focal length, see Figure 15. The output map is a Geotiff (.tif) format, real world scaled, whereas measurements can be performed. The map resolution is +/-3 cm, which is more precise and clear scanning when compared to satellite maps of +/-30 cm resolution. Such high-resolution maps can easily be used in digitalizing different city objects with higher accuracy, or even tracking and monitoring developments through multiple flights (Gevaert et al, 2016). The difference in resolution between the produced orthomosaic map and Esri ArcMap (Web-8) satellite base map can obviously be observed in Figure 16; buildings' footprint for example can barely be manually produced or checked through the satellite imagery of ArcMap.

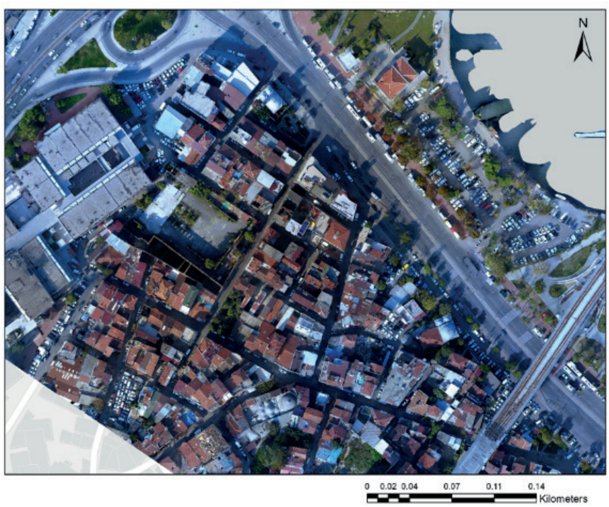


Figure 15. Ortho-mosaic Map.

Although the produced orthomosaic map show high detailing of buildings, streets, vegetation, and roofs, with real world 1:1.166 scale, high shadows can be significantly observed in the map. The scanning time accordingly is a crucial factor to be considered during the flight planning, whereas the optimum time for UAV scanning is between 11:00 am and 02:00 pm, where the sun is almost perpendicular on the surface, for less sun shadow effect. Worth mentioning, the data captured of such resolution may fall under the data protection UAV regulation mentioned in the UAV Regulations and Public Acceptance section above, whereas it may include personal or private data (Fotouhi et al, 2019), thus data must be wisely stored, processes, or transferred.

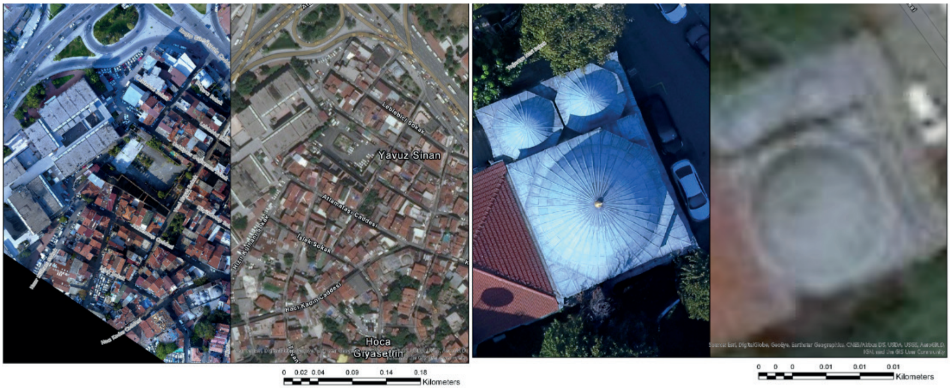


Figure 16. Ortho-mosaic Map (Left) and Satellite imagery (Right).

Point cloud Dataset

Point cloud data is the major deriver of all the upcoming data, including DSM, DTM, and 3D mesh model. Point cloud database contains huge number of three-dimensional coordinated points, these points are the produced data of 3D scanners or imaging, which are used to represent points on the surface of scanned objects (Chua et al, 2017). The Las file produced is of 733MB size, containing 29,588,885 points, 89.19 mean density per meter, with about 70 meters z range, containing RGB value for each point. Unlike the point cloud datasets derived from satellite imagery or aerial photos, the highest point densities can be seen on the buildings' facades, due to the high matching points of oblique imagery that captured the sides of buildings, see point cloud density map. The created point cloud is generated through matching key points of aerial and oblique imagery captured by UAV, whereas the geo-referenced imagery matchings of object surfaces are processed via Drone Deploy software of different perspective imagery, section of the created point cloud can be seen in Figure 17.

Figure 17. Point Cloud Sections.

Point Cloud Classification

The production of various datasets from point cloud data are depending mainly on the classifications of the points into different categories, including ground points, buildings, building roofs, high vegetation, low vegetation, and others (cars, lamp post, etc.). Ground points were automatically detected using classification tool of ArcMap software, which helped in the generation of the DTM. Point cloud sections seen in Figure 17 helped in the recognition of various city elements for the classification process, which depended mainly on training sessions and machine learning classification technique. Both LIDAR 360 and CGAL classifier software are open source that provide point cloud data classification via training session, where section of the dataset is chosen to be classified manually, then machine learning technique takes the manually classified section as a reference for classifying the whole datasets, see Figure 18.

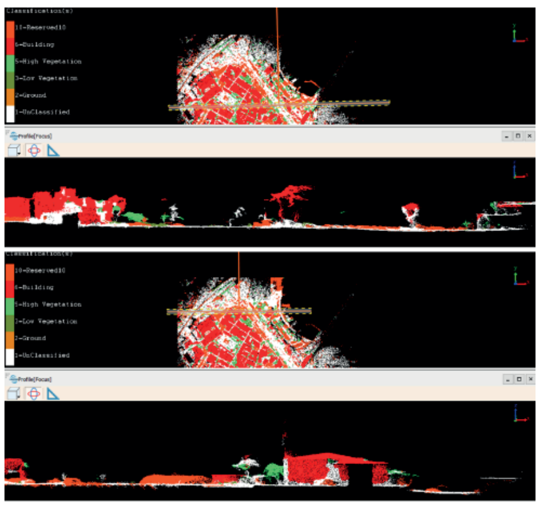


Figure 18. Point Cloud Data Classification using Machine Learning Technique.

Some accuracy control should be done to check the precision of the classification, errors can be fixed manually or by repeating the processes. Automatic classification of point cloud datasets is also provided by other software (PIX4D, Drone Deploy), but mostly are not open source, or not provided by the trial version of the software.

DSM, DTM, NDSM

Digital Surface Model (DSM)

Digital surface model is a three-dimensional map, it represents the maximum height of natural and build-up environment, including buildings' roofs, trees' surfaces, bridges and other above surface features. DSM can be extracted without the classification of point cloud data, the points that represents maximum height of both natural and build-up environment are all used in the generation of NDSM map. The map produced in Figure 19 shows RGB three band of elevations in Tiff format for buildings, streets, vegetation, bridges and other manmade features (Web-9, Web-10). Buildings' roofs include the slope lines, domes of historical mosques can also be observed, attached buildings are also separated with black lines. The DSM produced is used as an input for the generation of NDSM, which is a reference to buildings' heights for the 3D model generation.

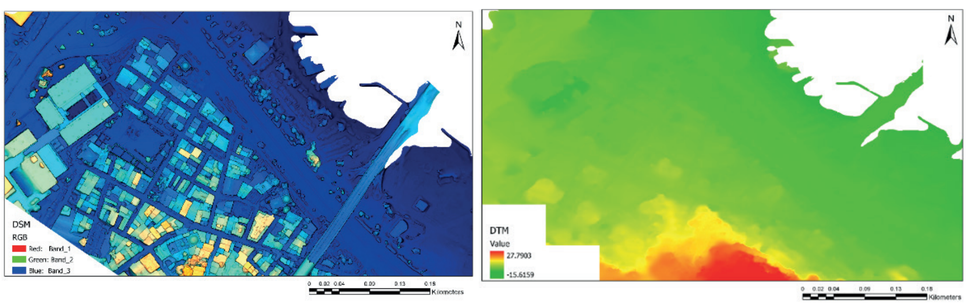


Figure 19. Digital Surface Model (DSM-DEM) (left), Digital Terrain Model (DTM) (right).

Digital Terrain Model (DTM)

Digital Terrain model similarly is a three-dimensional map, but it represents the geographical and natural features of the ground, excluding buildings, vegetation, bridges, and other manmade features (Web-9, Web-10). DTM is extracted from classified point cloud dataset, including only ground points after excluding various points that falls under built-up environment or vegetation, the map can be extracted, see Figure 19. The produced map shown in Figure 19 shows the hilly feature of the neighbourhood ground, lowest point is shown in green falls aside to the Halic, highest points above ground can be seen in the southern part of the map. The DTM is considered as an important input, whereas terrain is a valuable input when considering 3DCM, especially when running urban analysis of built environment like visibility analysis, or other analysis regarding natural hazards like flood and earthquake. DTM also has a significant contribution as an input for the creation of NDSM, which is the reference to the absolute buildings' heights.

Normalized Digital Surface Model (NDSM)

Normalized digital surface model is the absolute height of above ground elements, it resembles the distance between terrain surface and buildings, trees, etc. Both DTM and DSM are inputs for the production of a NDSM, where it results from subtracting DTM (Figure 19) from DSM (Figure 19) (Burdeos et al, 2015). The produced NDSM shows the heights of all above ground elements, and their absolute height above ground surface resembled in DTM. The main purpose of NDSM in the 3DCM production is giving the value of buildings' heights from ground disregarding the terrain, in order to form different city elements independent city elements, but carrying spatial relations to each other, so as to be used in various analysis or applications.

3D Textured Mesh Model

Also called 3D reality mesh, polygonal mesh and triangulation mesh model. Textured mesh has variable applications in filming, gaming, virtual reality, and scientific visualization (Min and Wei, 2019). 3D textured mesh is created using triangulation technique of RGB point cloud dataset, where points are connected to form the smallest geometrical element (triangles), connected together forming a polygonal mesh (Chua et al, 2017). Although the robust generated mesh model shows high detail representation of the current situation, with abilities to measure distances, areas, and volumes, the model lacks the independency of various city elements (Figure 20). The continuous mesh model generated format is OBJ, with MTL format material file attached to it. Buildings, roofs, vegetation, streets, and other man-made objects are continuously connected similar to the DSM, model is then recognized as one continuous object file, whereas the model can't be recognized as a smart city model, attributes can't be added to certain object, aside to its unmanageability and rigidness.

Figure 20. Buildings' Textured Mesh Model.

The mesh texture depends on vertices UV wrapping techniques, 2D texture is wrapped along various vertices of the model. Unlike vertex paint technique, UV texture provide higher resolution of 3D textured which are coordinated with the model, the assigned technique is so called PolyCube-Maps, depending on texture parametrization, see (Tarini et al, 2004). Mesh editing software were used to examine the ability of editing the mesh model, Blender open-source software was used for that purpose (Web-11). Blender has a wide ability for the editing of polygonal and triangulated textured meshes, some buildings were successfully separated from the created mesh, using Boolean tool given the buildings' footprint, while sustaining its vertices-based UV texture, see Yavuz Sinan mosque (Figure 21). The mosque model face counts are 7,700 faces, by using Decimate tool, planar option delimited to UVs, the face counts can be decreased while sustaining the model's texture, 2,900 face counts were found satisfactory as a result, less faces results in the distortion of the faces geometry, see Figure 21. The separated building's model at that stage can have attributes or spatial data added to the separate objects, but the model lacks the geometrical flexibility of changing parametric values like height, length, and width, which is found satisfactory in the case of historical and conservative buildings (unlike residential, commercial, etc., see Figure 21.

CityEngine software provides the ability to import either static or initial shape model in OBJ format, static models have no ability to import separate objects of the same file, objects are merged into one layer in this case, while initial shapes can be uploaded in multiple separate objects, texture has to be reassigned in this case. The best solution to handle the 3DCM is to build the model from scratch, taking in consideration the generated 3D mesh as a reference, historical and conservation buildings can be either manually modelled, or separated meshes of these buildings can be used as static model. The next chapter briefly discuss the model generation through its various procedures, model data produced and processed according to this chapter are considered to be input dataset for the model generation in the next chapter.

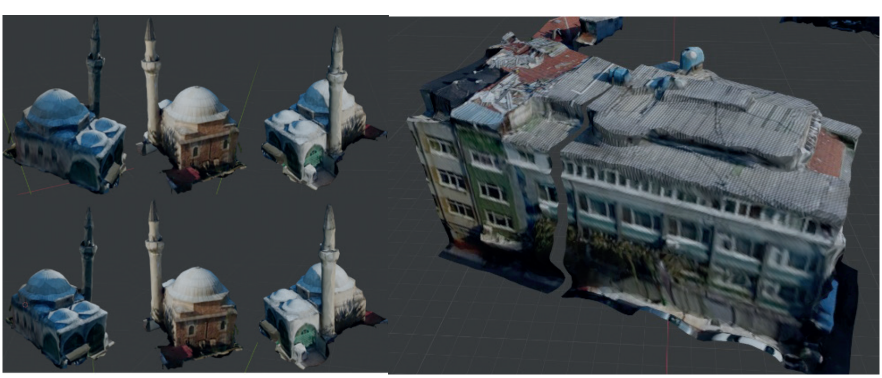
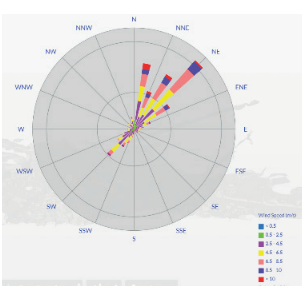


Figure 21. Yavuz Sinan Mosque Textured Mesh Model, 7,700 faces model (upper left), 2,900 faces model (down left). Residential Buildings' Textured Mesh Model (right).

Pedestrian Wind Comfort Analysis

Pedestrian Wind Comfort Analysis is a Computational Fluid Dynamics (CFD) application depending on 3D models to assess wind comfort and safety in urban areas (Shi et al, 2015; Blocken et al, 2012). The main purpose behind running the simulation, is examining the ability of running urban simulation of various UAV based 3DCM. Accordingly, 3D reality textured mesh model was uploaded to a commercial based CFD analysis platform names Simulation hub. The model passed firstly took long time to be uploaded to the platform, due to its large size and the huge geometries it contains. The model passed through the first two processes of simulation, but failed in the meshing process. The reason is that running this simulation should be on closed solid surfaced polygonal masses. Since 3D textured mass model failed to run such analysis, solid mass model of least polygons was generated based on data input from point cloud database generated from UAV processing above.

Pedestrian wind comfort analysis is an urban space-based assessment, running the analysis for selective location will be less effective than entire assessment of categorized spaces (including pedestrian streets, city square, parks, etc.) (Shi et al, 2015). Wind assessment in open area thus relies mainly on the wind data provided from the wind station. Wind data collected to run the simulation were obtained from the nearest wind station to the neighbourhood (Weather station TUR_Istanbul.170600_IWEC), which is about 8.19 miles from the neighbourhood, see the wind rose of the data provided in Figure 22. Various pedestrian comfort criteria were developed for assessing different wind frequencies and their relation to spaces and pedestrians. Lawson (1978) criteria of wind assessment depends on calculating the average hourly wind speed and categorizing these velocities into spaces where different activities are most likely to be done in these spaces.



Class	Colour	Description	Velocity (m/s)	Exceedance
A		Sitting/Standing Long	> 4.0	< 5.0%
B		Sitting/Standing Short	> 6.0	< 5.0%
C		Leisurely Walking	> 8.0	< 5.0%
D		Fast Walking	> 10.0	< 5.0%
Safety		Distress	> 15.0	< 0.0002%

Figure 22. Weather station Data TUR_Istanbul.170600_IWEC (left), Lawson Wind Comfort Assessment Criteria (Lawson, 1978) (right).

Several aspects should be considered when running CFD wind comfort simulation, buildings models should all be included with their relative massing, the fluid outer domain should be large enough to overcome the artificial acceleration. 3DCM buildings were thus imported into Simulation hub, other city objects like vegetation couldn't be included in the model for technical concerns. Wind analysis was performed in 32 wind direction, which were then combined to assess the wind comfort according to Lawson (1978) criteria (Figure 22). Assessment plain was drawn as a circle of 1km diameter, located 1.6 meters above ground, see figure 23.

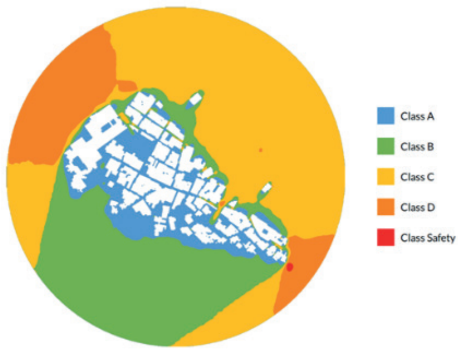


Figure 23. Wind Comfort Assessment for Yavuz Sinan Neighbourhood.

CONCLUSION

In data collection, day and timing choice should be considered, weather status, sun exposure, sun angle is highly recommended to be checked in the pre-flight stage, camera lens suitable to the weather status will provide better image resolution and exposure. Case study choice should be highly related with the country's regulations, where sensitive areas and zones should be avoided. Following the regulations provided by the country in terms of applicability technical requirements, operation limitations, admirative procedures, and human resource requirements. Adjustment of the overlap, 60% is a default recommended by the data processing software, but may give some distortions in dense urban areas, where some streets couldn't be captured, also increasing the overlap leads to longer scan timing, where UAV endurance should be taken in consideration. The lower the flight height, the higher the detail it captures, but height limitations (minimum flight height, buildings' maximum height) should be taken in consideration. UAV choice should be dependent on its weight (which directly affects the license), endurance, range, etc. and also on its availability in the country of the case area. In Data Processing, High hardware device should be taken in consideration when running the processing of images, cloud-based software are the alternatives in case of the absence of such devices. Maximize the dependency on open-source database, or consider a cost plan in case of commercial software. Reviewing the data quality report in terms of image matchings and images overlap is highly recommended for better results.

In 3DCM Implementation, examining the OpenStreetMap database or different sources accuracy is important, as it may affect the results of the analysis. Overlapping the datasets for accuracy thus is highly recommended. Depending on data driven software in the 3DCM generation should be tested before processing, where it needs a high pre-knowledge in the script languages at some stages, also the setup of CGAL library needs a computer specialist, high storage, and high processor power. Knowing the analysis intended to be performed before 3DCM is highly recommended, so as to ignore unneeded data, which will not affect the results. In the analysis, knowing the needed and compatible data to the analysis software will save much time and effort. When depending on commercial software, cost plan is highly recommended. Open-source software were found not user friendly and need high knowledge of script language, also it lacks examinations and tutorials. Choosing the analysis software, minimum hardware requirements, and the compatible data in the pre-processing stage is highly recommended.

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