

Combined 3D modeling from UAV aerial images and Mobile Mapping laser-scan point clouds

Prof. em. Dr. Armin Gruen

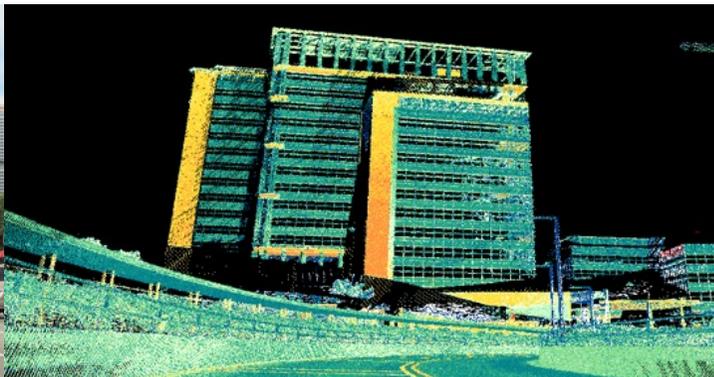
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1. Introduction
2. Project NUS campus modeling
3. Conclusions, perspectives



SEC-FCL project – UAV over NUS campus

Prime Minister of Singapore Lee Hsien Loong, National Day Rally 2012, UAVs as a key breakthrough technology for the next 20 years: **”UAVs will have many uses in the future – civilian and military”**.



AscTec Falcon 8

500 g load

max 20 min flight time

max 10 m/s wind speed

redundancy through 8 rotors

GPS, height sensor, compass, IMU

max. Total weight 1,8 kg



Various UAVs



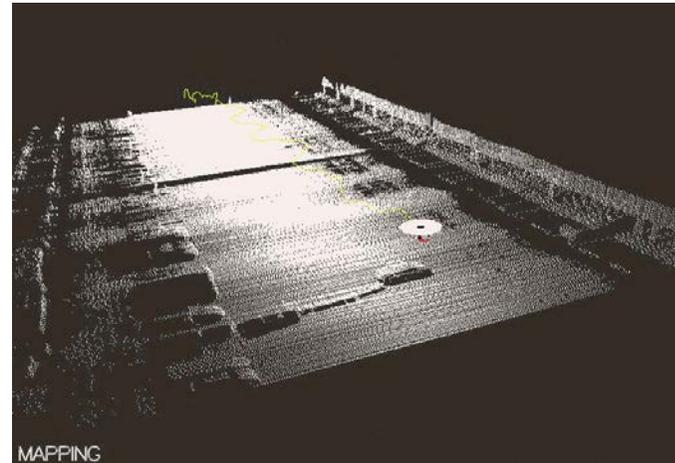
Mini-drone turns Serbia-Albania football match into Balkans bust-up



Stanford University, Autonomous Helicopter



Autonomous Flips



Mapping

ETH Zurich: Quadrocopter ball juggling

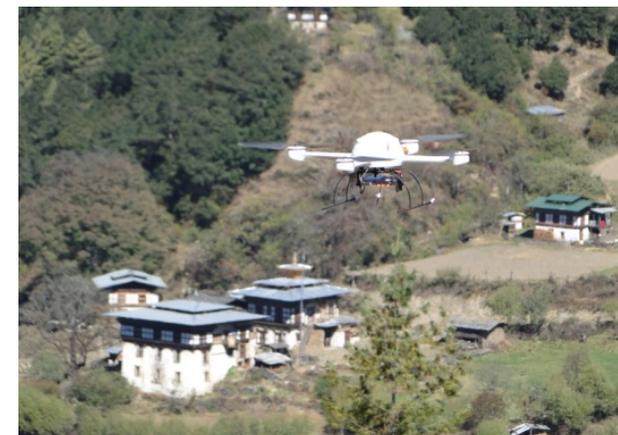


ETH Zurich, Future Cities Laboratory: Digital Fabrication



Messages

- + UAV technology is interesting, relevant and exciting
- + Many systems on the market. Low costs (?)
- + New applications (niche functions)
- Not mature (hardware and software problems)
- Good application software missing
- Safety issues



Unfortunate events (Polibino)



Unfortunate events

A28 | ASIA

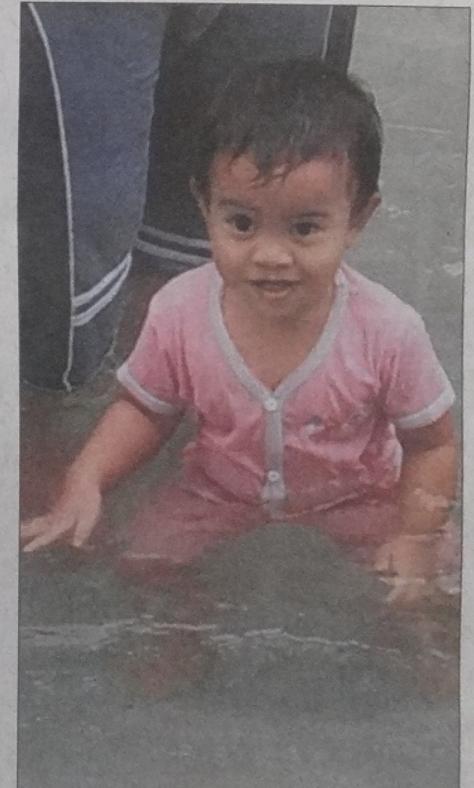
SATURDAY, MARCH

Toy copter kills toddler in freak accident

SEREMBAN (Malaysia) – A radio-controlled miniature helicopter crashed into a crowd and killed an 18-month-old baby girl in a freak accident that marred the official opening here of the country's first synthetic football pitch.

Nurdamia Hisnina was in her father's arms when the helicopter, which was being flown as a gimmick at the event on Wednesday, flew through the crowd at the Paroi Sports Complex and slashed her head with its blades.

Her father, Mr Bane Yamin Idris, 35, who works in the Attorney-Gener-

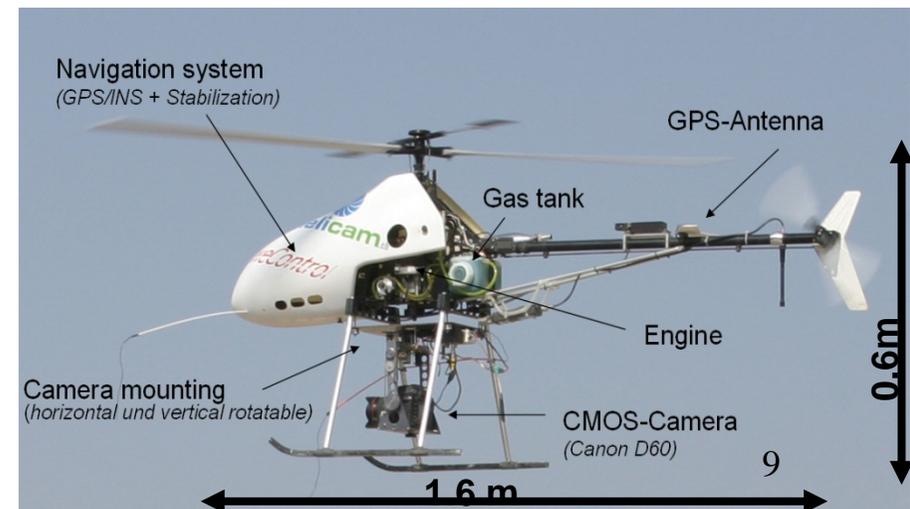


In a freak accident at the Paroi Sports Complex in Seremban on Wednesday, this radio-controlled miniature helicopter (above left) crashed into the crowd there and killed 18-month-old Nurdamia Hisnina (above right). PHOTOS: CHINA PRESS

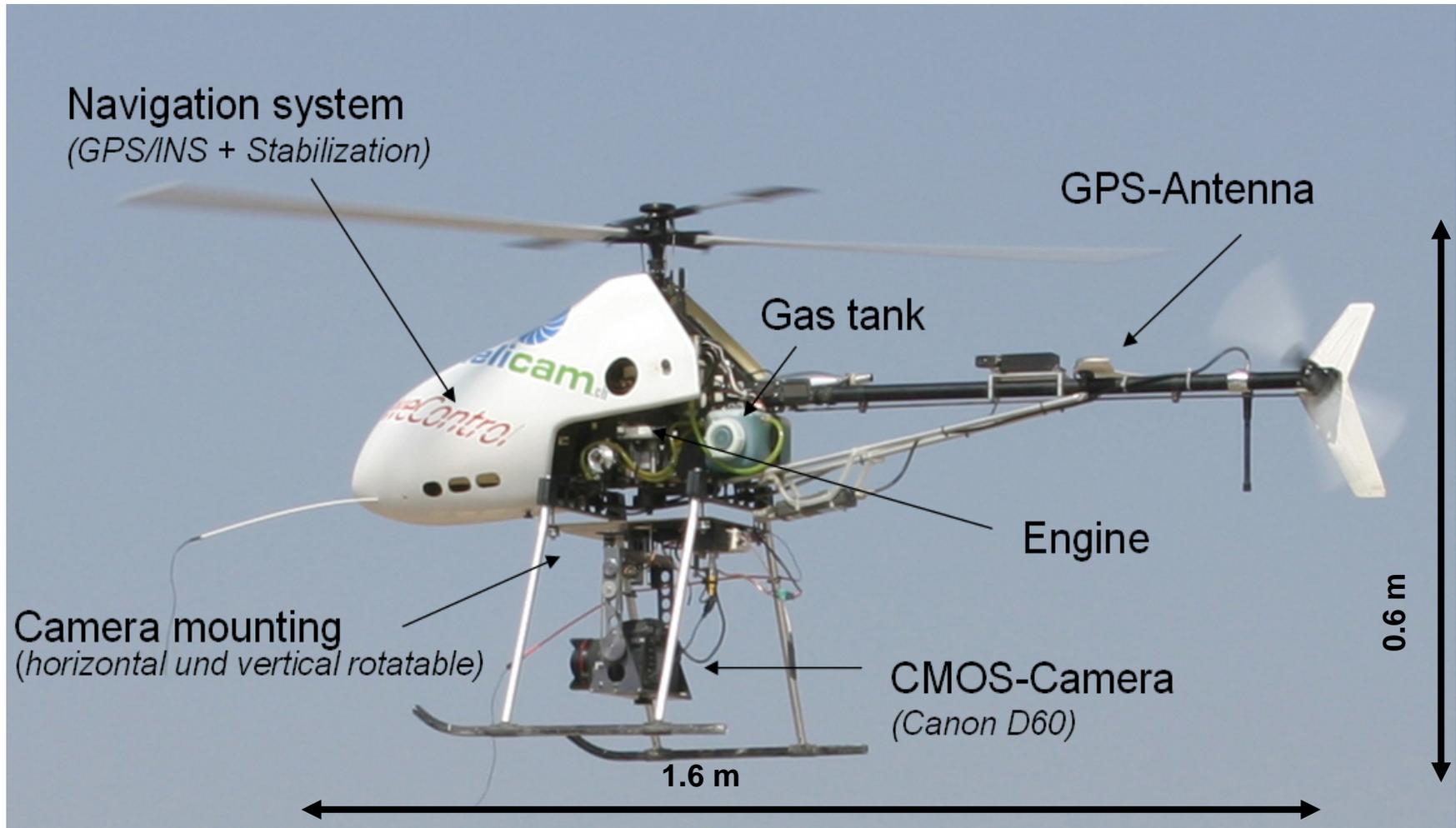
Photogrammetric UAV systems

Characterization of “photogrammetric”:

- + Long flying time for image block data acquisition
- + Large image sequences (100 – 10 000)
- + Navigation devices for automated control of trajectory and orientation
- + Image-based and/or range-based sensor(s), modular/exchangeable
- + Calibration of sensors and system
- + Image-based navigation
- + Accurate geo-referencing (direct/indirect)
- + 3D modeling of objects and processes (geometry and texture)
- + Automated image analysis and fast processing (sequential estimation)
- + Standard photogrammetric pre- and post-processing functions
- + Good software !!!!!



Our model helicopter Helicam (weControl, 2004)





AscTec Falcon 8 - Facts

- 500 g load
- max 20 min flight time
- max 10 m/s wind speed
- redundancy through 8 rotors
- GPS, height sensor, compass, IMU
- max. Total weight 1,8 kg



Falcon-8 flight

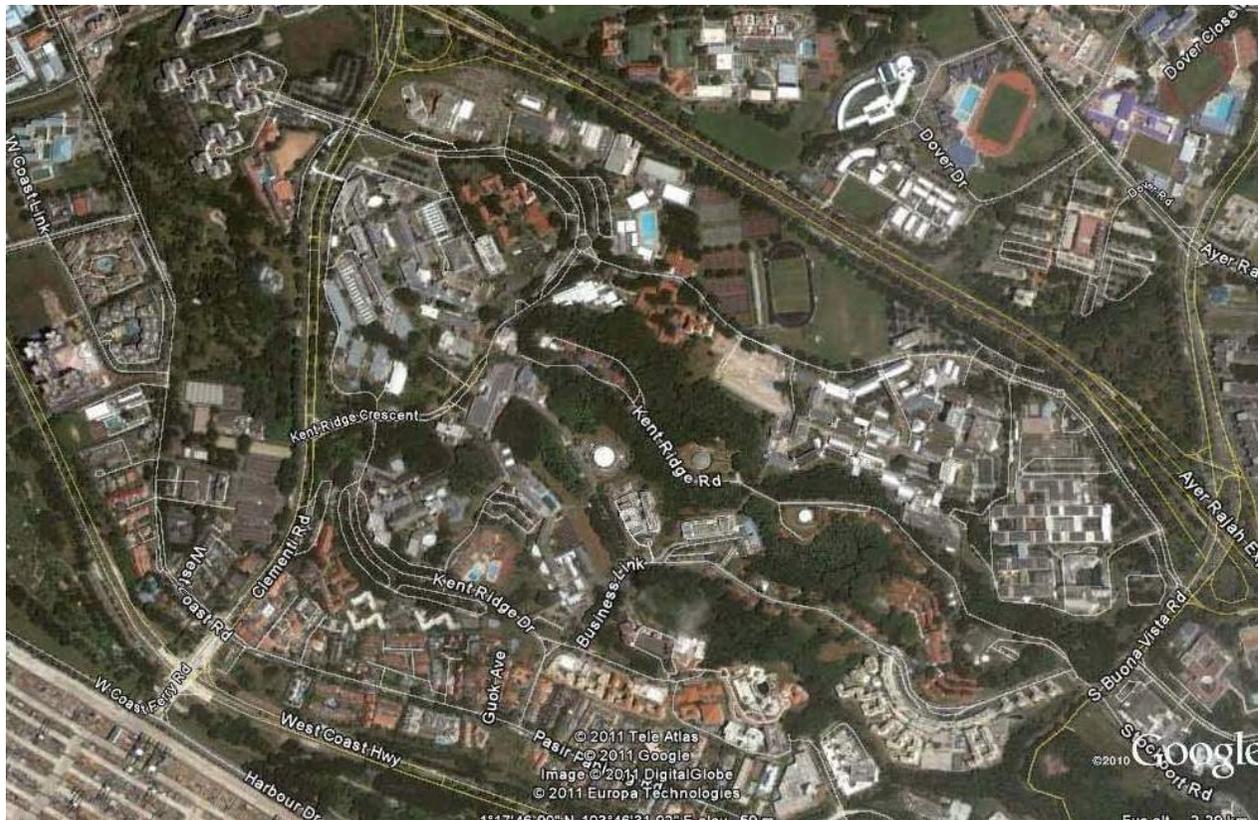


Our examples, projects

- Pinchango Alto, Palpa/Nasca, Peru (archaeology)
- Copan, Honduras (Cultural Heritage)
- Maize field (plant sciences)
- Randa (geology)
- Landenberg (Cultural Heritage, student work)
- Volumetric changes of gravel pits (civil engineering)
- Drapham Dzong, Bhutan (archaeology, Cultural Heritage)
- *NUS, Singapore (city planning, hydrology, autonom. car navigation, pedestrian simulation, etc.)*
- *Shuhkov towers, Russia (construction engineering)*
- Chiliwung River, Indonesia (hydrology, landscape architecture)
- Singapore: Detection of breeding grounds of Dengue fever mosquitos (pest control)

SEC-FCL project – UAV over NUS campus

Singapore – ETH Centre for Global Environmental Sustainability
Future Cities Laboratory (Simulation Platform)



2.2 km²

SEC-FCL project – UAV over NUS campus

Singapore – **ETH** Centre for Global Environmental Sustainability
Future **Cities** Laboratory (Simulation Platform)

Purposes of project

- + Pilot project to refine our data processing algorithms and software
- + Test-bed for demonstrations of technology and products
- + Results will be applied by a variety of different users for analysis, animation and simulation (autonomous vehicle driving, hydrology, crowd movement, etc.)

Difficulties in UAV urban data acquisition

- **Permission** application, **various flight restrictions**
- **Radio interference** in urban area
- Limited **take-off/landing spaces**
- Short **flying times**
- **NUS Campus: Steep terrain, high buildings, tropical vegetation**

SEC-FCL UAV NUS campus flight

Take-off and landing stations



CREATE
take-off



Falcon roof
landing



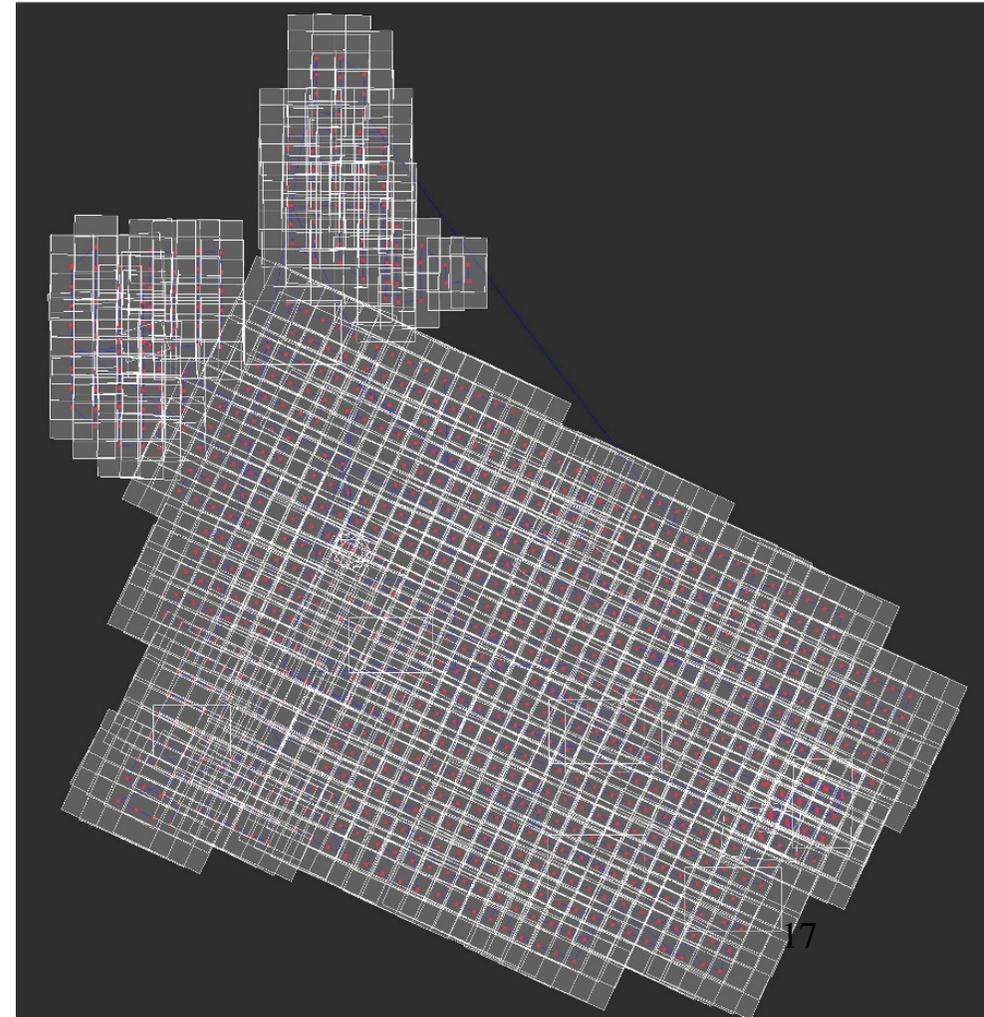
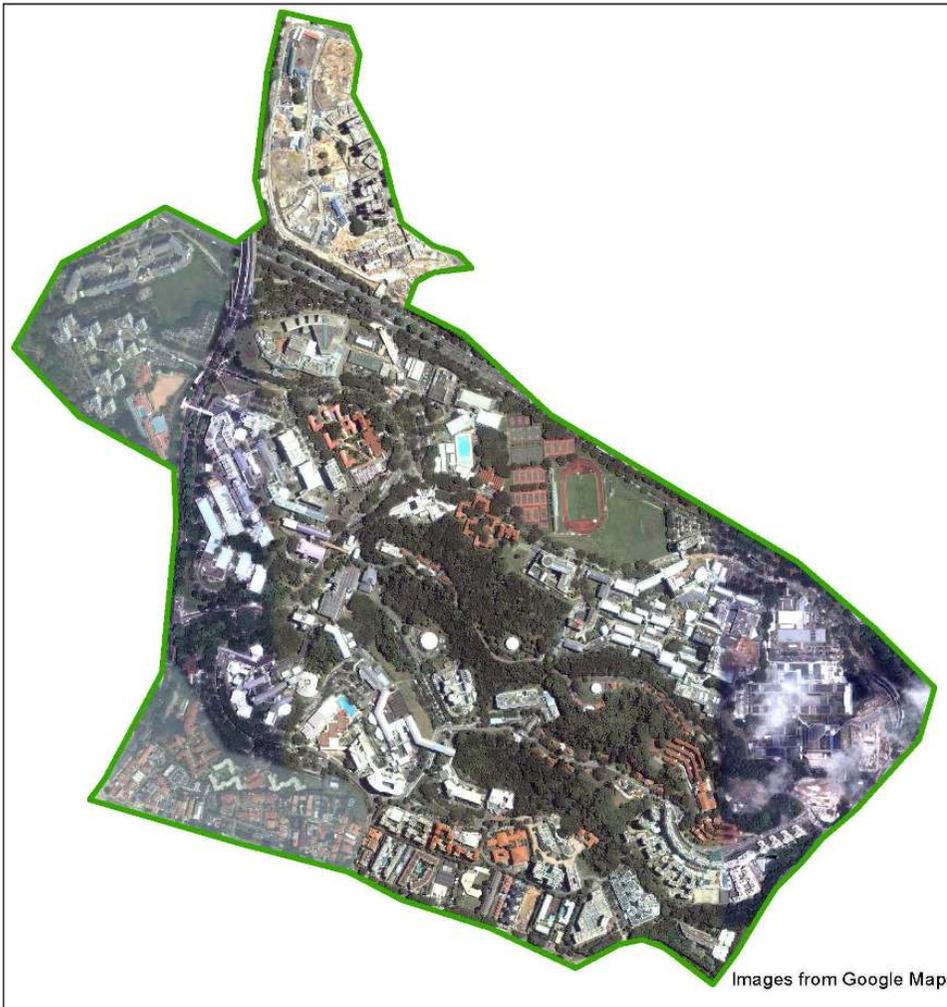
Education Resource Centre



CREATE Tower

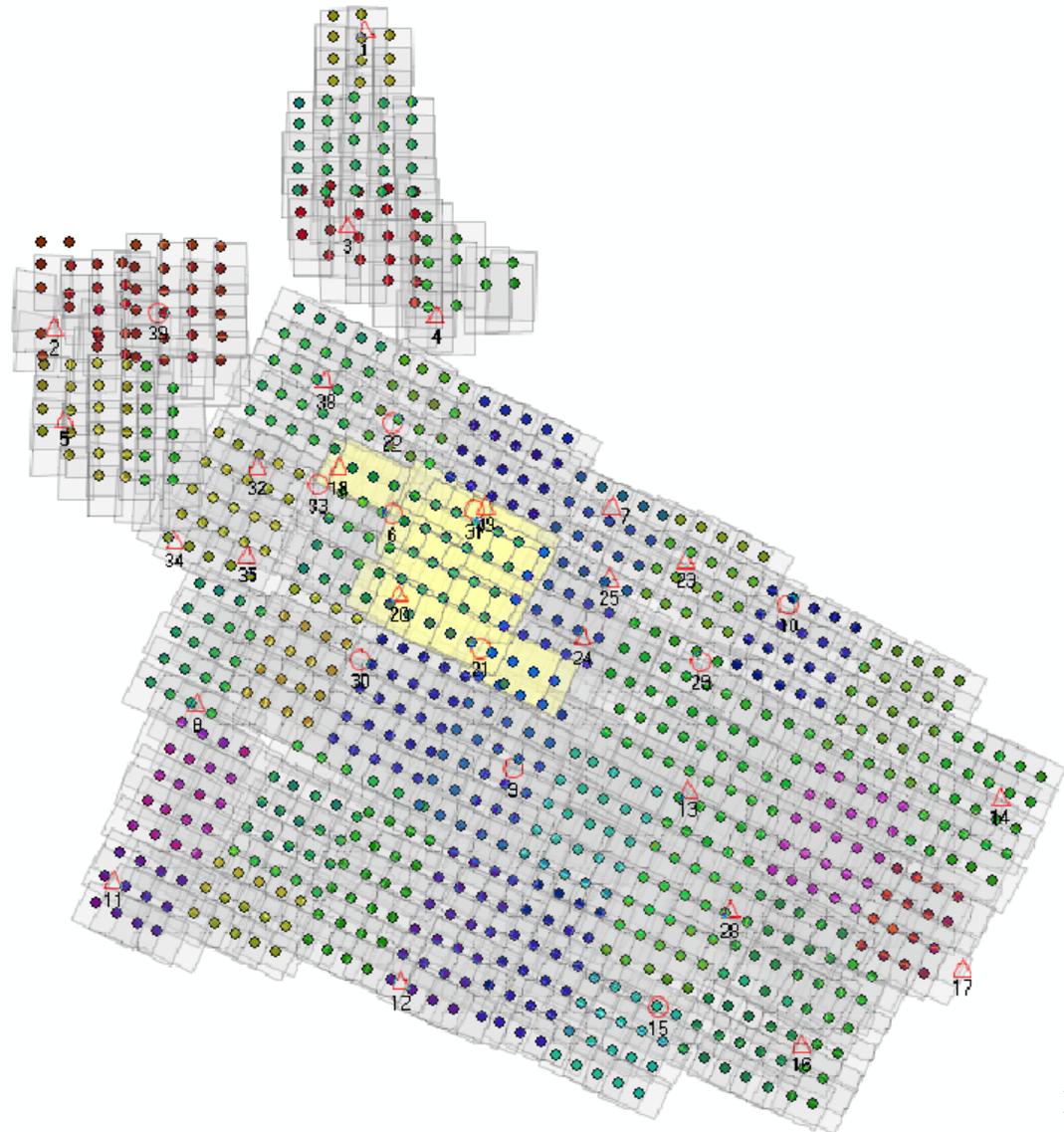
SEC-FCL project – UAV over NUS campus

Singapore – ETH Centre for Global Environmental Sustainability
Future Cities Laboratory (Simulation Platform)

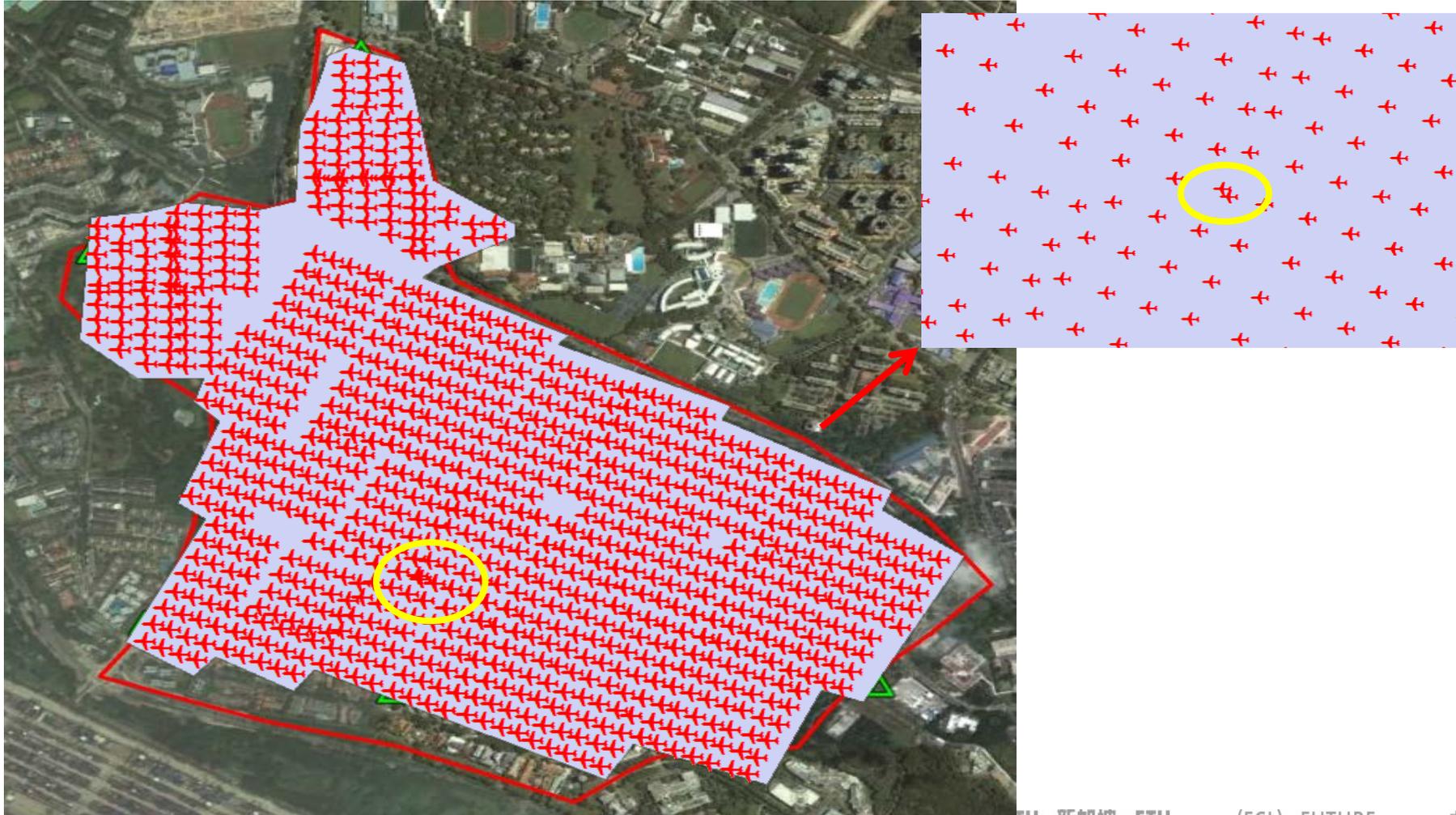


Actual Blockstructure

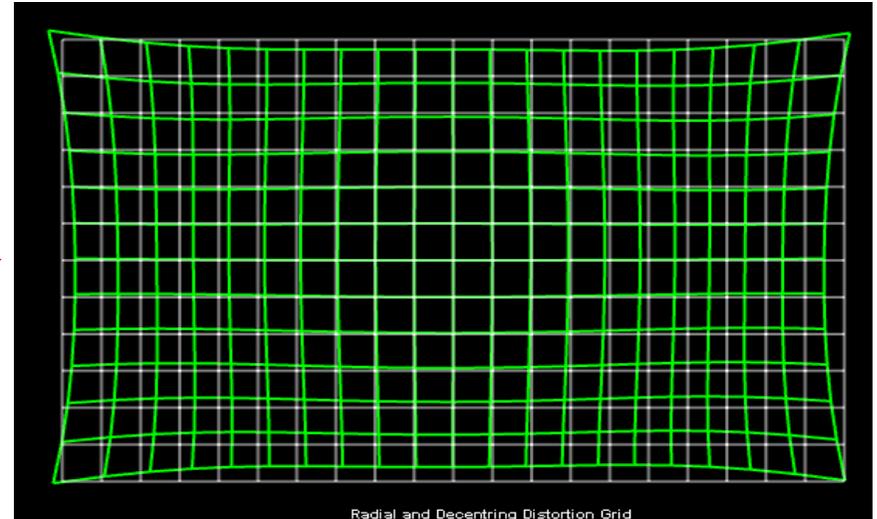
43 sub-blocks



Errors in data acquisition



Data processing - camera pre-calibration



f, x_p, y_p : interior orientation parameters
 k_1, k_2, k_3 : symm. radial distortion
 p_1, p_2 : decentering distortion
 b_1, b_2 : affinity parameters

4x4 image block University Hall

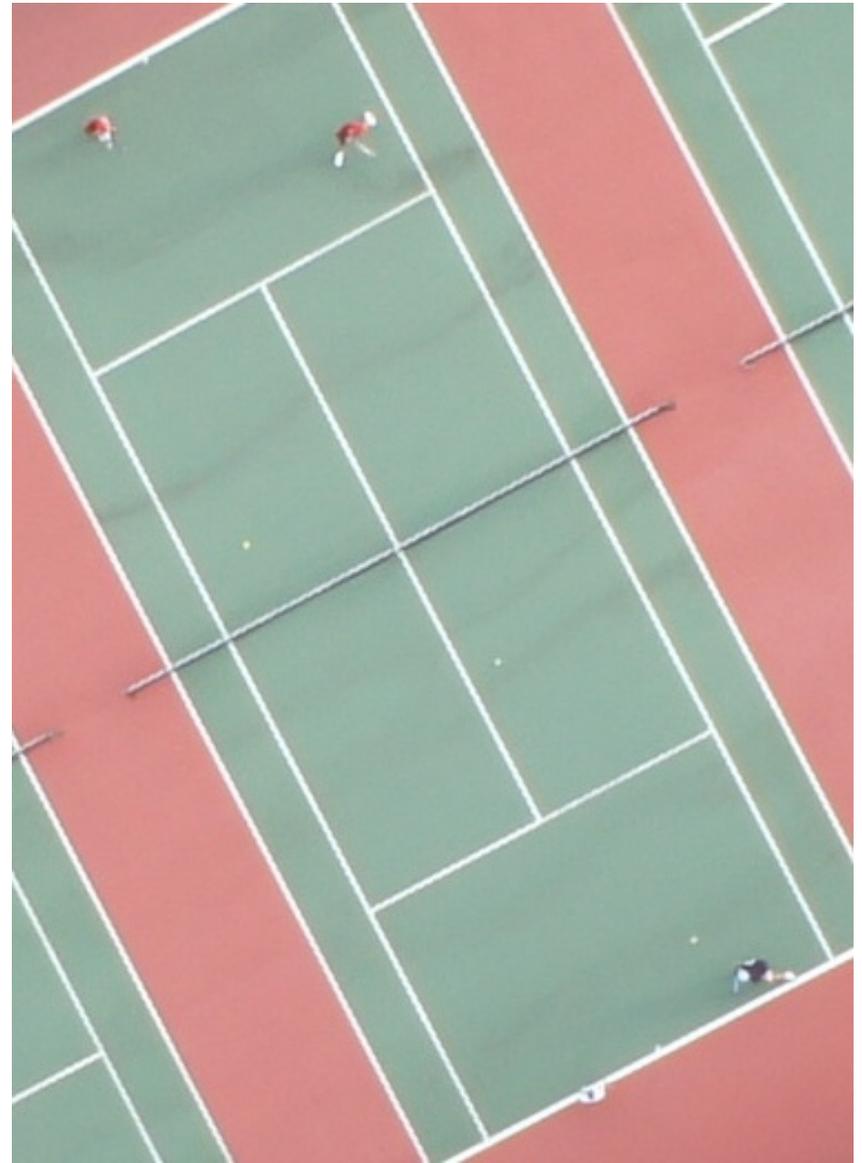
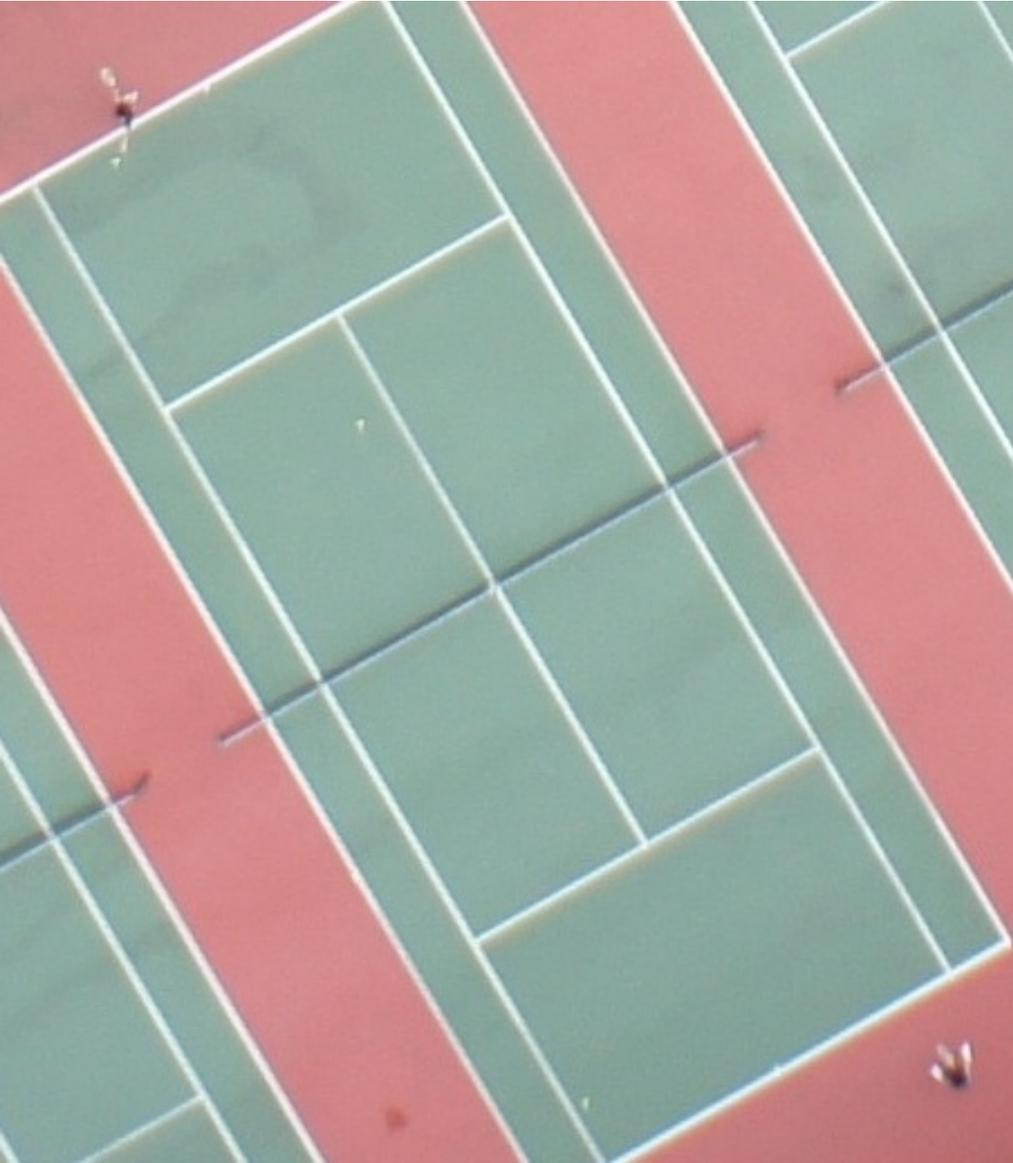


4x4 block



P-Centres
total block

NUS tennis courts, tennis balls



Data Processing

- Georeferencing: GCPs by GPS (datum)

Image triangulation/bundle adjustment

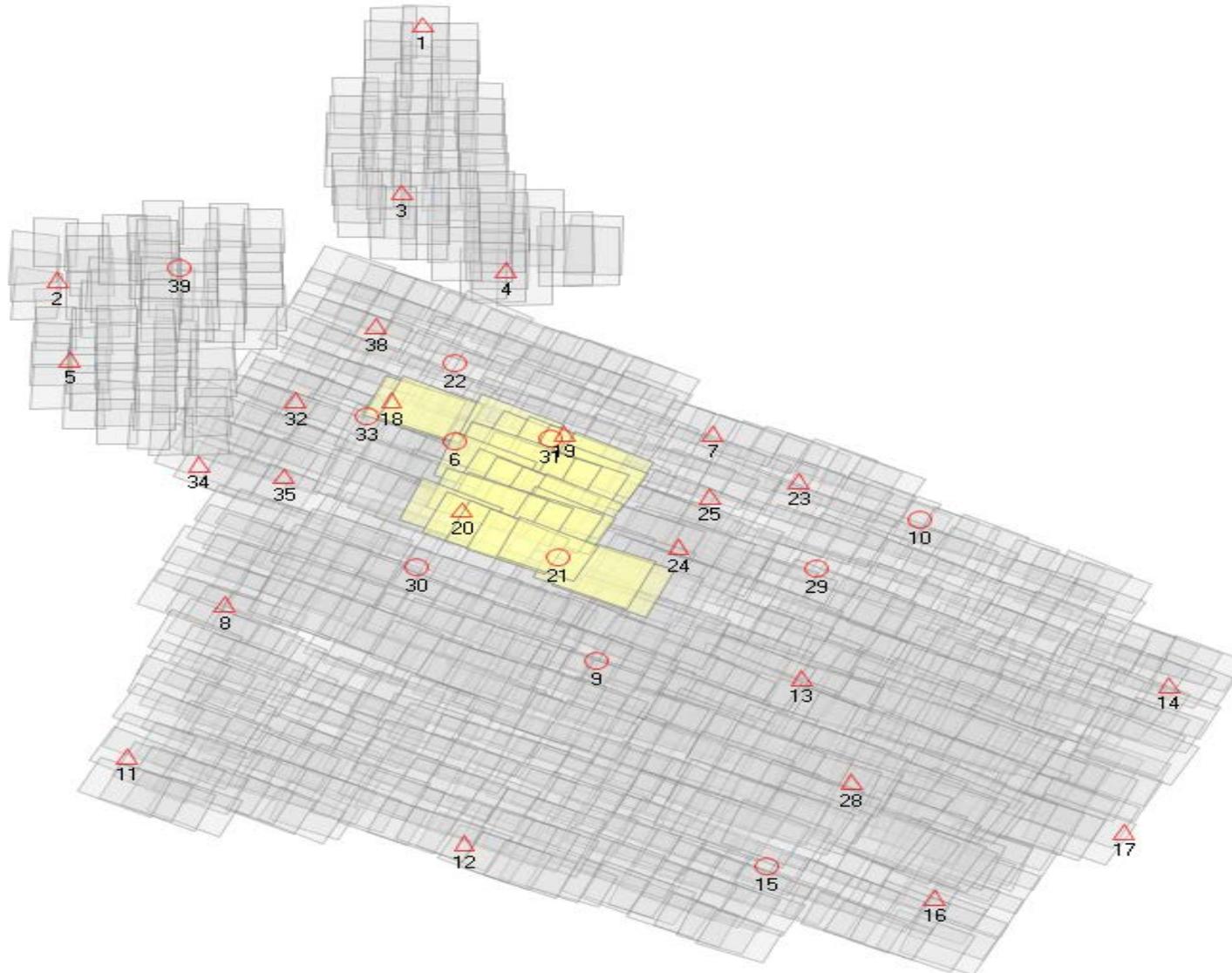
- Model generation: DTM, man-made objects, natural features (trees, etc.)

Photo texture: Roofs, terrain

Tree models



Ground Control Point Distribution



Geo-referencing – with LPS

LPS failed in tie point generation.

Image 505



Self – developed tie point generator:

Sift + Ransac algorithm in relative orientation for blunder detection.

Triangulation results with LPS

Check Pt No.	Max ImRes x(pixel)	Max ImRes y(pixel)	ResX(meter)	ResY(meter)	ResZ(meter)
6	0.76	0.29	0.198	0.176	-0.910
9	1.28	1.19	-0.081	0.142	2.074
10	0.68	0.35	0.303	0.113	4.351
15	0.26	1.03	0.005	0.074	0.347
21	1.74	0.25	-0.040	-0.071	0.202
22	3.27	1.96	-0.193	0.120	1.742
29	0.61	0.88	0.136	0.137	-0.346
30	1.48	1.22	-0.099	-0.089	0.189
31	0.38	1.22	-0.076	-0.071	-0.173
33	1.04	1.22	0.104	-0.116	0.113
39	1.09	0.98	0.125	0.109	0.999
Mean			0.035	0.048	0.781
Std			0.143	0.105	1.406
RMSE			0.147	0.115	1.608

Software Packages for Trial



high automation, easy to use, less customized settings.
The mean projection error is 0.11 pixels, gcp residuals are provided but without image point residual of gcp



high automation. Mean projection error in free-network bundle adjustment is 2 pixels. Maximal around 2 meters in check point residual

Customized software from University of Graz^[1]

Oriented 600 images

[1]Towards Fully Automatic Photogrammetric Reconstruction Using Digital Images Taken From UAVs Arnold Irschara, Viktor Kaufmann, Manfred Klopschitz, Horst Bischof, Franz Leberl. Proceedings International Society for Photogrammetry and Remote Sensing Symposium, 100 Years ISPRS - Advancing Remote Sensing Science, 2010

Software Packages for Trial



Support only traditional aerial mapping, but hard to configure our block into strips. Not applicable for our dataset.

Inpho MATCH-AT Failed

Apero Linux open source software developed by (IGN France), Successful in free-network triangulation, obtained 8cm, 6cm,6cm of RMSE in x,y,z direction, information on tie points and object points is not accessible.

Triangulation results of Apero

Check Pt No.	Max ImRes x (pixel)	Max ImRes y (pixel)	ResX(meter)	ResY(mete r)	ResZ(met er)
6	1.89	0.87	0.102	0.066	0.016
9	1.53	0.64	0.004	0.04	0.08
10	1.93	1.46	0.142	0.005	-0.099
15	1.4	1.06	0.142	0.134	-0.014
21	0.74	0.43	-0.009	-0.007	0.006
22	1.98	1.25	0.038	0.057	-0.148
29	1.1	0.53	-0.005	0.039	0.026
30	1.57	0.77	-0.012	-0.024	0.016
31	1.57	0.94	0.05	0.027	-0.026
33	1.6	0.82	0.057	0.052	-0.044
39	2.39	0.79	-0.108	0.122	-0.061
Mean			0.061	0.052	0.049
Std			0.057	0.036	0.048
RMSE			0.080	0.066	0.065

Multi-sensor data

- (1) Vertical aerial UAV images at 5 cm footprint
- (2) Oblique UAV images (in planning)
- (3) Raw point clouds from MMS
- (4) Terrestrial images from off-the-shelf cameras
- (5) Ground Control Points (GCPs)
- (6) Existing data (maps)

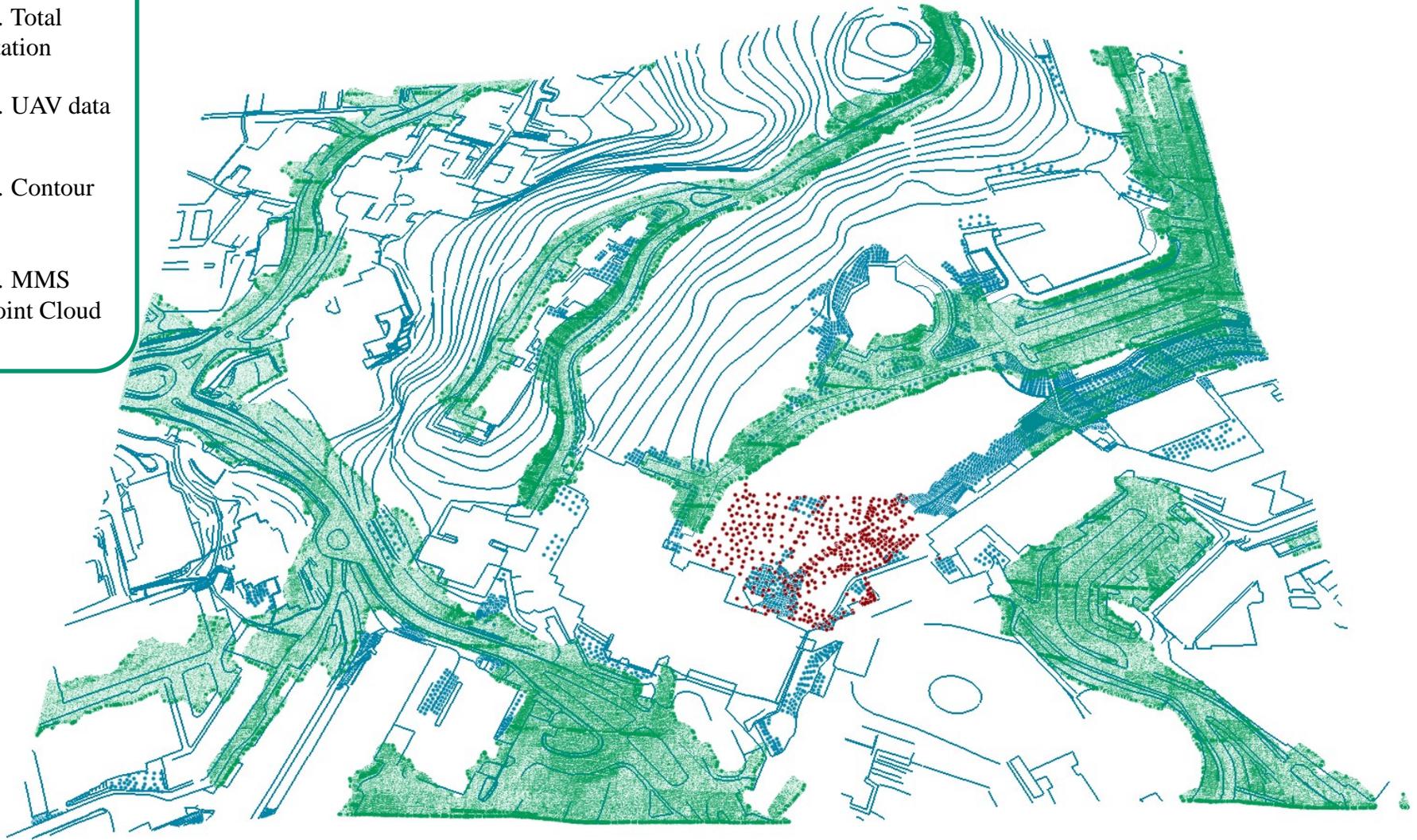
Output

3D hybrid site model, achieved by integration of these input data

DTM from multiple sources

Legend

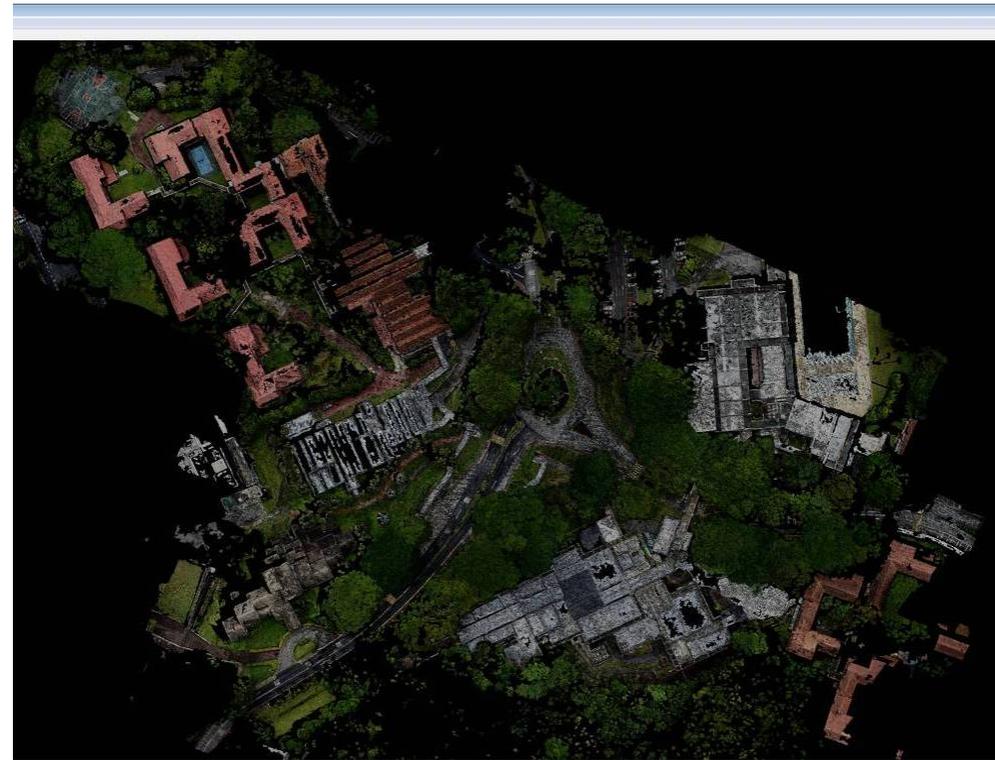
- ... Total Station
- ... UAV data
- ~ ... Contour
- ... MMS Point Cloud



Object measurement strategy

- **Buildings/roof-landscape** : Cyber City Modeler: semi-automatic procedure
- **Facades**: 3ds Max, manual modeling from point cloud
- **DTM**- manual measurement: Profiles + break-lines, combining with mobile LiDAR data for area under plant canopy and contours from older maps
- **Vegetation**: Parametric measurements: one point on tree top, tree diameter.
Use of plant pre-defined model (2000 trees).
- **Light poles** (>900): Similar approach
- **Texture**: Self-developed software for roof texturing.

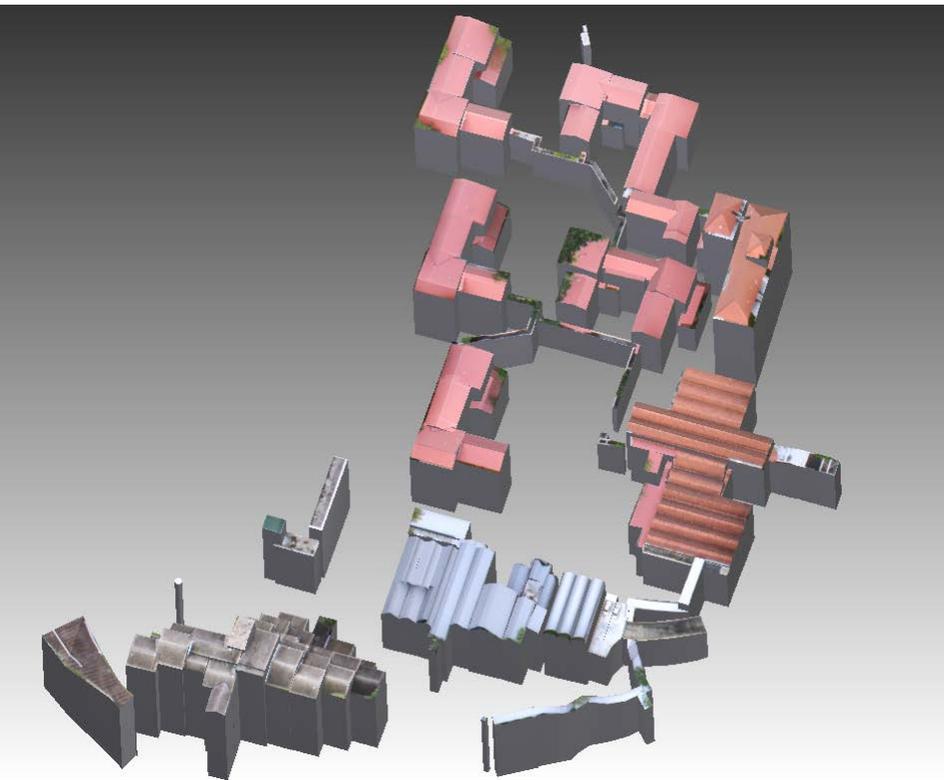
NUS test area point cloud (SURE)



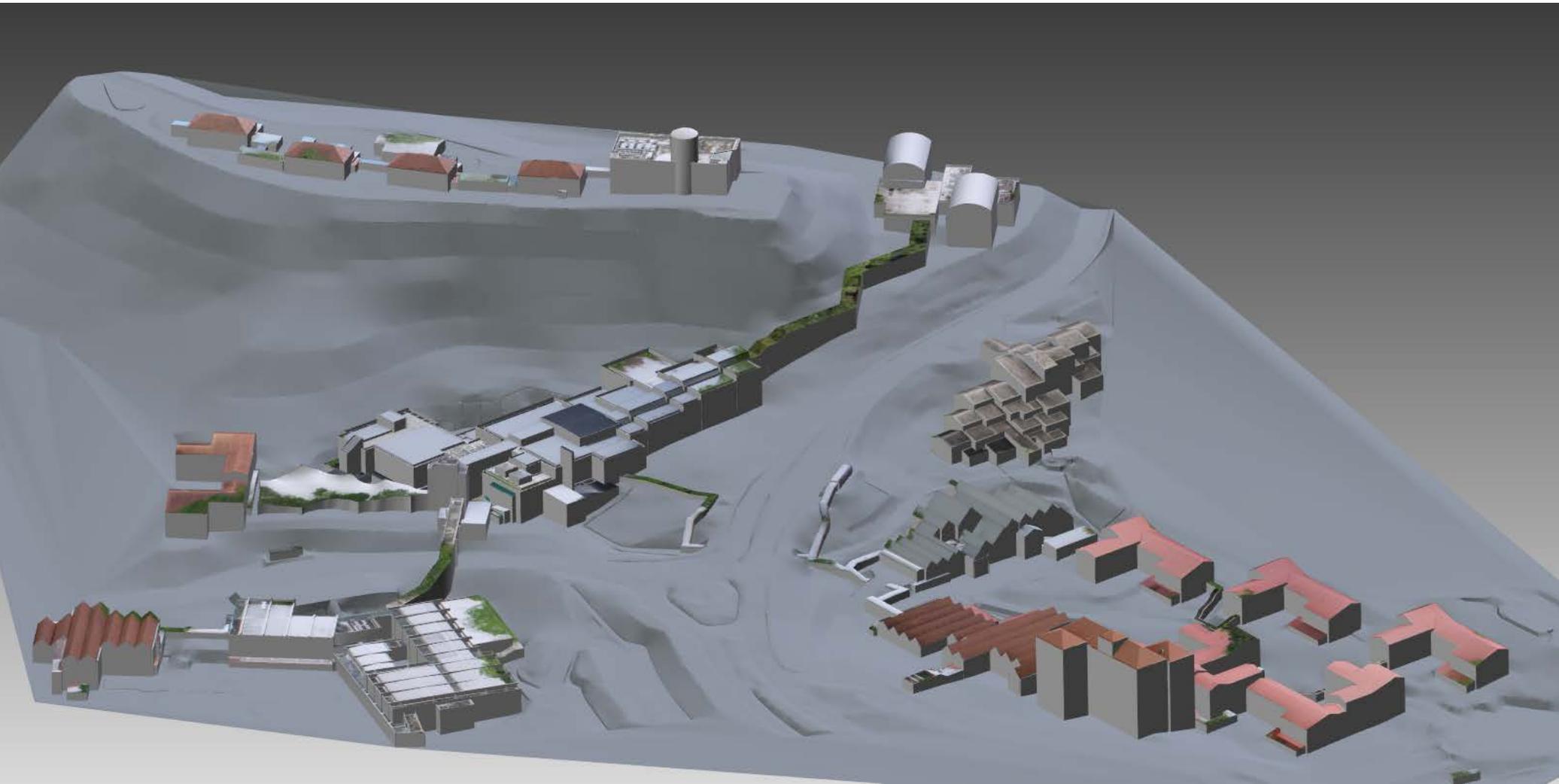
Problem: Model content definition



NUS Campus



NUS Campus



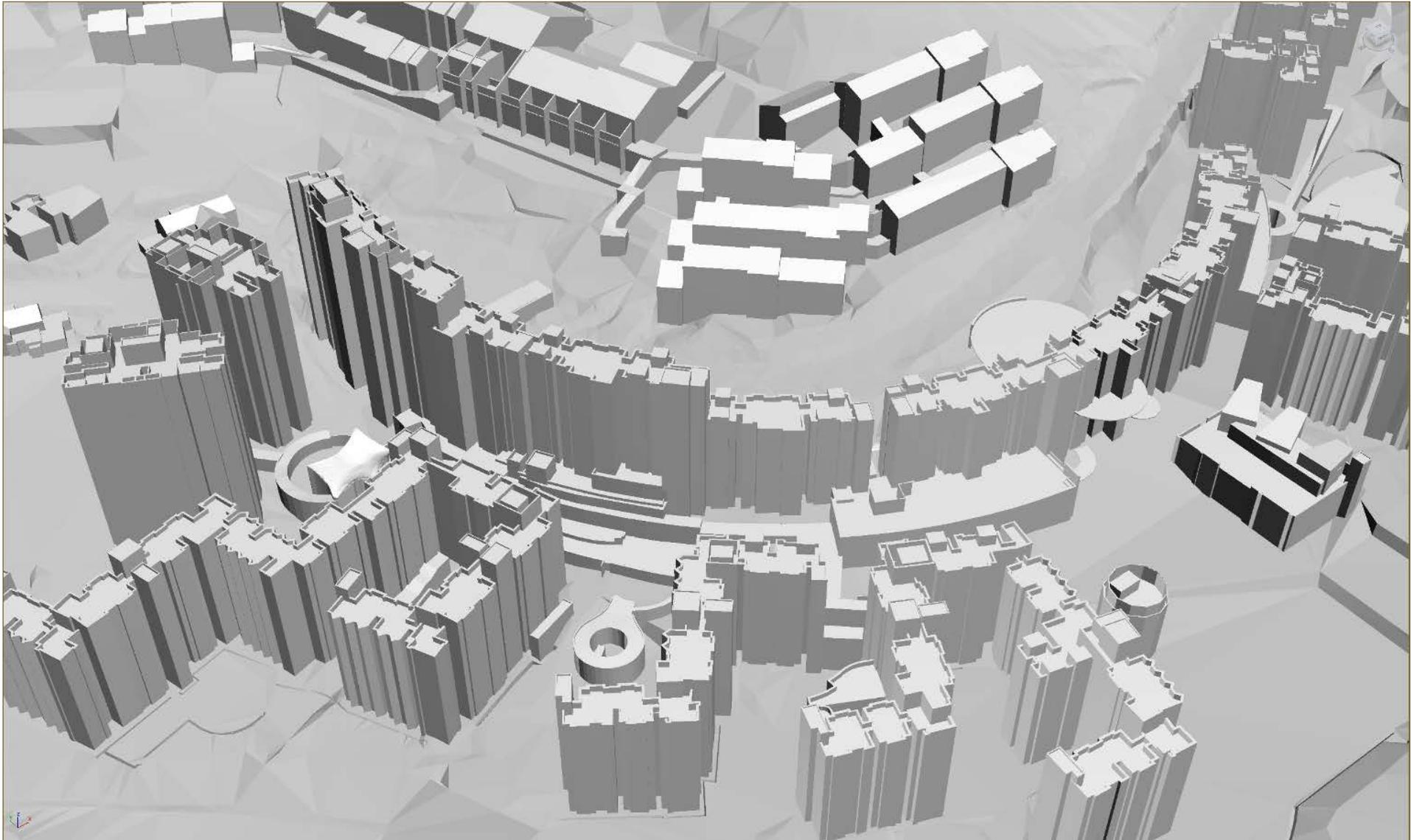
NUS Campus



NUS Campus

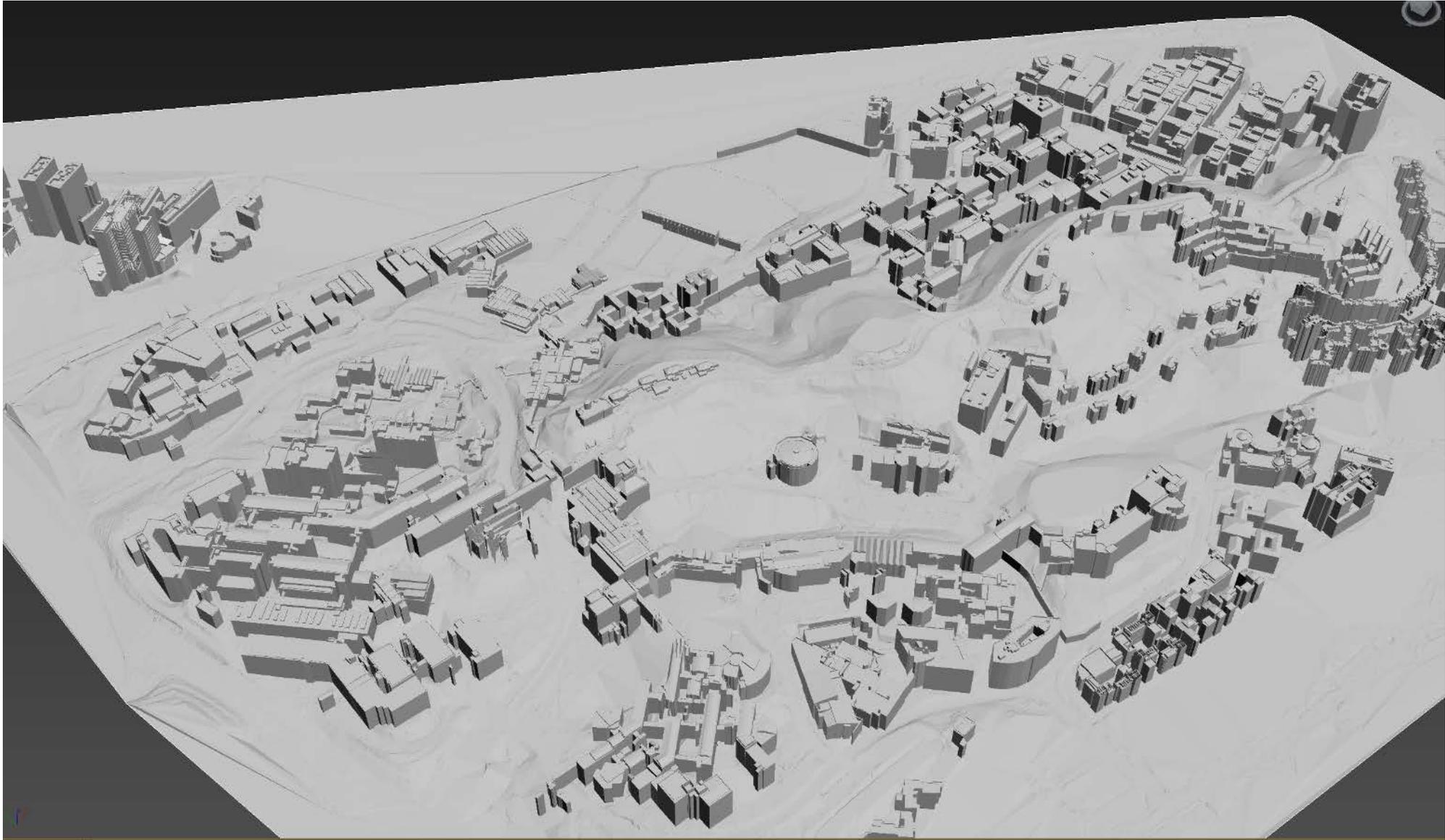


NUS Campus: Model resolution



NUS Campus: Overview

 Flyover geometry



NUS University Town



Flood modeling for Singapore

**The Straits Times
Published on Jan 14,
2012**

Elevation map that can help fight flooding may cost up to \$125m
Data from such mapping can be used in a computer model to predict floods, experts say
By Feng Zengkun

The Straits Times, 21 Jan 2012.



JakartaGlobe
Your City. Your World.

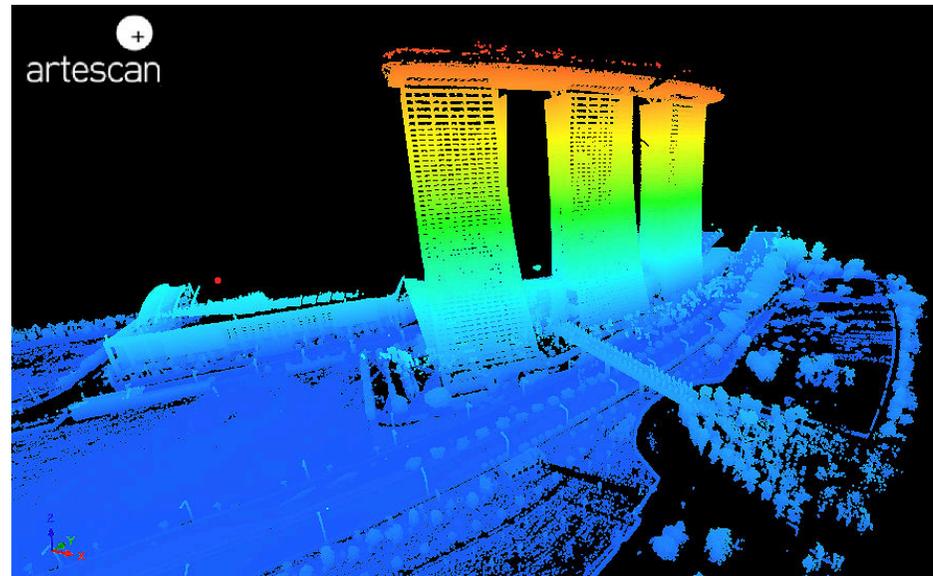
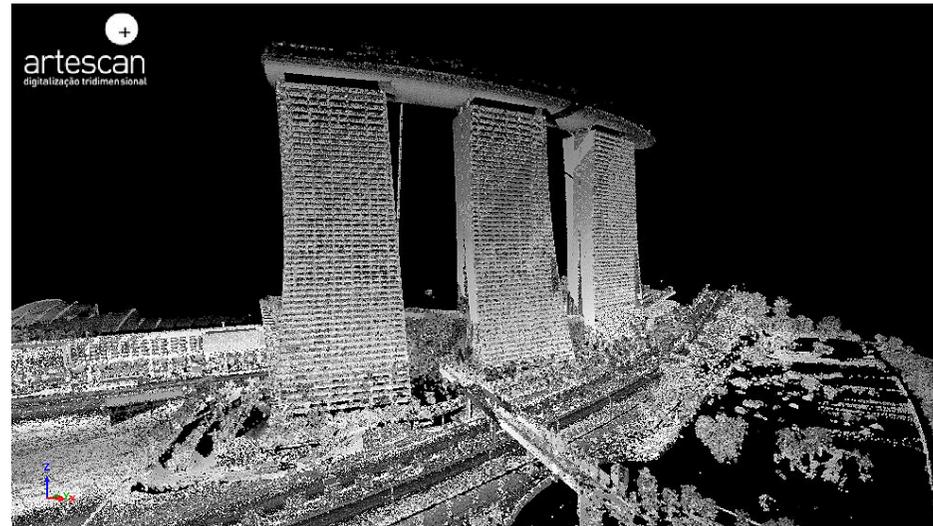
Better Model to Predict Floods Likely in Singapore
Feng Zengkun - Straits Times Indonesia | January 21, 2012

National water agency PUB could be using a better flood-prediction computer model in the near future.

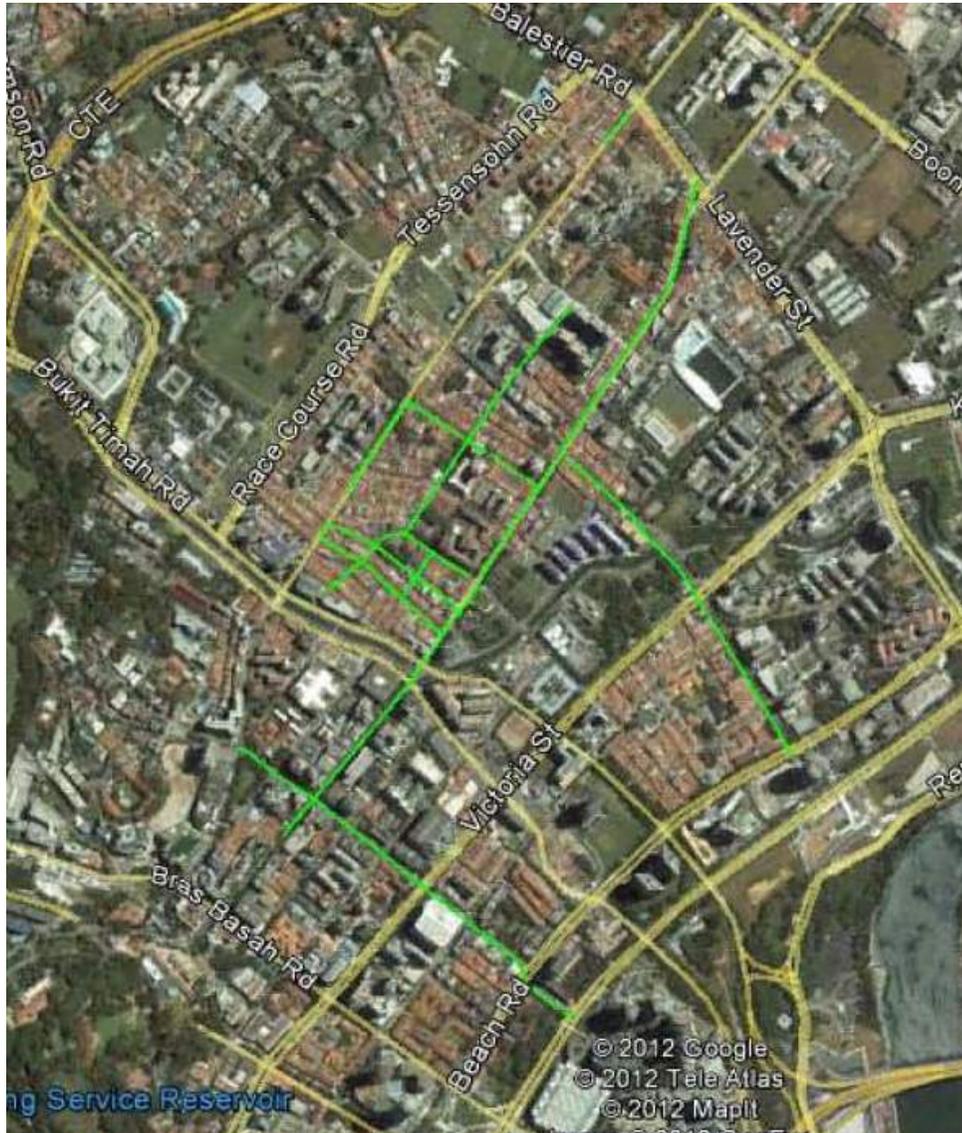
It will include a 3-D land-height map of just the Marina catchment area for a start, to predict the direction in which rainwater will flow at ground level during storms, and where flooding might occur.

Such a map, which the PUB has commissioned, will depict land height in that area to within 10cm accuracy.

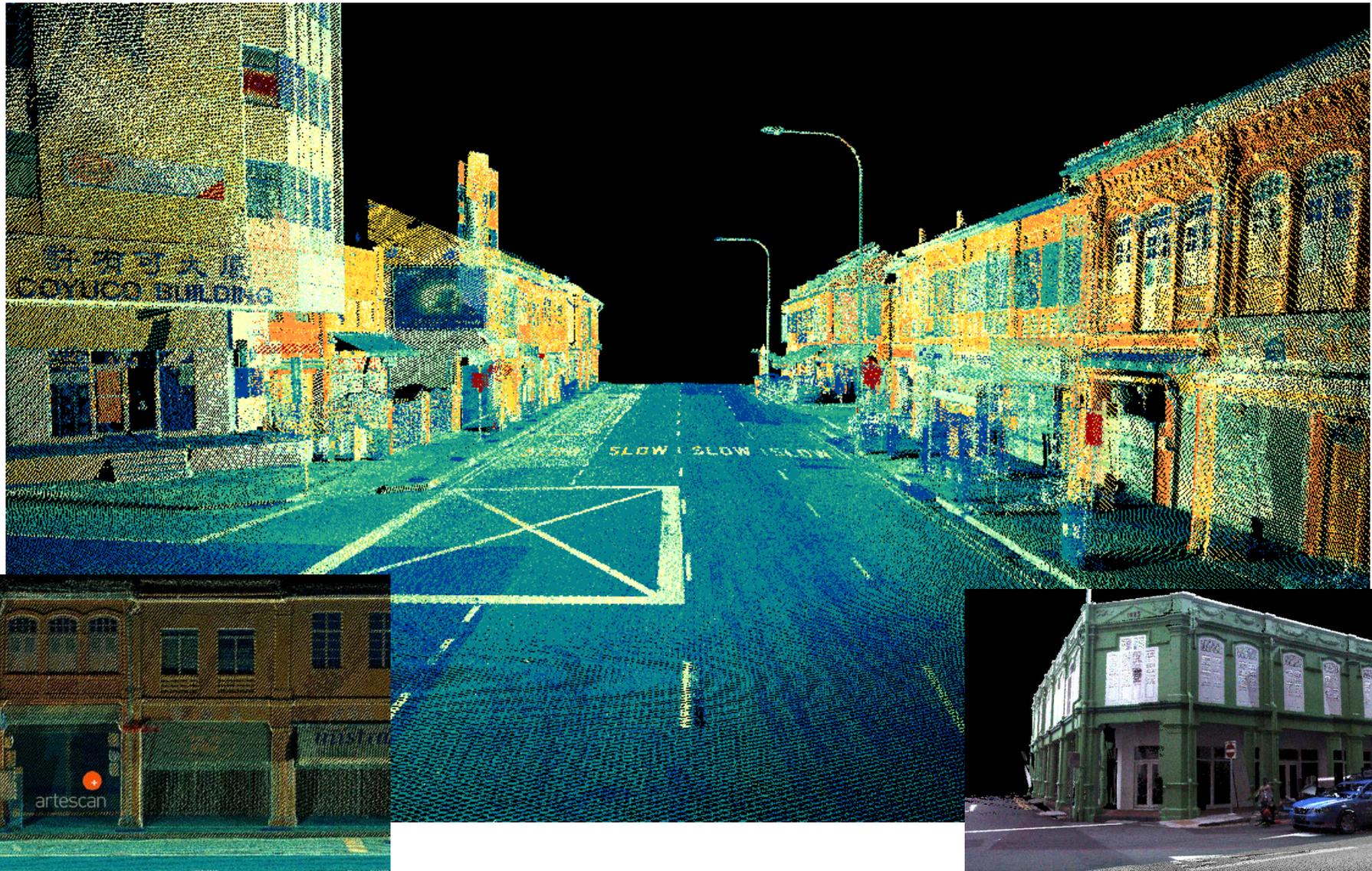
Singapore Mobile Mapping (flood simulation)



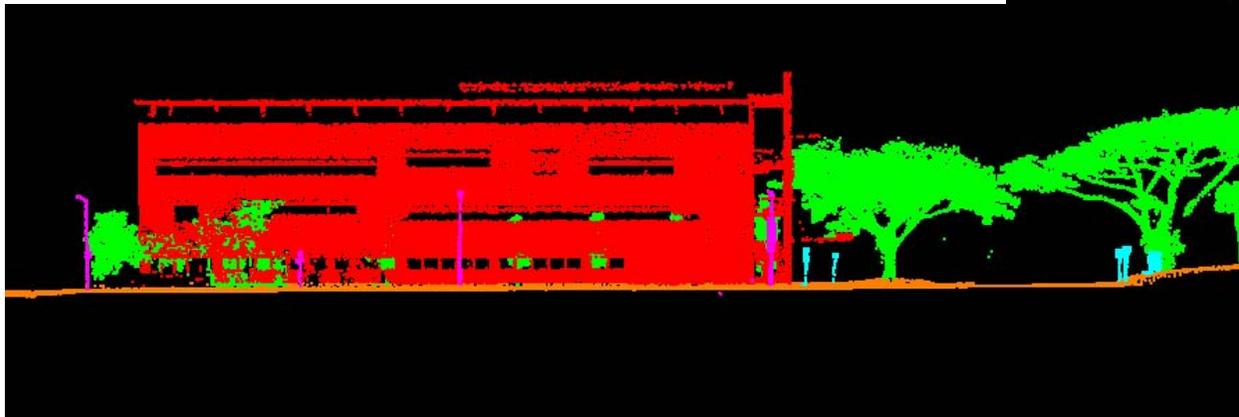
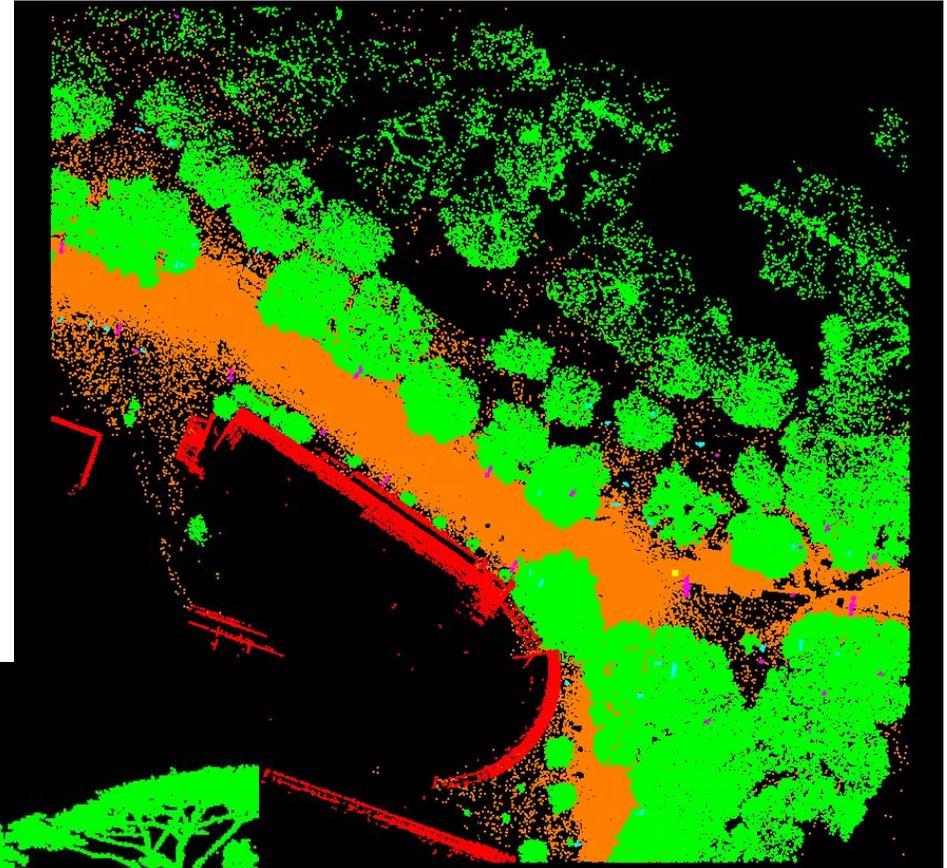
Mobile Mapping Little India – selected roads



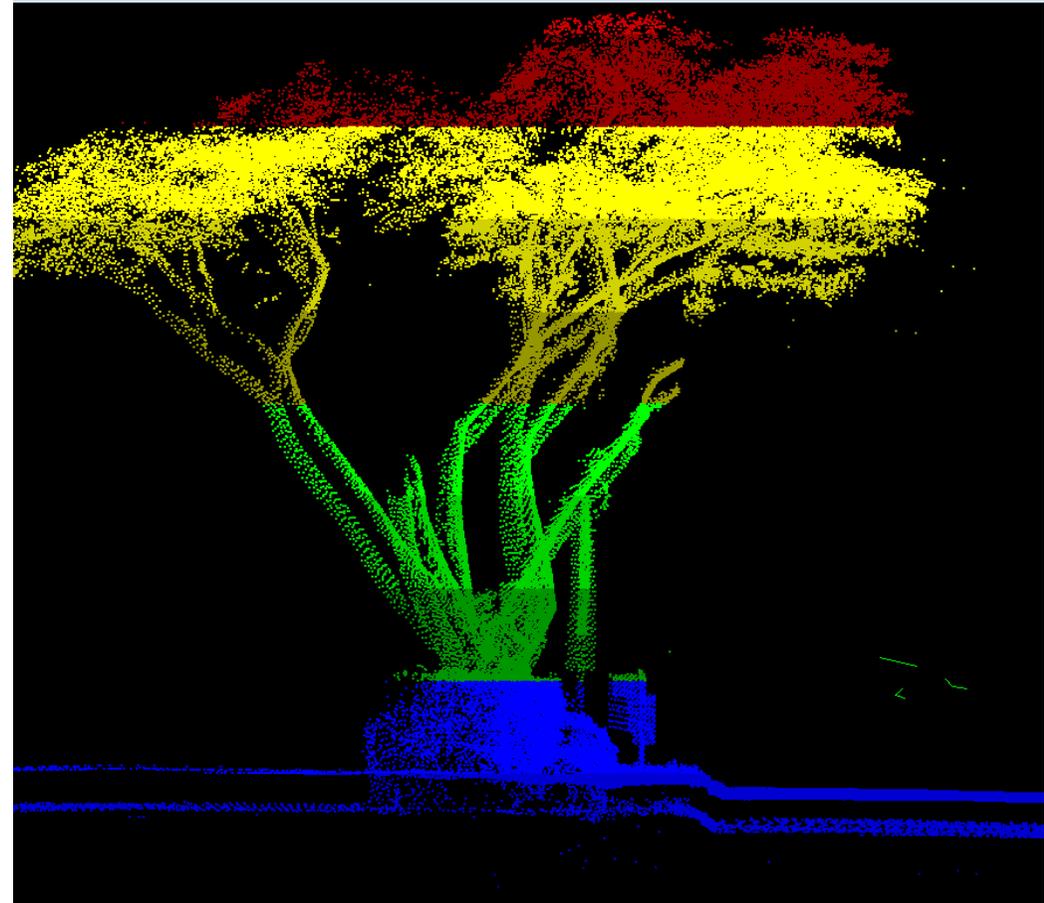
Mobile Mapping Little India – colored point cloud



NUS pointcloud classification



Errors due to loss of GPS signal

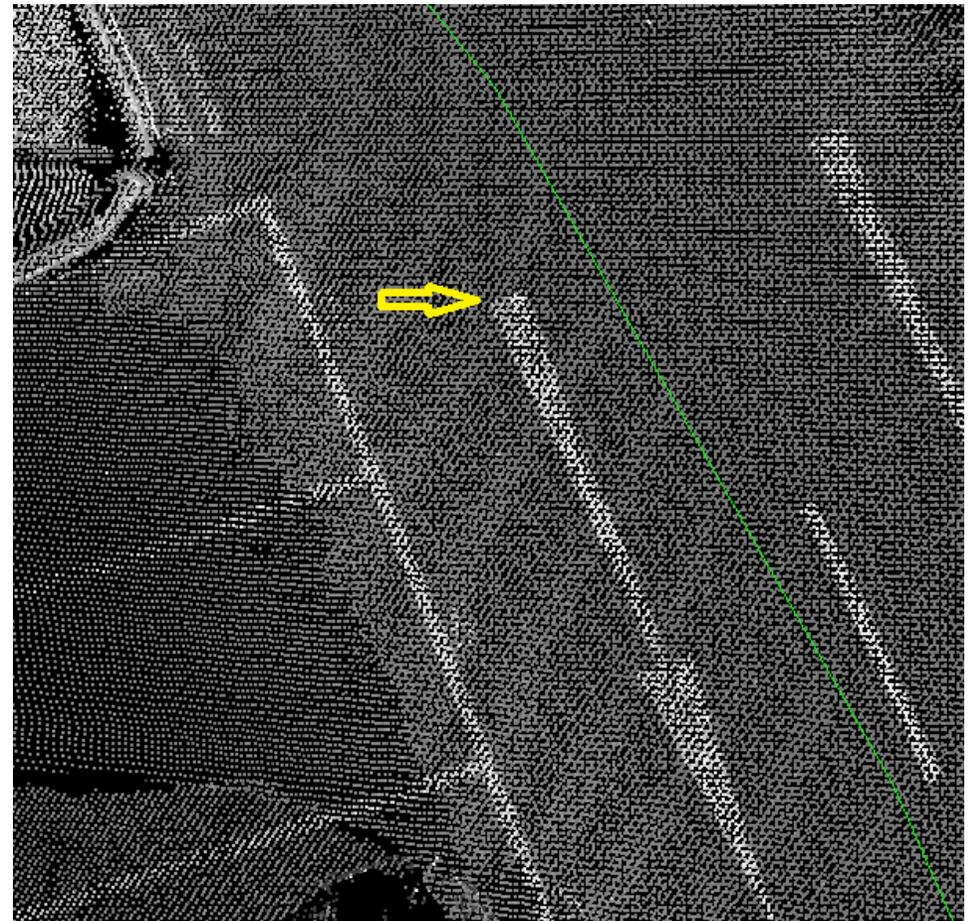


Cross-section

Control point selection

169 points measured manually in UAV stereos

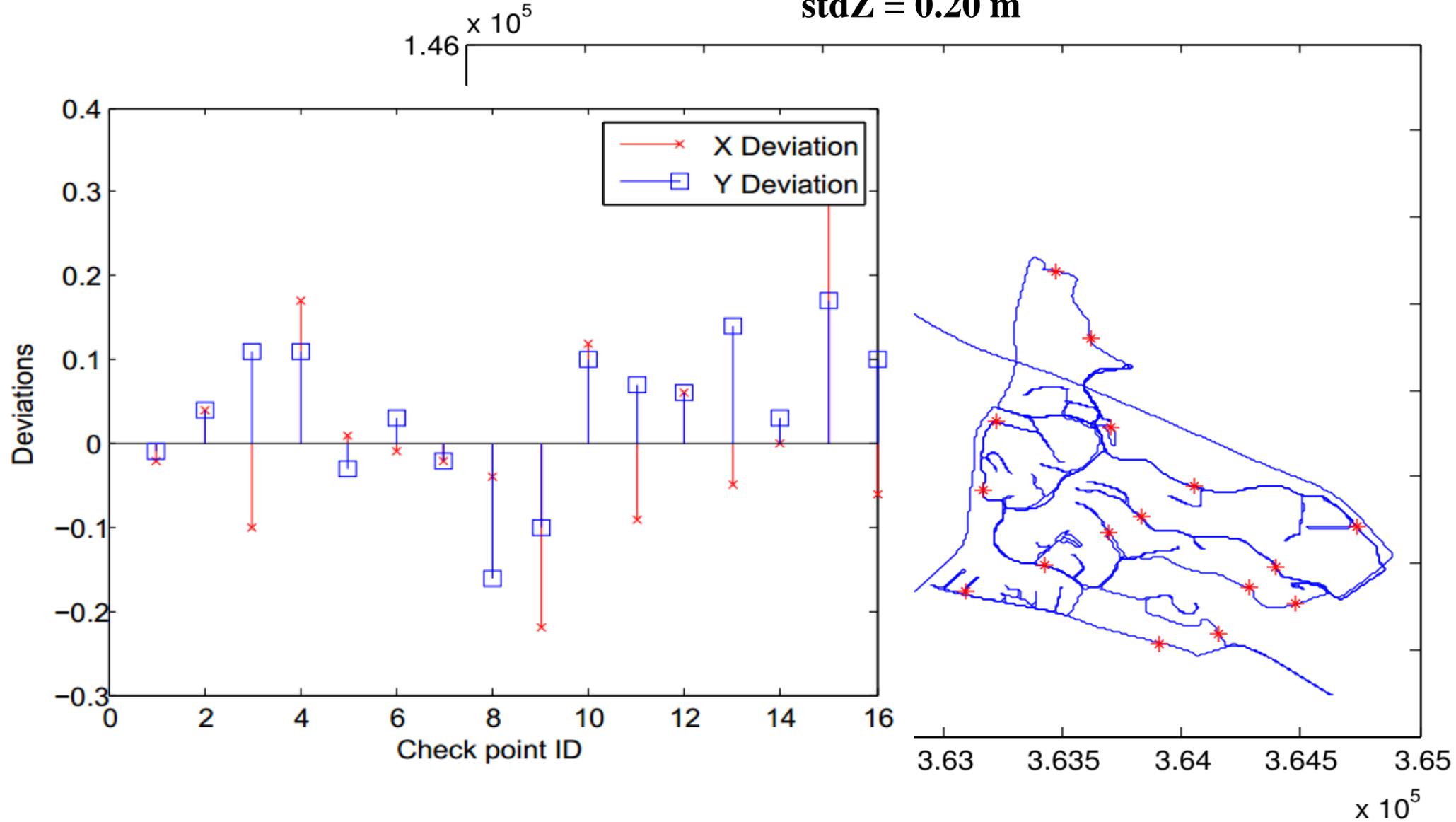
Accuracy $< 1\text{pi}$



Check point distribution

stdX = 0.12m stdY = 0.09m

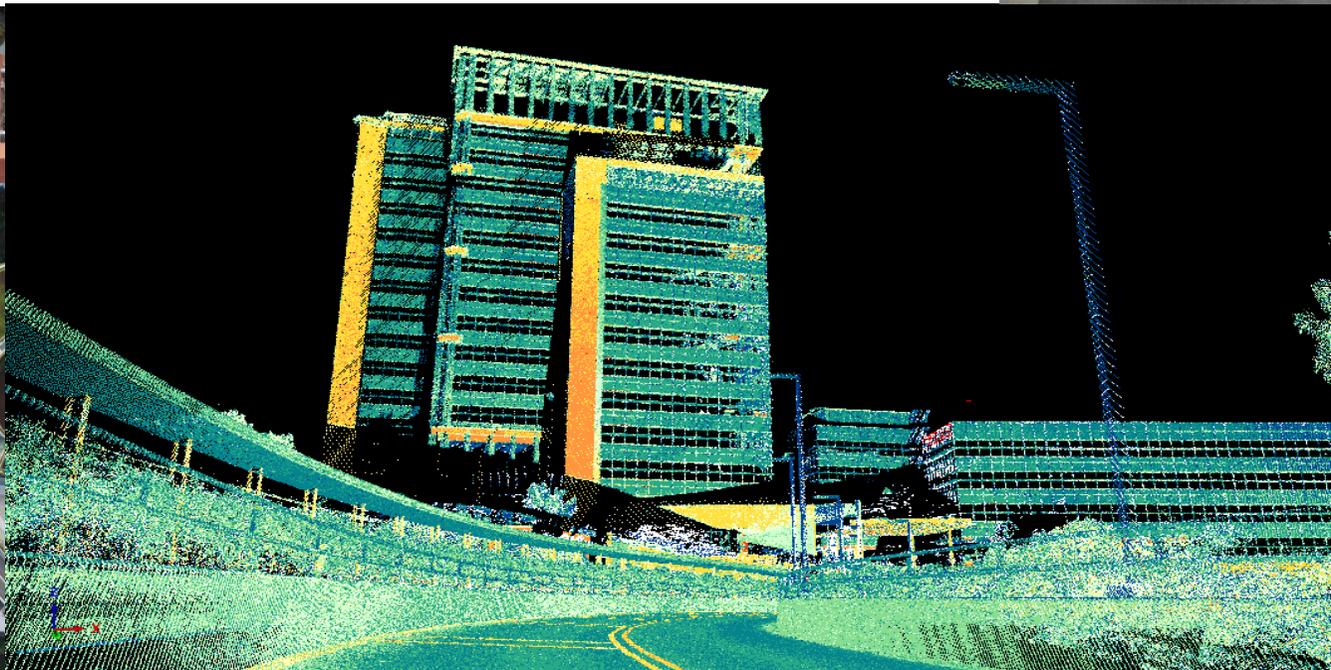
stdZ = 0.20 m



NUS (CREATE) building reconstruction raw data

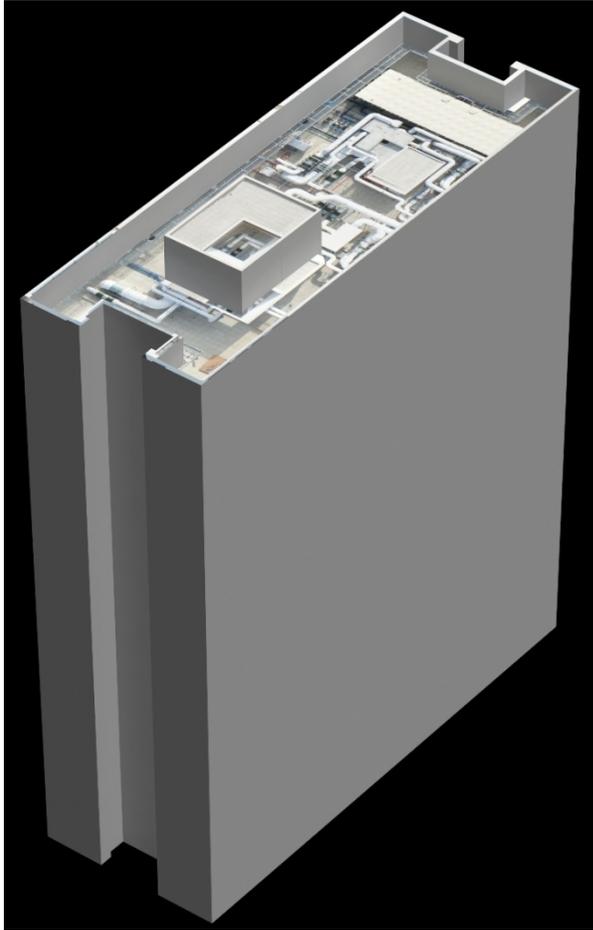
UAV images

MMS laserscans

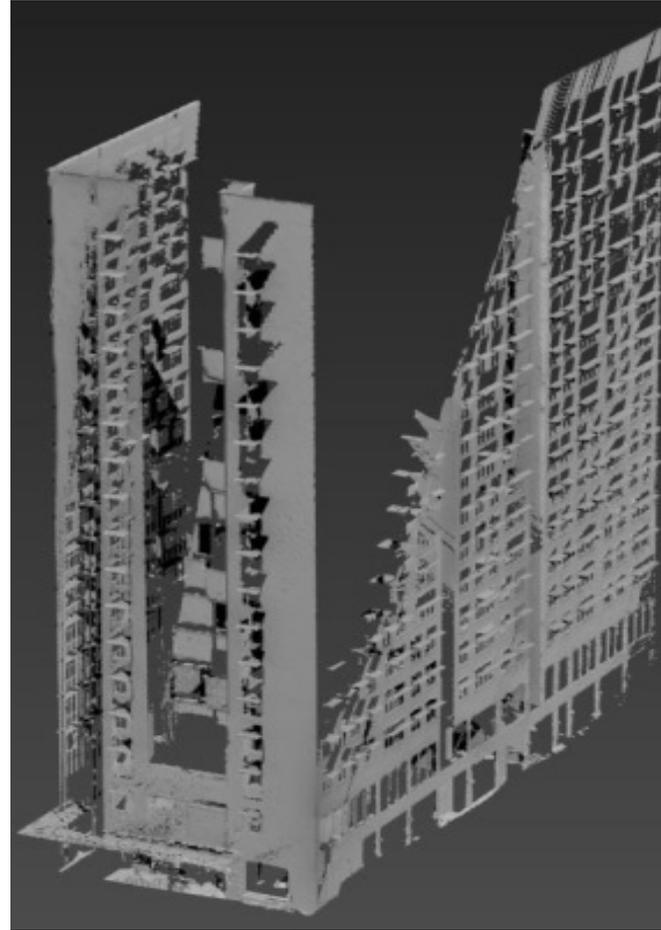


NUS building reconstruction

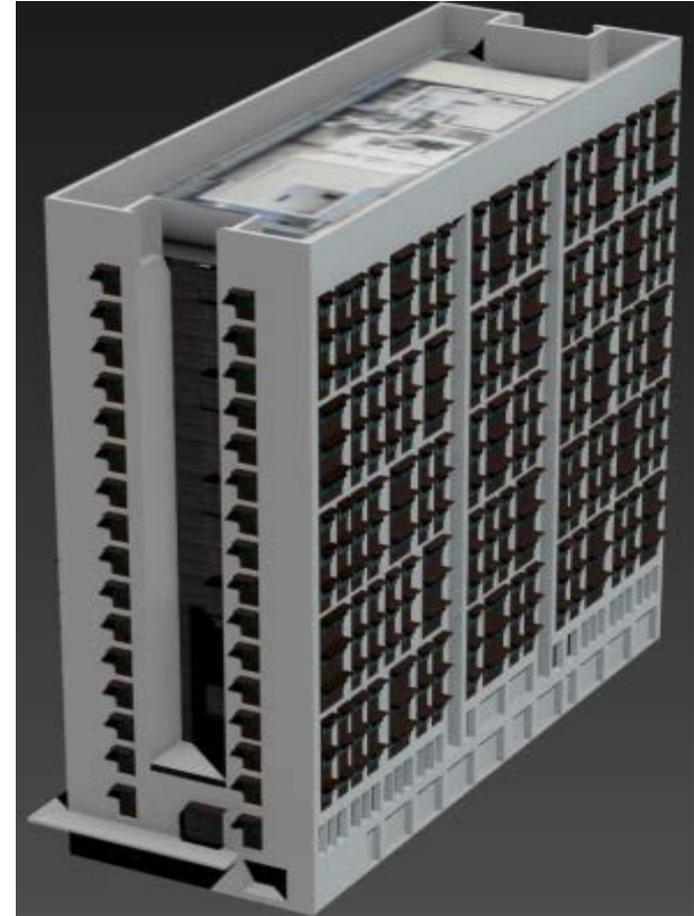
UAV images and MMS laserscans



Roof from UAV images



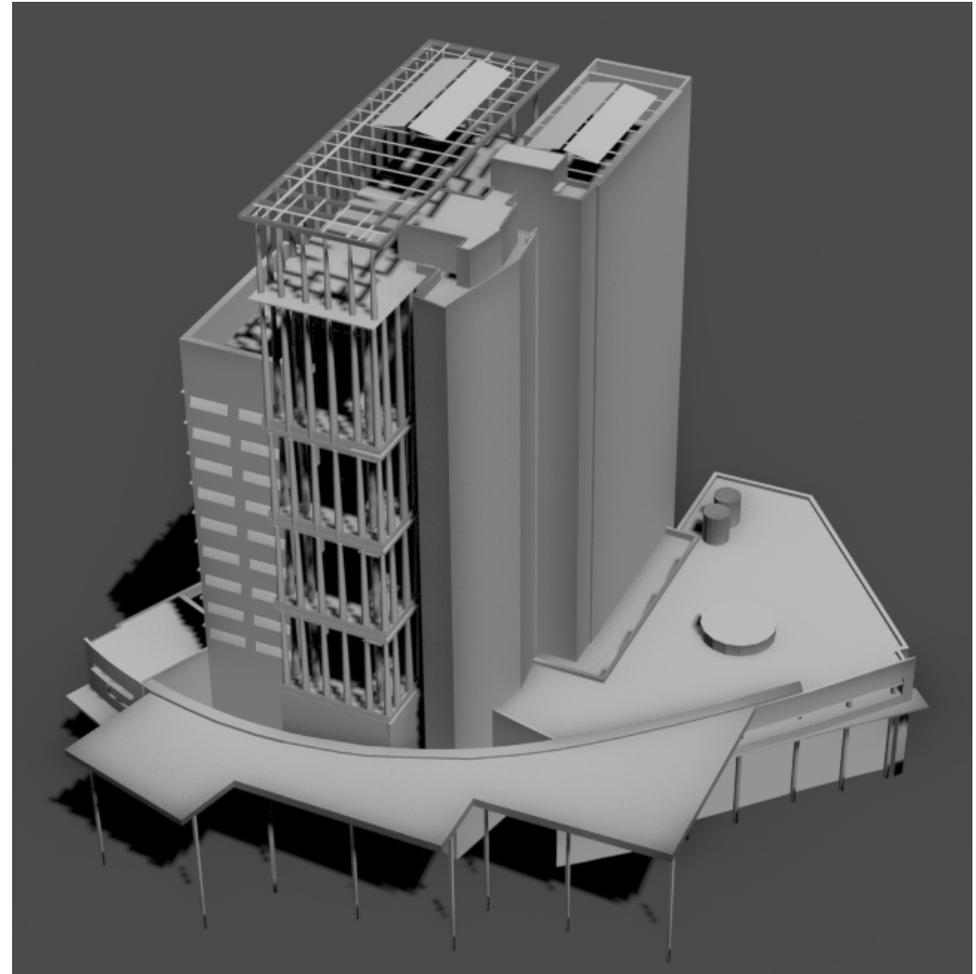
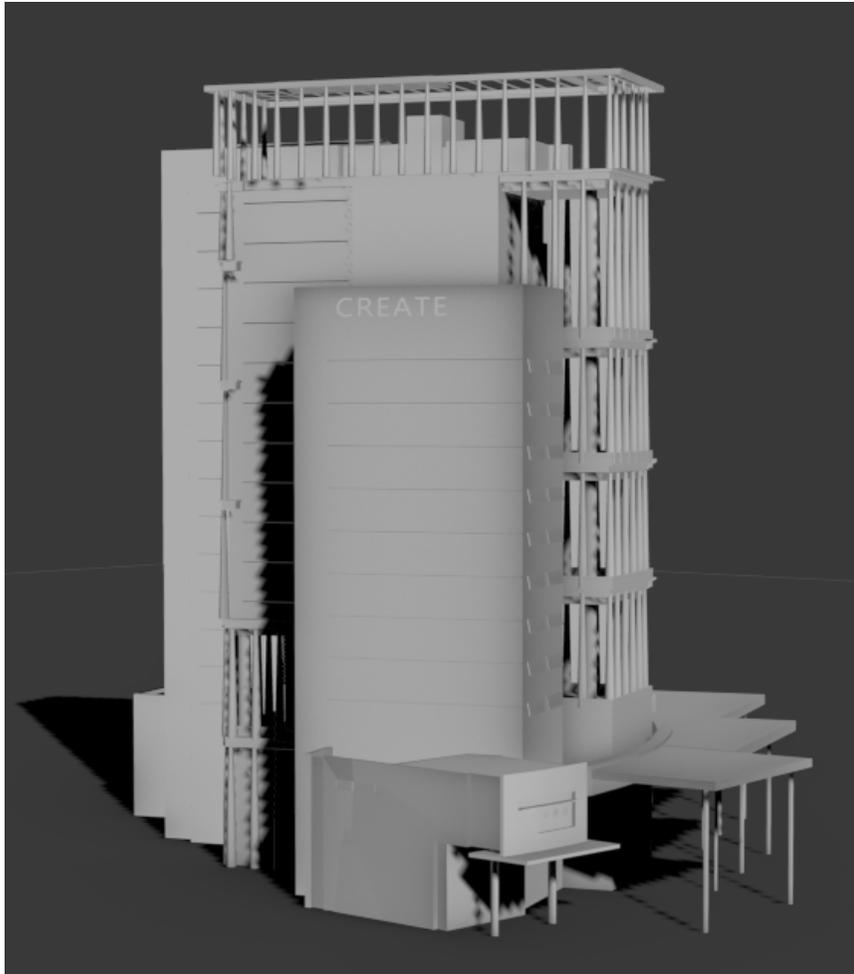
Wrapped point cloud



Complete Model

NUS (CREATE) building reconstruction

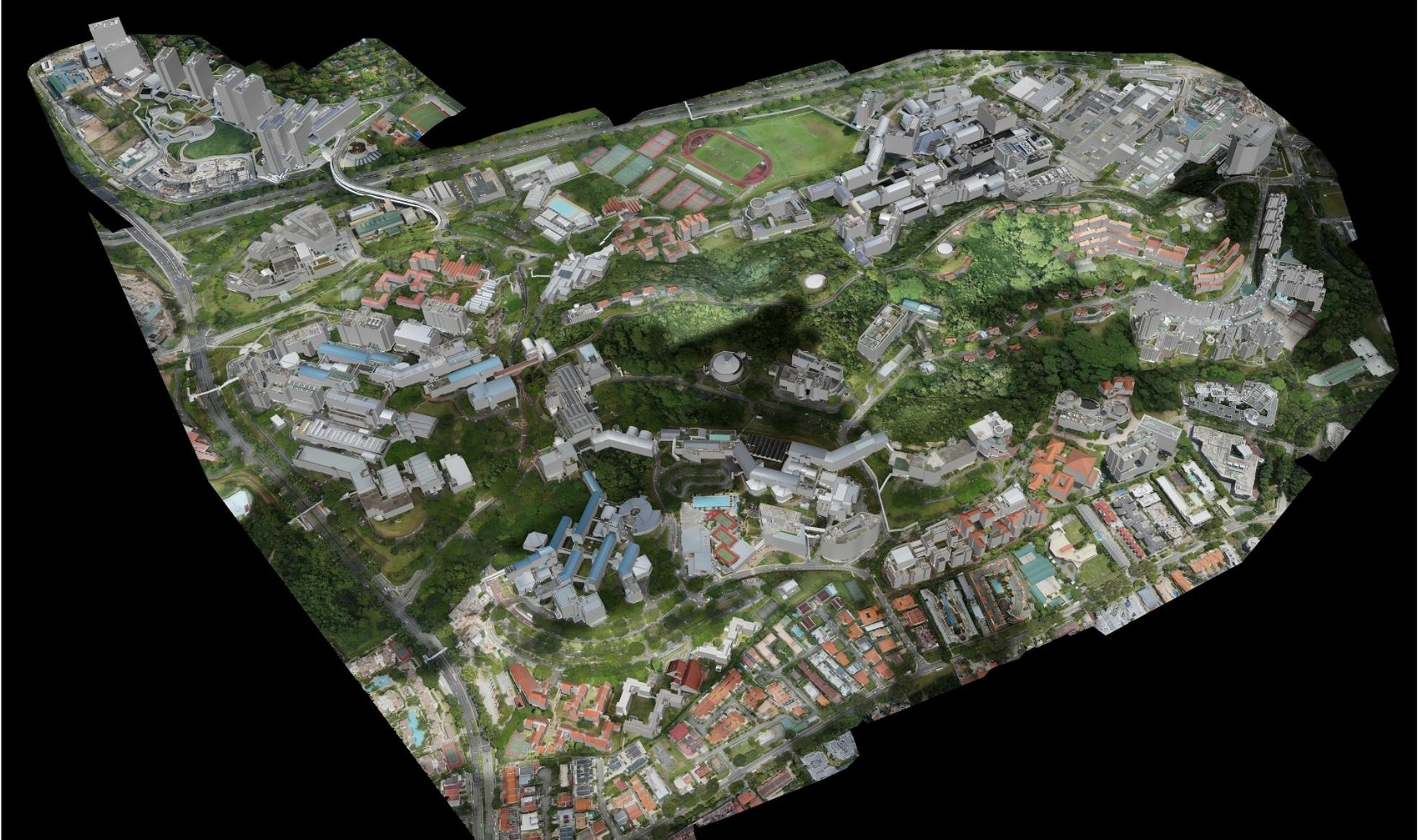
UAV images and MMS laserscans



CREATE building

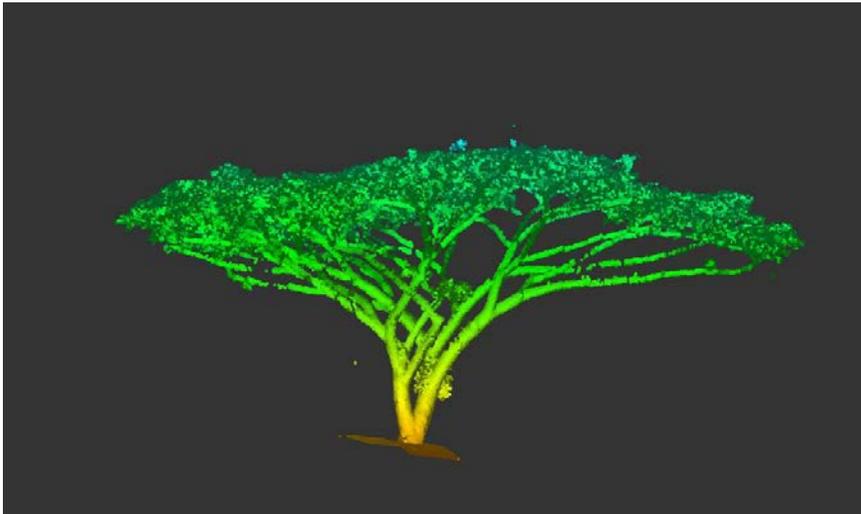


NUS model - overview



Tree modeling from terrestrial laser-scans

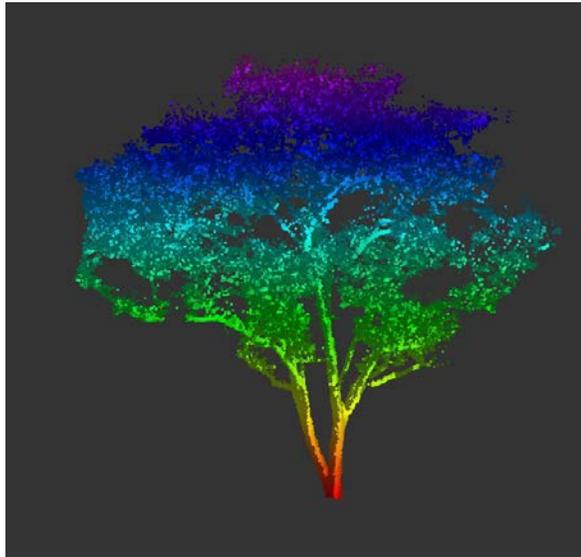
Rain Tree



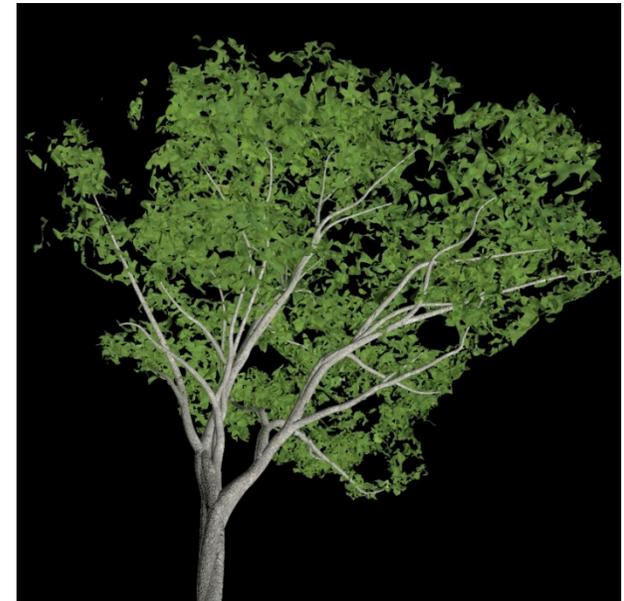
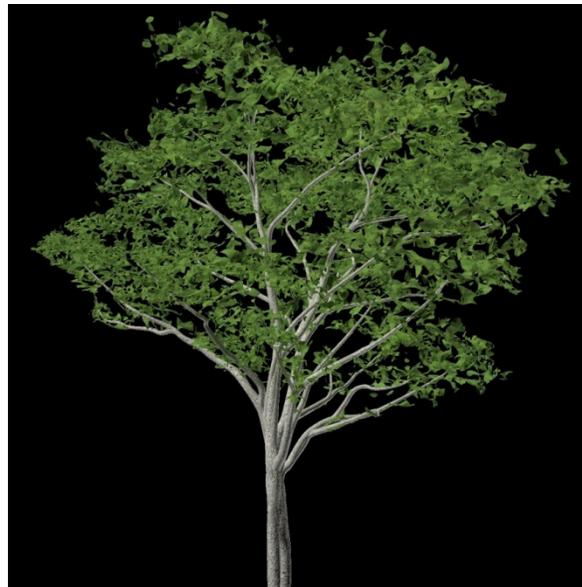
1. *Pointools Edit*. Separate point cloud of a tree from the whole scene
2. *Geomagic Studio*. Wrap the tree points into triangular mesh
3. *3ds Max*. Draw spline lines manually along the stems: skeleton of the tree
4. *3ds Max*. Generate columns along the spline lines using the tool “loft”
5. *3ds Max*. Texture the loft as stems and the loft triangles as canopy, using images captured in the field.



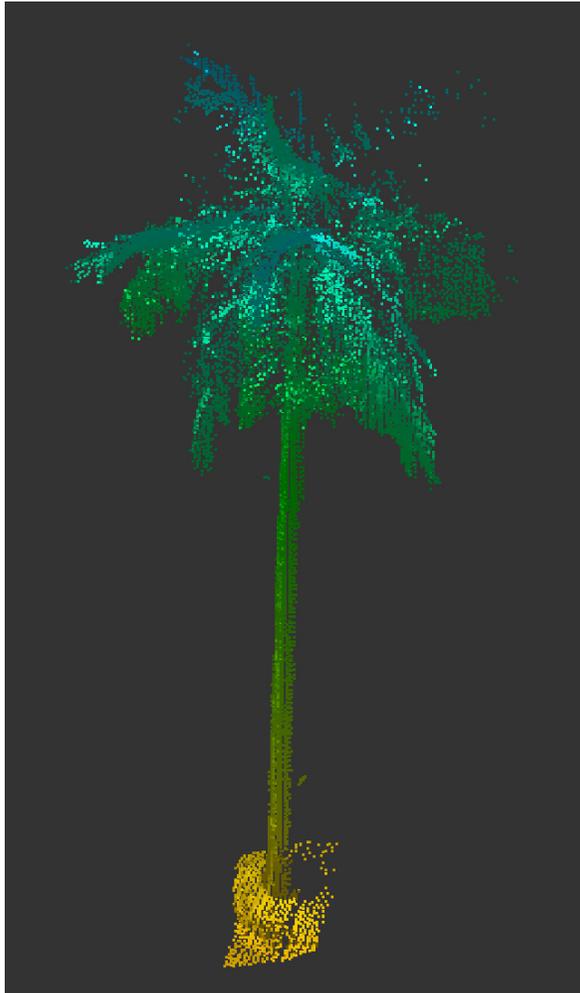
Tree modeling from terrestrial laser-scans



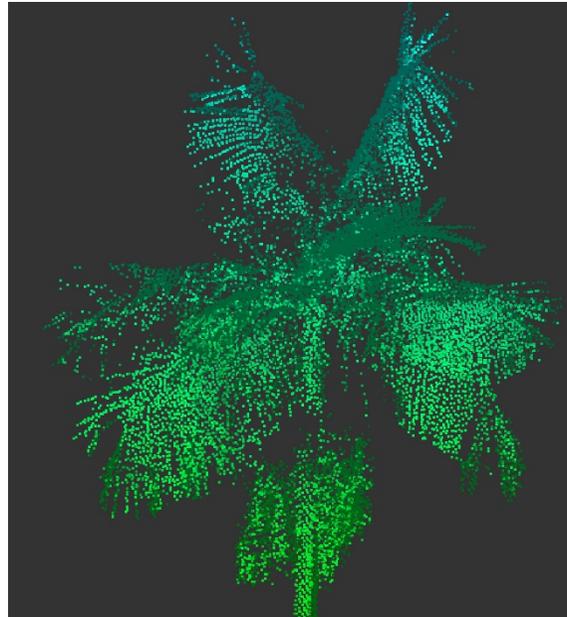
Tree A



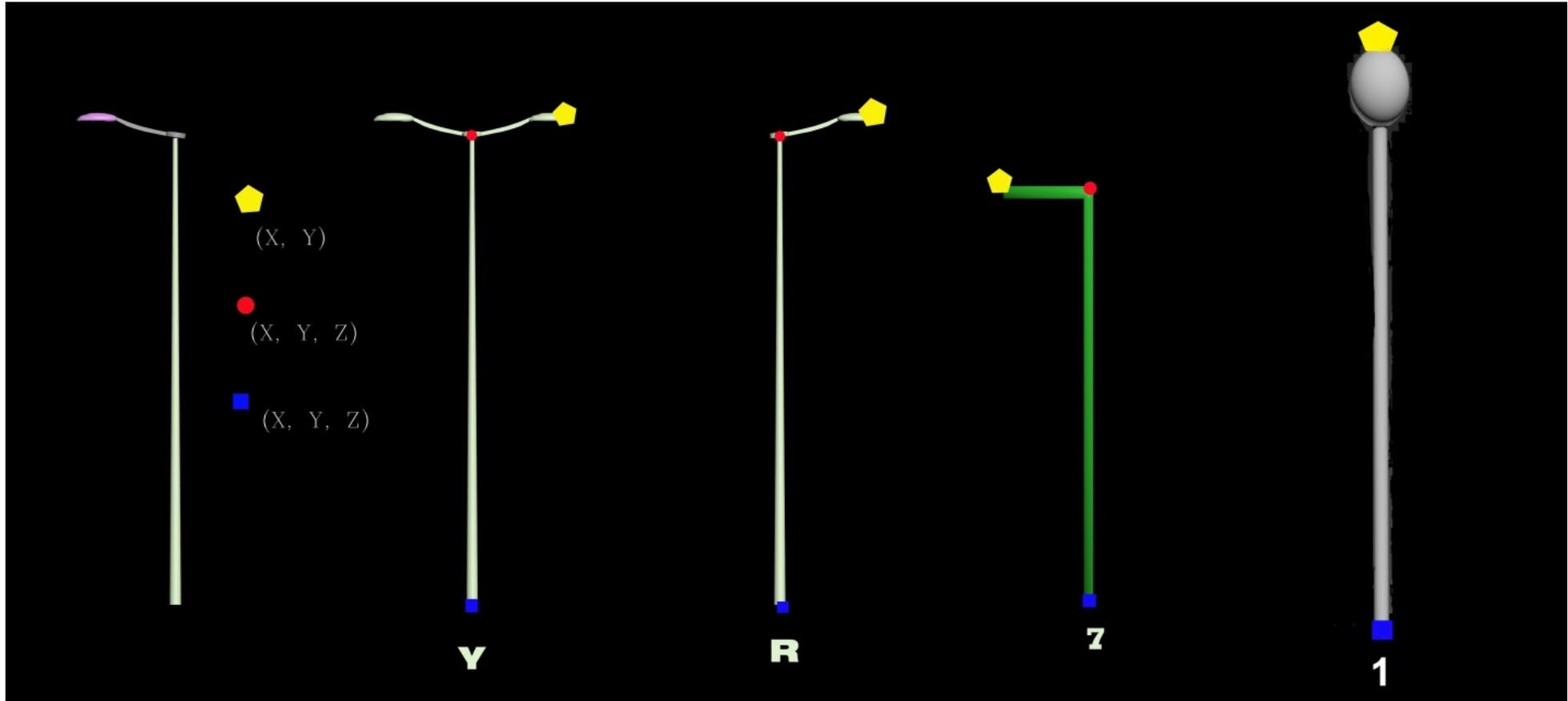
Tree modeling from terrestrial laser-scans



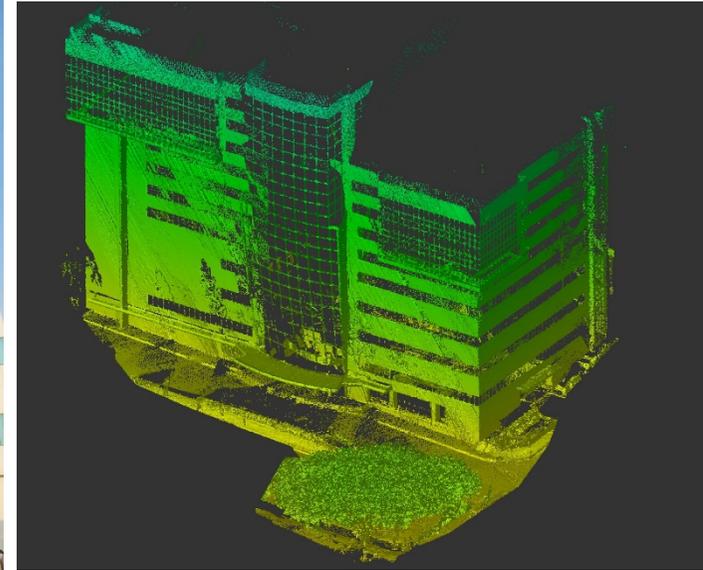
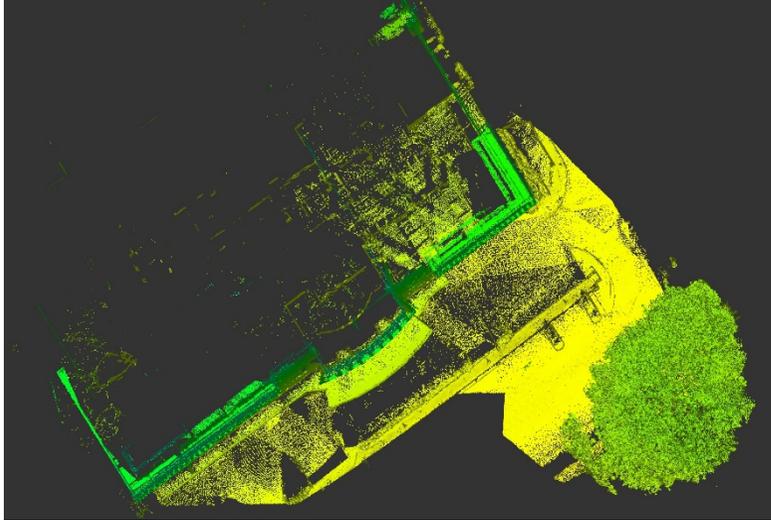
Palm tree



Light pole models (900)



T-Lab building



GIS integration

The screenshot displays the ArcScene interface with a 3D city model. The 'Table of Contents' on the left shows layers for 'Singapore Roads' and 'NUS Building Models'. A cyan selection box highlights a building in the 3D view. The 'Identify Results' window shows the following data:

Field	Value
Location:	(363808.604792 142870.677082)
FID	33420
Shape	Point
name	KWIX PTE. LTD.
rno	201306841K
streetno	62
street	21 HENG MUI KENG TERRACE
postcd	119613
ctg	COMPUTER PROGRAMMING, CONSULTANCY AND REL
indcd	INFORMATION AND COMMUNICATIONS

Below the identify results, a data table is visible:

me	rno	streetno	street	postcd	
	201010588D	62	111 NORTH BRIDGE ROAD	179098	COMPUTER PROGRAMMING, CO
	53220280E	47	365 SERANGOON ROAD	218117	RETAIL TRADE
	T12LL2092F	55	127 TYRWHITT ROAD	207551	ACCOMMODATION
	53220203A	47	681 RACE COURSE ROAD	210681	RETAIL TRADE

The 'Catalog' on the right shows a folder structure for 'nus' with various data files like 'Obj_Files', 'Resized04.mdb', 'bizinven.shp', 'nus-building-height.tif', 'nus_img_18.jpg', and 'singapore' sub-folder containing 'bldgelev', 'onemap', and 'SDpremium' sub-folders with various shapefiles.

At the bottom, the status bar shows '0 features selected' and 'NUS Building Models poi'.

Potential UAV projects in Singapore (Gov. Agencies)

National Environment Agency (NEA):

- Real-time detection and tracking of oil spills
- Detection of water pools where Dengue fever mosquitos reside
- Micro-climate modeling, city hot spots

Urban Redevelopment Authority (URA):

- Building and tree (vegetation) models for smart city management

Public Utilities Board (PUB):

- DSM generation for flood modeling. Generation of 3D façade models for water entrance analysis

Singapore Land Authority (SLA):

- Base map data in 3D and benchmark for new 3D consortium. Modeling of change with street images

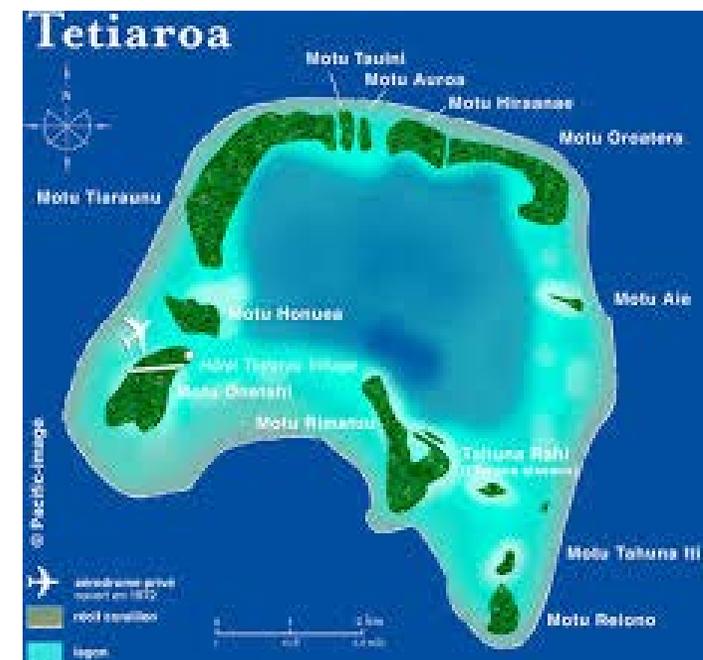
Port Singapore Authority (PSA):

- Inspection of cranes for corrosion and deformation analysis

Moorea IDEA – Island Avatar, incl. Tetiaroa

Material:

- + Existing data (maps, statistical, social, etc.)
- + Highres satellite images, Aerial images
- + UAV images (?), LiDAR (?)
- + Bathymetric data (reef)
- + GIS platform
- + Visualization/animation



Conclusions

- + Model helicopters are very flexible devices for recording (cameras, orientation, navigation, real-time capabilities)
- + Cost-efficient
- + Many diverse applications, if area is not too large

But:

- + **Technology (system hard- and software) not mature**
- + **Operational processing of hybrid data not available yet**
- + **Much room for improvement of data processing methods**
- + **Flight permissions, safety concerns**

