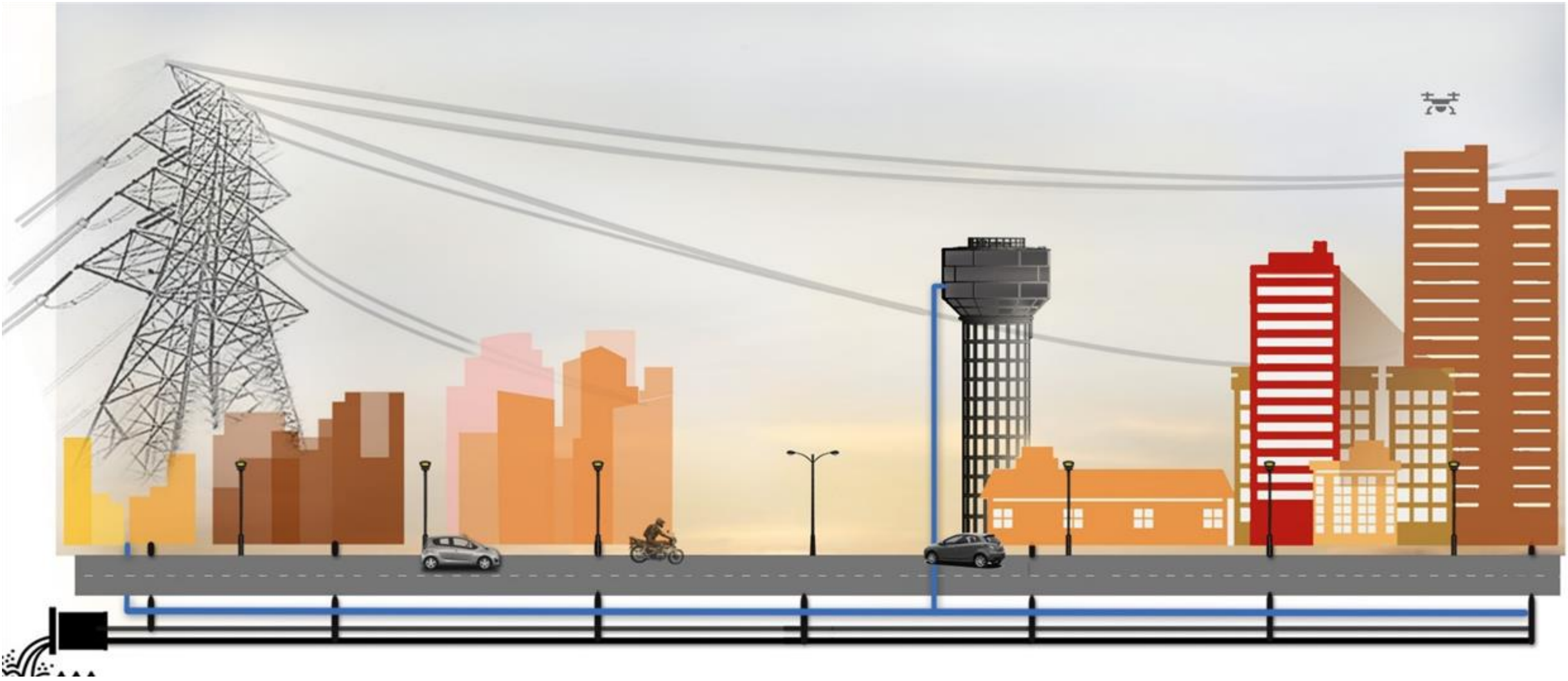

India-UK Joint

Integrated Urban Model for Built Environment Energy Research

(iNUMBER)

Approaches to Urban Stock Model

January 2019

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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

January 2019

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iNUMBER (iNtegrated Urban Model for Built Environment Research) 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 review of both remote sensing and UAV technical capabilities and processing techniques to achieve the desired 3D building stock model output.

The methodology adopts advanced aerial surveying technologies such as LiDAR and Photogrammetry attachments of UAV to capture the required resolution of building stock data and process into fully textured 3D Building stock model.

The report further includes the investigations and identification of methods to integrate the high precision 3D Building stock model to generate a robust City Energy Model. Further, the report comprises the literature review of the existing ‘Urban Building Energy Models’ to analyze the underlying methodology of the same. This is to critically examine and extract the best-suited framework for simulating Ahmedabad city energy model. The model 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.

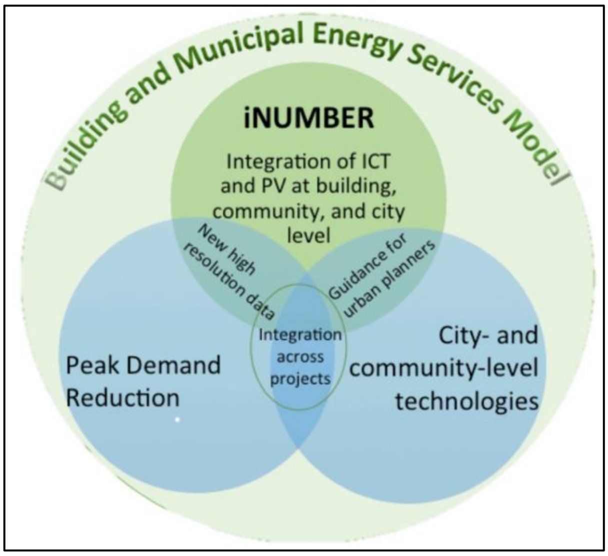

Figure 1 Schematic representation of the iNUMBER project

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 an 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 Literature review

2.1 Urbanization and Energy Security

The next 30 years will be challenging for municipalities in Indian cities to manage their energy and water services, as India's population is shifting fast to the urban areas and will soon overtake its rural population, the phenomenon creates major concerns for city planners and administrative authorities to adopt efficient strategies in the way they manage and build future building stock and energy consumption. With more than 300 million people predicted to reside in urban settlements it is crucial to identify and assess the implications of this growth on demand for energy consumption. ("World Urbaniztion Prospects: The 2018 revision, online edition," 2018) Studies further warn that there will be a pressure on the existing urban settlements and future building stock to meet their energy demands, failing to identify and implement sustainable energy strategies at the municipal level of the cities can cause significant threat to India's energy security. (2013)

2.2 Urban Building Energy Model (UBEM)

Urban-scale building energy models (UBEM's) are modelling tools that are effective in simulating and analysing energy demands of a city, UBEM's are also widely used to conduct critical analysis of buildings with peak energy demands and help municipalities identify potential urban areas to develop and implement retrofit strategies to provide adequate thermal comfort inside buildings for current and future climatic conditions. (W. Li et al., 2017)

2.3 Classification of existing UBEM's

Through classifying all the existing Urban Building energy Models (UBEM's) across the world we can infer that almost all the models generated till date, are geographically located in the higher latitudes such as USA and UK (Refer Table 1). Moreover, many of these models are the aggregated scaled up representations of single building unit types. In order to accurately model the energy flows at an urban scale often poses many technical challenges such as poor data granularity, variation in occupant behaviour at large scale and also dynamic climatic interactions between buildings.

(Frayssinet et al.) (2018) Developing a detailed 3D building stock model will resolve some of these challenges and increase the reliability of the City Energy Model in policy making.

Table 1 Classification of existing UBEM's (Sample)

Model	*Location*	*General*	*Building geometry*	*Context and orientation*	*Solar gains*	*Aims*
CEPT	Ahmedabad	Archetype based	Archetype based	Not included	Included	Assess impact of ECBC compliance
MIT UBEM	Boston, Kuwait, USA	Citywide model based on 52 use/age archetypes, buildings simulated individually	2.5D Massing based on building footprint and roof height/expected no. Floors	GIS	Ray tracing algorithm used to identify shading surfaces	Test urban design compliance predict peak loads
City BES	San Francisco, USA	Authors state more automated than MIT's UBEM, each building simulated individually, only commercial and retail buildings currently	GIS + building height and no. Storeys (from city data file). Algorithm creates thermal zones automatically	GIS, shared walls detected	Shading buildings notes need to perform shading calculations multiple times. Could this be done once and results used in energy Plus	Retrofit analysis
BREDEM-12	UK	Model for a single dwelling	2 zone model no. Storeys	Degree day region) wind speed level of overshading	Not included	Allow comparison between different energy efficiency measures

2.4 Building Stock Data and City Energy Modelling

As discussed above UBEM's have faced challenges in integrating the dynamic nature of urban geography, building stock and microclimate conditions as it is computationally quite intense to process large volumes of data and time taking to gather high resolution data as well to simulate real time energy models (Jagani & Passe, 2017) Identifying fast and accurate aerial survey approaches to capture a fully detailed urban building stock model, will allow in linking crucial building information pertaining to building geometry, surface texture, window and overhang details correlated with urban land form, land cover, land use and topography information will lead to a robust City Energy Model.

2.5 City Energy Model's for Policy Making

Urban-scale building energy models (UBEM's) are considered to be an effective way of visualizing energy demands of a city, studies reveal that GIS based urban building solar energy models are being considered to inform policy making for Non-renewable retrofits. (Quan, Li, Augenbroe, Brown, & Yang, 2015) The findings from using an accurate City Energy Model shall allow stake holders such as municipalities, architects, urban planners to inform effectively integrating site suitable renewable energy and building retrofit strategies as a technological solution to optimise current energy consumption thus increasing the credibility of using the models in policy making.

3 Approaches to capture 3D Building Stock Model

According to the classification model presented in Table.1, Most of the UBEM's use high resolution building stock information captured from aerial survey technologies such as RS-Remote sensing satellite imagery, analysing the classification chart we can identify that the potential of UAV survey data capture and construct of 3D textured models of a building stock are still yet to be fully explored in integrating with City Energy Models.

Below are the three most widely used building stock model approaches:

1. **RS- Remote Sensing Satellite-** This technique is useful to extract large scale surface terrain models, Building heights and land cover from a medium resolution Imagery in very short time. Satellite Imagery taken from two angles by a satellite (Stereo pairs) gives building heights upon overlapping the two images.
2. **Google Earth Satellite Imagery** – In case of inexpensive and easily accessible Satellite date, the freely available medium resolution Satellite images procured from GLCF – Global Land Cover Facility is a viable option to fall back on, in order to determine quick and accurate land use shifts in urban areas.
3. **Unmanned Aerial Vehicle (UAV) Technology** – The 3D models are developed by stitching many high resolution images using reference points of the object known as Aerial

Photogrammetry. The method includes fine details such as building texture, facade details of buildings, windows and overhangs. UAV attachments such as Thermal camera and LiDAR, can further collect highly precise measurements by at very high speed, a surveying method to create a point cloud data in space.

3.1 Remote Sensing Satellite Image Processing

3.1.1 Objectives of Study

- To identify various Satellite Instruments and Imagery to capture the urban built environment
- To generate a Digital Surface model (DSM) and Digital Elevation Model (DEM) with accurate elevation points embedded in the datasets
- Land cover classification such as vegetation, water bodies and Building Footprints
- Land use change detection of urban areas across time
- To identify a methodology to extract building geometry and height at maximum accuracy

3.1.2 Building Footprint Extraction Technique

High resolution Satellite Imagery, will allow to conduct an Automated Object based extraction technique using software's such as Arc Map, PCI Geomatica, Overwatch. The software's incorporates machine learning algorithms as illustrated in Figure 2, by training itself to identify the building object's edge line and to convert it into vector polygons used for measuring the area of building footprint.

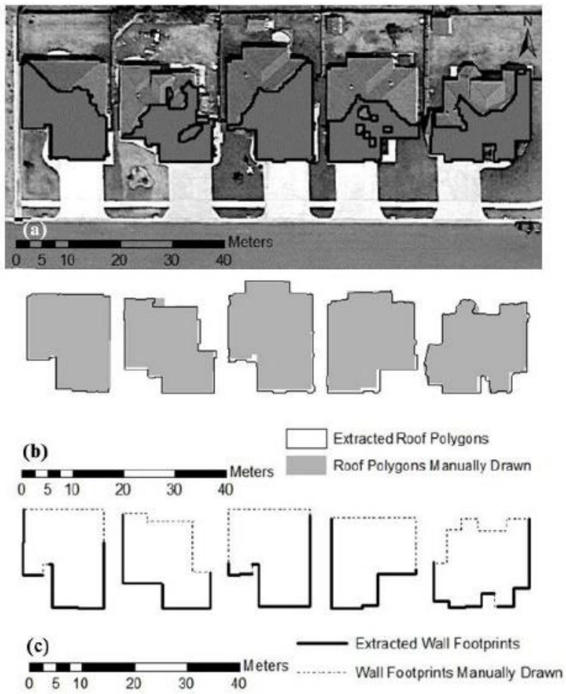

Figure 2 Building footprint extraction process

(Jalaei & Jrade, 2014)

The stepwise process of how to manually extract a desired object from the satellite image dataset is explained in Table 2, this method will allow to identify and group similar objects from large datasets of the city to conduct quick statistical analysis to understand the building stock and land cover dynamics. The methodology below in Figure 3 and 4, is an example study which integrates four major stages from generating a point cloud using semi-global imaging technology, detection of buildings from the point cloud, classification of roof and creating building outline to vector format which can then accurately building area and heights. (Wang, 2016)

Figure 3 Extracted building outlines in an open area

(Wang, 2016)

Figure 4 Automatic detection of trees

(Wang, 2016)

Table 2 Object based extraction - Stepwise process

	GIS Extraction Modelling Flow	*Output information*
1	Raw input satellite data ⇩	Ortho rectified, Geo referenced (Stereo pairs) 0.5m Resolution
2	Digital surface model (DSM) ⇩	Create Slope map, Contours and elevation point model using surface analysis tools Arc Map
3	Land cover classification ⇩	The locality is classified and features such as vegetation, road surface, building, pavement and water body are extracted into measurable polygons using Rule-Based classification technique in Arc Map
4	Building foot print extraction ⇩	Image classification and Edge detection of the Building outline to extract a vector polygon
5	Building cluster / Grouping ⇩	The extracted building polygons are analyzed for identical physical attributes such as Area, No. of story's, Height
6	Building height model ⇩	Overlapping 2 satellite images (Stereo pairs) at 60 to 80% area, allows to extract heights of the buildings in a locality and create a detailed 3D building model using Arc Map.
8	Multi-layered – overlay analysis	The building clusters and energy consumption patterns are then analyzed with overlaying other physical layers of the locality such as slope, contours, land cover, vegetation, solar exposure using classification and surface modeling techniques in GIS.

3.1.3 Satellite Data and 3D Building Models

Conventional methods of building height extraction is done using only a single satellite image and are often very low in their accuracy as shown in Figure 1, poor resolution of the images will make it hard for the machine to classify and extract the exact boundary line of the urban object and often have overlaps with trees, buildings and other obstructions resulting in inaccurate numbers of building stock count. However using Stereo pairs overlapping techniques can extract a highly accurate 3D building model from overlapping of paired Satellite Images. As the Satellite takes images from 2 points in time and space, the resultant DSM (Digital surface model) file generated will accurately measure the difference of building top and the ground level clearly thereby extracting in a reliable 3D building model in short time, shown in Figure 5, However, since the image resolution is medium, this technique has its limitations in capturing the close range details such as building texture, over hang and window details compared to that of the UAV survey technology.

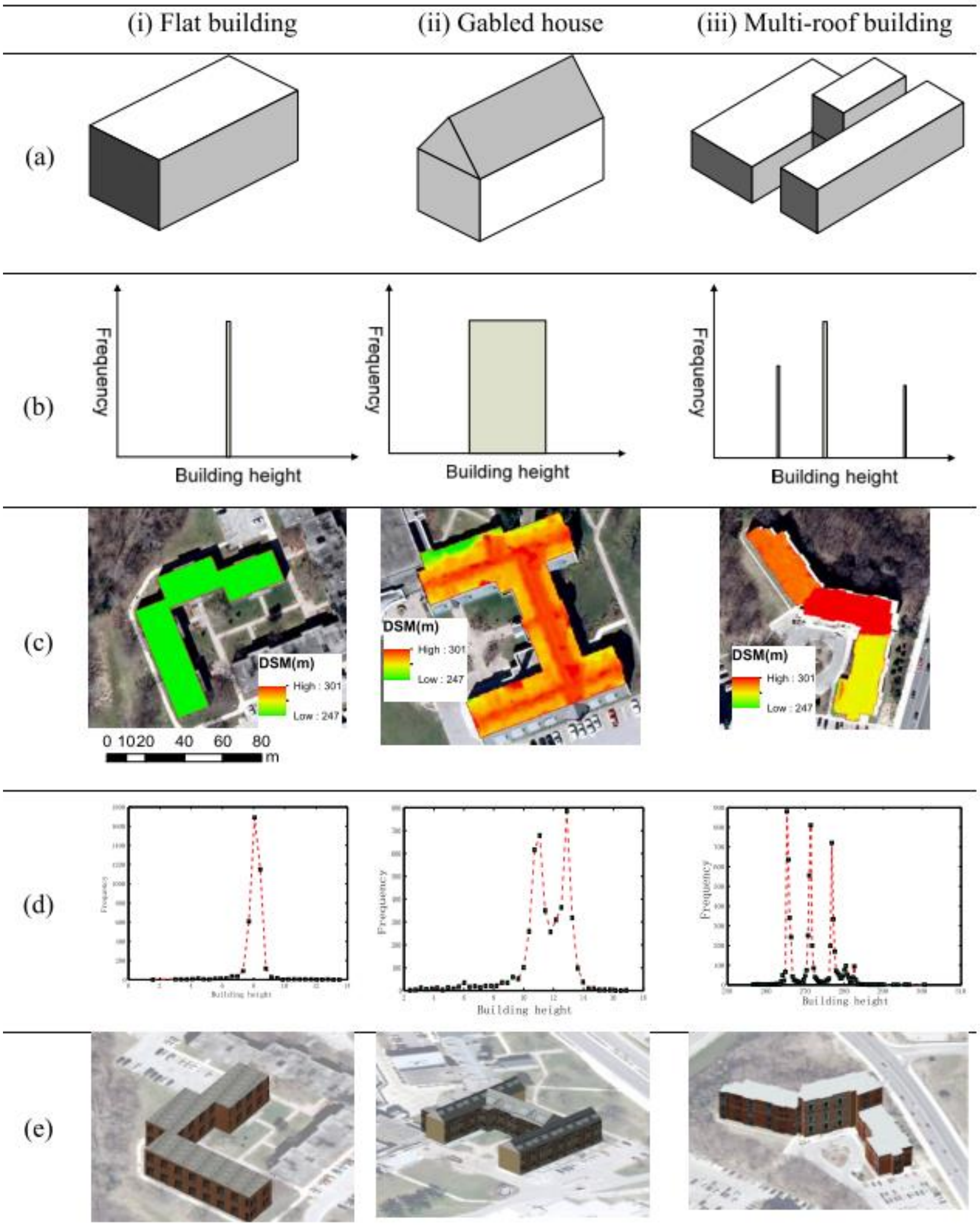

Figure 5 Comparison of Satellite data building models and parametric digitized models (Zeng, 2014)

a) Parametric models of different sample Building types b) Histograms of parametric buildings c) DSM superimposed on aerial images of buildings d) Histograms of buildings seen in (c) e) 3D buildings

3.1.4 Software

- ArcMap, Q.GIS, OSM, PCI Geomatica, E-cognition
- City Engine for advanced 3D analysis by Arc Map

3.1.5 Satellite based LiDAR technique for Building Models

LiDAR (Light Detection and Ranging) survey is a method to capture extract building boundary using laser beams, there are numerous studies done on LiDAR technology and validated its point accuracy to be superior compared to any other techniques for precision aerial mapping.

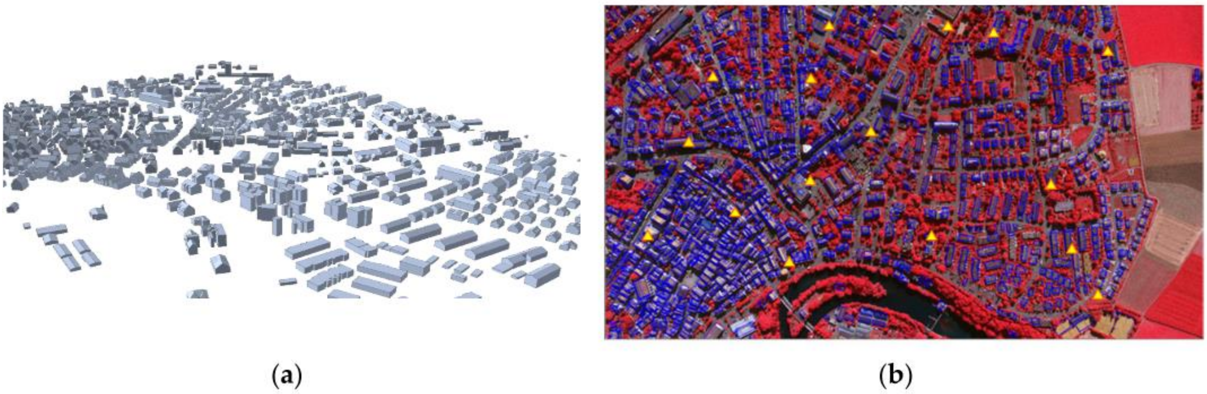

Figure 6 Vaihingen dataset a) LiDAR driven models reconstructed b) LiDAR Building models(Blue) Checkpoins (Yellow)

(Jung et al., 2016)

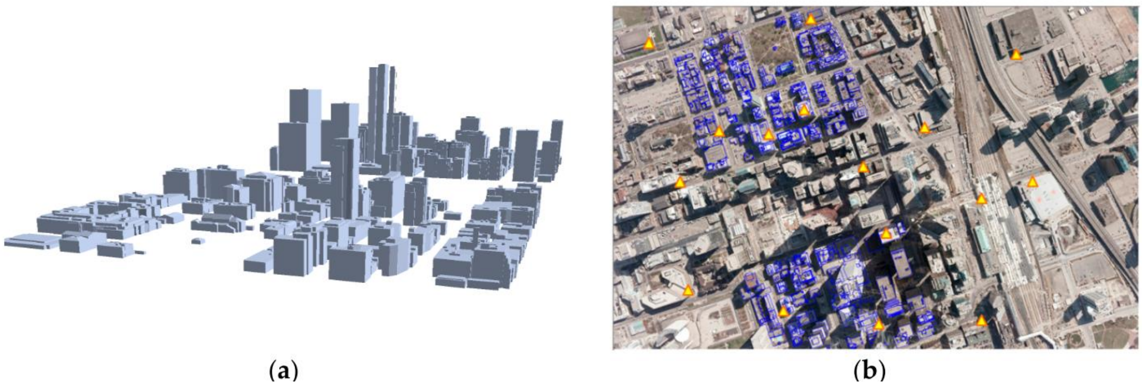

Figure 7 Toronto Datasets –LiDAR drivern Building Models

(Jung et al., 2016)

As seen from Figure 6 and 7, a very detailed digital model of a landscape can be created using LiDAR data which is comparable to manual digitizing using computer applications. (Jung et al., 2016)

3.1.6 Satellite Imagery - Selection Requirements

In order to select the most suitable satellite image dataset according to the requirement of the urban building stock model, product parameters, specifications and sources should be initially identified as per Table 3:

Table 3 Satellite product selection requirements

Satellite product Parameters	*Technical Specifications*	*International (Digital globe and Land info)*	*National (ISRO, NRSC)*
➢ Projection ➢ Resolution ➢ Datum ➢ Bit depth ➢ Dynamic Range Adjust ➢ Resample method ➢ Image file format ➢ Delivery Media	➢ Satellite Model ➢ Tiling - Pixel based ➢ Product - Imager type ➢ Bands	➢ GeoEye-1 ➢ WorldView-2 ➢ WorldView-3 ➢ WorldView-4 ➢ Pleiades-1	➢ CartoSAT-1 ➢ CartoSAT-2 (Stereo pairs) ➢ LISS-4 ➢ Resource SAT

3.1.7 Satellite Products Identification

High Resolution Archive Stereo Pricing (50cm)	WorldView-1	WorldView-2 WorldView-3	QuickBird (60cm)	GE-1/ WV-4	IKONOS (80cm)	Pléiades 1A/1B
Panchromatic	$28.00	$28.00	n/a	$28.00	$20	$25
3-Band Pan-Sharpened	n/a	$35	n/a	$35	$20	$25
4-Band Pan-Sharpened	n/a	$35	n/a	$35	$20	$25
Panchromatic + 4-band Multispectral Bundle	n/a	$35	n/a	$35	$20	$25
8-Band Multispectral	n/a	$38	n/a	n/a	n/a	n/a
8-Band Panchromatic + Multispectral Bundle	n/a	$38	n/a	n/a	n/a	n/a

Figure 8 Satellite products list – International (Land info)

Table 4 High resolution satellite product list – India (IRS/NRSC)

#	*Product Type*		*Accuracy*	*Price in Rupees*
	1.0 PAN (1m – Resolution) (Cartosat-2)			
1.1	Mono Geo-referenced/ Ortho Kit	9.6 Km x 9.6 Km	100	2,440
1.2	Ortho Corrected	9.6Km x 9.6Km	15	2,890
	2.0 PAN – A/F (2.5m) (Cartosat-1)			
2.1	Mono Geo-referenced/ Ortho Kit	27.5 Km x 27.5 Km	50	4,440
2.2	Stereo Ortho Kit	27.5 Km x 27.5 Km	220	5,110
2.3	Ortho Corrected	27.5 Km x 27.5 km	15	6,450
2.4	Carto DEM	14 Km x 14 Km	15	6,290
3.0	LISS- 4 MX (5m - Resolution) (ResourceSAT – 1,2)			
3.1	Geo-referenced / Ortho Kit		50	1,540
3.2	Geo-referenced / Ortho Kit	70 Km x 70 Km	50	4,170
3.3	Ortho rectified	70 Km x 70 Km	20	10,470

Source- ISRO / NRSC/ IRS

3.1.8 Satellite Imagery Selection

The highlighted satellite datasets which are of high in resolution of Table 4, will allow to perform a precise feature extraction process to create an urban 3D model using Arc Map, GIS and other city modelling plugins. Moreover, High resolution images Ortho Stereo (0.5m, Stereo pairs) from ISRO is a cost friendly option. NRSC official website (ISRO) is the gateway to procure CartoSAT (Stereo pairs) – 2A / 2B Series with 2m / 1m / 0.8m resolution. (Read RS data policy by ISRO) The images are issued with embedded GCP (Ground control points) and can be pre-processed to extract building feature information. Expensive options include procuring High resolution satellite imagery scenes such as Pleiades (Stereo pairs), IKONOS, COMSAT and QUICKBIRD (0.5 to 0.3m resolution). Small size samples of stereo pairs can be initially purchased (5Km^2) and processed as a pilot study to test the methodology.

3.2 Google Earth Satellite Imagery

According to studies conducted by researchers from VIT University, The freely available Satellite images provided by Global Land Cover Facility (GLCF) are highly useful to predict land use and urban stock changes as illustrated in Figure 9, In order to conduct the accurate comparative land classification activity, the researchers advise to use at least a medium resolution images such as Landsat ETM+, TM or LISS-3 and process the extraction and digitizing in a GIS based application to view the results. This can be a readily available option if buying expensive satellite images is a hurdle.(Malarvizhi, Kumar, & Porchelvan, 2016)

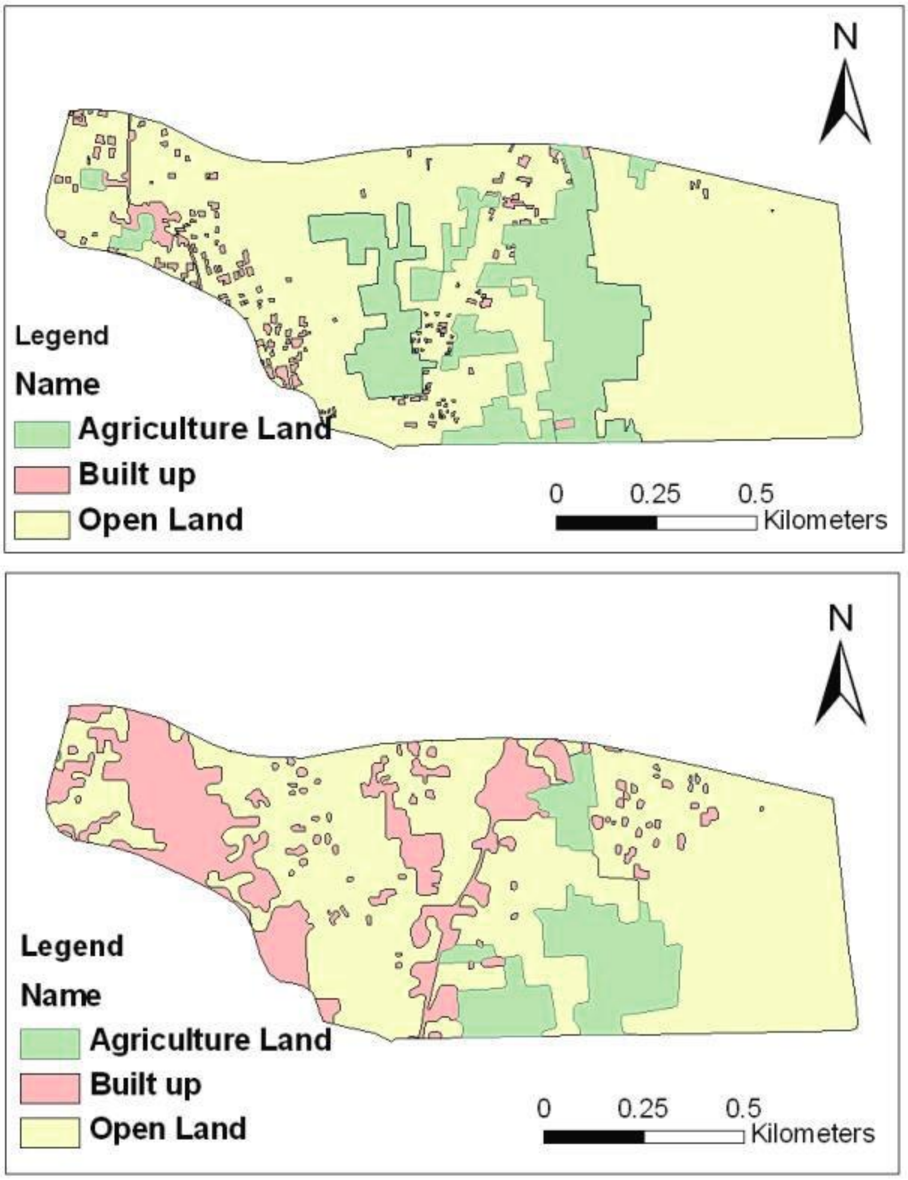

Figure 9 Land use change detection from 2007 to 2014 of Ward 8, Vellore Corporation (Malarvizhi et al., 2016)

3.3 Unmanned Aerial Vehicle (UAV) Technology

3.3.1 Objectives of Study

- UAV techniques to generate 3D building stock model that would feed into the City energy model are still yet to be completely explored.
- Improved data granularity of buildings includes extracting information about WWR – Wall to Window Ratio, F/F – Floor to Floor height, Surface texture and Overhang dimensions
- Analysing the thermal maps of the building clusters and surrounding context using thermal camera attachment will help in analysing the heat exchanges between buildings
- Photogrammetry and LiDAR technique are two widely used techniques and will help to resolve and improve the accuracy of the urban building stock model as they are considered to be advanced precision mapping techniques.

3.3.2 UAV - Photogrammetry based 3D models

Photogrammetry is a technique to construct 2D to 3D cartometric model, the model is created from stitching high resolution images taken at an oblique angle above 40˚ by UAV flight and processed into a 3D model using image detection technology. UAV technologies have become a valuable source of digital mapping for large regions, the technology has wide range of customizable options from low cost amateur cameras to expensive SLR. There are many open source flight planning and processing software's which can allow a stage wise extraction as in Figure 10, Scenes starting with Nadir and Oblique Imagery, (DSM) Digital surface models and a photogrammetry 3D texture model. (Remondino, Barazzetti, Nex, Scaioni, & Sarazzi, 2011)

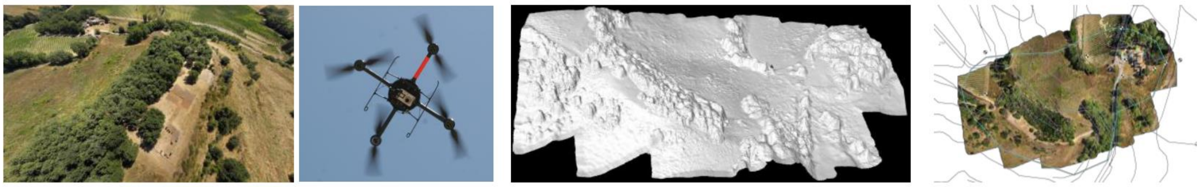

Figure 10 Photogrammetric results and Scenes form Micro drone (MD4-200) - Montalcino, Italy (Remondino et al., 2011).

With GPS equipped drones, digital cameras and powerful computers, UAV surveys with an accuracy down to 1 to 2 cm is possible today, there are several drones with cameras which are ready made for 3D mapping, these oblique cameras are capable to capture complete 3D surfaces of the building facades. The limitations of using UAV based photogrammetry technique is that the measurement is based only on camera sensor and the ambient light it can detect and can't capture details covered with vertical obstructions as trees.

UAV based survey and 3D models are being adopted in many civil and infrastructure projects, the model generated using multi-camera and nadir images using image detection technique allows in capturing crucial details of a building such as façade details as shown in Figure 11, which were challenging to retrieve using the conventional remote sensing satellite data and applications. (Nex, Rupnik, & Remondino, 2013)

Figure 11 UAV based 3D Reality Model

(Nex et al., 2013)

3.3.3 UAV - Photogrammetry models using Bentley - Context Capture

Automatic processing techniques of such images is still under research, the capabilities of using Bentley system's Context Capture automated 3D generation of building models will help in capturing and retrieving fast and highly detailed 3D building stock model achieving the aims of WP1.

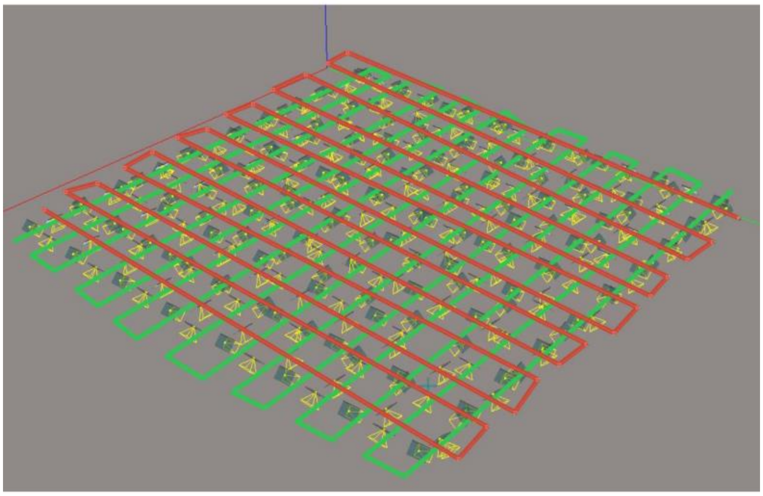

Figure 12 Oblique grid

(Academy, 2018)

This type of flight planning shown in Figure 12, allows the drones with multi directional movement such as Quadcopter and Hexacopter to capture images with an oblique angle of 30˚ and as shown in Figure 14 orbit patterns in 4 directions, which is a considered to be a robust image acquisition pattern for generating a 3D model, this type of flight planning is not possible with fixed wing flights hence should be avoided. (Academy, 2018) Other possibility to Bentley products would be exploring open source software like Pix4D, Drone-deploy, ACAD 360, Global-mapper with LIDAR plugin etc.

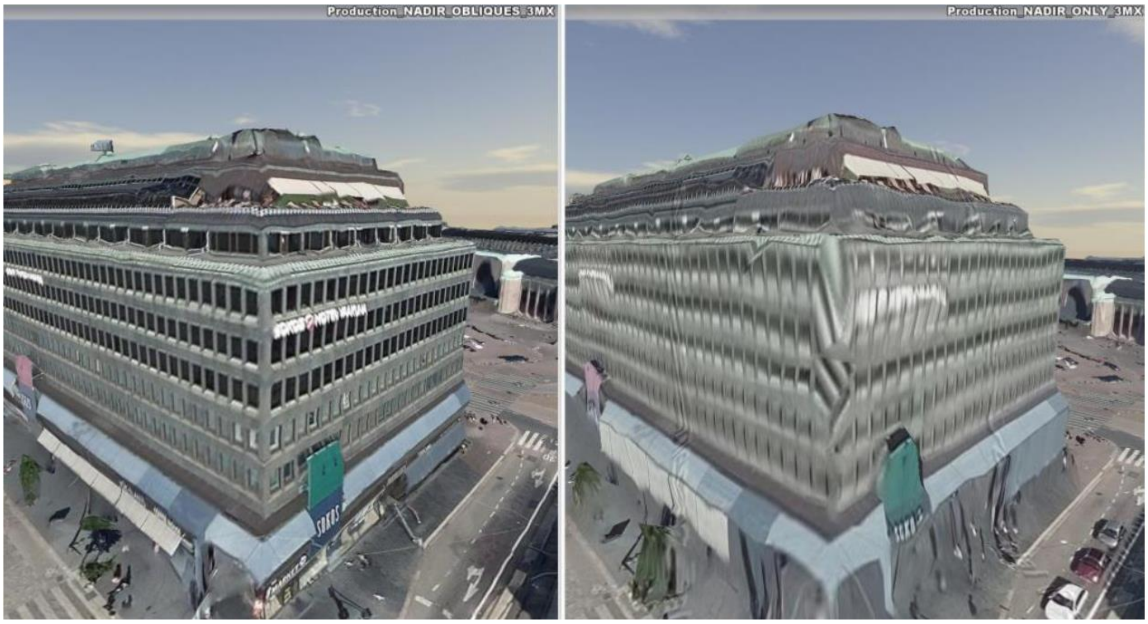

Figure 13 Comparison between Oblique (Left) and Nadir Image models (Right)

(Academy, 2018)

Figure 14 Orbit pattern using flight planning applications

(Academy, 2018)

3.3.4 UAV - LiDAR based 3D models

UAV is undergoing constant improvement. Researchers inform that low-altitude laser scanners will soon be used widely in mapping ancient architectural structures for precision mapping and retrieving point cloud data of large regions. Best practices to use LiDAR sensor is to include selecting a UAV instrument which has waypoint Navigation technology. LiDAR scanners can capture hundreds of square kilometres in a single day using fixed wing flights, LiDAR's centimeter level accuracy is close to terrestrial laser scanning accuracy, this type of data as seen from Figure 15 and useful for making height models and extracting regions with complex urban entities.(Z. Li, Yan, Jing, & Zhao, 2015)

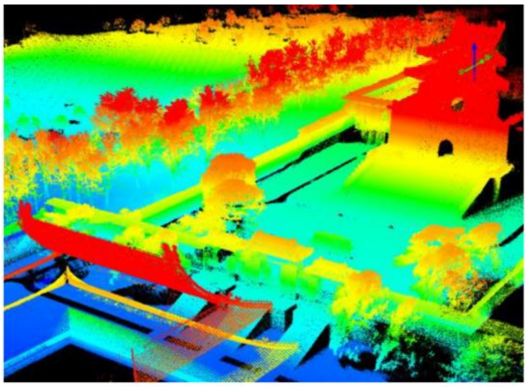

Figure 15 LiDAR scanning of Ancient building complex using UAV

(Z. Li et al., 2015)

3.3.5 UAV - Instrument Selection Criteria

For moving ahead with selection and procurement of the instrument, the specifications should achieve the City Energy Modelling aims. The UAV will include general parameters such as Flight time, Dimensions of the body, Camera type, Payload options and capacity, Attachments have all been discussed in detail Table 5.

Table 5 UAV Instrument selection criteria

UAV Equipment Requirements	*Suitable Specification*	*Required File Format and technicalities*
➢ UAV Make to resist wind conditions ➢ Geo positioning accuracy to be high to achieve precision mapping ➢ Oblique camera to capture various surfaces of the wall ➢ High Camera Resolution to	➢ Hexacopter ➢ RTK, PPK, GCP ➢ 5 Camera / 3 Camera ➢ 30 MP ➢ 2-6 Kg ➢ Flight time app 50mins	➢ RAW Data sets include ➢ Ortho mosaic high resolution imagery ➢ Contours, DSM model (Auto CAD, .Dwg) ➢ Feature Marking ➢ 3D textured model of

capture WWR Details and Over hangs of Buildings ➢ Pay load capacity to carry High Resolution Camera and accommodate other sensors such as Thermal and LiDAR. ➢ Flight time – High in order to cover large portions of urban areas ➢ Maximum Transmission to operate the UAV ➢ Software used for automated flight plans ➢ Transmission distance Operating frequency	➢ 4K, 1080 P, 720P ➢ At least 5 Km ➢ Interval between 2 flights to be low ➢ 8 Hour	all buildings ➢ Model to be viewed in Sketch fab, ➢ which captures details of windows, projections and spaces in between buildings ➢ 3D Point Cloud Data ➢ ACAD .Dwg ➢ Data accuracy should be mentioned both Relative and Global ➢ Ground Sample Distance to be mentioned (GSD)

3.3.6 UAV - Instrument Technical Comparison

Table 6 UAV Instruments and attachment sensors comparison chart

UAV Name	*Type*	*Dimension*	*Flight time (*Minutes)	*Range (Mile)*	*Camera*	*Payload capacity*	*Attachments*
H520-CGOET Bundle	Quad copter	520x457x310 mm	28	1	Integrated with Gimbal	Not required	Thermal camera
DJI Matrice 200	Quad copter	887×880×378 mm	24	4.3	Integrated with Gimbal	2.34kg	Thermal yes
Sense fly ebee pro	Fixed wing	96 cm	50	43167	-	-	Thermal yes
Matrice 600 pro	Hexa copter	1668 mm x 1518 mm x 759 mm	18	3	Integrated with gimbal	6kg	Thermal yes

DSLR Pros Flir VUE pro	Quad copter	289.5mmx 289.5mmx 196mm	28	3 miles	2 cameras included in gimbal	Not required	Thermal camera
Phantom 4 VUE pro	Quad copter	289.5mmx 289.5mmx 196mm	20	2 miles	2 camera included	Not required	Thermal camera
P560 CHC Navigation	Hexa	520mm x 440mm x 200mm	70	3 mile	AP5600 Micro Tilt Camera	10Kg	Thermal

3.3.7 UAV - Instrument selection and specification

After conducting a detailed comparative analysis Table 6, and guidance from field experts, P560 custom make from CHC Navigation is considered most suitable and robust option for conducting the city wide survey and capture the 3D building stock model. The highlights of the instrument include High wind resistant capacity, High Pay load capacity to include wide variety of sensors, Superior flight time and Battery power in order to cover large urban regions in a single flight and good control distance.

Table 7 Physical

Manufacturer	CHC Navigation
Model	CHC P560 
Features	• High stability level 7- wind • RTK/PPK GNSS Module • FADW Ground control station
Material	Fiberglass
Single Rotor Wingspan	820mm
Symmetric Motor Wheelbase	1550mm
Fuselage Diameter	550mm
Undercarriage Size	Span:630mm / Height:400mm
MTOW	20Kg

Table 8 Electrical

Stator size	81mm
KV Value	KV170
Max Power	1800 W/R
Operating Current	80 A
Operating Voltage	25 V
PWM Driver Frequency	600 Hz

Table 9 Flight

Payload	10Kg
Image Transmission	SD-SDI / HD-HDI
Flight Endurance	70min no load / 50 min standard load
Control Distance	3 – 5 Km
Flight Altitude	5 Km
Wind Resistance	13.8 Km/s
Battery Capacity	22000 mAh, 22.2 V
Operating Temperature	-20 °C to + 40 °C

Table 10 Ground Station

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

Table 11 AP5600 Micro Tilt Camera (Optional)

Size (L x W x H)	230mm x 260mm x 260mm
Weight	2.5 Kg
CCD Quantity	5
CCD Size	23.2mm x 15.4 mm
Pixel Size	4.25 um
Min Exposure interval	2s
Focal Length	20mm
Total Pixels	>100 million
Camera inclination	45°

Source – CHC P560, Unmanned Aircrafts, CHC Navigation, Shanghai, 2018.

3.3.8 UAV - Technology Analysis and conclusions

In conclusion, advantages of using UAV based technology include capturing accurate 3D building stock compared to satellite imagery, moreover various camera options allows customizing and upgrading of high resolution aerial imagery, Thermal imagery information of the building stock over time. The latest automated software’s such as Bentley systems- Context Capture is a reliable tool to generate fast 3D textured building with high level of building detail such as window to wall ratio and façade surfaces.

LiDAR attachment for precise Digital elevation model of the building stock generates highly precise models as the sensor technology uses laser pulses for measurements in Point cloud and lastly thermal camera attachment options to capture thermographic imagery of urban areas such as anthropogenic heat dissipation.

There are many limitations using this technology such as data clean-up is required to eliminate the vertical obstructions and bad lighting level, UAV is not capable to capture wall surface details if the area has dense vegetation, In order to capture a highly detailed 3D model the flight planning has to be orbital in nature and takes a lot of time and is only feasible for individual building level compared to single shot Nadir imagery of the whole city. UAV flight have restrictions to fly over sensitive zones which are listed in the Drone Policy-2018, and lastly UAV flight procurement and operations for survey requires high level technical expertise and may pose to be expensive and time consuming involving the detail of the 3D texture modelling.

3.4 Integration of RS and UAV technologies

After analysing both RS and UAV technologies it is clearly understood that both have their own advantages and limitations in order to capture the urban building stock data, hence a mixed use methodology might be useful to take advantage of the single shot readily available satellite imagery combined with close range improved granularity of UAV.

Table 12 Comparison chart of both RS and UAV Technology

Scale	*Type of Technology*	*Techniques*	*Software*	*Sources*	*Pros*	*Cons*
City	Satellite Image Stereo pairs- 2.5 D Imagery (Object based extraction)	Object based feature extraction using	ArcMap Ecognition	CARTO SAT / Pleidas (Stereo pairs)	Low cost, Fast, Low Computation power	Low Resolution, Low level of Detail on Buildings

Local / Building	UAV with LiDAR & Photogrammetry	Photogrammetry of aerial images using Layered mesh analysis	Context Capture	P560 – CHC	High Detailed 3D textured Buildings, IR Thermal Imagery and LiDAR Point cloud Data for High precision	High Cost, Operations require advanced Technical Expertise, Computation Heavy

Since the Urban Building Stock scenario is constantly changing and complex in nature with various land use typologies, an easy and fast way to capture and assess the building stock data should be adopted in the project, Methods such as UAV combined with GIS- Satellite Imagery as presented in Table 12, can reveal precise building information, Thermal Imagery, High precision point cloud data to capture detailed 3D urban stock model which might not be readily available at the local authorities.

4 Context and Study Area

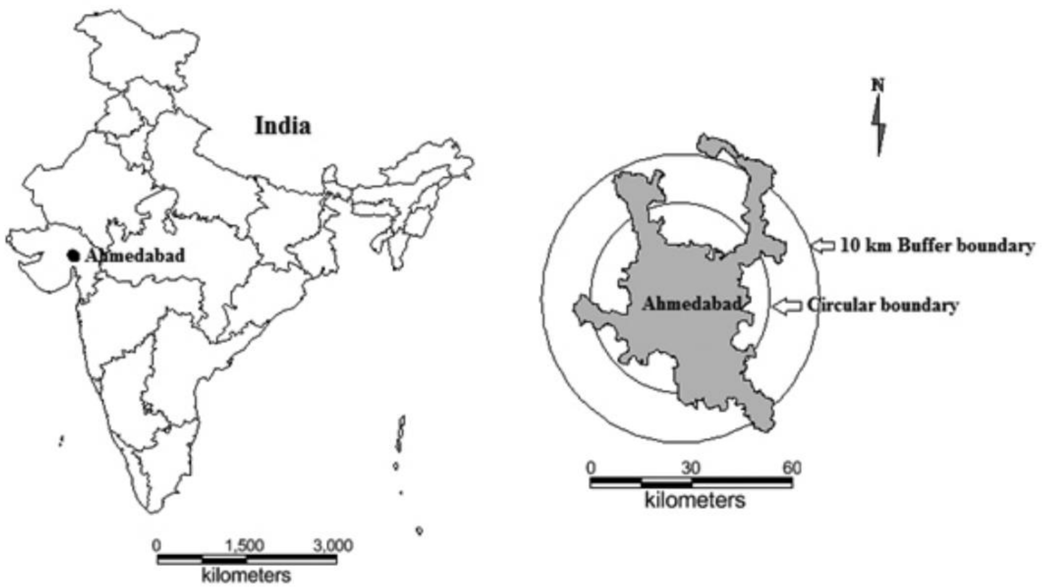

Figure 16 Context and Study Area

(Ramachandra, Aithal, & Sowmyashree, 2014)

The temperature data from 1981-2015 measures the warming trends are significant in the region to the north of 20° N. Ahmedabad lies in Northwest zone at coordinates 23°N and lies in the region with mean temperature of 26 – 28°C and is highly prone to the climate change impact. Studies further state warming is more significant in North west part of India when compared to rest of the country, The author informs that there has been an approximate 0.6°- 1° C increase in temperature in the recent 35 years. (R. Krishnan and J. Sanjay, 2017)

4.1 Ahmedabad Context

Ahmedabad lies in between geographical coordinates 23°N and 72.5°E. The city lies on the river banks of Sabarmati and covers an area of 484 km^2. The climatic context is identified to be hot and dry with Average summer temperatures varying from 36°C to 43°C and winter temperatures ranging from 15°C to 23°C. (Ramachandra et al., 2014)

According to studies conducted by Indian Institute of Science (IISC) Bangalore. Ahmedabad is the one of the largest metropolitan city in India with residing population of approximately 7.2 million, over the decades the city has expanded horizontally from the central zone to the new west, and is divided into 2 parts the eastern and western parts which have varied typologies of building types and land use. During last two decades the city has attracted many foreign investments, and this would increase job growth, urbanization and increase in current urban stock of Ahmedabad. However, the UHI phenomenon in cities is a complex phenomenon and often results in increased mortalities from extreme summer heat waves, such as the case in 2010 at Ahmedabad. (Azhar et al., 2014) This climatic phenomenon pose concerns to the municipalities to keep the residents thermally comfortable inside the buildings while meeting the growing energy demands.

4.2 Climatic conditions and Building Energy

The extreme climatic conditions urges municipalities to take up measures to improve the safety, health and thermal comfort of the residents. The municipality's further advocate that cool roofs on buildings made of lime wash will decrease the indoor temperature to approximately 3 - 6° C. (Azhar et al., 2014) Rapid urbanisation and population growth in UK focuses on housing research that reveals that majority of domestic stock pre date energy standards, there is clearly a need to include climate resilient housing and energy optimising strategies in order to achieve sustainable goals of meeting the cumulative building footprint of the city close to zero according to carbon plan 2011. (Gupta & Gregg, 2017) The peak summer conditions also pose a heavy demand on energy required for cooling the Buildings, Studies in UK clearly warn that by 2050 the increased temperature in urban centres are resulted to have heat wave periods and this only poses to be a burden to urban planners, architects and municipalities to ensure the occupants are thermally comfortable inside the buildings. (Mavrogianni et al., 2011) UHI is a complex phenomenon and to reduce energy demands from prolonged heat exposure to the buildings, it is crucial to analyse and integrate the surrounding context in urban scale energy models. (Kolokotroni, Ren, Davies, & Mavrogianni, 2012) Capturing and generating a high resolution 3D building stock and generating an City Energy Model for Ahmedabad (Hot and Dry climate), will allow municipalities in other cities of India to follow the approach in using modelling tools to identify areas where the climate resilient retrofit strategies can make the most impact and further optimize their building and municipal energy demands, especially while facing climatic conditions such as heat waves.

4.3 Identifying Available Datasets and Analysis – Ahmedabad City

Table 13, summarizes all the existing data Spatial and Non-Spatial collected so far by CEPT research team from various administrative sources of Ahmedabad City. The Data sets are analysed to identify data gaps and accuracy issues and justifies the significance of adopting advanced aerial survey technologies to improve the granularity and validity of the urban stock model in achieving WP1 goals. The chart shows a snapshot of each individual layer stored in the GIS Data base with CEPT (2016-17). All layers are digitized and are manually corrected to achieve improved accuracy, however there are many data gaps and over lapping issues in the GIS layers, which may lead to highly inaccurate building stock model. Using High precision aerial survey technologies and sensors such as UAV combined with High resolution satellite imagery extraction process would allow to superimpose an accurate and precise 3D building stock model.

Table 13 GIS - Data Analysis

(*Centre for Advanced Research in Building Science and Energy, 2015*)

	Type of Data	*Source and Granularity*
1.	City Boundary	➢ AMC Boundary – 450 Sq. Km
2.	Zone Boundary	➢ 6 zones - central, east, west, north and south and new west zone. ➢ Property Tax data is collected zone wise
3.	Ward Boundary	➢ AMC - 48 Wards
4.	TP – Scheme Boundary map	➢ TP scheme boundary numbers allow to understand the zoning regulations and laws applied to building construction in that area.
5.	Plot Boundary	➢ Attached attributes such as Unique ID, DP_2021 Zone classification, TPS-Number and name, Road width, Plot Area etc.
6.	Building Footprint	➢ Building Footprint extracted does not match plot boundaries, contains position errors and must be resolved ➢ Attached data such as Ward no. and Area

7.	Building Height	➢ Poor Model ➢ Had been assumed referring to zoning laws and including factors such as Building FSI, Road to Plot margins, maximum buildable area of plot in located - TP zone.
8.	Transport Railway, Roads	➢ Width of roads available, identification of BRTS and MRTS, TOD Transit oriented zones
9.	GIS integrated Data	➢ TP scheme number, Road width, Area, Land use, Building Typology etc.

4.4 UAV Survey - Pilot Study Selection Criteria

In order to export the 3D building stock model into building energy simulations to analyse and visualise the energy consumption patterns of the selected locality. It is necessary to first try and test the modelling techniques as pilot study on a sample region of 3.0 km^2. The sample region should ideally be selected that it best suites the building type and composition of the city Ahmedabad, and that the area meets the modelling objectives.

Table 14 Selection criteria for UAV Survey

CLASS	*REMARKS*
RED ZONES	DISCARDED **RED ZONES** According to National Drone policy – 2018
5 Km from Airport	
3 Km from civil, private and defence airports	
3 Km off Military grounds	
3Km from radius of State secretariat complex	
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	
LAND USE WITHOUT BUILDINGS	Refer to DDP 2021 - (Second Revised Edition)
Water body	

Burial and cremation ground	DISCARDED No Building units in region
General Agricultural zone - A1	
Prime Agricultural Zone-A2. P	
Parks gardens and open spaces - P	

LAND USE WITH BUILDING UNITS	**FSI (Base 0.15 / Max 5.4)**	Refer to DDP 2021 - (Second Revised Edition)
Residential Zone - R1	1.8 - 2.7	**YES** (INCLUDE) Building Units SUITABLE UAV AERIAL SURVEY REGION
Residential Zone - R2	1.2 - 1.8	
Residential Zone - R3	0.3	
Industrial Zone-IG	1 - 1.8	
Industrial Zone Special-IS	1	
Knowledge and Institutional zone- KZ	1.8	
Commercial Zone - C	1.8 - 2.7	
Central Business District - CBD	1.8 - 5.4	
Core walled city - CW	2	
Logistics Zone - LI	1 - 1.5	
Transit oriented Zone - TOZ		
Residential Affordable Housing - RAH	1.8 - 2.7	
Gamtal - GM	2	
Gamtal Extension - GE	1.2	
Special Planned Area Development - SPD1/ SPD2/ SPD3/ SPD-4		
Sewage/Water treatment Plant		
GIS -SATELLITE DATA		NO Building units (DISCARD)
Areas with only Vegetation		
Water		
Barren land		
Only Roads		
Built-up + Vegetation + Roads		YES

Table 15, Displays that according to the Land use plan, Ahmedabad city consists of a complex mixture of urban built form distribution with various proportions of manmade and natural land cover configurations, therefore it becomes difficult to identify a sample region for a pilot study that best represents the building composition of entire city. The Table discards all the regions which do not allow aerial survey and are mentioned as RED ZONES, according to Drone Policy-2018. By following the method of exclusion the sample region which is appropriate can be highlighted using the chart.

4.5 Ahmedabad City Zones - Property Tax Data Analysis

Figure 17 Ahmedabad city Zone map

(*Centre for Advanced Research in Building Science and Energy, 2015*)

The section represents the selection process that guides in choosing the most suitable sample region after understanding the building criteria required to perform an urban scale energy model. For example

- The selected sample should consist diverse building types which shall be a representative of the building composition existing in the entire city of Ahmedabad
- Property tax data analysis of the building count, type of the existing building counts and types would assist in identifying the statistics of existing building stock
- Property Tax data is divided into 6 Zones (Figure 17)
- T-Number is unique for each property and has associated data such as building type, year of construction etc. No common fields to connect data directly to GIS spatial plot boundaries Address/ location details are not available

- Statistical analysis can be conducted using the numbers from Property Tax Data, AMC to reveal the sample pilot study region representative of Ahmedabad city building typology
  1. Count of tenements from 1970-2015
  2. Total Floor Area of the tenements in each zone

3. Total number of tenement types in each Zone
4. Land use - Zone F.S.I – (Base 1.2 to 5.4 Maximum)

- By conducting statistical analysis of all the zone wise Tenement count, type, area and growth patterns in the zone over time can infer the best suited building zone to conduct the UAV pilot study.

5 Conclusions

There is a need to use advanced aerial survey approaches to capture the urban stock dynamics, UBEM's are proven tools to visualize and optimize municipal services specifically energy flows through urban buildings, Most of the existing UBEM's use Satellite based data capture techniques to generate their models, however using UAV technologies will increase the granularity, retrieve thermal exchanges between buildings, while increasing the credibility of generated City Energy Models in policy making,

The two most widely used survey techniques are RS-Remote sensing and UAV technology, which explained the technical analysis, advantages, and limitations, criteria in selecting the most suitable instruments, post processing methodology to create a precise and robust 3D building stock model.

Ahmadabad as a pilot study region has been chosen as the climatic conditions are severe in summers in the urban areas and reflect directly on the city energy demands, Ahmedabad's existing geographical and administrative data are poor in quality with overlapping and accuracy issues, the city further has a complex diversity in building variations which can only be statistically assessed using property tax data. In the next stage WP1 will gather all the data pertaining to buildings from AMC and conduct statistical analysis and numerical modelling to identify most suited sample region which represents the building composition of Ahmedabad city and conduct the pilot UAV survey.

WP1 will identify methods to scale up BIM based energy simulations to integrate with the captured 3D building stock model and generate an City Energy Model is yet to be fully explored, and requires further research, technical assistance and computational power.

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Appendix A Property Tax Zone wise Data, AMC

Below are the graphs of tenement count change from 1970-2015 and the Total area of tenements for each zone in Ahmedabad. By conducting statistical analysis of all the zone wise Tenement count, Type, Growth pattern over time and Area we can infer the best suited zone and region to conduct the pilot study.

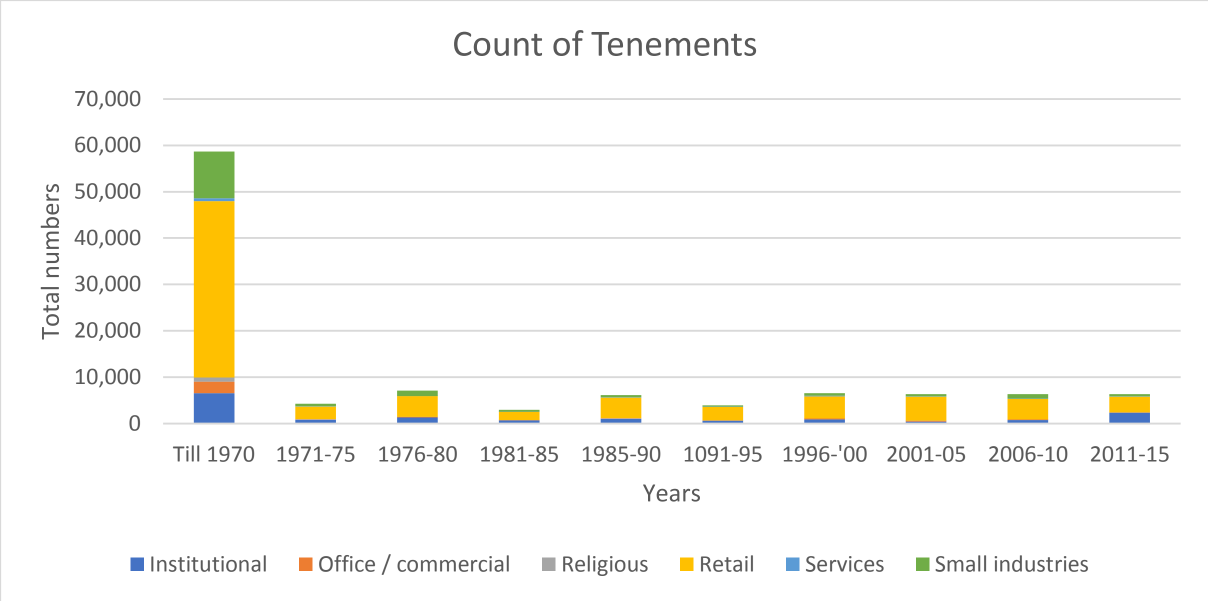

Figure 18 Central Zone – Count of Tenements

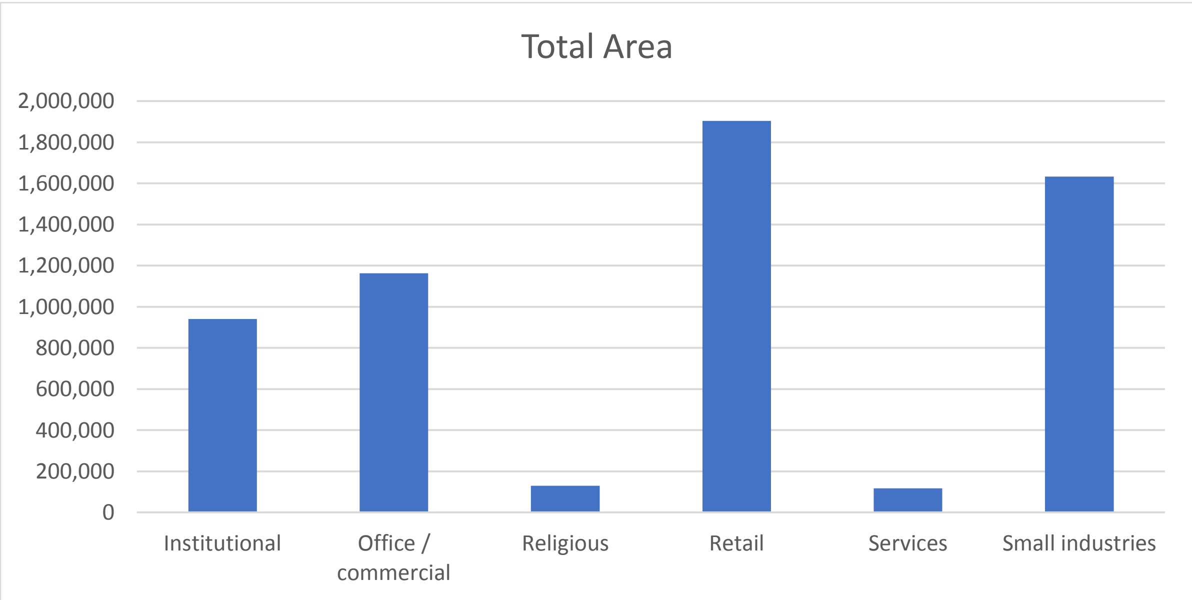

Figure 19 Central Zone- Area of Tenements

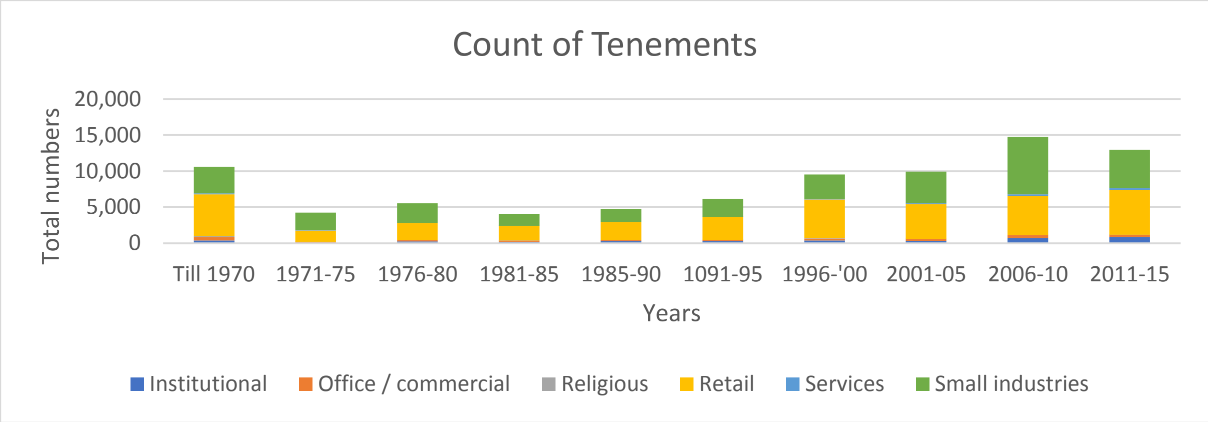

Figure 20 East Zone- Count of Tenements

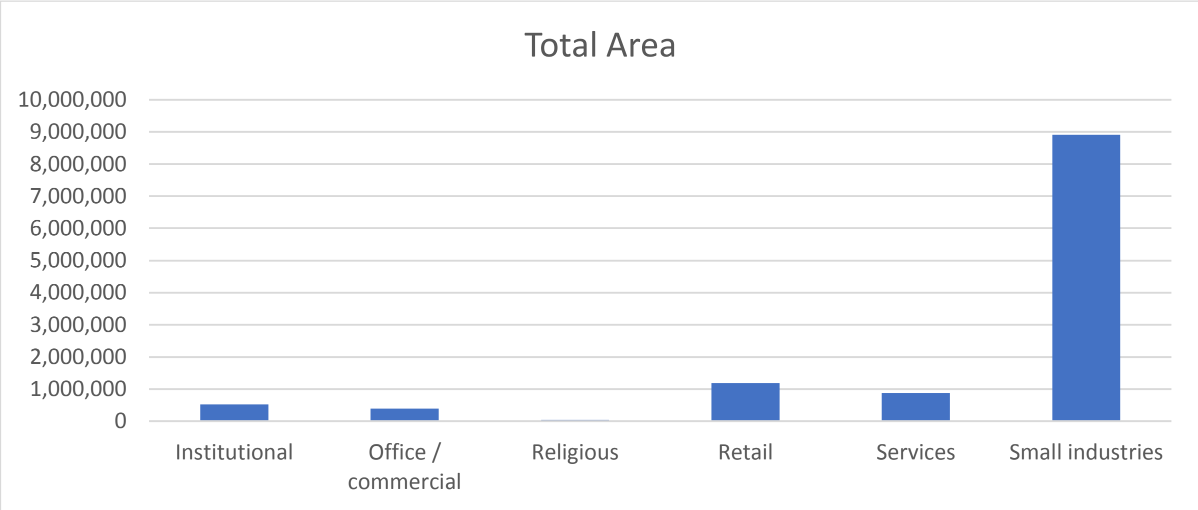

Figure 21 East Zone - Area of Tenements

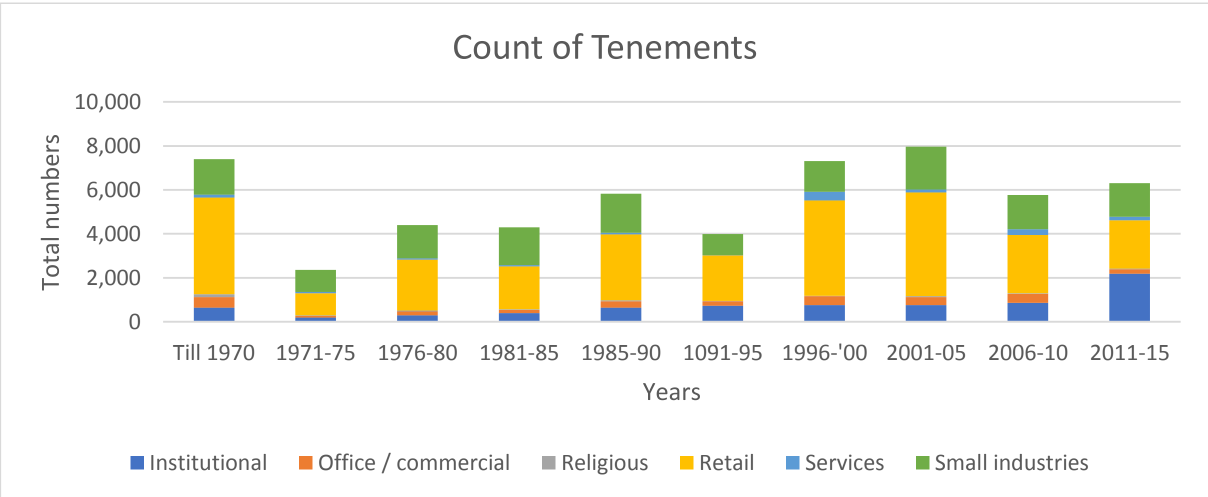

Figure 22 South Zone – Count of Tenements

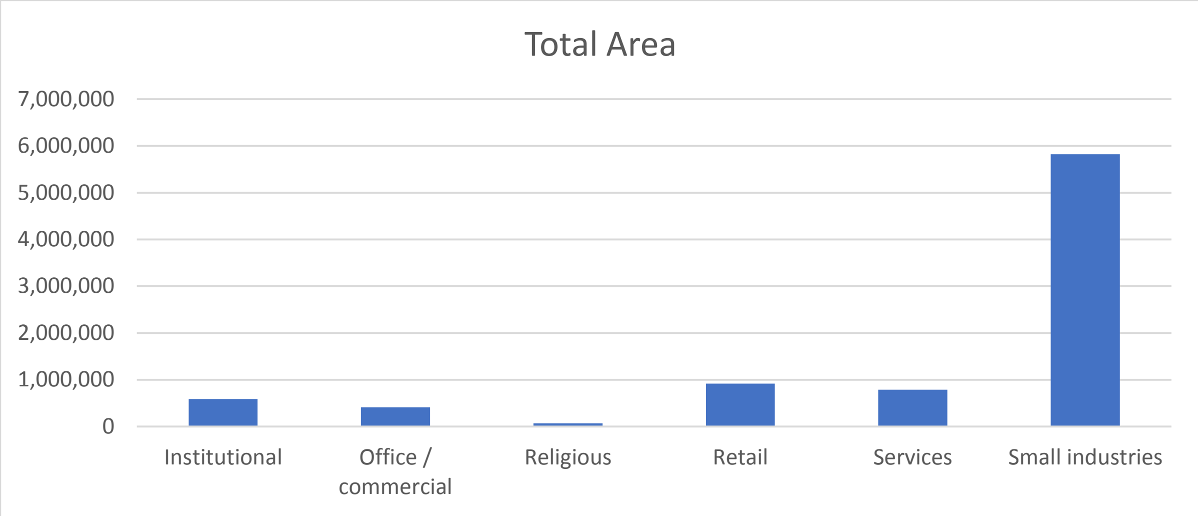

Figure 23 South zone - Area of Tenements

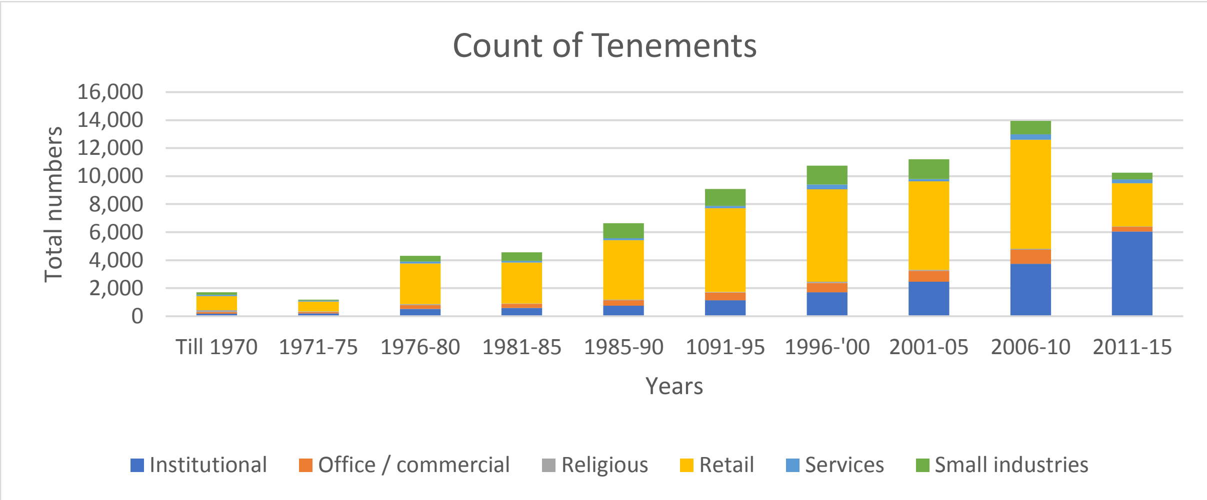

Figure 24 New West Zone – Count of Tenements

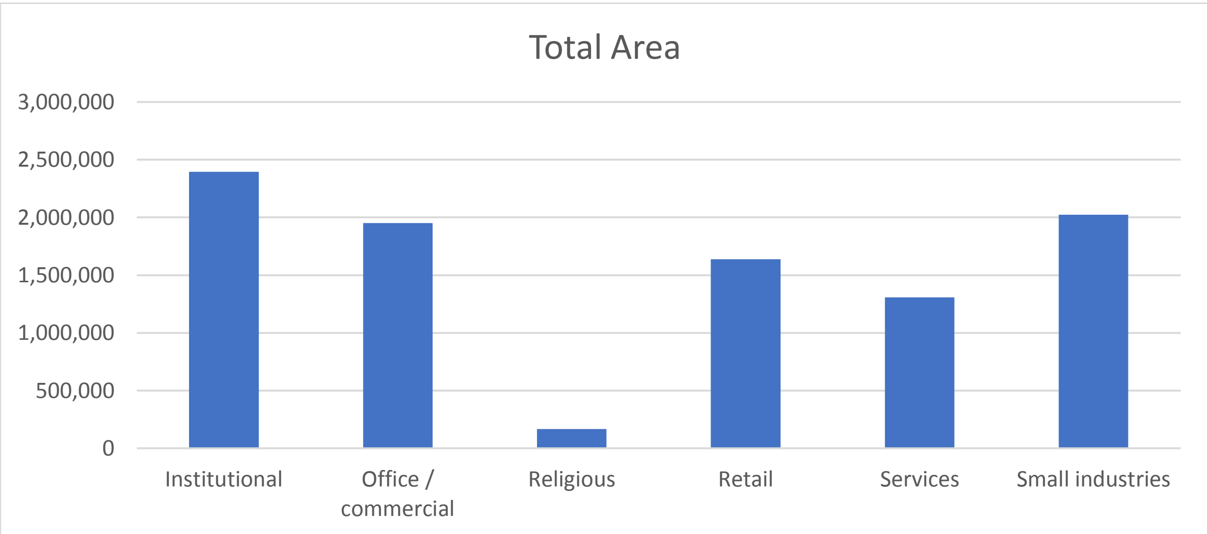

Figure 25 New West zone - Area of Tenements

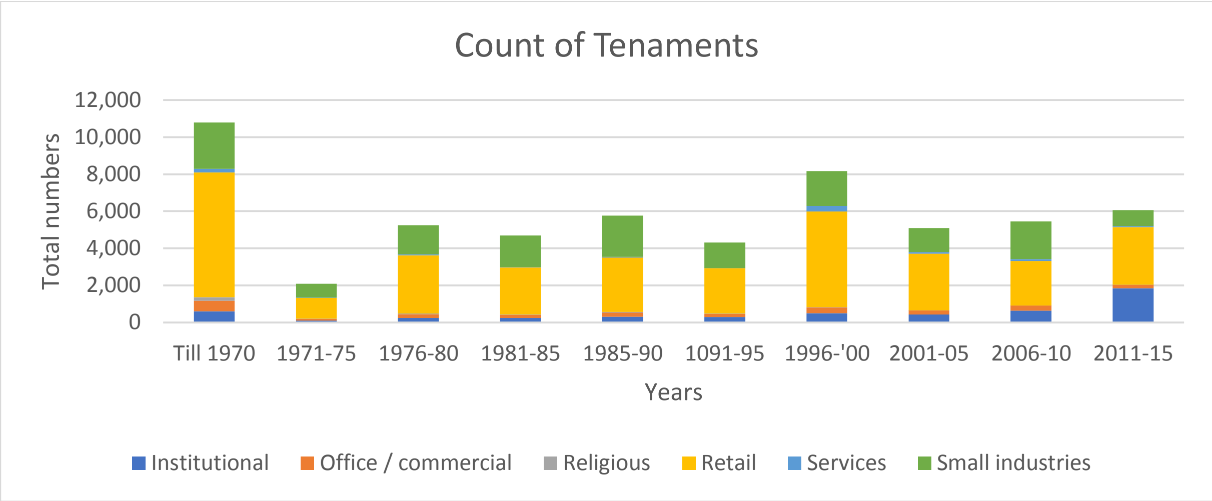

Figure 26 North Zone – Count of Tenements

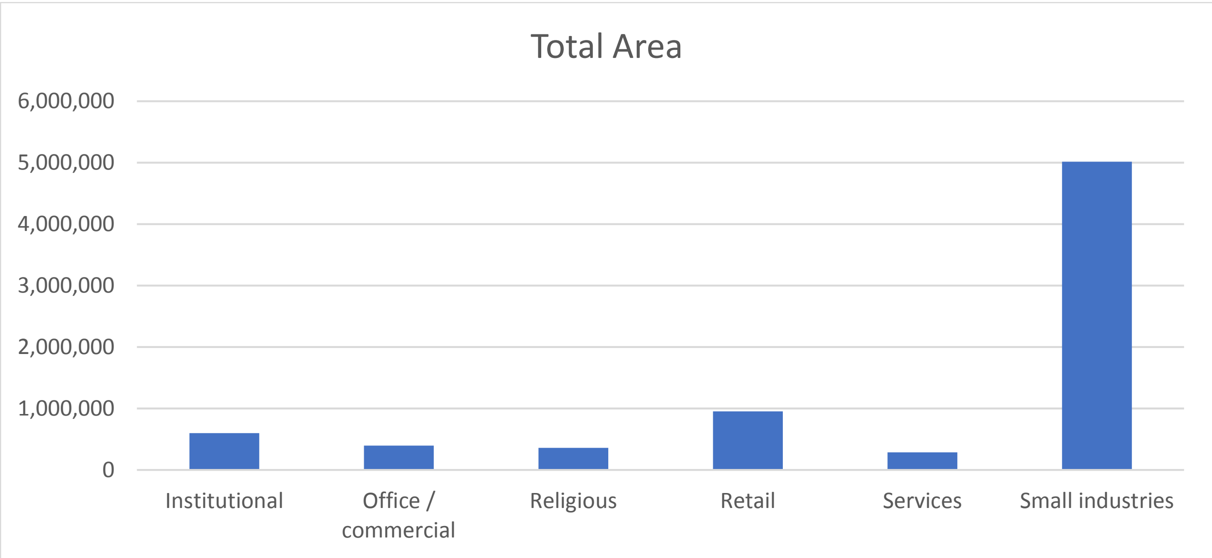

Figure 27 North Zone – Area of Tenements

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