DERIVING FIRST FLOOR ELEVATIONS WITHIN RESIDENTIAL COMMUNITIES LOCATED IN GALVESTON USING RTK-UAS BASED DATA

Presented by: Nicholas D. Diaz

Coastal and hazard planners rely on spatial and elevational datasets across multiple scales to fulfill geometric practices (GIS based products, or mapping), scenario planning, and mitigation and adaptation strategies. 1,14,15,20

Capturing ‘hard-to-get’ FFEs as a specialized dataset can further parameterize flood modeling at the local level.

Available large-scale datasets for FFEs are generally not available.

Ball-park estimates make damage assessments at smaller scales difficult.

Lack of data or data gaps in existing datasets

Lack of cost effective alternatives

Cost to get one FFE using traditional methods: $500 - $2,000

Cost to perform aerial LiDAR land survey: >$20,000

The Importance of First Floor Elevations

RTK-UAS approach

- RTK-UAS, required photogrammetry software, and additional equipment all cost less than $10k USD and has the ability to produce equivalent, in some cases, better dense point clouds (DPCs) than the low-tier LiDAR packages.
Photogrammetry and Remote Sensing (PaRS) and 3D modeling before RTK integrated UAS technology

- Studies using Structure-from-Motion (SfM) imagery capture for low-relief modeling demonstrate up to 40 ground control points (GCPs) must be established.\(^1\)\(^2\)

- Built environment and structural recreation can be modeled using UAS technology as seen with historical monuments and technological sites.\(^16\)\(^7\)\(^8\)

- Accurate 3D DPC and models were created by combining methods of UAS SfM capture and terrestrial laser scanning (TLS) to establish 2117 GCPs for just one structure.

- RTK enabled drone requires only 3-5 GCPs, dramatically reducing field time and labor.

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QUESTION

Can the use of an RTK-UAS coupled with photogrammetry methods survey FFEs and other flood-sensitive measures with accuracy comparable to traditional elevation certificate (EC) methods?

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The National Flood Insurance Policy (NFIP)

Elevation Certificates (ECs)

The Elevation Certificate (EC) provides insurers with information for insurance rates in relation to the base flood elevation (BFE) zones.

Obtained through certified surveyors, engineers, or architects by using a total station theodolite (TST) and must complete, seal, and submit the EC to the community code official.\(^9\)\(^10\)

The cost range is $2k - $10k, not including labor and other equipment.
- FEMA recognizes the lowest floor as the lowest enclosed area (including basements).\(^{13}\)

- C2.a – FFH
- C2.b – next highest floor
- C2.c – bottom of lowest horizontal member
- C2.d – attached garage slab
- C2.e – grade supporting services to house (LSG)
- C2.f – Lowest adjacent grade (LAG)
- C2.g – Highest adjacent grade (HAG)

Aside from NFIP policy ratings, FFEs are critical to...

- Estimating individual inundation risk/damage
- Feeding into GIS-based regional flood risk modeling
- Augmenting other existing flood risk approaches and methods

Site selection

<table>
<thead>
<tr>
<th>Community</th>
<th>Year</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lafitte’s Cove</td>
<td>1996-Current</td>
<td>Slab, Raised, Pier</td>
</tr>
<tr>
<td>Campeche Cove</td>
<td>1978-2004</td>
<td>Slab, Raised</td>
</tr>
<tr>
<td>Evia</td>
<td>2004-Current</td>
<td>Slab, Raised, Pier</td>
</tr>
<tr>
<td>Silk Stocking District</td>
<td>1890-1975</td>
<td>Slab, Raised, Pier</td>
</tr>
</tbody>
</table>
Pre-flight planning
Field labor workflow
Image capture

PROOF OF CONCEPT WORKFLOW

WORKFLOW FOR EACH SITE SELECTED

Image acquisition
Image storage and backup
DJI RTK Geo-location storage
Converting to same vertical datums
Image processing
Post-processing kinematics (PPK)
Manual derivation of FFEs

Comparison analysis

Data acquisition
Comparative analysis
Data Security

Proof of concept method workflow

DOUBLE GRID

Parameter Description
Flight plan type
Flight plan altitude (m)
Flight plan area (length and width)
Flight plan margin
Gimbal tilt (degrees)
Oblique lateral and front overlap (%/%)
Start and end points

Residential Community Flight plan type Flight plan altitude (m) Flight plan area Flight plan margin Gimbal tilt (degrees) Oblique overlap (%/%) Start and end points
Lafitte’s Cove Double Grid 100 4 sections (~40-50 acres each) AUTO 60 70/75 Closest to launch location. Center of full 4 sections.
Campeche Cove Double Grid 100 1 section (~61 acres) 10 AUTO 60 70/80 Closest to launch location.
Evia Double Grid 100 2 Sections (~60 & 115 acres) AUTO 60 70/80 Closest to launch locations center of each section.
Silk Stocking District Double Grid 45 4 sections (~10 acres each) AUTO 45 *80/80 Closest to launch location. Center of 4 sections.

Table 3: UAS flight parameters for each residential community.*: nadir 70/70 percent overlap combined with oblique capture.
3/22/22

FFE = points at the bottom of front, side, and back doors.
Surface points of balconies and patios were generally assigned the same value as the points at the bottom of doors within Pix4D. Attached garages or enclosures below elevated floors were not used as FFE.

Next highest floor (if present) = points at the bottom of doors or surface points of that area.
LAG = points at the end of driveways connecting to the road or points at the bottom of entry stairs connecting to the public sidewalk.
HAG = points at the top of the driveway directly adjacent to the home or garage.

Deriving the data within Pix4D

Data
A dataset of 70 EC was compiled by cross referencing Certificates of Occupancy (COs) given by the City of Galveston and addresses located in the sites selected.

Pairwise comparison of RTK-UAS based FFE estimates vs City of Galveston EC

Comparative analysis results

- 66 total comparisons – 4 excluded due to repeated address or lack of information

<table>
<thead>
<tr>
<th>Top of bottom floor (FFE)</th>
<th>Top of next highest floor</th>
<th>Lowest service grade (LSG)</th>
<th>Lowest adjacent grade (LAG)</th>
<th>Highest adjacent grade (HAG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE</td>
<td>0.52 ft</td>
<td>1.01 ft</td>
<td>1.44 ft</td>
<td>1.64 ft</td>
</tr>
<tr>
<td>p-value</td>
<td>0.832</td>
<td>0.034</td>
<td>0.768</td>
<td>0.000</td>
</tr>
</tbody>
</table>

- Drone FFE, LSG, and HAG estimates were accurate to EC measures
- Drone next highest floor and LAG estimates were not as close as expected… why!
This study demonstrates the use of an RTK-UAS coupled with photogrammetry to derive FFEs within residential communities is viable in achieving measurements accurate to ECs.

### Challenges and lessons learned

#### Labor and processing times

<table>
<thead>
<tr>
<th>Community</th>
<th>Field labor time</th>
<th>Pix4D Processing time</th>
<th>Data derivation time</th>
<th>Houses Captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lafitte's Cove</td>
<td>6.5 hours</td>
<td>10 hours</td>
<td>23.3 hrs.</td>
<td>280</td>
</tr>
<tr>
<td>Campeche Cove</td>
<td>2.5 hours</td>
<td>3 hrs. total</td>
<td>24.4 hrs.</td>
<td>205</td>
</tr>
<tr>
<td>Evia</td>
<td>8 hours</td>
<td>8 hours</td>
<td>17 hrs.</td>
<td>205</td>
</tr>
<tr>
<td>Silk-Stocking District</td>
<td>5 hours</td>
<td>20 hours</td>
<td>14.5 hrs.</td>
<td>174</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22 hrs.</strong></td>
<td><strong>41 hrs.</strong></td>
<td><strong>79.2 hrs.</strong></td>
<td><strong>952</strong></td>
</tr>
</tbody>
</table>

### Interpretation inconsistencies

#### Some EC FFEs were corresponding to drone HAG estimates

<table>
<thead>
<tr>
<th>Address</th>
<th>EC FFE (m)</th>
<th>UAS FFE (m)</th>
<th>Error (1-2) (m)</th>
<th>UAS HAG (m)</th>
<th>Error (1-4) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3443 Eckert Drive</td>
<td>1.64</td>
<td>5.97</td>
<td>4.33</td>
<td>5.96</td>
<td>0.01</td>
</tr>
<tr>
<td>3439 Eckert Drive</td>
<td>1.80</td>
<td>6.05</td>
<td>4.25</td>
<td>6.13</td>
<td>0.08</td>
</tr>
<tr>
<td>3410 Eckert Drive</td>
<td>2.22</td>
<td>5.88</td>
<td>3.66</td>
<td>6.00</td>
<td>0.12</td>
</tr>
</tbody>
</table>

#### Some EC FFEs were corresponding to drone HAG estimates cont.

<table>
<thead>
<tr>
<th>Address</th>
<th>EC FFE (m)</th>
<th>UAS FFE (m)</th>
<th>Error (1-2) (m)</th>
<th>UAS HAG (m)</th>
<th>Error (1-4) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3209 Fontaine Drive</td>
<td>1.8</td>
<td>6.05</td>
<td>4.23</td>
<td>6.15</td>
<td>0.06</td>
</tr>
<tr>
<td>3216 Fontaine Drive</td>
<td>2.22</td>
<td>5.88</td>
<td>3.66</td>
<td>6.00</td>
<td>0.12</td>
</tr>
</tbody>
</table>

### Figure 4: Housing addresses Sunrise Row 13, 11, and 9 located in the Evia community seen in (a) Google Street View (GSV) and (b) screenshot of Pix4D dense point cloud.

### Figure 5: Example property 13522 Moyenne Pl demonstrating (a) EC measure interpretations seen through Google Street View (GSV); (b) UAS-based measure interpretations displayed on screenshot of generated DPC (front of structure); (c) UAS-based measure interpretation displayed on screenshot of generated DPC (back of structure).
Captured four residential (952 parcels) communities and provided FFE and other flood-sensitive data in under 18 working business days.

- Drone-based FFE estimates were as accurate as traditional EC measures.

- Initial equipment used cost less than that of alternative aerial surveying techniques as well as traditional methods for the amount of FFEs captured.

- Efficient in collecting large amounts of FFE data regardless of flood insurance participation and EC challenges.
Future work

- Explore machine learning in data derivation workflow object and point recognition within aerial photo population or Pix4D
- Develop service and product cost estimation models
- Continue to capture flood sensitive data within vulnerable communities located in the Houston-Galveston region

Until then...

- Preliminary flight protocol and methods used in this study provides some guidance for similar or future studies seeking UAS data collection in dense, built environments.
- RTK-UAS captures small scale spatial and elevational data crucial to other practices
- Scalable and adaptable across diverse settings creating many implications for flood planning and management.
CONTRIBUTORS AND FUNDING SOURCES

Funds to purchase equipment used to collect and process data for this research were provided by the TCRF and Center for Texas Beaches and Shores (CTBS).

Thanks to Coastal Resource Manager, Dustin Henry, and Planning Technician, Karen White, with the City of Galveston Planning and Development Division provided Certifications of Occupancy (COs) and Elevation Certificates (ECs) and Benjamin M. Ritt for equipment and ...
METHOD LIMITATIONS

- Weather (wind and rain)
- Batteries - $150/ea.
- Federal Aviation Administration (FAA) Part 107 UAS certification
- Compliance with airspace and air safety regulations

PHOTOGRAMMETRY AND REMOTE SENSING (PARS) AND 3D MODELING CONT.

SFM IMAGERY AND PHOTOGRAMMETRY

- SFM imagery overlapping, offset images of an area or 3D structure
- Photogrammetry software (Pix4D and Agisoft Photoscan) can then use these images to create 3D maps and models

GALVESTON: CITY OF STORMS

- "Queen City of the Gulf"
- Principle port and gateway to the Southeast during 19th Century (CoG, 2020)
- 1870 to mid 1890s was the apex of Galveston’s prosperity (CoG, 2020)
- The Strand was the “Wall Street” of the Southeast
- University of Texas Medical Branch (UTMB) established in 1891
GALVESTON: CITY OF STORMS

GREAT STORM OF 1900

- 8,000 deaths, 8,000 homeless
- After the storm, the construction of the 16-foot-high mean low water, 17-foot-wide seawall was begun (Davis, 1974).

GALVESTON TODAY

The city is still a valuable asset in multiple dimensions. Economically, the Port of Galveston and its relations with the Houston ship channel allow for shipping, fishing, and shrimping functions (CoG, 2020).

Tourism is also an integral part of the Galveston Island Economy (TE, 2016).
- Visitors spent $790 million
- Generating $3 billion in business sales and $115 million in tax revenues.
- Visitor volume and spending increasing on average 2% annually since the 2008 recession.

SECOND HOMES AND LAND

- Second homes in high risk areas may not directly affect those who visit rarely; however, socially vulnerable communities within Galveston could experience higher flood risk as a result of homes being built on natural buffers such as beaches and wetlands.

The land cover change of natural landscapes to impervious and developed alters the overall landscape capacity to mitigate and store water (Highfield and Brody, 2004; Brody et al., 2007; Brody et al., 2014, Highfield, Brody, & Shepherd, 2014).
GALVESTON: CITY OF STORMS
THE FUTURE OF GALVESTON

- Since Hurricane Harvey, The United States Army Corps of Engineers (USACE) (Galveston District), The Texas General Land Office (GLO), and various other partners, are working to secure concept projects that mitigate against future natural disasters and flooding in Galveston and Greater Houston Area (GLO/GAUSACE, 2020; GLO, 2020). Projects that include beach and bay modifications, multifunctional, or hybrid, structures, and dikes and barrier systems.

- Monitoring vulnerable communities via UAS technology could be valuable in assessing the change created by these projects and their role in reducing flood risk and damages.

METHODS
FLIGHT PARAMETERS TESTING FOR 3D MODELING

- Flight plan type - 3D photogrammetry flight plan including double grid and multi-oriented.
- Flight altitude - altitude (m) at which the drone captures aerial imagery.
- Flight plan area - area of flight plan type based on ROI or sections of ROI.
- Flight plan margin - flight plan boundaries the drone can or cannot exceed from flight plan area.
- Gimble tilt - tilt of the gimble positioning the camera capturing SfM imagery.
- Lateral and front overlap - 2D (90-degree gimble tilt) photo capture overlap percentage.
- Oblique lateral and front overlap - 3D (45-60-degree gimble tilt) photo capture overlap percentage.
- Start and end points - where the drone starts and ends relative to the flight plan and launch point.

METHODS
FLIGHT PLAN TYPE

- DOUBLE GRID
- MULTI-ORIENTED
**METHODS**

**FLIGHT ALTITUDE, AREA, AND MARGIN**

- **Flight altitude** - Large ROIs could be flown at a higher altitude (75–100m) while small ROIs could be flown at a lower altitude (45–60m).

- **Flight plan area** - Flight plan area varies based on the ROI. Depending on battery limitations, ROIs can be divided into subsections and flown at the same parameters. Assigning a large flight area that cannot be completed in a given day due to battery constraints will cause model issues.

- **Flight plan margin** - To increase oblique capture, the margin parameter is set to AUTO. This places the drone flight paths outside the assigned flight area. Switching the margin setting from AUTO to MANUAL would save battery but reduce oblique capture. In some tests, the outer portions of the Pix4D 3D models were not rendered correctly. This parameter can be customized to fit the unique conditions of a ROI and save about 5–10 minutes of flight time, but not recommended.

**METHODS**

**GIMBLE TILT**

- **Oblique lateral and front overlap** - Excluded due to Double Grid

- **Oblique lateral and front overlap** - 50% front/50% side or greater.

- **Starting and ending points** - Did not directly affect data quality (only flight efficiency).
METHODS

GCPS WITHIN ROIS

- DJI RTK mobile base station to hand held linking
- Thank you Benjamin M. Ritt!

FIRST FLOOR ELEVATIONS (FFE) AND THE NATIONAL FLOOD INSURANCE POLICY (NFIP) CONT.

TRADITIONAL SURVEY FOR ECS

- Obtained through certified surveyor, engineer, or architect by using a total station theodolite (TST) and must complete, seal, and submit the EC to the community code official (FEMA, 2020).
- Cost upward of 10k USD not including labor and other equipment.

GALVESTON: CITY OF STORMS

CLIMATE TRENDS AND LAND COVER CHANGES

- Hurricanes and precipitation intensity are expected to increase due to climate trends (Knight and Davis, 2009; Donat et al., 2016; Pfahl et al., 2017).
- Air and ocean warming
- Sea-level rise
- Land cover changes
- Second homes
- Development within natural buffers

Studied specific to Galveston and Galveston Bay confirmed that Hurricane Harvey, which made landfall just east of Rockport, caused environmental and housing damages primarily due to rainfall (Du et al., 2019; Du and Park, 2019; Amadeo, 2019).