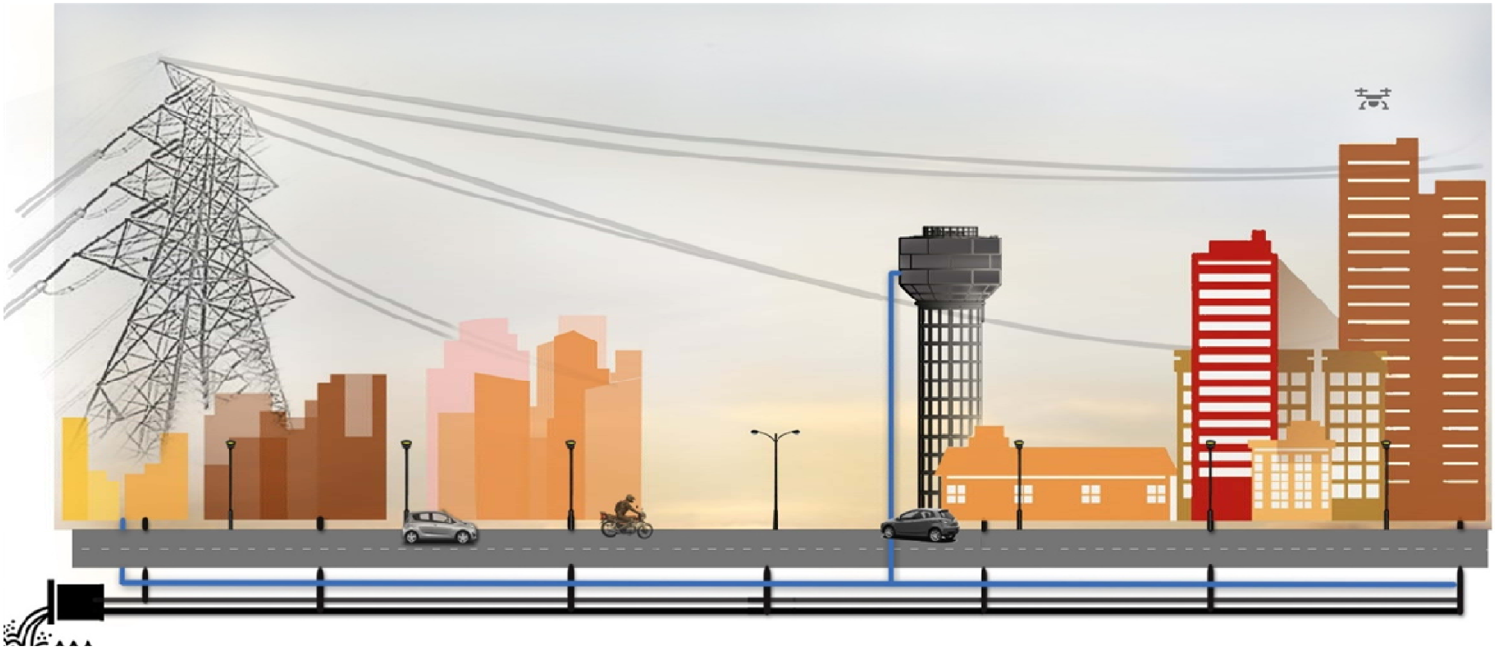

India-UK Joint

Integrated Urban Model for Built Environment Energy Research

(iNUMBER)

Approaches to Urban Stock Model- Part II

March 2020

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UK India Joint Integrated Urban Model for Built Environment Energy Research (iNUMBER)

Work Plan 1 (WP1): Create a 3D Building Stock Model

Approaches to Urban Stock Model - Part II

March 2020

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iNUMBER is a four-year (2017-2021) research project to help cities reduce their energy demand and improve their municipal services. This goal is led by CEPT University, Ahmedabad and supported in India by Indian Institute of Technology Bombay, Mumbai. It is led by University College London, London, and supported by the University of Oxford, Oxford.

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Acronyms

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AUDA	Ahmedabad Urban Development Authority
BIM	Building Information Modelling
DEM	Digital Elevation Model
ISRO	Indian Space research organization
LiDAR	Light Detection and Ranging
UBEM	Urban Building Energy Model

Abbreviations

AMC	Ahmedabad Municipal Corporation
BOT	Build-operate-transfer
BES	Building Energy Simulation
DST	Department of Science and Technology
DSM	Digital Surface Model
EAP	East Asia and the Pacific
ECBC	Energy Conservation Building Code
EPI	Energy Performance Index
EAP	East Asia and the Pacific
FSI	Floor Space Index
GIS	Geographic Information Science
GLCF	Global Land Cover Facility
IRS	Indian Remote Sensing
NRSC	National Remote Sensing Centre
RS	Remote Sensing
UAV	Unmanned Aerial Vehicle
WP	Work Package
WWR	Wall to Window Ratio

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Executive Summary:

iNUMBER is an Indo-UK collaborative research project that was co-created to address the Newton research topic: "Integration of information, communication and renewable energy technologies at building, community and city level interventions". The project aims to address this research topic by developing a data-driven Intelligent Urban Model for Built Environment and Energy Research (iNUMBER). The primary focus of this tool is to support the Indian Municipalities to understand the variations in energy demand and thereby assist in providing clean and sustainable energy services to its citizens. iNUMBER being a four-year collaborative research project (2017-2021), Ahmedabad has been selected as the primary case city for the research. Further, the project could be extended by considering other cities as well.

The key objective of the project is to develop a City Energy Model that includes the 3D building stock and the municipal services energy model. The project aims to achieve the same by linking the existing and new data sets and testing the validity of the developed model for a range of scenarios in accordance with different data availabilities. To achieve this overarching objective, the project has been sorted into 3 work packages (WP) as mentioned below,

1. WP1: Create 3D Building Stock Model
2. WP2: Incorporate Municipal Energy Services
3. WP3: Improving Data Granularity

This executive summary provides a brief account of the activities carried out under the WP1: Create 3D Building Stock Model. This WP primarily focuses to incorporate and benchmark the data sets on cities, buildings and municipal services to build a viable 3D Building Stock Model. The report provides a comprehensive understanding of utilization of imagery data collected from UAV & Oblique camera equipment and its processing in a photogrammetry software to develop a precise 3D geometrical model. The developed model can be later used to derive a 3D building stock model

The methodology adopts advanced aerial surveying instruments technologies such as oblique camera as attachments to a Robust UAV to capture required resolution of building stock data later to be used to obtain fully textured 3D building stock data, which has an association of both spatial and non-spatial data sets.

The report further includes the methodology to develop a 3D geometrical model for a pilot study area and its outcome, challenges faced, and lesson learned. The report also includes a update methodology followed to prepare a mission plan for Ahmedabad city which will be used to plan an execute image data collection for all over Ahmedabad city. The image data collected will then be processed using the enhanced data processing equipment procured and photogrammetry software. The obtained results will

later be used to develop a framework for energy modelling of the 3D building stock model. The model framework develop shall finally integrate other work packages (WP2 and WP3) to build a complete City energy model for Ahmedabad city

The integration of the outcomes from all 3 work packages will assist in understanding the energy demand of the entire city. Through a fourth work package, the activities under iNUMBER will further be integrated with other projects, related research in India, and across the world. Further, this integrated approach will develop new areas of inquiry related to future building stock and municipal services in India.

1 Introduction

Cities have often been described as the engines of economic growth (Colenbrander, 2016). Currently, 55% of the world's population is residing in the urban areas. This proportion is expected to stretch to 68% by 2050 (United Nation, 2018). As per new data sets launched by United Nations, it is observed that the overall shift in the human residences from rural to urban areas, combined with the overall growth of the world's population could add around 2.5 billion more people to urban areas by 2050. It is expected that, nearly 90% of this increase in the urban population would be accounted by Asian and African countries alone.

As the urban population increases, the demand for the basic amenities and living comforts will also increase. Thus, it is very important to plan and allow the urbanization to attain in a sustainable manner. In order to attain this, it becomes very necessary for the cities to develop and provide required amenities towards meeting the future demand of its citizens. One of the primary aspects that need to be accounted with the process of urbanization is the provision of the secure energy for the better health and comfort of the citizens.

As the urban population increases, the city's demand for the clean energy will also increase. Thus, with the changing lifestyle and growing cities, it becomes very important to understand the energy demand of the city and identify more efficient methods of utilizing available resources in catering the demands. This can be achieved by assessing and understanding the variations incurring in the energy demands of the city. These variations can only be studied by constant observation and analyses of the data sets specific to the respective services. Thus, the tools capturing variations in the demand for the energy over the time and space will serve the greater cause in understanding the trends, rationalizing the energy demands and thereby assist in planning and attaining a sustainable energy services for the cities.

iNUMBER focusses on developing one such tool for assessing and understanding the variation in energy demand of the city over time and space. iNUMBER is an iNtegrated Urban Model for Built Environment Energy Research. The research program aims at developing a City Energy Model to help in planning a secure energy supply for the urban population. Further, the tool will support the urban energy management process and assist municipalities and local partners for developing a data driven intelligent urban model for assessing the built environment energy and the municipal planning.

1.1 About iNUMBER

'iNtegrated Urban Model for Built Environment Energy Research (iNUMBER)' is a four-year collaborative research project between India and United Kingdom to help cities reduce their energy demand and improve their electricity and water services. Funded by the Newton-Bhabha Fund, iNUMBER is jointly supported by the UK Engineering and Physical Sciences Research Council

(EPSRC), and Economic and Social Research Council (ESRC) in partnership with the Government of India's Department of Science and Technology. The main objective of iNUMBER is to work towards reducing greenhouse gas emissions, stabilizing the electricity grid, and help the ULBs in rationalizing and planning the city's energy demands thereby, assisting in provision of secure and sustainable energy services. The tasks under the project are to develop a new model of building & municipal energy demand, grounded in appropriate empirical data and applicable to reducing energy demand in a wide range of different contexts and with varying data availability.

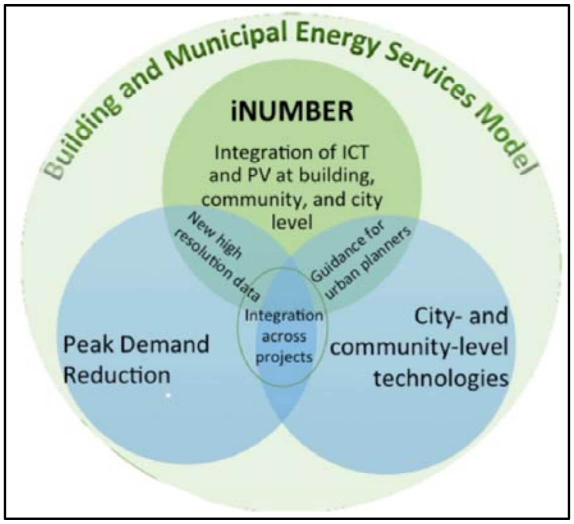

Figure 1 Schematic representation of the iNUMBER project

iNUMBER was co-created from the India-UK workshop to address the India-UK Newton research topic, "Integration of information, communication and renewable energy technologies at building, community and city level interventions" by developing a data- driven intelligent urban model for built environment energy research and municipal planning. It supports Indian municipalities and local partners by diagnosing urban energy problems, testing solutions, verifying progress and improving policy through state of art monitoring, data science and analytics. It will also meet interrelated elements of the other two topics, "peak demand reduction" by contributing new high-resolution data city and community technologies by providing guidance to urban planners.

The iNUMBER project is systematically sorted into 3 work packages (WP) and are classified as described below,

1. Work Package 1: Create a 3D Building Stock Model

The WP1 aims at identifying and analysing various approaches suitable for capturing the urban environment using advanced aerial survey technologies and develop a 3D Building stock model. WP1 incorporates existing geographical and administrative datasets available at the city level and integrates the information with the developed 3D Building Stock Model. Finally, WP1 in association with partners, investigates techniques to scale up Building Information Modelling (BIM) based energy simulations to develop a viable City Energy Model, thereby allowing municipalities to effectively optimize their current and future energy demands.

2. Work Package 2: Incorporate Municipal Energy Services

The WP2 primarily focusses on assessing the energy consumption in delivering the municipal services. The energy data sets obtained with regard to the municipal services feeds into the City Energy Model. Further, the work package also focusses on developing a framework for evaluating the municipal services with respect to their energy consumption.

3. Work Package 3: Improving Data Granularity

The WP3 primarily focusses on gathering intense datasets at dwelling unit level and common amenities at community level pertaining to the energy consumptions, indoor environment parameters and thermal comfort conditions. The data sets collected in this work package regarding the energy consumption will act as feeder for the City Energy Model, thereby assisting in improving the data granularity of the model.

The integration of the 3 work packages will assist in understanding the energy demand of the entire city. Through a fourth impact work package, the activities under iNUMBER will be integrated with other projects, related research in India, and across the world. Further, the integrated approaches incorporated in each of these work packages will help in answering additional questions and develop new areas of inquiry related to the future building stock and municipal services in India.

1.2 About Work Package 1: Create a 3D Building Stock Model

WP1 supports the project by conducting a city-wide aerial survey to capture the information of urban building stock. The scope of aerial survey approaches such as Satellite and UAV technologies are fully explored and the most suitable instrumentation, datasets and model extraction techniques are identified to construct a viable 3D building stock model as part of WP1 objectives. The work package moreover incorporates existing administrative datasets available at the city level and integrates the information to develop the 3D building stock model. The data gathered from other work packages in the project shall support WP1 in generating a City Energy Model.

1.2.1 Objectives of Work Package 1

- To identify and assess the various approaches to capture urban built environment using aerial survey technologies
- To identify various digital processing techniques to extract the data and generate 3D Building stock model
- To incorporate and assess multiple data sets at the city level such as Land use, Property Tax and GIS and integrate the information with the generated urban stock model

- To identify the pilot study region to conduct the aerial survey
- To investigate methods to scale up BIM (Building Information Modelling) based energy simulations to develop a City Energy Model

1.2.2 Outcomes of Work Package 1

- Identifying an aerial surveying methodology to capture 3D Building stock
- Technical analysis, specifications and selection for Satellite and UAV Survey instrumentation
- Methodology to extract urban built environment layers and digitally process it into a viable urban 3D Building stock model
- Methodology to integrate urban building stock model with building energy simulations

2 iNUMBER Hardware equipment selection and specification

The approach of Photogrammetry using UAV combined with Oblique Imagery is selected for the iNUMBER project. For the project; The equipment selected can be majorly divided into two categories:

1. **Data collection equipment**: the equipment identified here focuses and handles all requirement of capturing different datasets that are needed for the geometry dataset, which are in turn required to build a 3D model. The 3D model will then be utilized in different workflows to obtain the Urban Building Energy Model
2. **Data processing equipment**: The equipment here are focused on processing all the acquired datasets to obtain a resultant 3D model. The equipment will also be used for processing theUrban Building Energy Model (UBEM) and its different scenarios.

2.1 Data-collection equipment

The quantum of the datasets that needs to be collected for the whole Ahmedabad city is very huge, thus the equipment selected here are capable of capturing the required dataset in considerably low amount of time, robustly high quality and with low margin of error.

The initial draft calculation of the approximate data size that needs to be collected is depicted in the table 1. The Ground Sampling Distance (GSD) taken into calculation here is 2.2 cm/pixel. The rationale for the was based on the discussion with experts and studying the user manual of the UAV. The major parameters that affects the total flights are the area covered and approximate size of a single aerial image.

Table 1: Pverview of data-size for the iNUMBER_WP1

Area to be covered (km^2)	**230**
Area covered per flight (km^2)	0.5
Flights to cover 1 km^2	2
Total Flights	**460**
Images per flight	2950
Images per km^2	5900
Total Photos	1357000

Approx. Size per photo (MB)	8
Total image size (MB)	**10856000**
Total Image Size (GB)	**10856**
Total Image Size (TB)	**10.856**

2.1.1 UAV: CHC P-550

The Unmanned Aerial Vehicle (UAV) selected for the data collection is CHC P-550 (figure 2), which is a hexa-copter configuration UAV with Real Time Kinematics (RTK) capabilities.

The complete setup of the UAV consists of total 3 components:

1. **The Aircraft**: The aircraft is the main part of the system which flies with the help of the Remote Controller and the Base-station
2. **RTK base-station**: The base station is a fixed component on the ground constantly communicating to the Remote controller and the aircraft
3. **Remote controller**: It consists of a tablet PC, joystick to control aircraft. The Remote controller is of JAPANESE Style Configuration

2.1.1.1 The aircraft:

The configuration of the aircraft selected is a hexa-copter configuration. The hexa-copter configuration is selected here because of the 6-wing configuration, as there is need for increased manoeuvrability which is useful for capturing close-up the images of the buildings for all direction.

In urban settings, the distance between buildings is sometimes very close and details of such buildings cannot be captured by fixed wing aircrafts. Hexa-copter configuration is useful to increase number of images in such settings so more details can be captured.Since the UAV is of the copter configuration, the take-off and landing of the UAV is possible on any place as in anurban setting places for take-off and landings are limited for a fixed wing UAV.Also, the copter configuration allows the user to take-off/land on building rooftop also which is useful when operating UAV.

The specification of the aircraft including overview, physical dimensions, ESC specifications, electrical parameters, power management, propeller specification, working environment & Flight parameters are listed in table 2 to table 9.

Table 2:CHC P-550 UAV overview

Figure 2: CHC P-550 UAV

Manufacturer	CHC Navigation
Model	CHC P550
Features	• High stability level 7- wind • RTK/PPK GNSS Module • FADW Ground control station
Material	Fiberglass

Table 3:Physical Dimension for CHC P-550

System diameter	1300mm
Arm Length	380mm
Main Body Diameter	670mm
Aircraft dimensions (propellers, frame arms and GPS mount unfolded	≤ 1300 mm* 1300 mm* 450 mm
Aircraft dimensions (propellers, frame arms and GPS mount folded	≤ 650mm * 650 mm * 200 mm
Weight including batteries	10.7 kg

Max take-off weight	18.7 kg
Max payload	8 kg

Table 4:ESC specifications for CHC P-550

Electrical motor size	68mm or less
KV	160 kV or less

Table 5: Electical parametersfor CHC P-550

Working current	80A
Input voltage	50v

Table 6: Power Managementfor CHC P-550

Standard battery	2 * 22000 mAh 6s 25C 22.2V

Table 7: Propeller specificationfor CHC P-550

Propeller	6
Material	Carbon fibre or better
Size	24 inch or less

Table 8: Working Environmentfor CHC P-550

Operating temperature	-25 °C to + 55 °C
Relative Humidity	≤ 95 (+25 °C)

Table 9: Flight parametersfor CHC P-550

Take-off weight	10.7 kg including two 22000 mAh batteries
payload	Max 8 kg
Video transmission	720P/1080P (optional)
Flight time	50 mins with payload

Remote distance	3-5 km (max 10 km)
Height	3000m or more
Wind Resistance	7 level
Battery Voltage	44.4V
Battery Capacity	22000 mAh

2.1.1.2 Remote controller:

The remote controller (figure 3) is responsible for controlling the aircraft. The remote controller is an android tablet connected to a joy-stick controller which has a battery and thus a limited usage time. The android tablet is equipped with a CHC inhouse application, which is used for mission planning of the mission and uploading the planned mission to the UAV. The application has options of 3 operating modes:

1. Auto mode
2. Altitude-hold mode
3. Manual mode

2.1.1.2.1 Auto-mode:

In this mode, the UAV operates automatically as per the mission uploaded in the UAV, which is previously planned in the UAV. The operator only has to manually take-off the UAV. Once the UAV is in air, it automatically follows the mission plan uploaded and completes the mission in auto-mode. The operator can observe the path of the UAV, progress and technical parameters related to the flight in the dashboard of the UAV.

2.1.1.2.2 Altitude-hold mode:

In this mode, the altitude of the UAV is kept on Hold and this restricted vertically, but the horizontal movement is not restricted, and UAV can move in any direction horizontally. This mode is useful when the aerial-skyline of the environment is known.

2.1.1.2.3 Manual mode:

In this mode the total control of the aircraft is manually controlled by the operator. In this mode, the left stick is used to turn on the rotors and change the head (direction) of the UAV. The Right stick i.e. Throttle is used to control the altitude of the aircraft along with the side motion (flying left & right without changing head).

Along with the two joysticks, there are two additional buttons. These functions are also listed on the UAV app. These buttons can be accessed from any operational mode the user is currently in. The functions of the two buttons are listed below:

1. **Call UAV to home**: this button is used to call back the aircraft back to the Home or land at immediate place in case of emergency. This can be done during any phase of the flight.
2. **Trigger for Camera**: the button is used to trigger the capture of the images for taking image of take-off or landing location or ground location. Such images are helpful in distinction of aerial images in between two distinct flights

The parameters of Remote controller are listed in the table 10.

Table 10: Flight Performancefor CHC P-550

Figure 3: Remote controller (Japanese configuration)

Hovering Accuracy	± 0.1m, Horizontal: 0.05m
Max pitch angle	45°
Max Speed	18 m/s (no wind)
Max wind resistance	10 m/s
Max flight altitude MAMSL	3000m
Flight time	With two 22000 mAh 6s 25C 22.2V

No payload	64 mins
Typical (1.2 kg)	50 mins

2.1.1.3 RTK (Real-time Kinematics) base-station:

The third component of the UAV system is the base-station (figure 4). The base-station is assembled and fixed on a tripod and is kept at fixed location during the UAV operation on the highest onsite location possible. Due care must be taken that the Base-station is not touched under any circumstances when the UAV is in flying operation. The base-station also operates on a battery and thus it needs to be adequately charged. The base-station works on an advanced RTK technology. RTK technology is astate-of-the-art technology used for obtaining enhanced position data from satellite navigation system such as GPS.

RTK technology is superior compared to the PPK (Post Processing Kinematics) technology as the RTK technology provides real time data and no correction has to be applied to the obtain positioning and image data where as in PPK technology post processing has to be applied to obtain accurate positing and image data.The specification of the base-station has been listed in the table 11.

Table 11: Ground Stationfor CHC P-550

Figure 4RTK Base-station

Size (L x W x H)	520mm x 440mm x 200mm
Internal Battery	3SIP 10000 mAh
Operating time	>8h

2.1.2 Oblique camera equipment: CHC HC 5020 5-angle Camera

For the oblique Camera attachment, the CHC HC-5020 (figure 7) Oblique 5-angle camera was selected and used for the pilot study, which will later be replaced by an updated version of the same. The updated version of the camera is CHC HC-12 (figure 8) which has been reduced in size to increase overall battery. Both the version of the camera are battery operated and thus needs to be charged.

The 5-angle oblique camera helps to capture all 5 sides of the area of the interest. Figure 5 explains the working of an oblique camera. The oblique camera is attached to the UAV via a slider Gimble which can be removed after each flight to change the battery of the Oblique camera. The viewing angle of the camera are fixed and cannot be changed. Thus, With the help of additional 4 cameras additional images are captured captured oblique views of the requied subject.

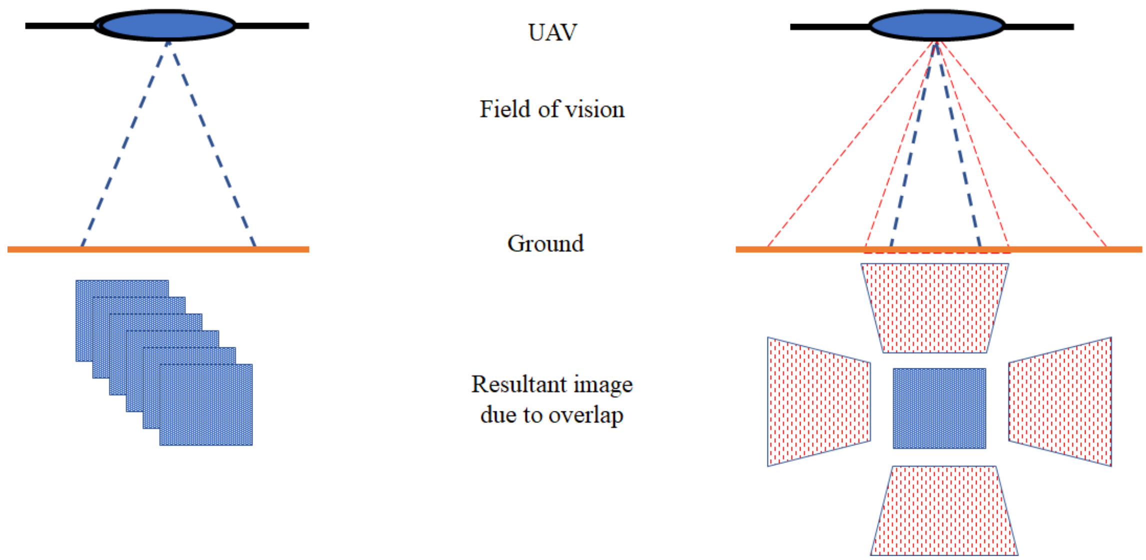

Figure 5: Working of an Oblique camera angle

The presence of oblique images in addition to Nadir images significantly helps to increase the quality of a 3D model. Figure 6 shows two distinct models; the first model on the left is prepared only by the help of Nadir images whereas the second model is prepared with the help of the both Nadir and Oblique images. As it can be clearly seen that in the model with only Nadir images, the vertical elements of the model like building facades are not capture properly and distorted. In figure 6, it can be observed that the windows are not present in the model developed only from the Nadir images (Left side) whereas the windows are present in the model developed from both Nadir and Oblique images (Right side).

Figure 6: Difference of presence of Oblique Images in 3D modelling.

Thus, in a model with both Nadir and Oblique images, much more details are captured compared to a model with only Nadir images. The data processing software understands these images with the position data, which is also imported along. Depending on the algorithm used in the photogrammetry software, it can stich a much better detailed 3D model. Also, it must be noted that the details of the 3D model are dependent on the image overlap in either of the cases. The overall specifications of the oblique camera selected for the project are listed in table 12&13.

Table 12:CHC HC-5020 Oblique 5-angle Camera

Figure 7: HC-5020 Oblique 5-angle camera

Size (L x W x H)	246.7mm x 246.7 mm x 115.4mm
Weight	<2 Kg
CCD Quantity	5
CCD Size	23.5 mm x 15.6mm
Pixel Size	3.9 µm
Min Exposure interval	2s

Focal Length	16mm, 20mm, 35mm or better
Total Pixels	6000 x 4000
Camera inclination	45°
Power supply	Camera Battery /Drone Battery
CCD turn on mode	One button
Battery remaining warning	Low voltage beep or light warning or similar
Working temperature	-10˚ C to 40˚ C
Maximum Humidity	95% or better
Storage	5 x 32 GB or better
Data Transfer	USB or mini USB
Carrier Platform	Multi Rotor
Weight	less than 2kg
GPS	Onboard GPS and RTK modular

Table 13: HC-12 Oblique 5-angle camera Overview

Figure 8: Updated camera from CHC: HC-12

CCD	5
Sensor Size	APS Frame (23.5mm ×15.6mm)
Pixel Size	3.9µm

Single Camera Pixel	6000×4000
5 Total Camera Pixel	1.2 Billion
Tilt Angle	45°
Memory	Standard：5×32Gb
Operating Temperature	-10□～+50□
Humidity	95%

Table 14: HC-12 physical parameters

Exposure Mode	Timing/Fixed Exposure
Power Supply	Independent/Onboard
Charging Method	Independent Charging
CCD Boot	Unified Switch
Battery Test	Low Voltage Alarm
Image Data Reading	USB Interface
Total Weight	Standard：980g
Support Lens	Medium Camera： 25mm Four Cameras Front and Rear：35mm
Dimensions	190mm×190mm×79mm

2.1.3 Complete setup of the equipment: CHC P-550 + HC 5020 Oblique camera

The complete setup of the data-collection equipment includes all 3 components of the UAV along with the attached Oblique camera. The complete assembly/disassembly of the data collection equipment is completed in approximately 1 hour for each. Apart from the listed components many other minor components are used along. Few of the examples includes a Mat for take-off and landing of the UAV, markers for the GCP.Figure 9 shows the complete setup of the equipmentalong with the operator.

Figure 9: Complete setup of CHC P-550 UAV with HC-5020 Oblique camera

2.2 Data processing equipment

For processing the imagery datasets captured by the UAV and further using them in the Urban Building EnergyModel simulations, Computing systems with high performance are required to process the data in required timeframe.

After selecting the image data-processing software[1], it was observed that such software intensively uses both Processing and Graphical processing. Thus, for such software, system with High CPU and GPU is recommended.

The simulations performed in the UBEM framework are also Processing power intensive. Thus, it was decided that systems needed for the iNUMBER projectneeds to have a powerful Processor unit along with an equally powerful GPU. For getting the list of compatible components for the selected software, the hardware recommendation guide (Bentley, 2019) from the software was carefully studied. Carefully understanding the guide, a comparison for the options for GPU and CPU was carried out. After understanding the available options, a High-performance desktop computer from Dell was selected. The specification of the selected Desktop computer is listed below in table 15:

Table 15: Specification of Dell High performance Coputing system

System Name	**Dell Precision 5820 Tower X-series**
GPU	Nvidia Titan RTX 24GB GDDR6
CPU	Intel I9-9820X @ 3.30GHz, 3312 MHz, 10 core(s), 20 logical core(s)
RAM	128 GB (2666 MHz)
Storage	2 × 1 TB SDD 2.5” SSD
OS	WIN 10 PRO 64 bit

Figure 10: High performance PC

[1]The software selected for the image data processing is discussed in the chapter 2.

The processing power and Graphical processing power needed for the processing the imagery datasets for the Ahmedabad city is exhaustive. Thus, to distribute the workload a cluster setup of 3 numbers of Dell precision 5820 tower X-series was established. Cluster computing helps to distribute the workload from one system to multiple systems, thus the cluster setup significantly helps in reducing the processing time required for the project. The layout of the cluster computing is explained in the chapter 2

2.3 Data-storage:

As mentioned in table 8, the data size estimated for the imagery dataset is 13.8 TB, which does not include any backup. When the processing of the image dataset to obtain 3D model is started, the size of the resultant model will also increase respectively considering the backup data. Thus, to store all the data, a local server setup is selected for the WP1.

3 Software selection for WP1

Worldwide many distinct software are used for the photogrammetry applications and urban energy modelling framework. This includes both open source software and proprietary software. For the WP1 part of the iNUMBER project, combination of various software are used. The objectives of the software ranges from the Mission planning, data-extraction, image data geo-tagging, image data processing &finally for the Urban Building Energy modelling framework. The majority of the software used for the mission planning are by the CHC-NAV i.e. the UAV manufacturer.

For each of the stage, a different workflow for a specific dataset are followed for the processing and compilation of the results. This workflow is followed in either a single software or multiple software.

3.1 Mission planning software

The mission planning software is used for Mission planning for the UAV flight and execution of the UAV flight. The input parameters of a single mission are uploaded in either desktop version or android version by the operator. Much of the input parameters can be grouped in Region of interest input & Flight parameters input.

3.1.1 Region of interest

The area that needs to be surveyed and thus analysed by collecting the images of the area is defined in the region of interest.

3.1.2 Flight parameters

The flight parameters include the technical input that needs to be defined. Some examples include height of the flight, image overlap etc.

Once the input parameters are defined and uploaded, the operator executes the mission while keeping an eye on the in-flight parameters that are displayed on the software screen. It is also possible to plan the mission on the desktop version of the software and then upload to the android version. This is useful as it is convenient to use an android tablet on site instead of a Windows laptop. Some specific operation for the UAV i.e. Recalibration of the UAV can be only completed in the Windows version of the software.

3.1.3 CHC-GCS planning software: Desktop version

The desktop version of the software is called CHC-GCS i.e. CHC Ground Control Software, and the software is only compatible to run on Windows OS on Win 7 & or above version platforms. Figure

10shows the dashboard of the mission planning software. As it can be seen, there are 4 main tabs of the software:

1. **Flight data**: the dashboard shows the in-flight parameters for the ongoing flight
2. **Flight plan**: the option used to define the mission
3. **Initial setup**: The option used for the first-time setup of the UAV.
4. **POS GET**: this option is used for extraction positioning data and for geo-tagging images

Before performing any action under the 4 options, the UAV with batteries needs to be connected to the computer system using a COM port cable which is identical to an USB cable. Once the cable is attached, the communication between the computer system and the UAV needs to be initiated, by using the connect button on the software. Also, the COM port driver has to be updated for the windows before the first application of the software and an appropriate data-transmission speed has to be chosen. The option is viewed in the figure 11.

If the GCS software is used only for the mission planning of the flight, the UAV doesn't need to be connected to the computer system. If the GCS software is also used for both mission planning and mission execution, the wireless communication between the UAV and the computer system has to been performed by selecting the specific module. If the GCS software is only used for the data-extraction, the UAV needs to be connected to the computer system, but the rotor wings of the UAV needs to be detached from the UAV.

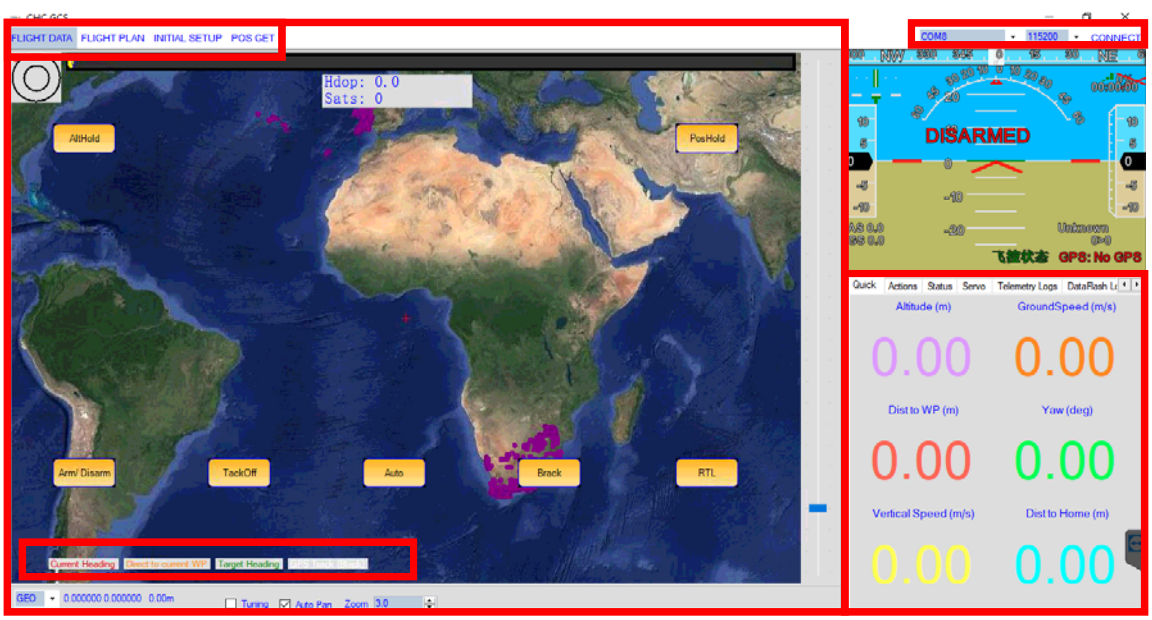

Figure 11: Home-screen of the CHC-GCS Software.

The top-right of the screen shows the option to connect the software to the UAV. The map on the screen shows the flight parameters, the buttons shows the flight control parameters and right side of the screen shows the UAV parameters

3.1.3.1 Flight Data:

The flight data option is used to view all the inflight parameters of the current flight. The option is only used once the mission is planned. As viewed in figure 10. The flight data option can be further divided in to three screens:

1. Flight parameters display
2. Flight control parameters
3. UAV parameters display

3.1.3.1.1 Flight parameters display:

The flight data is a map that displays below listed points in respective coloured lines for ease of viewing:

1. Current heading: Displays the direction of the UAV in real time in red color
2. Direction to current Way-Point: Displays the direction in which UAV us headed to in Orange color
3. Target heading: Displays the defined target or waypoint in Green color
4. GPS track: Displays the real time position of the Base-station in real time in Black color

3.1.3.1.2 Flight control parameters

Along with the display options stated below, there are also interactive button options for following controls of the UAV:

1. AltHold: option to hold the current altitude of the UAV
2. PosHold: option to hold the current position of the UAV
3. Arm/Disarm: to enable or disable the rotor arms of the UAV only during the take-off and landing
4. Take-Off: to takeoff the UAV for the current mission
5. Auto: to enable the current mode to Auto mission mode for the planned mission
6. RTL: Return to launch mode

3.1.3.1.3 UAV parameters display

The Current flight parameters are also displayed in the right side of the screen: the parameter displayed are:

1. Altitude (m)

2. Ground speed (m/s)
3. Distance to Way-point (m)
4. Yaw (degree)
5. Vertical speed in m/s
6. Distance to Home (m)

Theother important parameter to consider amongst them is DataFlash logs. The option is used to review logs and download the logs for the executed flights. The log is later used in the geo-tagging the images are extracting the position data of relevant images.

3.1.3.2 Flight plan

In flight plan options, all information related to the mission planning is defined. The primary information needed for the mission planning is the shape file for the intended flight, which can be prepared in google earth software. The shape file needs to be prepared in a *.grid file for the GCS software. Once the file is prepared and uploaded into the GCS software, modification to the mission plan can be done for e.g. the waypoints of the flight can be added, removed or redefined. The information regarding the camera attachment (HC-5020 oblique camera here) image capture time, distance, etc. can also be changed in the options here. Along with the waypoints following parameters as per table 16 also needs to be defined. Figure 12 shows the screen of flight planning.

Table 16: Parameters for Flight plan

Simple Options:	
Camera attached selection	
Altitude	m
Angle	degree
Flying speed	m/s
Add take-off and land location as a Waypoints?	Yes/no
Grid options:	
Distance between lines	m
Overshoot	m
LeadIn	m
Start from Home/Waypoint?	Yes/no
Overlap	%

Side overlap	%
Enable cross-grid?	Yes/n
Copter options:	
Delay in waypoints	seconds)
Heading hold	Yes/no
Lane separation	m
Camera configuration	
Focal length	m
Image width	pixels
Image height	pixels
Sensor width	mm
Sensor height	mm
Trigger method	distance/digicam-control/repeat

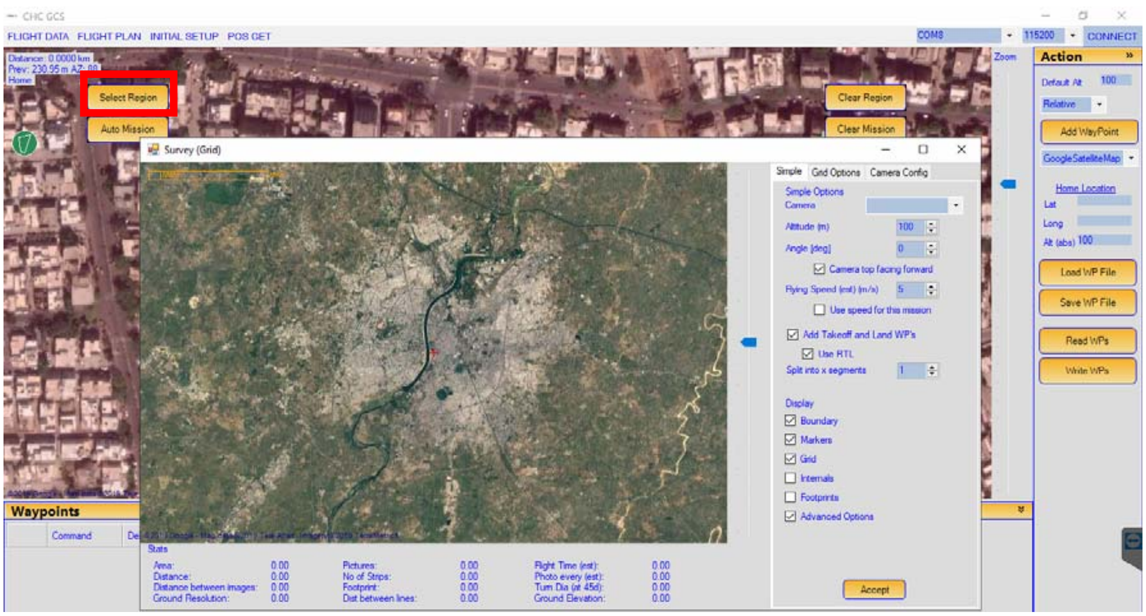

Figure 12: Flight planning screen

3.1.3.3 Initial setup

This option is used to configure the UAV for the usage of the first time. The different options that are used for calibration of the UAV are:

- Acceleration calibration
- Compass calibration
- Radio calibration
- Failsafe test
- Motor test
- Geo-fence options

3.1.3.4 POS GET (GEO-TAGGING IMAGES)

The oblique camera attached to the UAV collects and stores all the images. The UAV stores also all the accurate position data for each image captured (with the communication between UAV and RTK base-station) in local storage.It is then extracted using the CHC-GCS software as mentioned in the Flight data part. For the image dataset, the images are stored in the local storage of the oblique camera. It is to be noted that although the oblique camera does contain a GPS module, the images does not contain any position data as meta with them.

For a photogrammetry software it is very crucial that the image data contains the respective position data as a meta-data or as a different *.txt file that can be corresponded with every image. Thus, the images are here geo-tagged using the POS GET option in GCS software. The option is shown in figure 13.

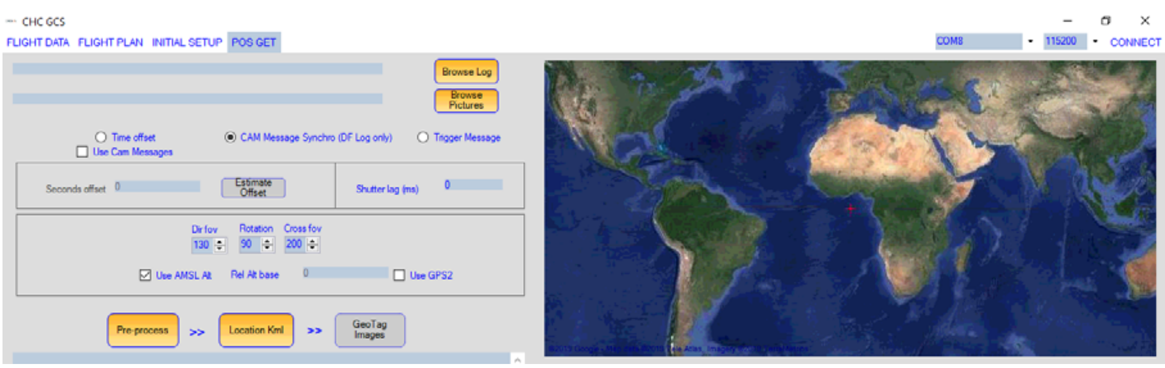

Figure 13: POS GET option in CHC-GCS

Using the logs downloaded from the previous flights in *.bin file format, the POS GET option is used to extract a *.txt file containing the position coordinates of all the images along with a *.kml file showing the geographical area the mission. For using the option once must initially locate the *.bin log file from flash data-log optionsand all the images captured transferred to store in the computer system. Once both are located, the pre-process can be performed; which reads the log file selected. Post reading the log file a *.kml file is prepared which is used to then geo-tag the images for the respective locations.

3.1.4 CHC-GCS planning software: Android-tablet version

For the iNUMBER project, the android software version of CHC-GCS software was used for all flights of the Ahmedabad city. The android version of the software is similar to the desktop version of the software. The major difference between the desktop version and android version is that the desktop version can be operated without the use of the remote controller whereas the android version can only be used when the tablet is connected to the remote controller via a USB cable.

Figure 14: Home-screen of the CHC-GCS android app

The home-screen of the android app shows the map view along with the onscreen controls. The controls have the same functions as described in the desktop software section. The operator first must connect the remote controller with the Tablet & then the UAV with the app using the bottom right section of the screen. Once the UAV is connected, the mission planning and other UAV related activities can be done in the app. Figure 15 shows the home screen once the app is connected.

Figure 15: Home-screen of CHC GCS android app

The main menu of the app shows 5 main options as seen in figure 16:

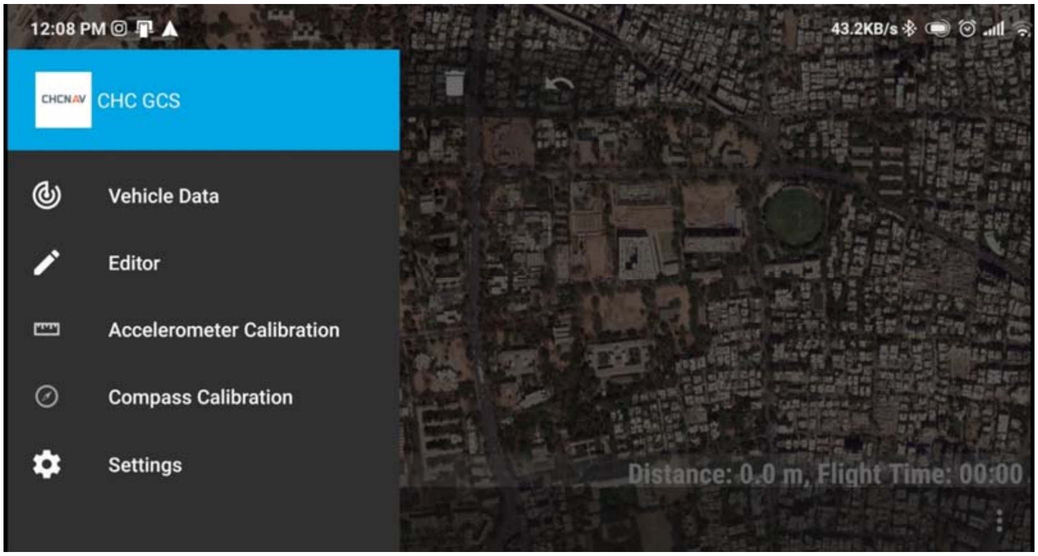

Figure 16: options for the App

1. Vehicle data: used to display UAV parameters
2. Editor: Used for mission planning, mission uploading
3. Accelerometer calibration: used for calibration of the accelerometer
4. Compass calibration: used for the calibration of the compass
5. Settings: used to change the settings of the App for e.g. change the map providers

The editor option is used to plan the mission and define the input of the flight parameters to the app.

Figure 17: Editor screen in the app

On the editor option, the survey option needs to be selected from available four different options for the data collection from the UAV. Once the option is selected the operator needs to manually a polygon around the area of interest. The operator can also upload a previously planned mission, or also upload a mission that has been planned from the Desktop application. Once the mission is planned, the other options pertaining the mission can be changed/defined. The parameters are listed in table 17.

Table 17: Options for mission defination

Camera model	Select from available option
Enable cross gird	Yes/No
Lock copter orientation	Yes/No
Hatch angle (°)	
Flight altitude (m)	
Overlap (%)	
Sidelap (%)	

Once all the mission parameters are defined, the mission can be uploaded to the UAV and then be executed. The settings that can be changed in the application are mentioned below in the table 18.

Table 18: Settings for the CHC-GCS android app

Which link to use to connect to drone	USB/TCP/UDP/Bluetooth
Telemetry connection setup	Options for each connection
Maps providers	Google map: Global/China
Enable map rotation	Yes/no
Enable Realtime camera footprint	Yes/no
Max altitude value	(m)
Min altitude value	(m)

Default Altitude value	(m)
Mission editor default speed	(m/s)

3.2 Data processing software

Photogrammetry i.e. image processing software are one of the main parts of the UBEM as they process and compile the image data to give the necessary input parameters that are required in the UBEM. The data that is envisaged to use in the iNUMBER project is primarily imagery data which is later converted in to point-cloud data wherever required. It is to be noted that as mentioned in the previous chapter, only aerial imagery data is collected through the UAV+Oblique camera setup and no point-cloud data is collected through the data-collection equipment. With the current updated technologies, there are option available to even convert one data source into each other i.e. the image data can be converted in to point cloud data and vice-versa, depending on the need.

There are a lot of photogrammetry software options available in the market in both open source and proprietary category. Few of the widely used software are:

1. Bentley ContextCapture
2. Aegisoft MetaShape (formerly known as Aegisoft PhotoScan)
3. Pix4D.

After comparing the capabilities of different software Bentley ContextCapture was selected as the main image data processing software i.e. photogrammetry software. One of the main reasons to select the ContextCapture was the options of using images and point-cloud as both input parameters, as this would be very helpful later in developing the UBEM framework. the other selection factors for ContextCapture were cloud computing, cluster computing, efficiently handling unlimited data and other features.

3.2.1 ContextCapture:

ContextCapture is a reality modelling software published by Bentley in its Reality modelling portfolio. Out of many available output options, It provides the output in form a 3D digital information layer which is referred to Reality mesh. The software can combine numerous types of input ranging from images to point cloud to orthophotos.

There are total 5 different modules in the ContextCapture software suite:

1. **ContextCapture**: The standard desktop version of the software able to process a limited data
2. **ContextCapture Centre**: The desktop version of the software which is able to process unlimited data

3. **CC Cloud processing service**: This module is used if the user intends to use the cloud processing capabilities
4. **CC Mobile**: If the user intends to use the images from the mobile, this module can be useful
5. **ContextCapture Viewer**: the only use of the viewer module is to view the 3D model

For the iNUMBER project, the ContextCapture Centre version was used along with the ContextCapture viewer. The key difference between the ContextCapture and ContextCapture Centre version is listed below in table 19:

Table 19: Version of ContextCapture (Source: Bentley)

Features	ContextCapture	ContextCapture Center
Input imagery datasets	**≤ 300 gigapixels**	**Unlimited**
Automatic aerial triangulation / calibration	●	●
Automatic true 3D reconstruction (3D TIN)	●	●
Georeferencing	●	●
True orthophoto / DSM generation (GeoTIFF, JPG…)	●	●
Dense point cloud generation (POD, LAS)	●	●
CAD interoperability (3MX, OBJ, FBX, Collada, STL…)	●	●
3D-GIS interoperability (CityPlanner, Virtual Geo, Blaze Terra, TerraBuilder, SpacEyes3D Builder, SuperMap, …)	●	●
Area / Volume measurement	●	●
Free viewer / web publishing	●	●
Unlimited tiling	●	●
Task queuing/ background processing	●	●
SDK / Python scripting		●

Ultra large project management / Grid computing		●
Reconstruction constraints (water surfaces, …)		●
Quality Control		●

Furthermore, the ContextCapture software (both standard version and center version) consists of 3 different part to work. Without anyone of the 3 parts it is not possible for a user to complete the processing and developing of a 3D model.

There is also a separate application for editing model developed using the ContextCapture Master and Engine, and the application is called ContextCapture Editor. The total parts of the ContextCapture centre are listed below:

1. ContextCapture Master
2. ContextCapture Engine
3. ContextCapture Settings
4. ContextCapture Editor

3.2.1.1 ContextCapture Master:

ContextCapture settings is the chief application for defining the input parameters for the model. The software can take numerous files as an input type which includes both images and point cloud data. The ContextCapture Master is used to define the aero-triangulation parameters as soon as the images are imported in the software. With the Help of the GCPs (Ground Control Points) the final aero-triangulation is carried out, after which the user can define the reconstruction settings which can be used for enhancing the processing of the model and optimization of the processing. Finally the 3D model is obtained.

ContextCapture master is the only application which can be used to obtain the desired output type from the available data, which includes 3D model (*.3mx/*.obj) or 3D Point-cloud models (*.LAS/*.POD format) or Ortho photo DSM (*.geoTIFF/*.JPEG).

Figure 18shows the home screen of the CC master software. As seen in the image the main screen consists of the 5 main parts:

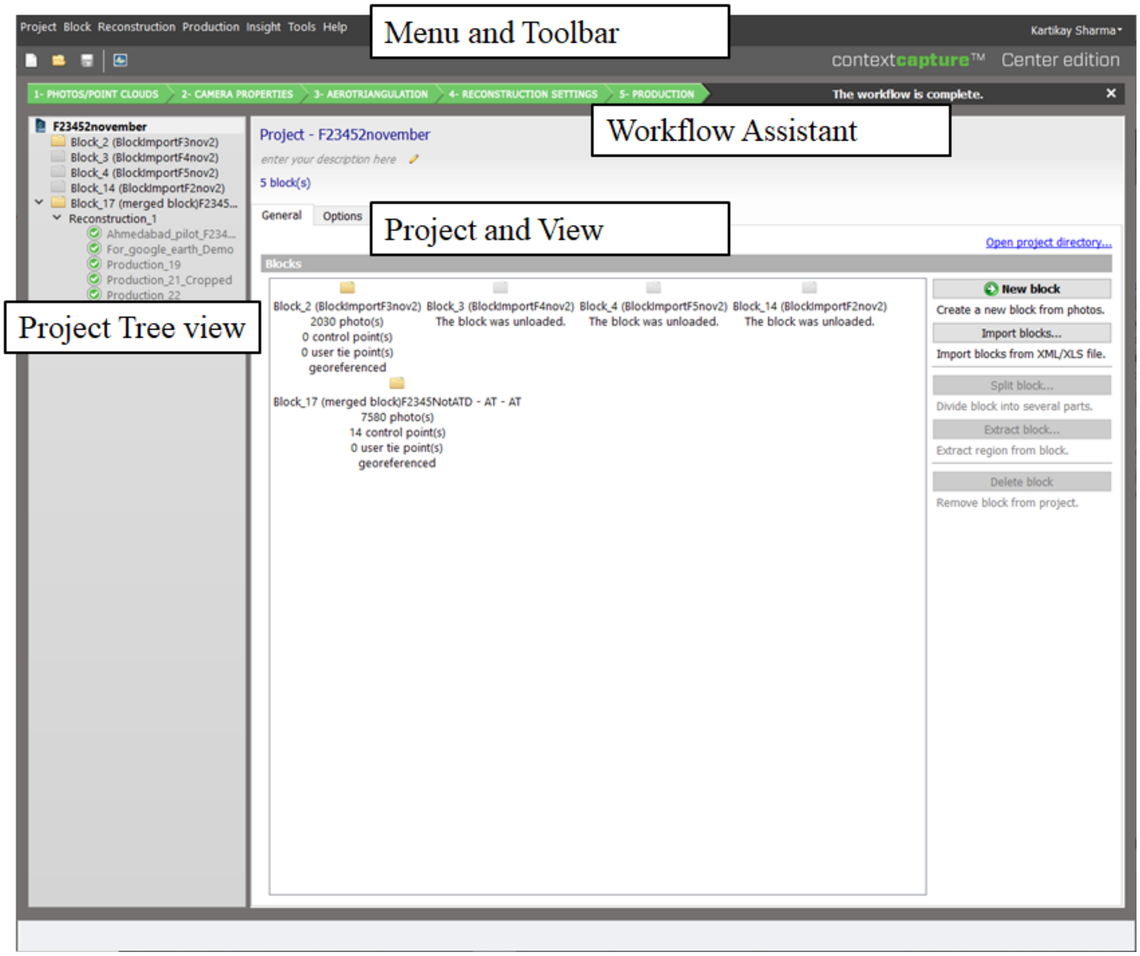

Figure 18: Default view of the ContextCapture Centre Version Software

3.2.1.1.1 Menu and toolbar

The menu and toolbar are the primary tools to save, load and open past or new projects. Along with the project directories options, there are other tool options which can be used for Base map managing, Reference managing Job queue managing and monitoring, reconstruction settings and production settings and lastly for converting a model to scalable mesh (format for another Bentley application) and software dashboard options. The Block, reconstruction& production settings are further explained in the section 2.4

3.2.1.1.2 Workflow assistant

Workflow assistant tool is designed to keep a track on the stage of workflow a user is currently in. there are total 5 stages of workflow, the user needs to follow to complete the workflow:

1. Photos/Point-cloud
2. Camera properties
3. Aero triangulation
4. Reconstruction settings

5. Production

The detailed explanation of the workflow is later in the section 2.4.

3.2.1.1.3 Project tree view

Project tree view helps user navigate to the specific project file easily. There is also an option to load/unload file to make processing optimized. Other options include importing/exporting options, Clone, Delete, Rename.

3.2.1.1.4 Project and view

Project and view are the main workspace of the software, it is used to define model input parameters for the data. The view option can be used to view the model in 3D.

3.2.1.2 ContextCapture Engine

ContextCapture Engine is the back-end engine of the ContextCapture Master. All the processing pertaining to the queued jobs of ContextCapture is executed by the ContextCapture engine. ContextCapture engine can be turned on once the model input parameters are defined. To process a model, it is mandatory to start the ContextCapture engine on each computer of the Cluster setup. The relation between the ContextCapture matter and engine is explained in the figure 19.

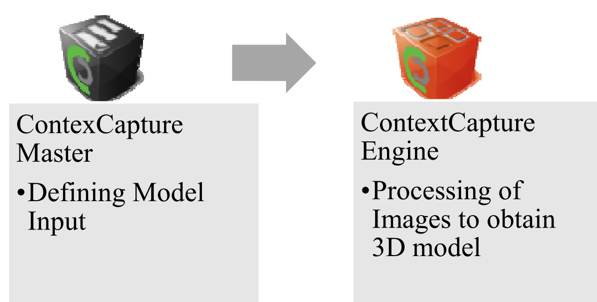

Figure 19: Relation between ContextCapture Master and ContextCapture Engine

The view of the ContextCapture engine can be seen in the figure 20.

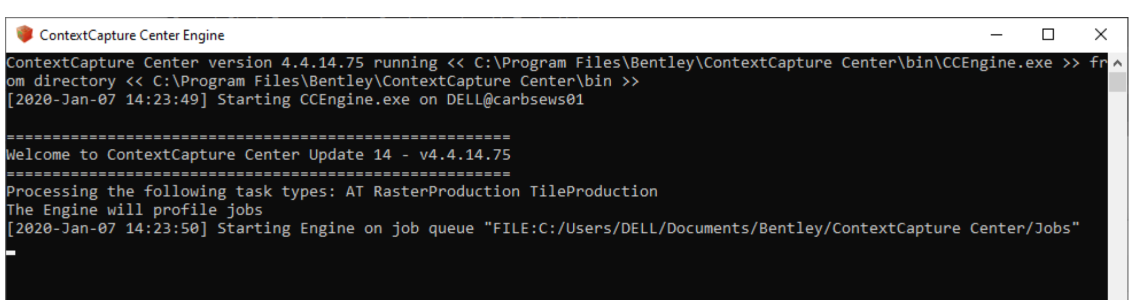

Figure 20: Homescreen of ContextCapture Engine

3.2.1.3 ContextCapture Settings

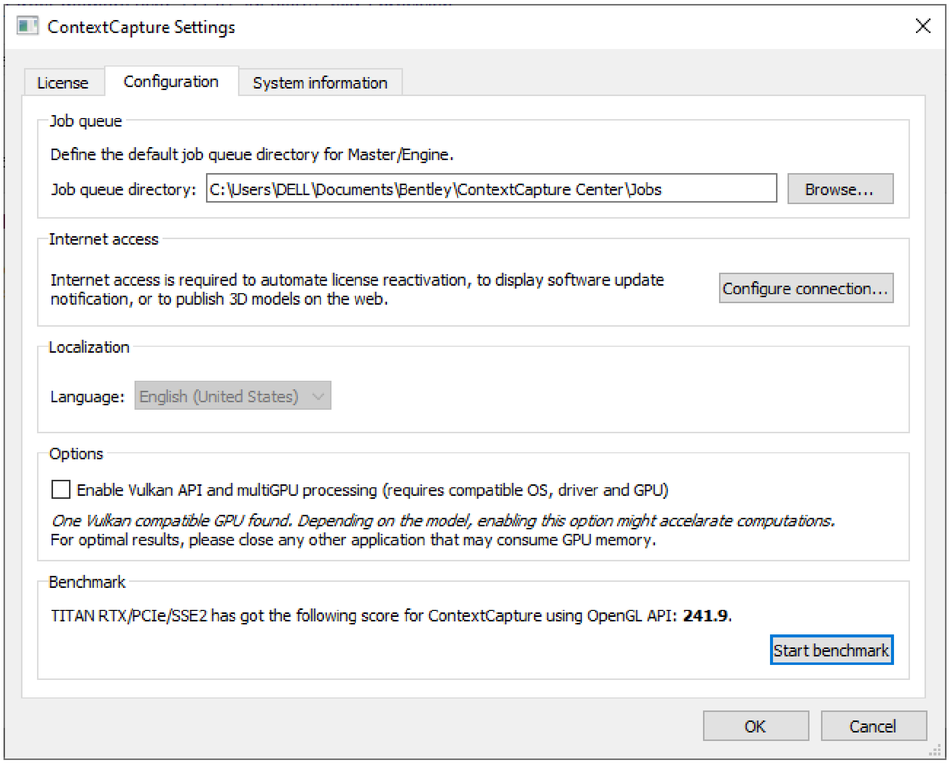

Figure 21: ContextCapture settings options

ContextCapture settings (figure 21) is used to configure the operation of the ContextCapture. The licensing of the software is managed by this setting along with the configuration of the internet. This setting is the only setting where the cluster computing setup can be defined. The user can also configure the access and location of job queue from this option so it can be accessed by the other computers in a cluster setup. The benchmark score of the GPU can also be obtained from the settings option. The setting up of the cluster setup is explained in the section 2.3

3.2.1.4 ContextCapture Editor

ContextCapture editor is the only optional software of the ContextCapture software suite. The editor is mainly used for the editing and cleaning of a ContextCapture produced 3d model. It can also be used for post processing of models to obtain ground model and terrain model.

The editor software has many workflow options available but for the iNUMBER context, the reality modelling workflow is mainly used. Home screen of ContextCapture editor can be viewed in figure 22.

One of the main use of the ContextCapture editor is to perform postprocessing of the developed 3D model which includes cleaning and cropping the model, extracting a image view etc.

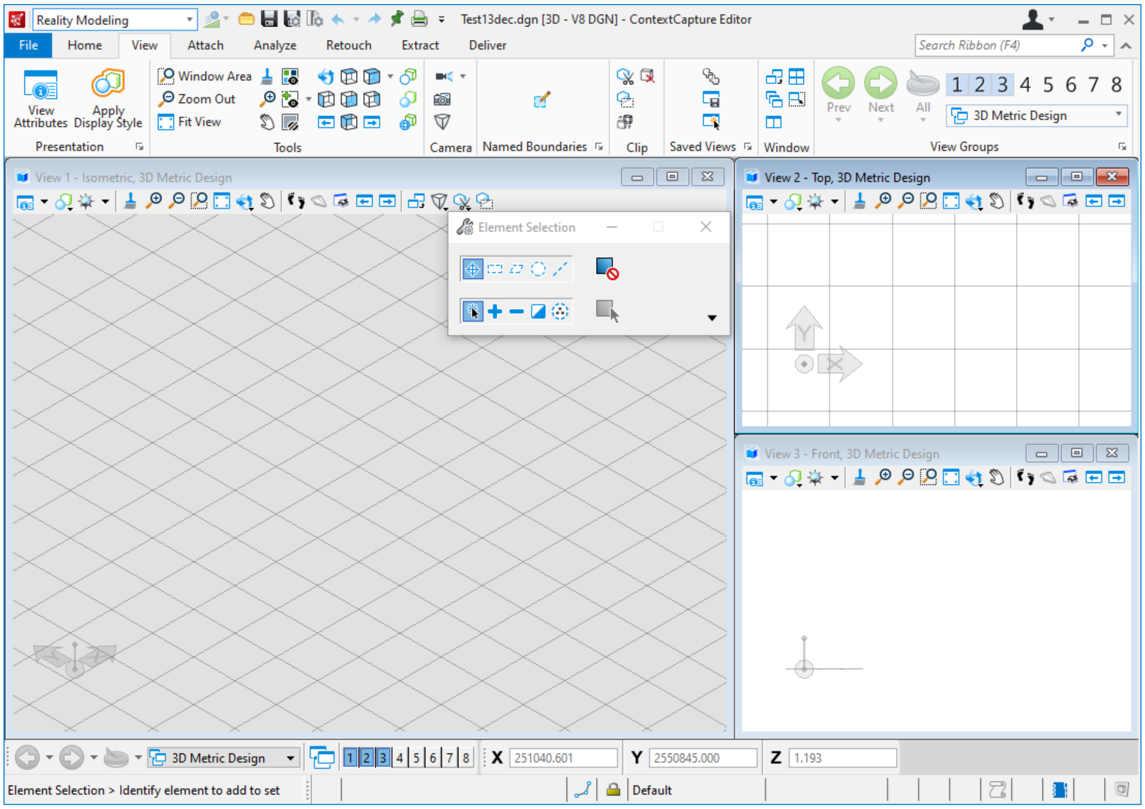

Figure 22: Homescreen for the contextcapture editor software

3.3 ContextCapture Cluster setup

As discussed before, to process very large imagery datasets for a city context, it is difficult for a single computer system to process it locally. By using the capabilities of the cluster setup of ContextCapture, the workload cab be distributed between two or more computer systems. Thus, the processing time for the specific task is decreased significantly. Figure 23 explains the working of a cluster setup vs a single PC setup. In Bentley's term this cluster relation is called a master-worker setup, where there are only one master and multiple workers. When the master computer defines the model and keeps it in a share location, it can be accessed from the worker computers.

Once the master computer completes defining the input parameters of the model and queues the jobs for processing, the jobs are assigned to worker computers randomly and processed. The user must be careful to keep all the data and Job queue in such a manner that it can be accessed from all the computer systems involved in the grid. The job queue can be configured for the worker computer systems using the settings option.

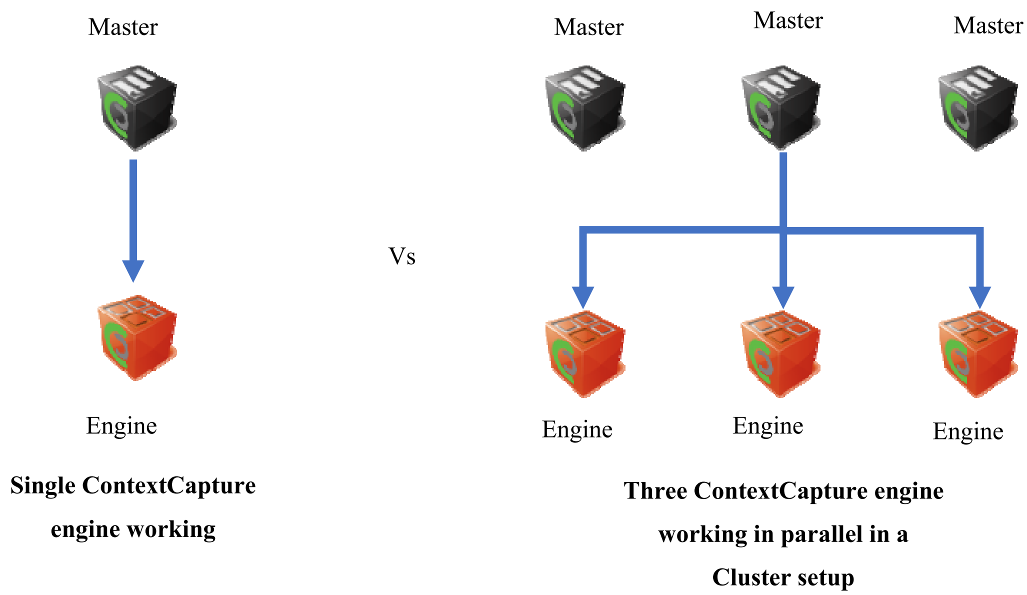

Figure 23: ContextCapture Cluster setup explained

All the worker computer systems must follow the job queue defined in the master computer system for the processing to continue. To ensure image data access to all computer systems in cluster setup, the sharing option of the Windows settings can be used. The UNC naming convention must be used for the image directories (figure 24) to make it compatible for other computers to access the image data in the cluster setup.

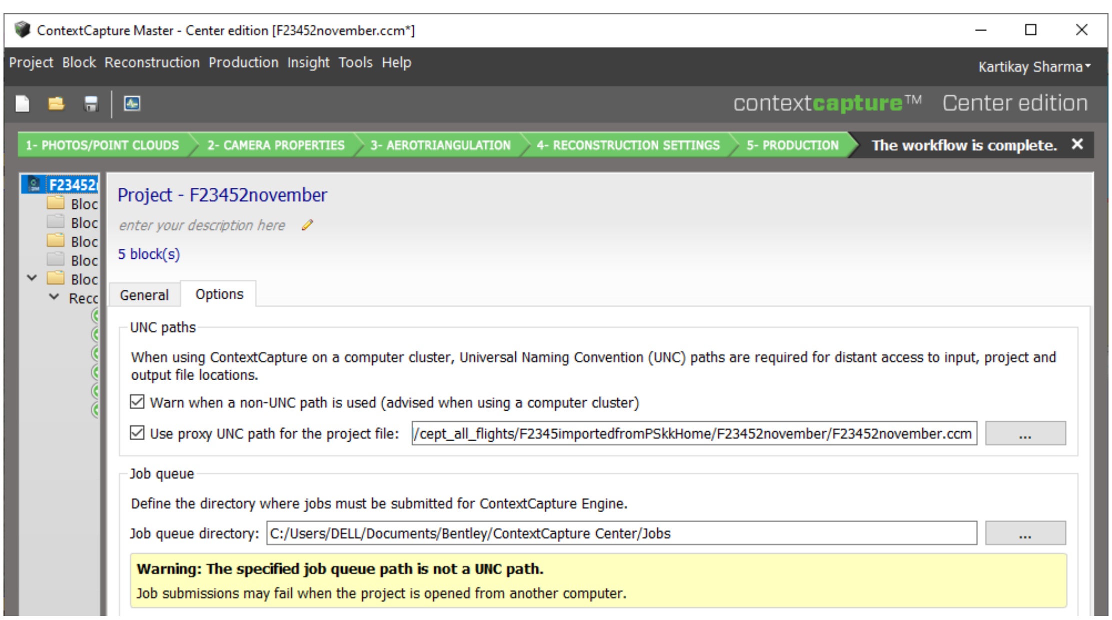

Figure 24: Setup options for the Cluster setup

Other tools namely reference manager (fig 25) and base-map manager can be used to check, modify the properties of the images at once so the properties of each images don't need to be changed individually.

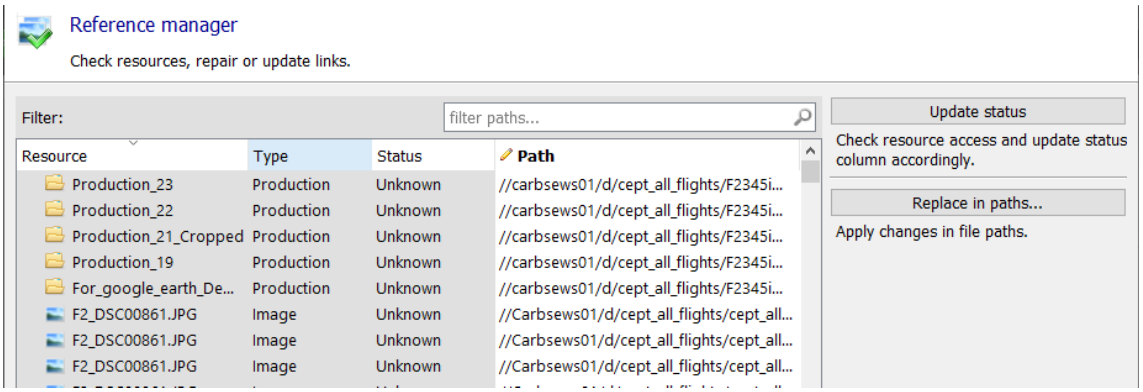

Figure 25: Reference manager to manage image reference

The physical setup of the cluster setup for the iNUMBER Setup can be seen in the figure 26.

Figure 26: Physical cluster setup

3.4 ContextCapture Workflow general

The workflow here refers to steps the user must follow to obtain a 3D model. To ensure, the user reaches this stage; the aerial image data collection on the field must be completed. The workflow assistant helps user to understand the process of obtaining a 3D model. There are total 5 stages involved for developing a 3D model. These 5 stages can be modified as per the users need. For the iNUMBER the workflow has been modified and is explained in the section 3.7.

3.4.1 Photos/point-cloud: Importing raw aerial imagery data or point cloud data

In this step, the input data i.e. aerial imagery data must be located and imported in the software. There are three options to import images in the project file. The option of importing the position data of the images depends on the options used to import images.

3.4.1.1 Importing photos/directories

To import the raw images the user can either upload the photos individually or select an entire directory of images. As the images are imported alone in this option the position data of the respective images needs to be imported separately. The option to import images and position data is shown in the figure 27.

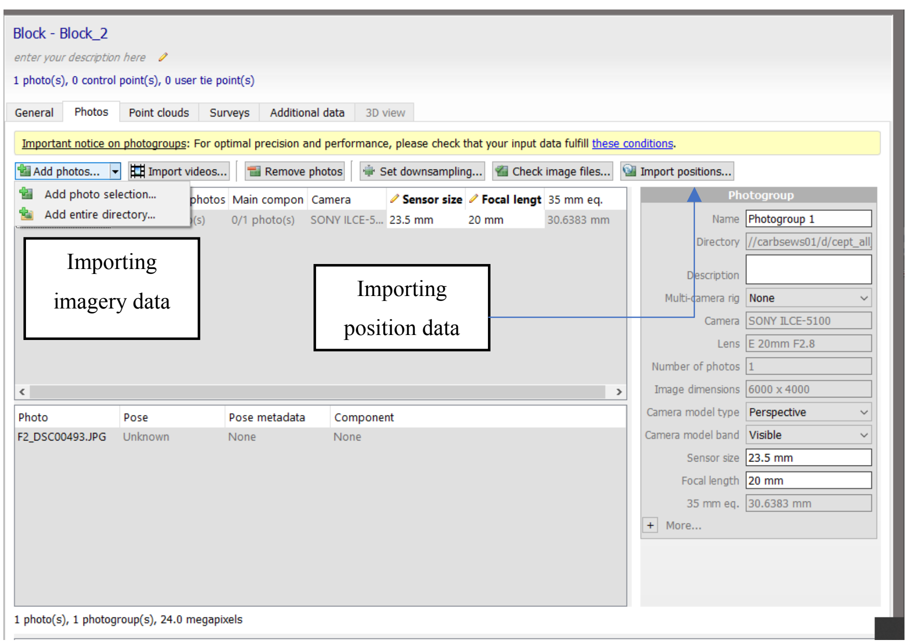

Figure 27: Importing Photos and position data in to contextcapture.

Once the images are imported, the software automatically deduces other parameters from the images metadata. Some of the imported image parameters are camera name, sensor size, focal length, image dimensions.

3.4.1.2 Block file import method (*.xlsx or *.xml)

In case of using an oblique camera setup, there are a lot of images that needs to be imported. This process is made easier by the help of a block import excel file.

The path of the image files along with the position data is required to be compiled in the excel file along with the camera properties in different excel sheets of the template file. The GCPs can also be included in the template file if needed or can be imported separately using importing GCP option. The path of the image file i.e. the location of the image file can be obtained using a script prepared by the software which fetches and reports the location of each image. The position data of each image can be obtained from the data extracted from the UAV.

There are total of 4 sheets in the block import file out of which information for 2 sheets is mandatory. The 2 sheets are explained below:

3.4.1.2.1 Photo-groups:

As an oblique 5 angle camera is used here to capture the aerial imagery, there are a total of 5 images capture at any single point. Thus the 5 camera represents the 5 different photo-groups. A representation of the camera is shown in figure 28.

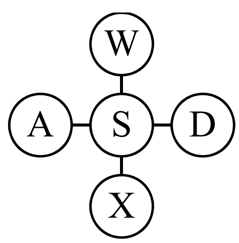

Figure 28: 5 camera setup explained

The W represents the top camera, D represents the right-side camera, A represents the left side camera, X represents the bottom camera and S represents the middle camera. It is required to store images from different photo-groups in different folders as all the 5 images will have the same name. the required data fields to be compiled in the photo-group sheet are shown below in table 20. This sheet will remain same for image from each flight.

Table 20: Camera properties template format

Name	Width	Height	FocalLength	SensorSize

A	6000	4000	35	23.2
D	6000	4000	35	23.2
S	6000	4000	20	23.2
W	6000	4000	35	23.2
X	6000	4000	35	23.2

3.4.1.2.2 Photos:

The path of the images captured are compiled in this sheet. With each image and its precise geographical location, the northing, easting and height of the images also needs to be compiled in the sheet. Other option details which can be included are yaw, pitch and roll of the aircraft at the specific geographical rotation. The format of the required data is shown in table 21.

Table 21: Block import format

Name	PhotogroupName	Northing	Easting	Height
D:\A\DSC00310.JPG	A	23.0416458	72.5663529	167.29
D:\D\DSC00310.JPG	D	23.0416458	72.5663529	167.29
D:\S\DSC00310.JPG	S	23.0416458	72.5663529	167.29
D:\W\DSC00310.JPG	W	23.0416458	72.5663529	167.29
D:\X\DSC00310.JPG	X	23.0416458	72.5663529	167.29

3.4.2 Camera properties

This step of the workflow is automatically completed, as the information related to camera properties are imported along with the images either in the case of direct photo import by meta-data or by block import method by manually entering. If a custom-made camera is used, then the camera properties needs to be manually defined and entered.

3.4.3 Aero-triangulation:

Aero triangulation is a one of the main process in the ContextCapture workflow. In the process where the ContextCapture algorithm aligns each image geographically with the help of position data. This step thus helps to create a preliminary sparse model is obtained which can be reviewed for any incorrectly aligned images. If the GCPs are also provided as input at this stage, the algorithm tries to pinpoint the GCPs, and as a result the stitching of images is more accurate, and the overall accuracy of the model is increased. It is mandatory to select the proper projection system in the settings to obtain the correct result.

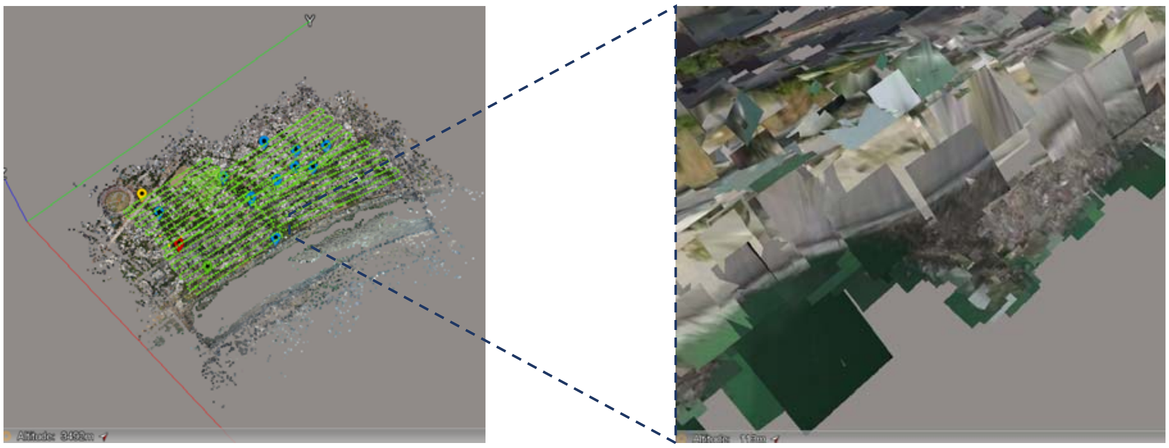

Figure 29: Aerotriangulation result

Figure 29 represents an aero-triangulation result. The right zoomed in image explains how the aero triangulation stiches images together using the position data. the green dots on the left image represents the location of images.

3.4.4 Reconstruction settings

Reconstructionsettings are the settings that are used to define the properties of the processing for 3D model required. The settings related to spatial framework, reconstruction constraints, and processing can be configured as per the requirement of the project. The settings related to the processing and its optimization can also be tweaked in this setting. Once the settings are frozen the model can be submitted of the production.

3.4.5 Production

Production is the last stage of developing a 3D model. Once the reconstruction settings are decided for the model, it can be submitted for the production. This stage is also the most time-consuming stage depending on the processing and graphical processing capabilities of either a single or a cluster setup.

The output type can also be selected by the user matching the user's requirement. Figure 30 shows the output of a 3D model developed.

Figure 30: 3D model obtained at the end of production stage

Thus, to encapsulate the workflow, figure 31 depicts the workflow of the ContextCapture software:

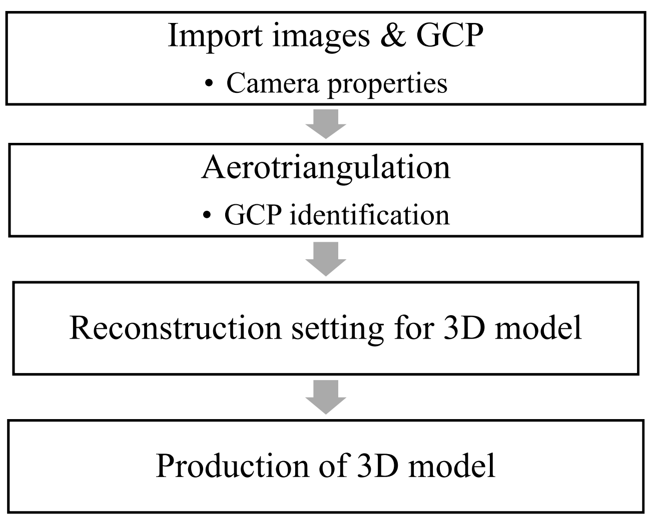

Figure 31: General workflow for ContextCapture software

4 Pilot project

A pilot project for the iNUMBER was conducted before the actual data collection for the project. the objective of the pilot was to understand the equipment, its working, operation and its use for collecting and processing the data. The main topic understood during the pilot project are listed below:

1. **Introduction of the P-550 UAV**: the basic principle of the UAV and the oblique camera are understood in this stage. It includes the assembly/disassembly of the equipment including the main aircraft, RTK base-station, Remote-controller, first time setup of the equipment along with the charging instruction of every components
2. **Introduction to HC-5020& HC-12 oblique camera:** this part of the study focuses on understanding the basics of the oblique camera, its distinction from a normal camera, assembly procedure, charging procedure, and operating procedure.
3. **Mission planning methodology**: this stage was focused on understating the basics of how to plan a mission with the required parameters including the overlap/Sidelap, height and GCPs. The instruction related to the safety and protocols are also understood in this stage.
4. **Mission planning software**: this stage was focused on understating the specific software part of the Mission planning applications, ways to export/import mission etc.
5. **On field flight**: this stage includes the actual flying of the UAV on the flight to collect data.
6. **Data extraction methodology**: once the flying on the field is completed, the process to extract the image data from the oblique camera and the position data from the UAV is understood.
7. **Data preparation methodology**: This stage includes preparing the data extracted in the previous step for the processing in a photogrammetry software i.e. ContextCapture here. This includes sorting and identifying data from each flight and sorting them in different location as per the flight logs& geo-tagging the imagery data-set
8. **Data processing**: In this stage the workflow to obtain the 3D model from the imagery data is understood which includes processing the image data in ContextCapture software to develop and clean the required geometrical 3D model.

4.1 Geographical context of pilot project

The area selected for the pilot project was the area of Vadaj and he SP stadium area, which falls in the respective administrative zones of Vadaj and SP stadium. The area selection was attempted considering the variation of built environment in the area and access to the site.

It was taken care that the pilot area does a representation of the Ahmedabad city. Figure 32 shows the extent of the area selected for the pilot study.The area selected for a pilot study is a rectangular area of approximately 1.15 km^2 of area which is on the west of the Sabarmati river and in the central part of the Ahmedabad city between the Gandhi bridge and the Dadichi Rishi bridge.

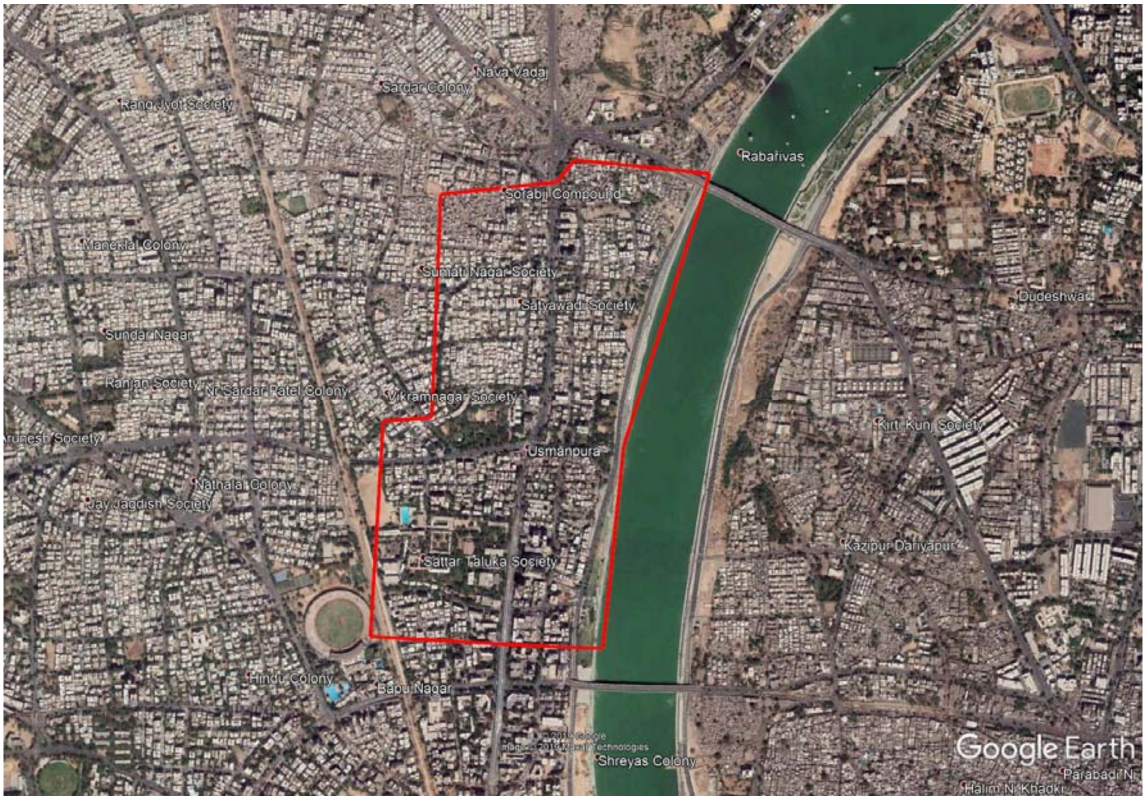

Figure 32: Geographical exten of the pilot area for the iNUMBER project

4.2 Overall Mission planning for the Pilot study:

A two-step coarse methodology for mission planning was used for the pilot study. The overall mission planning was executed by the team with the expert advice of the CHC training team along with the iNUMBER project partner. Appropriate permission for flying the UAV was acquired prior to the actual flying of the UAV.

The first step for the overall mission planning was to review the site and find out potential take-off and landing location using Google maps. The take-off and landing location are then visually verified on the actual site. The second critical step includes finding out the tallest building in the flying area, so that a safe margin can be maintained at the time of UAV operation.

Once the site related situations are reviewed, the equipment related parameters needs to be check carefully. All the components should be operational and if any fault is found in any component of the UAV or the Oblique camera, the fault needs to be resolved. The components of the UAV i.e. the UAV batteries, Base-station and the remote controller (both tablet and controller) are adequately charged along with the batteries of the Oblique camera. To store the images captured during the flight, necessary space for images needs to be allotted by backing up the old data.

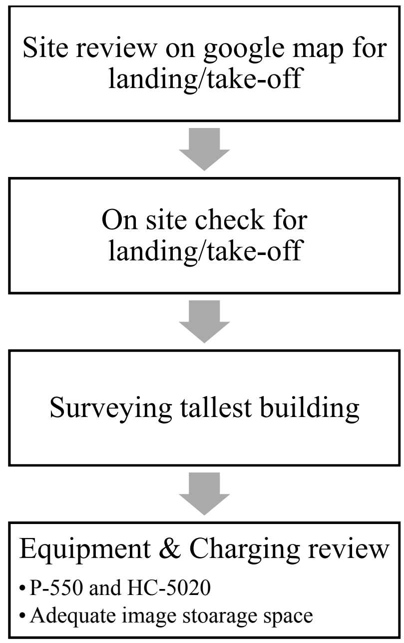

Figure 33:Overall Mission planning for pilot study

4.3 Mission planning for the individual Flight

For mission planning of each individual flight, the primary parameters considered was the available battery capacity. As discussed before, the CHC GCS software automatically estimates the area covered during the flight along with the flight time, when a polygon is drawn for mission. As the flight time for the battery in case of pilot study was known[2], all the pilot study flights were planned accordingly. The battery capacity in this case was for 30 minutes with oblique camera attached as a payload, which is adequate to cover an area of 0.5 km^2 for each flight, thus all flights planned for the pilot study were of 0.5 km^2 area and 30 minutes of battery capacity.

The summary of the pilot study project is listed in table 22.

Table 22: Summary of Pilot study

Total flights	4
Area covered (km^2)	1.2
Image captured	10500
Data size of image captured (GB)	105

[2] For the pilot study, batteries of smaller capacities were used.

From the available two options to plan mission i.e. importing a polygon or drawing a polygon, the drawing polygon method was chosen for all flights of the pilot study. Figure 34shows the flight path of each of 4 flights completed for the pilot study.

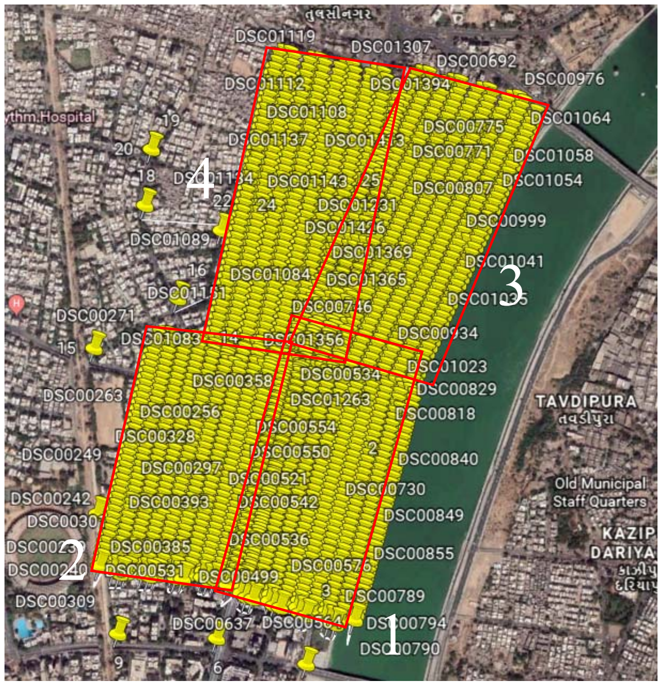

Figure 34: Flight plan of 4 flights for pilot study

Along with flight path, other parameters are also defined for each individual flight. i.e. camera model, height, overlap, Sidelap.

The finalized key parameters of each individual flights are listed in a table 23.

Table 23: Finalized parameters for each flight

Parameter	Value
Height	100 m
Time	30 minutes
Area	0.3 km^2
Overlap	80
Sidelap	70

Images captured	Approximately 400 for each camera
Data size per flight	5 GB per camera per flight

4.4 GCPs for the pilot study

GCPs stands for Ground Control Points. GCPs are reference points marked on ground such that their location and geographical coordinates are known, and the points are later identified in the aerial images captured by the UAV + oblique camera setup during and after the aero triangulation in image processing. The coordinates for the GCPs are captured by a Differential Global Positioning System (DGPS). Differential Global Positioning System is a modified version of Global Positing System with highly increased precision. Setting up of the system involves installing a base station at known coordinates. The DGPS receives the signal based on distance between the base station and DGPS. The signals received by the DGPS are from both base-station and various satellites.

To capture a GCP, first a suitable point on the ground is chosen, and the DGPS device is placed on the point. The figure 35 explain shows the process of capturing a GCP along with working of a DGPS for capturing a GCP.

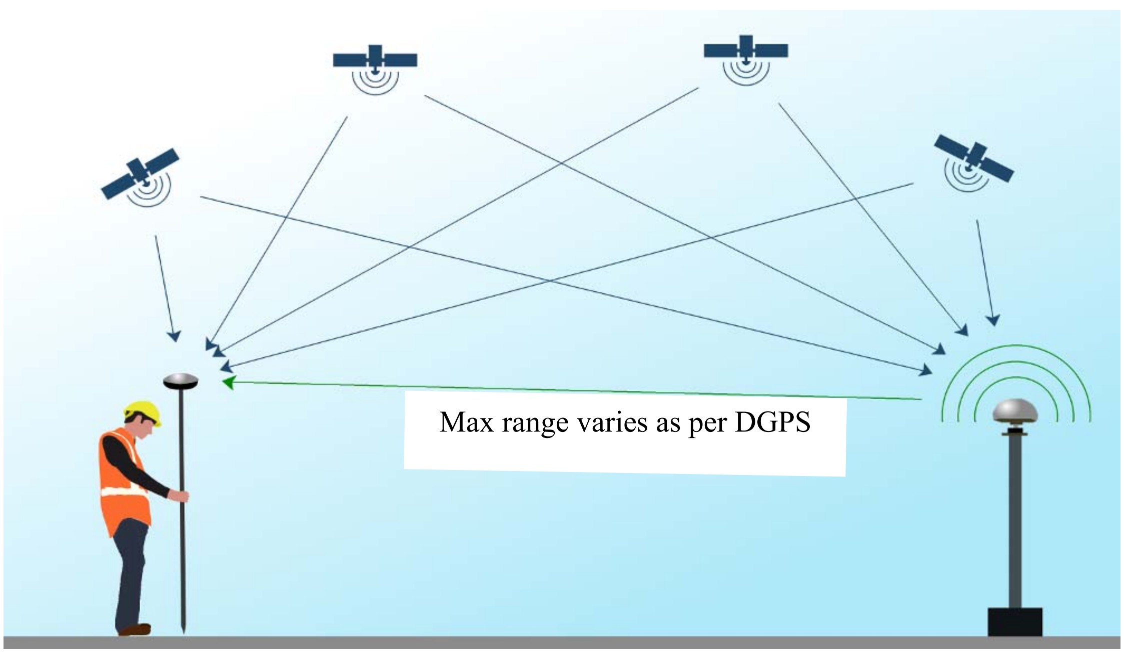

Figure 35: Working of DGPS explained to capture a GCP

GCPs helps to increase the accuracy of the model by helping and enhancing the alignment of photos and stitching images during the aero triangulation. Later during the processing of the pilot study data, it was learned that doing multiple round of GCP identification in the process of aero triangulation can be extremely helpful for increasing the accuracy of the model, and a precise and highly accurate resultant model is obtained as result.

Figure 36:(a) Marking GCP (b) identifying the GCP visually in aerial images by UAV

GCPs can be marked on the ground with various ways. Some of them are shown below in figure 37.for the pilot study a big X-mark was marked on ground by paint as shown in figure 36.

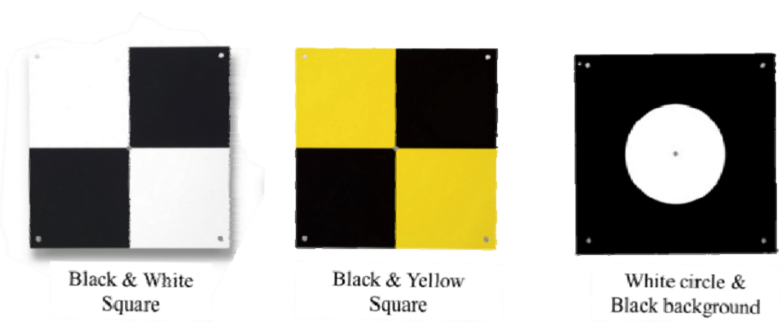

Figure 37: Examples of GCP markings on ground.

A total of 26 GCPs were captured for the pilot study flights. The GCPS can be captured before, during or after the flight, and for the pilot study the GCPs were captured during the flight. An example of the coordinates point captured is shown below in table 24:

Table 24: Data field for GCPs

Index	Northing (m)	Easting (m)	Altitude (m)
1	2551167	251448.5	50.327

Figure 38 shows all the GCPs captured for the pilot study.

Figure 38: GCPs captured for pilot project

4.5 Outcome of the model:

The main outcome of the pilot study is a 3D model of the surveyed area of the 1.15 km^2 of the Ahmedabad city, which was obtained after 62 hours of processing on cluster computing grid.

Out of many output formats available, the *.3mx format was selected for the 3d model. The developed model was of data size 20 GB and can be viewed in the both ContextCapture master & ContextCapture viewer application.

The model developed was further cropped to obtain a cleaner version of the same. This was executed to remove the disturbances and the distortion at the geographical boundaries of the model. There are 3 ways available to crop the model. One is from the ContextCapture editor application, the second is from using the geographical context during reconstruction constraint settings and the last one is using the import bounds in the processing settings. The last option was used in cropping the developed model of the pilot study.

4.5.1 Cropping model

To prepare the outline *.kml for cropping the model, the *.kml obtained from the UAV for each flight is combined to obtain a resultant *.kml file which contains all the 4-flight information. This file is then selected as the input for the boundary options when a submit new production option is selected. The option is shown below in figure 39.

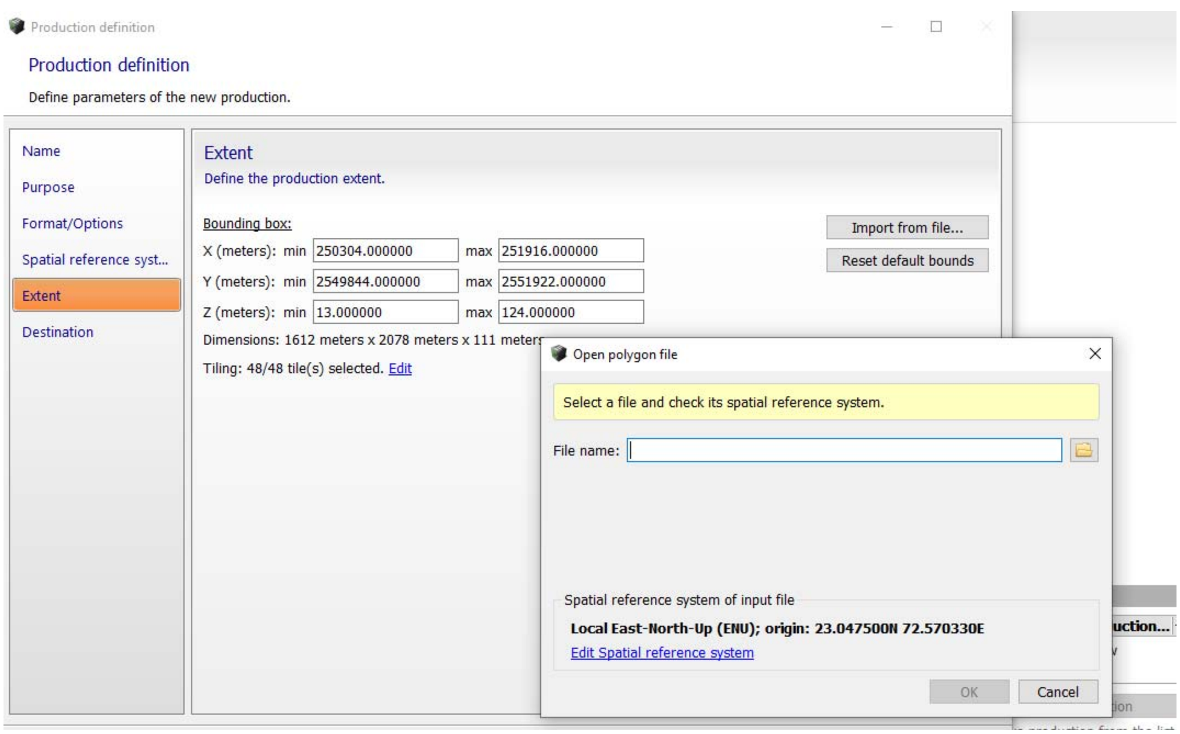

*Figure 39: *.kml file upload in submit new production option*

Once the *.kml file is selected and appropriate output is checked visually, the model is submitted to production. This time the production is not as time consuming as it was for the first time, because it uses the model that has already been developed. The model obtained at the end of this process is free from distortion and incorrect geometry at the boundary of the model. The model before and after the cropping is shown in figure 10.

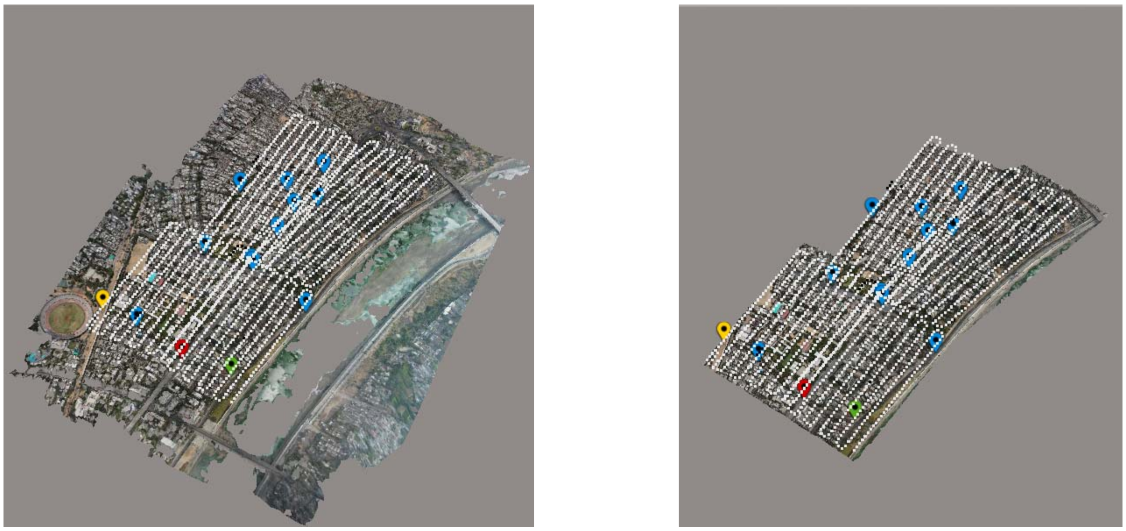

Figure 40: Impact of cropping on model

4.5.2 Final output of the model

The final obtained model can be viewed in the image 41. As seen in the model, the edges of the model are clear and not distorted.

Figure 41: Final output model

4.6 Lessons learned:

4.6.1 Final data size

After completing the workflow to develop 3D model from the imagery data for pilot study, important information was learned about the approximate size of the data that would be captured for the iNUMBER project. This data size falls is also close to the approximation attempted in table 25.

Table 25: Final data size calculation for iNUMBER project

Area to be covered (km^2)	**230**
Area covered per flight (km^2)	0.5
Flights to cover 1 km^2	2
Total Flights	**460**
Images per flight	3000
Images per km^2	6000
Total Photos	1380000
Approx. Size per photo (MB)	10
Total image size (MB)	**13800000**
Total Image Size (GB)	**13800**
Total Image Size (TB)	**13.8**

4.6.2 Hardware issues faced:

The hardware setup consists of many different components, and the connection of each component to other must be carefully executed. To understand the connection, manuals were referred and expert advice from the CHC authorities was considered wherever applicable.

A lot of video tutorials had to be carefully studied to understand the assembly/disassembly and charging of all components. The on-field operation was conducted only during the presence and supervision from the CHC-NAV authorities for the pilot project.

4.6.3 Software Problems faced:

The data size obtained during the pilot study project is huge and there are many different software used for data processing in different stages. Before data processing the data extraction and the data preparation has also to be done as per the perquisite of the selected data processing software. Once of the important lesson learned was to maintain the consistency of SRS/CRS for all the different software used. As the SRS/CRS system acts as the main geographical reference for all the data, it is important that it remains the same for the data to be correctly interpreted.

One of the other main issue faced was the setting up of grid computing for ContextCapture cluster computing. As the computer system needs to be connected and shared to each other to access each other, it is very necessary to configure it appropriately, so the workload can be distributed. If done incorrectly, the user faces error rendering him helpless as workload cannot be distributed and thus processing time increases notably.

4.7 Workflow adapted for iNUMBER:

During the processing of the imagery data to obtain the required 3D model it was observed that when aero-triangulation is done before the identification of the GCPs, the time taken is notably higher. But when the aero triangulation is carried after the identification of GCPs in aerial images, the processing time decreases.

It was also observed that once the GCPs are imported and aero-triangulation is done without trying to identify it, software automatically identifies the approximate location of GCPs in aerial images. The software also filters out images which may be potentially containing a GCP which is very helpful for identifying the GCP amongst numerous images.

Thus, it was concluded that if GCPs are identified after one round of aero triangulation and then after identification of the GCP the second round of aero triangulation is attempted, the overall accuracy of model increases, and the time to identify GCP reduces significantly

The adapted workflow helps to reduce the manual work of pinpointing GCP in each image as it filters out the image that would probably contain a GCP in its content. In a single flight data the difference of the impact of time taken for pinpointing a GCP is not noticeable, but for processing of data pertaining to a whole city, millions of images are collected and this it becomes practically impossible to identify & pinpoint each GCP manually.

Thus as a result there is an additional round of aero-triangulation that will be required to do which will add a small portion of extra processing time, but this additional aero-triangulation indirectly also helps us to reduce the overall time for the GCP identification, which is notable on the long-run of the project timeline. Thus, this learning was also considered to consider the final methodology of the study. The difference of general workflow for ContextCapture and adapted workflow for ContextCapture is visualized in figure 42.

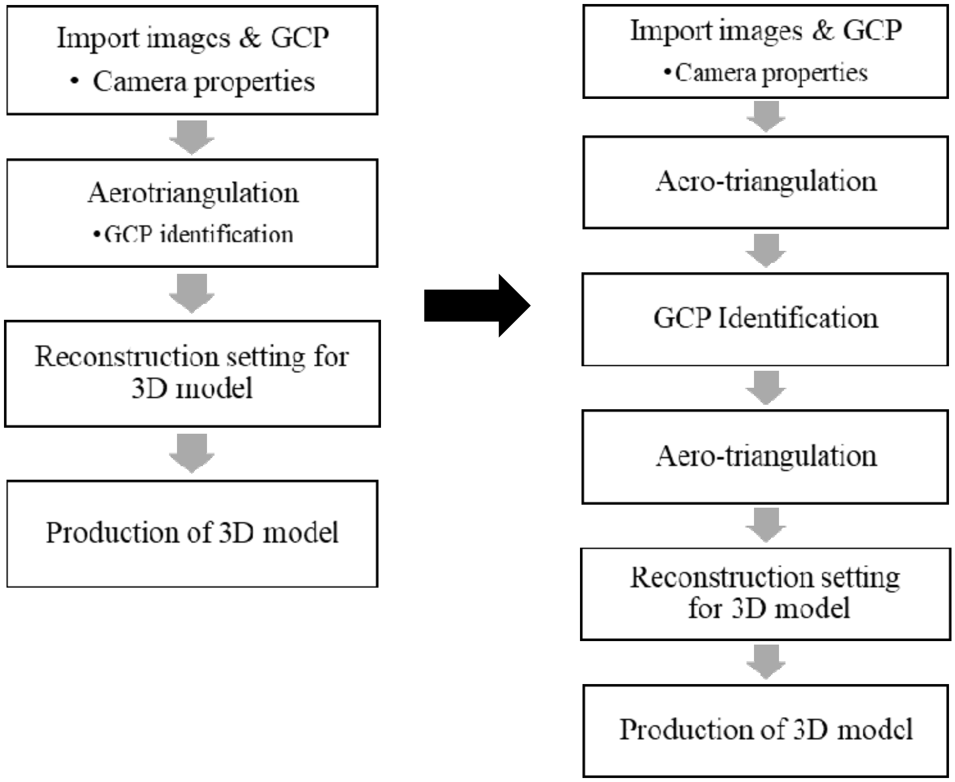

Figure 42: Adapted methodology for iNUMBER

5 Mission planning methodology for Ahmedabad city

During the pilot study, many facts pertaining the data collecting equipment i.e. UAV + oblique camera & Data processing equipment i.e. High-Performance computing systems were learned. These includes the working of the equipment, operation of the equipment for the mission planning, data collection, data processing data extraction and data processing.

Mission planning amongst them is the most crucial as it is required to pre-plan all the flights and other related parameters in advanced. Many aspects need to be considered when planning a data collection for the whole city as during the pilot study, the area selected was a very small representative area.

As the geographical context for the project spans over a vast area, the time considered for the overall flights, the statutory permissions from the relevant department, schedule for each flights and many parameters needs to be considered, as the city area is a public area and not a private area. Once all the parameters are defined and approval to conduct them is obtained from authority, only then the on-field operations of the data-collection are executed. Below is the list of all steps considered during the mission planning for the whole Ahmedabad city. These steps considered for the finalization of the data collection equipment, data processing equipment and storage framework (software and hardware) have already been discussed in the chapter 1 and chapter 2 of the report.

5.1 Understanding the software for photogrammetry (ContextCapture)

As discussed previously the software selected for the data processing is ContextCapture. To understand the requirement of the data processing software, the user manual of the software was carefully studied. This studyincludes the information related to camera properties, no of maximum images that can be captured in each flight, instruction of how an image should be captured, what type of flight path should be selected (Radial vs Grid pattern), overlap & Sidelap.The workflow to obtain the resultant 3D/point-cloud model was also studied and completed for the pilot study area.

5.2 Finalizing the technical parameters for Image data

In this step, the technical parameters for the images to be collected are decided. This decision is based on studying the Image acquisition guide[3] (Academy, 2018), data collected during the pilot study and expert opinions.

As the image data collection equipment had been decided, the parameters related to the camera cannot be changed i.e. the image resolution, focal length, sensor size of the camera etc. But the other parameters related to the UAV operation can have a huge impact on the resultant image data. One of

[3] The image acquisition guide is included in software resources

such parameters is Ground Sample Distance (GSD). GSD is a parameter describing the resolution of actual measurement in images. In simple term, GSD denotes how much actual distance is captured in a single pixel of the image. Thus, if an image data collection has a GSD of 1 cm, it means that each pixel has a dimension of 1 cm in ground. The calculation of GSD is shown in figure 43 and equation 1:

Equation 1: GSD

$$GSD_{cm} = \frac{Ls \times D}{f \times L}$$

Where, Ls is the greater size of the sensor in mm,

D is the distance between the camera and the subject in m,

F is the focal length of the camera in mm,

L is the greater size of the photograph in px(pixel),

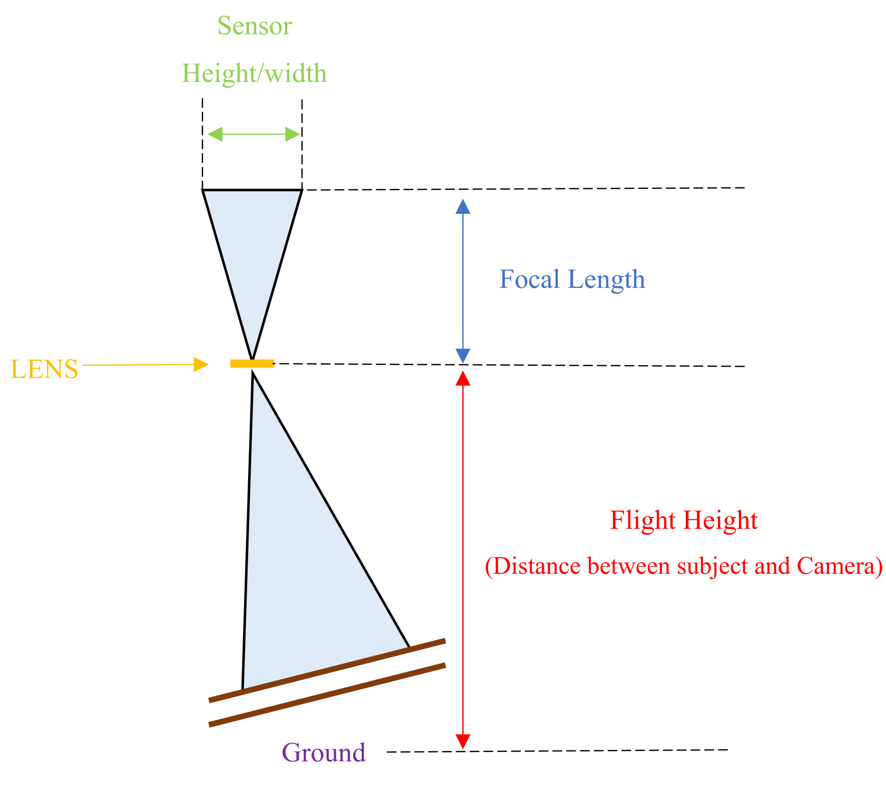

Figure 43: GSD calculation

The other important parameter to define for the flights is Overlap/Sidelap. The overlap/Sidelap indicates the % of same content covered in two consecutive images.Thus, if the overlap is 70%, 70%

of contentwould be same in two consecutive images. The % overlap decided depends on the target object. If more details need to be captured, user can increase the overlap and vice-versa.

Overlap also affects the total flying time, battery consumption and distance covered. Because the UAV + Oblique camera needs to take images between two position, the overlap parameter effects the distance between two positions. For a higher overlap the distance between two images is extremely low, thus as a result there are higher images, thus higher data consumption and battery consumption. For oblique camera, the distance between the gridline also decreases due to higher overlap thus the total flying distance increases.

The finalized parameters for all flights of Ahmedabad city are tabulated below in table 26:

Table 26: Finalized parameters for Image data collection

Parameter	Value
Height	100 m
Time	50 min
Horizontal overlap	80%
Vertical overlap	80 %
Area	≈ 0.5 km^2 for each flight
Ground Sample Distance	≈ 2.2 cm
GCP	4-5 GCPs per flight in Pt, N, E, Z format

5.3 Preparing flight logbook and Protocols for equipment operation

5.3.1 Flight logbook

To ensure the consistency of the required image data collected for all flights, a flight logbook has been created to ensure that all flight parameter is properly logged. The flight log helps maintain the quality of data collected. flight logs can also be used to review the past data and find out if any of the flights had some problem or error.

Each page of the flight logbook records all the parameters before the flying operation. These parameters include the battery percentage, data size left, site and weather conditions etc. Table below shows the prepared logbook:

Table 27: Flight Logbook

Parameters	Description
Name of Location	
Area (in Sq. Km.)	
Flight Start Time	
Flight End Time	
Voltage Level at Flight Start time	
Voltage Level at the Flight End time	
Height of Flight (MSL)	
Battery Level at Flight Start time	
Battery Level at the Flight End time	
Front Overlap	
Side Overlap	
Flying Distance	
No. of GCPs for each flight	
GCPs capturing time (each GCP)	
Projected coordinate system	
KML file for GCP	Attachment
Take off Location image	Attachment
Landing image Location	Attachment
Base-Station Location image	Attachment
Saved file for Mission planning software	Attachment
Flight plan image location	Attachment
Dashboard image	Attachment
Ground image from Drone	Attachment
GCP image	Attachment

5.3.2 Flight Protocols:

To ensure safe and intended operation of the UAV, a set of protocols are prepared which are majorly divided into 3 parts. First part focuses on pre-flying protocols, second part focuses on on-field instruction, and third part focuses on post fling instructions. These protocols are set of check-list instruction which needs to be mandatory followed for every flight.

5.3.2.1 Pre-flying instruction

Pre-flying instructions are focused for preparing the UAV for the planned mission. There are battery check instructions and assembly procedures in the pre-flying instruction protocols. This protocol can be either followed right before the mission plan or a day before.

5.3.2.1.1 Battery Charge Check

1. Drone Batteries (4) fully charged
2. Camera batteries (2) fully charged
3. Remote Controller fully charged
4. Tablets (2) fully charged
5. Base Station battery fully charged

5.3.2.1.2 Assembly Procedure

1. Attach 4 legs on the bottom of the UAV body and tighten using 2.5 mm Allen Driver
2. Attach RTK antenna on the M2 arm side
3. Connect Receiver Antenna under the UAV body
4. Attach Arms one by one - Push the rotor arm and lock it. Do not miss the thread while tightening. Do not lock it extremely tight.
5. Connect UAV batteries on the top
6. Connect the base station on the tripod
7. Attach 2 antennas on the side
8. Extend the Tripod base by opening the 3 clips. After extending a leg, lock the clips. Do the same for all legs.
9. Extend the RTK holder upwards by losing the bolt and again tightening it after fixing the position.
10. The camera will be attached at the end (RECHECK)
11. Connect battery in the slot provided on the backside of the camera. The orange vertical line should be on the camera button side.
12. Camera position - W comes in front, X comes on the backside
13. (All Camera identification - W - Front, X - Rear, S - Center, A - Left, D - Right)

14. Lemo Cable - 7 pin connector will be connected to Camera - DATA port and the 9-pin connector goes to the UAV body connection slot. Check the red dot on connectors (both sides) and insert them accordingly.

5.3.2.2 On-Site Operation

The onsite operation focuses on the instructions that needs to be followed just before the operation of the UAV on site. They are mainly focused on checking the fly worthy condition of UAV and Remote controller

5.3.2.2.1 UAV-CHECK

1. Base Station should be set at the safest and the highest position - in line of sight of the planned mission.
2. Turn ON the base station
3. Check base station LED indications: -
    a. Front - Battery level indicator
    b. Rear –
        i. Power - Red
        ii. GPS / Satellite - Blue
        iii. RTK - Green
        iv. Static - Yellow
4. Do not move the base station, once turned ON.
5. Connect the main tablet with the RC.
6. Turn ON the RC and Tablet
7. Place the UAV on the flat ground surface selected for Take-off and Landing.
8. Straighten the propellers
9. Remove Lens shutter
10. Attach the camera to the Camera mounting plate (Drone bottom) and lock the latch
11. Check the dampers and correct it, if required
12. Connect Lemo cable to Drone (9 pins) and Camera (7 pins)
13. Turn ON the camera
14. Attach external GPS cable with the camera and place the white box on top of the drone
15. Check no. of satellites on the screen (for the camera) - Should be more than 6
16. Take sample images of the ground and verify shutter sound
17. Check all the connections and attachments
18. Connect the batteries and lock the hatch

5.3.2.2.2 Remote controller check

1. Throttle - Right (Up & Down)
2. Roll/Aileron - Right (Left & Right)
3. Elevator - Right (Up & Down)
4. Yaw - Right (Left & Right)
5. Arming Drone - Aileron Right
6. Turn the toggle switch to GPS/Auto mode in between motor rotates and
7. Keep Throttle in the center during the flight

5.3.2.3 Post-Flying Instruction:

The post flying instructions are prepared for the procedures that needs to be followed once the UAV lands on the site. This includes data transfer, data collection from UAV and Oblique camera, Geo-tagging procedure for images.

5.3.2.3.1 Post-Landing

1. Turn off the drone
2. Turn off the Remote Control and application
3. Turn off the camera
4. Fold the propellers such that it does not disturb you while removing other equipment.
5. Remove both the batteries and keep them inside the bag or cool box.
6. Remove the Lemo connector (that connects Drone to the Camera) and put it inside the Camera case
7. Carefully hold the camera and remove it from the slider.
8. Attach the lens shutter and put the camera inside the camera case.
9. Remove the antennas and RTK
10. Remove the arms carefully
11. Loosen all the four legs using a 2.5mm Allen driver, remove the legs and then partially tighten the bolts

5.3.2.3.2 Data Transfer Instructions

1. Connect the battery to the camera
2. Connect Lemo cable on the camera DATA port and USB to the computer
3. Turn On the camera
4. All 5 camera folders will show up under My Computer
5. Prepare 5 New Folders in the desired drive where you want to save the data.
6. Name these folders as - A, S, X, D, W
7. Copy one by one folder images to the respective folders.

5.3.2.3.3 Geo Tagging Instructions

1. Connect Drone to the Computer using a Micro USB to USB cable
2. Select COM port and press Connect
3. Under FLIGHT DATA screen, on the right in Quick tabs - go to DATA FLASH LOGS - Download Data Flash Logs - Select Log files - Download Selected Logs
4. After the Log gets downloaded (of a particular flight) copy it into S folder (where S camera images are stored).
5. Open CHC GCS on windows
6. Go to POS GET - Browse log - Select .bin file

5.4 Endurance testing for data collection equipment setup:

During the pilot study it was observed that the flight time on the UAV is dependent on many parameters. Since the data collection for Ahmedabad city is a lengthy and exhaustive task, the planning of flying time must be properly done for the best use of the equipment. To address this, an exercise will be conducted to find out the maximum battery life of UAV on different& extreme conditions and thus finalize a single flight time which can thus be extrapolated for every flight mission for Ahmedabad city.

The exercise helps finalizing to estimate the total amount of time it would take for image data collection of Ahmedabad city.

Multiple flights for the parameters decided in the section 4.2 will be carried out in such a manner that only the minimum recommended charge is left in the batteries of the UAV. After analysing the data& log file for the executed flights final flight time will be decided which will be used in the final mission plan for Ahmedabad city.

5.5 Setup of charging infrastructure

As the number of the flights for the iNUMBER project are many, the charging of the equipment batteries plays an important role in the resultant total time for the mission. If this charging time for the equipment batteries is minimized, notable decrease can be observed in the overall project execution timeline.

To decrease the overall charging time, the first step that will be taken in the direction is the procurement of extra set of batteries. Higher number of the flights can be completed as the battery doesn’t needs to be charged once the flight has been completed as backup batteries are available.

Also, second step taken will be to setup a charging infrastructure to charge the batteries right after all the flights are completed for the day. This infrastructure will be setup with the help of the car-batteries available. Thus, all the batteries can be kept on the charge on the same immediate day, so they are available for the data collection round for the second day.

As the charger of the batteries are capable of modulating the current it provides (10-20 A) the charging time of the batteries are further reduced.

5.6 Finalizing of image data collection area

The total area of the Ahmedabad city as per the latest map of the AMC is 464 km^2. This area consists of total 6 administrative zones. This area also includes many such area where the operation of the UAV is restricted. There are many other areas also which do not have a portion of built environment on the area. Such areas include wildlands, farmlands, river, lakes, public park etc. As the objective of the data collection is to gather data for the geometry of the buildings; such non-building area needs to be excluded from the flying area to save time and resources.

Thus, to obtain the final area for which the image data collection needs to be done, two steps were taken:

5.6.1 Step 1: Obtaining latest map from government authorities

As the city is constantly developing, new areas are always being included in the city. For the iNUMBER project, the latest geographical boundaries available as per the latest information available on the AMCs website was utilized. This latest information includes all information about the administrative zones with newest additions.

5.6.2 Step 2: Inclusion/exclusion of area

The second step was to obtain the information regarding the restricted places for the UAV operation, the draft Indian policy[4] for the UAV was studied. Input from the expert were also considered for obtaining information regarding places where the operation of the UAV is restricted. These areas were also excluded during the scope of the pilot. The exclusion of such area are mentioned in table 28.

Table 28: Restricted places for the UAV operation

CLASS	*REMARKS*
RED ZONES	DISCARDED **RED ZONES** According to National Drone policy – 2018
5 Km from Airport	
3 Km from civil, private and defense airports	
3 Km off Military grounds	
3Km from radius of State secretariat complex	

[4] The draft Indian Drone policy can be accessed at: http://dgca.nic.in/cars/D3X-X1.pdf

Over Eco sensitive zones and National Parks	
Over Water bodies	
2 Km from perimeter of locations notified by Ministry of Home Affairs	
Above the Obstacle Limitation Surfaces (OLS) or PANS-OPS surfaces	
Restricted and Danger Areas including TRA, and TSA, as notified in AIP	

Thus, after obtaining the information of the areas for inclusion and exclusion the final map is considered for the data collection of the iNUMBER. The final scope of the area considered is shown below in figure 44.

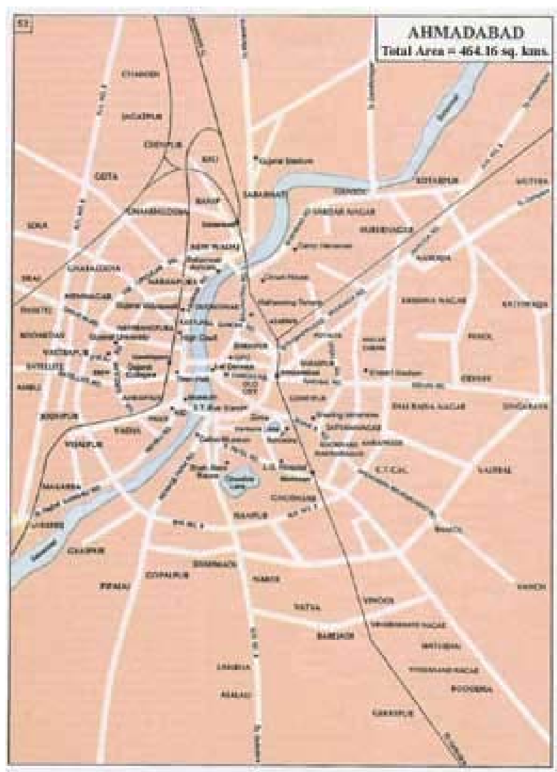

Figure 44: final map of ahmedabad city considered for iNUMBER project

5.7 Development of final *.kml file for Ahmedabad city

After completing all the above steps, a draft *.kml file was developed in a google earth software. Each grid on the file showed in the kml file depicts a single flight. The parameters of each flight are as per decided in the table 24. Each flight also has a corresponding schedule of operation and completion. The figure 45 shows the draft *.kml file prepared.

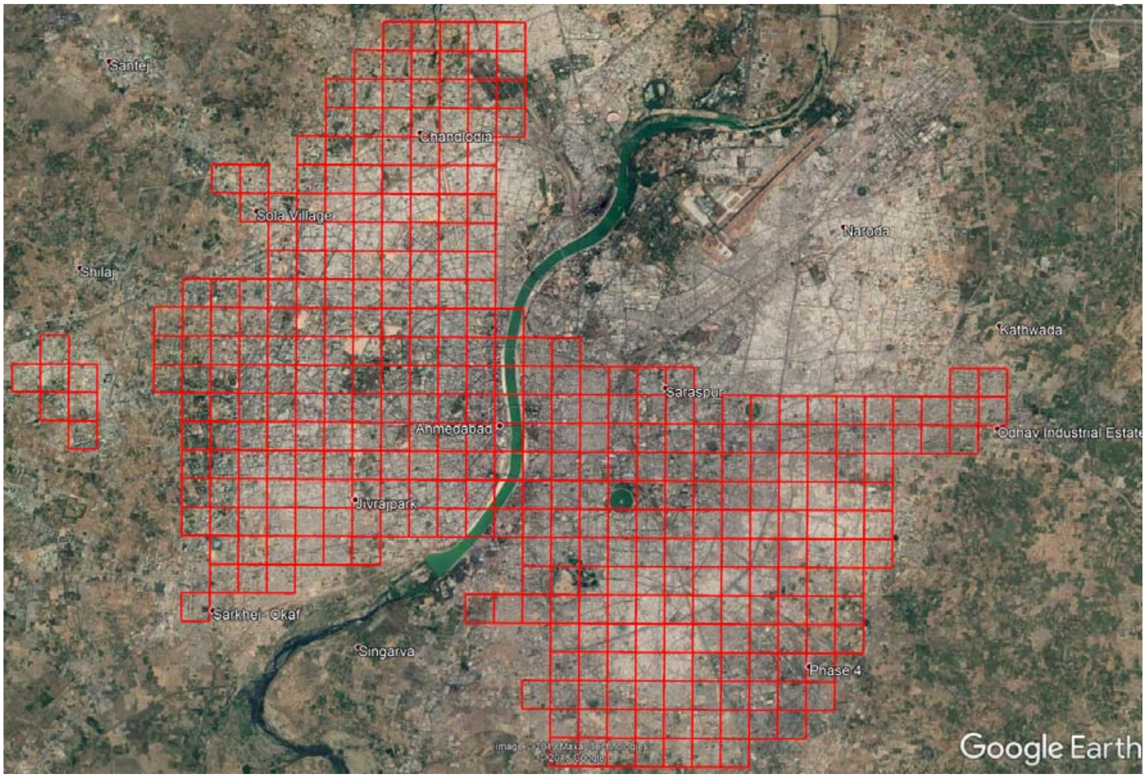

*Figure 45: *.kml file for Ahmedabad city*

The mission planning file is later submitted to authority for obtaining permission for the operation of the UAV

5.8 Applying for permissions

The operation of the UAV takes place 100 m AGL for the iNUMBER project flights. According to the draft drone policy of India, any drone operating over the height of the 60 m needs to takes clearance from the government authorities for each of the flight. As there are numerous flights for a vast geographical context for iNUMBER project, authorities also need the schedule of each flight ahead of the operation. Thus, to take approval from the authorities then mission planning file (*.kml) a flight by flight schedule also must be submitted.

Along with the details of the flights, the details of the specification of the UAV, details of the operation including contact information and emergency contact numbers are also submitted to the authorities.

5.9 Timeline for data collection mission

The timeline of the mission will be decided once the final *.kml file is prepared and approved from the government authorities.

6 Next steps:

Once the Final version of the mission plan for Ahmedabad city is prepared in conjecture with the approval of operations from the government authority, the data collection operations in filed will begin. Data will be extracted simultaneously at the end of operations of each day and can be prepared for the data processing software i.e. the data can be queued for the Aero-triangulation.

Once the data collection phase is completed as per the required image format and geo-tagging process and the data is compiled for both imagery data and the completed Aero-triangulated model in ContextCapture, it will be processed for the reconstruction to obtain the required 3D model for the Ahmedabad city. The developed 3D model can be further used to obtain other conversion format like point-cloud or ortho-DSM format.

For the iNUMBER project, the adopted methodology will be used for data processing and development of the final 3D geometrical model. This includes the processing of the data including the Aero-triangulation, identifying GCPS and final 3d reconstruction. Post the 3D model reconstruction, the process of cleaning and cropping the model will be executed with the help of the ContextCapture editor to obtain the desired quality of the 3D geometrical model output.

The later stage includes using the developed geometrical 3D model to extract the building footprints. This will be attempted in conjecture with the available GIS data as a validation check. The method of the extracting the building footprint data will be attempted by performing the machine learning algorithms developed by the iNUMBER project team on the developed 3D model, so the process can be done automatically. The output of the algorithms would be either the building footprint vector polygons which can be utilized in the QGIS/ARCGIS software or a Roof boundary vector polygon which can also be utilized in QGIS/ARCGIS software. From the various possibilities to perform building footprint extraction, two approaches are being explored which are ARCGIS Pro and ContextCapture Insights. Example of the results of building footprint extraction is shown below.

Figure 46: Building extraction from Point-cloud model

As seen in the Figure 46, the polygons are formed alongside the border of the buildings marking the exact footprints. The trees and other elements are excluded from the polygons. At this early stage of work, the precision of building footprint extraction is comparatively low.This would gradually increase and the building footprint detection will be more accurate in further stages.

Once the building footprint data is extracted and validated, it will be associated with other non-spatial attributes which mainly consists of building characteristics and administrative characteristics. These includes building age, building materials, schedule, building use type etc for the building characteristic's and building use type, final plot number, survey number, FSI, corresponding WARD, etc for the administrative attributes. Once the integration of both spatial data (3D model/building footprints) and non-spatial data (building characteristics/administrative data) is completed, the model can be analysed by addressing the spatial/non-spatial queries on the developed data set. This may useful in obtaining insights regarding the built environment usage in Ahmedabad city for e.g. Total office buildings in any area, average age of buildings etc.

After association of the spatial and non-spatial data, the energy modelling for the developed model can be attempted using the script developed with use of python environment and EnergyPlus building energy modelling tool. The script can be divided in to 4 main parts, out of which the first part can be used to prepared the data that would be required to associate all data to a single footprint and tabulate it so it can be used as a data-base for the individual building energy model. The second script would be used to develop the *.idf files from the data-base created. This *.idf files would contain all the required data that is needed to develop a building energy model. The third script prepared would be utilized to run the simulation on the building energy models developed on the previous step. This step would also be the most time-consuming step as all the processing of the building energy model would be completed in this step. Forth and the final script prepared would be to post-process, analyse and obtain the desired output from the simulation models and visualize the result.

The model than will be further integrated with the output from the WP2 and WP3 package to obtain a complete City Energy model for Ahmedabad city.

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