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STATISTICS, ANALYTICS, AND GIS IN ENERGY CONFERENCE

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VPS: 2D, 3D, and AI Approaches for Device Localization

Benjamin Alpert
Data Scientist
GTI Energy

Agenda

- Overview: GNSS Consortium
- Topic of Interest: Urban Canyons
- Emerging Methods
  - Merging the Digital and Physical
- GNSS Consortium Research
  - Google VPS
  - Immersal VPS
- Next Steps
- Questions and Discussion

GNSS Consortium

- The GNSS Consortium researches and shares information related to the use of GNSS technology for utility operations.
- High-accuracy GNSS data collection is essential for utilities geospatial data management and GIS operations. The consortium informs sponsors about industry developments, ranging from improvements in existing technology to emerging methods for high-accuracy geospatial recordkeeping.

GNSS Consortium

- GNSS performance has advanced dramatically over the past decade: multi-constellation, multi-frequency receivers, and real-time correction services have driven accuracy from meters to centimeters, while hardware costs have fallen sharply.
  - However, persistent challenges remain in signal-degraded environments such as urban canyons, under dense foliage, and indoors.

Consortium Topic of Interest: Urban Canyons

- Urban canyons are areas where GNSS reliability is degraded because of skyscrapers and dense buildings blocking direct satellite signals, reducing the number of visible satellites and lowering position precision (PDOP).
  - Reflections from glass and metal surfaces create multipath errors, where delayed, indirect signals distort range measurements.
- GNSS-only solutions in these environments struggle to achieve high accuracy without augmentation.
  - Positioning errors can cause misaligned work, false alerts, or safety risks, leading to costly rework, delays, and extra labor for manual measurements to overcome urban canyon limitations.

Emerging Methods

Software innovation is being explored as a key method for overcoming urban canyon limitations, complementing established GNSS methods with AI, 3D modeling, and vision-based techniques.

- **VPS with 3D Environmental Models**
  - Matches live camera imagery to geo-referenced 3D models for accurate position and orientation.
  - Maintains reliability in GNSS-degraded settings by using local visual and structural cues.
  - Supports applications from AR navigation to infrastructure inspection.
- **Benefits in Urban Canyons**
  - Accurate localization even in visually repetitive, narrow, or shaded streets.
  - Reduces the need for repeated manual surveying.
  - Enables real-time alignment of digital overlays with the physical world.
- **Other Complementary Methods**
  - **LiDAR/SLAM:** Structure-aware navigation via local mapping or point cloud matching.
  - **3D City Model–Aided GNSS**: Uses building geometry for signal validation and multipath mitigation.

Merging the Digital and Physical Worlds

- New technologies and workflows are being developed to complement established GNSS methods.
- These approaches leverage additional sensors, 3D environment models, and digital infrastructure to maintain accuracy when GNSS performance is degraded.
  - The goal is to create a seamless, hybrid localization that combines the global reach of GNSS with the robustness of local sensing and modeling.

Merging the Digital and Physical Worlds

Synchronizing digital and physical space **provides positional context where it might otherwise be impossible and unlocks opportunities for digitally enriched environments.**

- In urban canyons, where GNSS alone often falls short, this alignment supports precise navigation and efficient field operations without repeated manual measurements.
- More broadly, these methods create opportunities for reliable AR overlays and accurate digital annotations.

Merging the Digital and Physical Worlds

Methods	Benefits
High-resolution **3D environmental models** capturing buildings, streets, and landmarks.	**Reliable positioning** in GNSS-degraded urban canyons.
Visual Positioning Systems (VPS) matching real-time imagery to geo-referenced 3D models.	**Operational efficiency** by reducing manual measurements and site revisits.
Sensor fusion combining VPS, LiDAR, and GNSS for **improved robustness.**	**Better decision-making** through accurate, location-specific data in real time.
Dynamic model updates from resurveying data.	**Precise AR overlays** aligned exactly with physical features.
	Context-aware navigation with turn-by-turn or situational guidance.

**Grey indicates future potential outside the current scope of research.*

Research

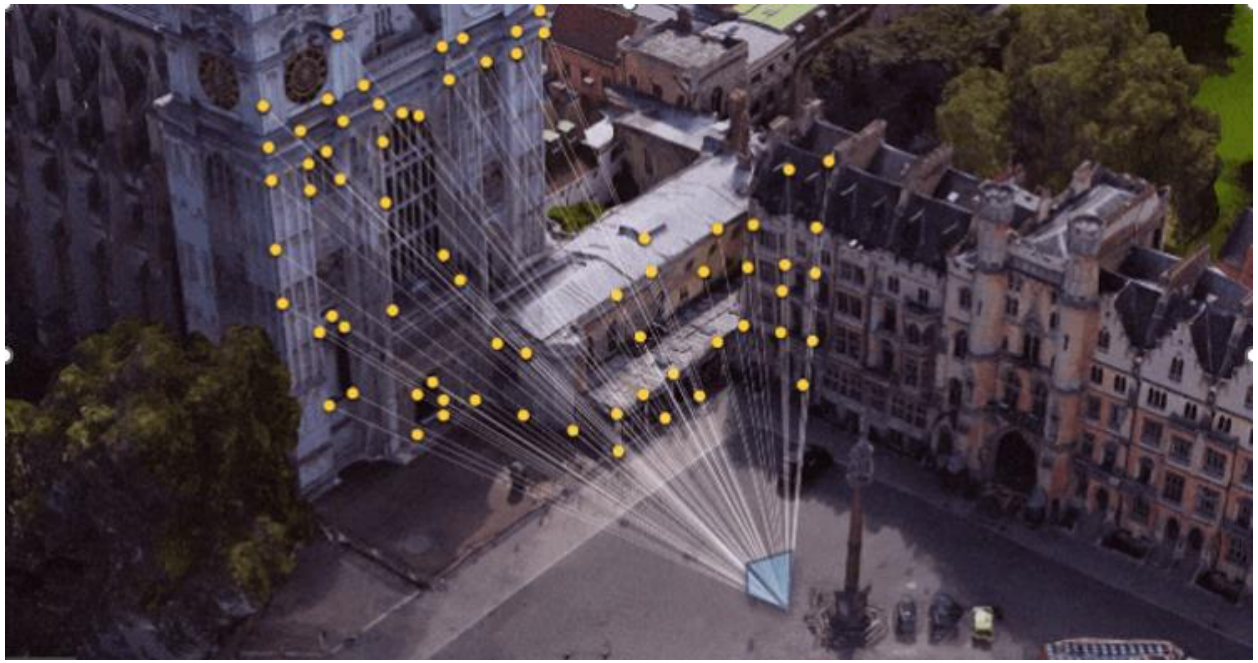
- The GNSS Consortium completed initial research on Visual Positioning Systems (VPS) as a complement to GNSS in urban canyon environments, and work is ongoing:
  - 2024 Research: Google VPS
  - 2025 Research: Immersal VPS

VPS: Complement to GNSS?

- **GTI Energy hypothesized that VPS might demonstrate an inverse performance relationship relative to traditional GNSS methods:**
  - While GNSS excels in less dense areas with optimal satellite signal reception, it encounters difficulties in urban settings due to signal interference.
  - Conversely, the team postulated that AR methods would perform optimally in urban canyons with abundant distinct visual input but might struggle in less visually distinct areas (such as open fields).
  - This hypothesis was supported by this year's experimental results, indicating that AR methods might hold promise as a complement to GNSS in dense, challenging urban environments where receivers are subject to signal interference.

GNSS 2024: Google Visual Positioning System (VPS)

- Google Visual Positioning System (VPS) combines Google Street View and machine learning capabilities to determine a phone's position.
- **Functionality**
  - Determines a device's location by also relying on visual input rather than solely relying on GPS signals.
  - Google converted its Street View database into a searchable index of visual features, providing trillions of strong reference points for triangulation.
  - VPS is included as a developer feature in Google's platform for building augmented reality experiences.
  - VPS cross-references the built environment in combination with the phone's signal reception, making it less susceptible to urban canyon and signal interference challenges.
    - Smartphones rely on a combination of GPS, Wi-Fi, cellular networks, and Bluetooth for positioning.

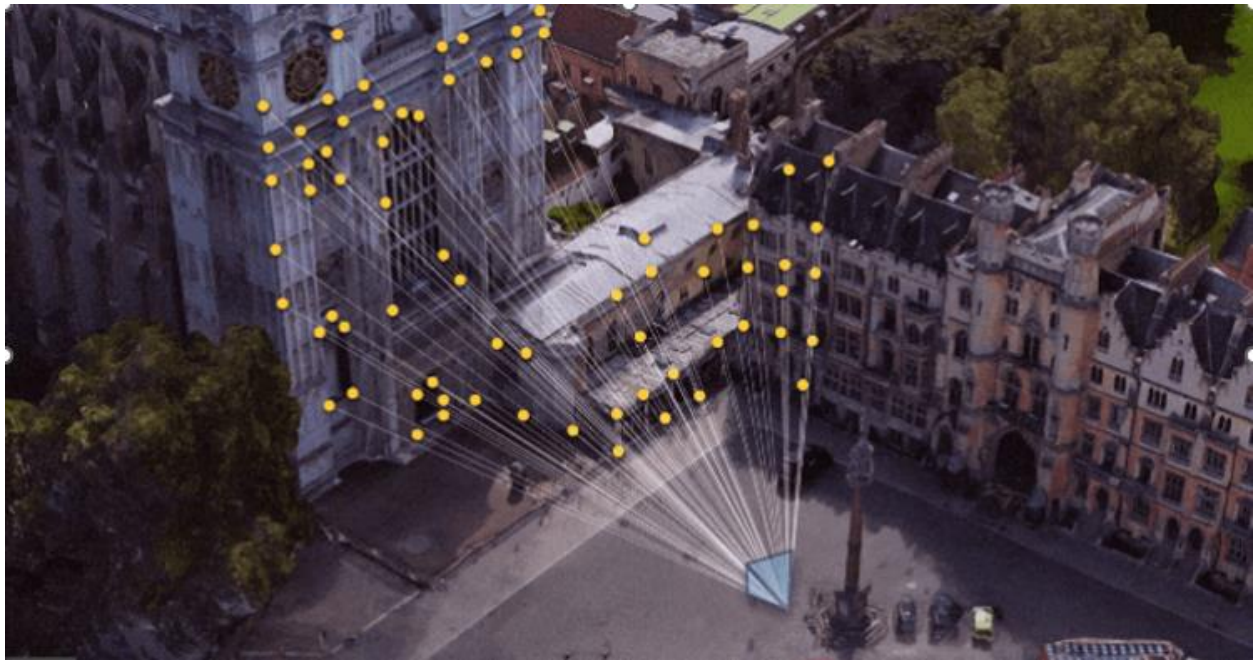


Google VPS matching points from Google Street View for localization. (Source: Google Research Blog)

GNSS 2024: VPS Testing Results

GTI Energy developed a custom app using Google's ARCore software development kit (SDK) to evaluate point-based localization consistency using Android smartphones relative to traditional GNSS devices.

- **Custom App**
  - Developed by GTI Energy using Google's ARCore SDK
  - Used to evaluate localization consistency on Android smartphones
- **Experiment Environments: Dense and Semi-Dense Urban Environments**
  - Semi-dense environment: GTI Energy's campus
  - Dense urban environment: Urban canyon in downtown Chicago
- **Data Collection**
  - Hundreds of point pairs recorded using custom app and traditional GNSS methods
- **Performance Assessment**
  - Comparison of app-collected VPS data against points collected using GNSS measurements.



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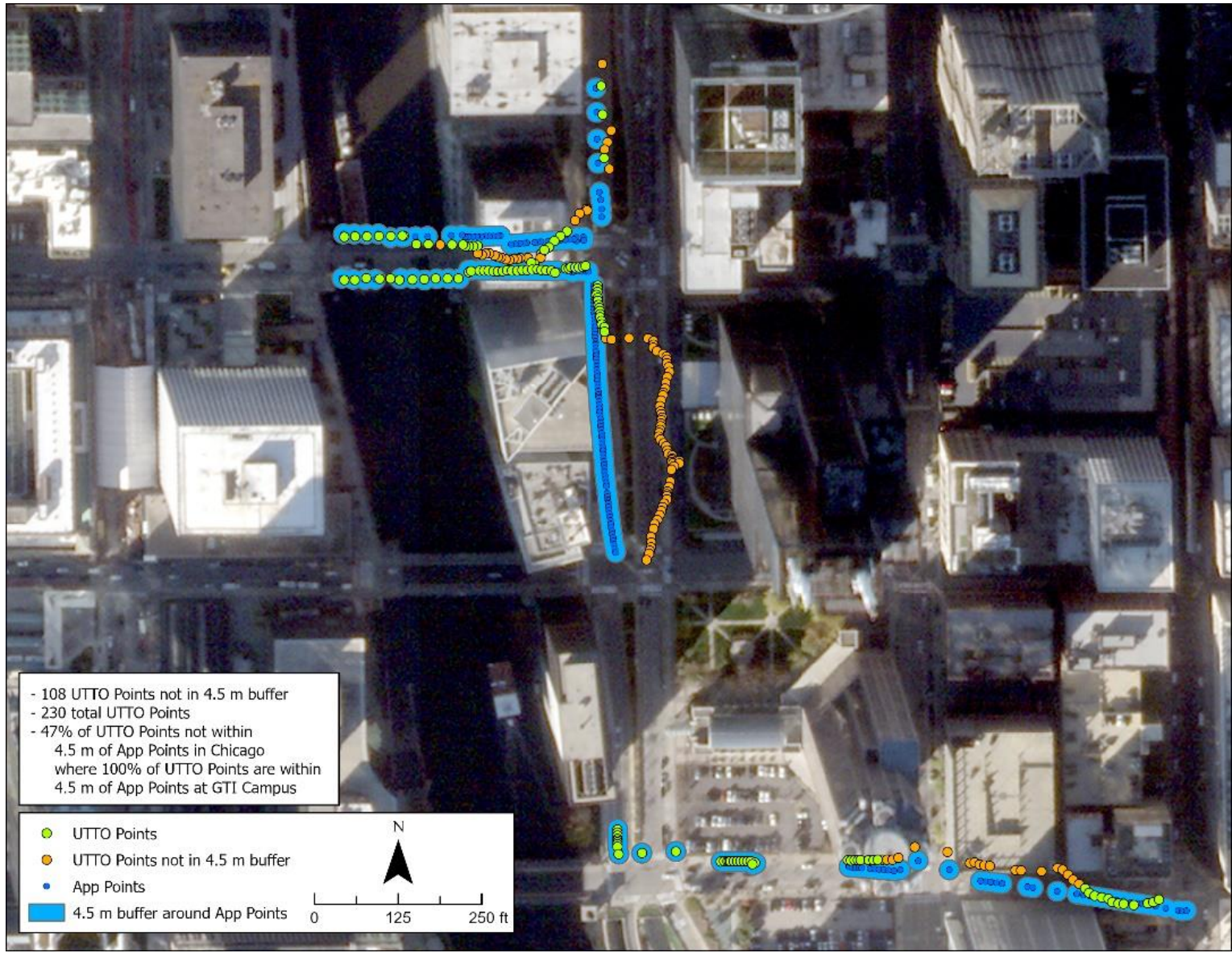
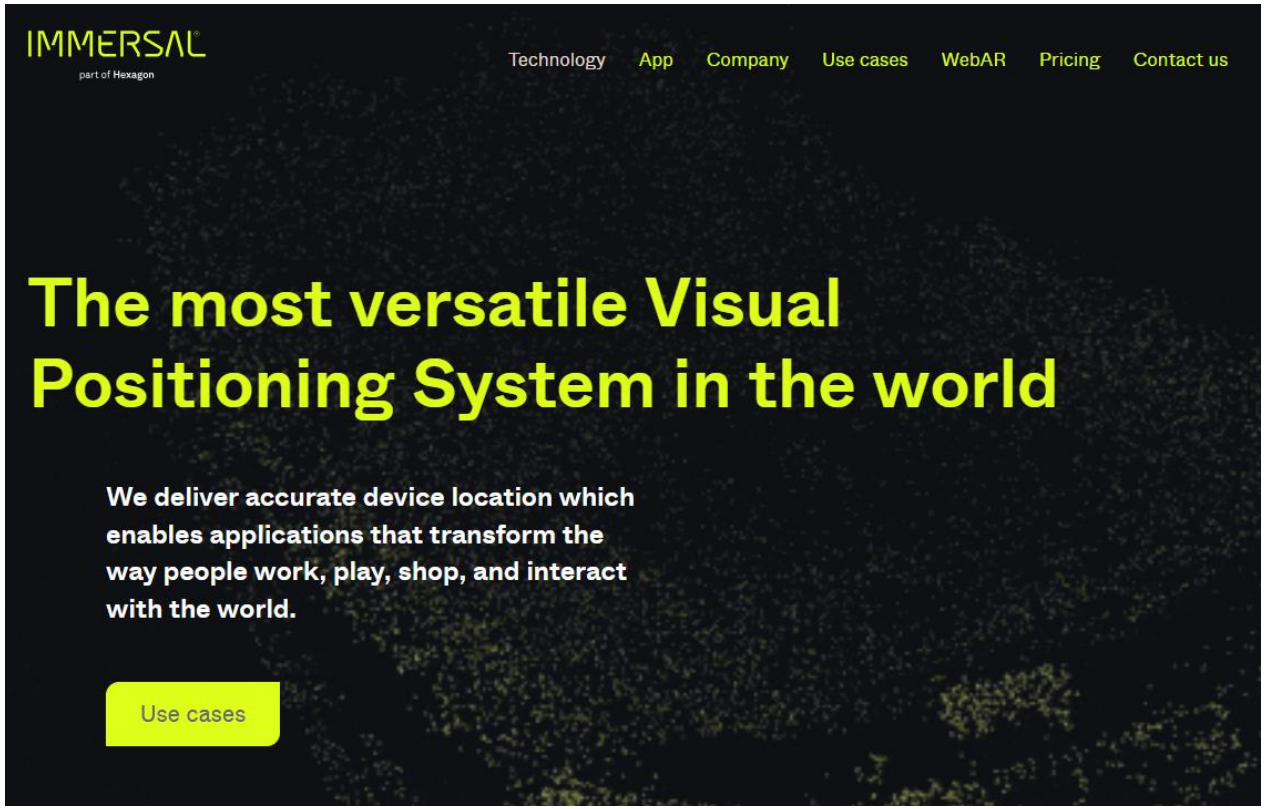
GNSS 2024: Proof of Concept

- **Validation of Hypothesis**
  - Google ARCore app showed consistent performance in urban canyons where GNSS encountered challenges
    - Unclear performance in sparsely built (rural) areas where visual referencing would be less distinct
- **Future Potential**
  - AR methods might act as a complement to traditional GNSS methods in dense urban environments
    - Receivers subject to signal interference might benefit from AR methods in certain contexts



2025 Research Overview

- The 2025 GNSS Consortium improves on the 2024 research design and continues examining VPS approaches to overcome urban canyon challenges.
- This year focuses on testing the Immersal platform for custom VPS establishment and field data capture.
- Goal of the research is to assess geolocational accuracy as well as practical operational benefits.



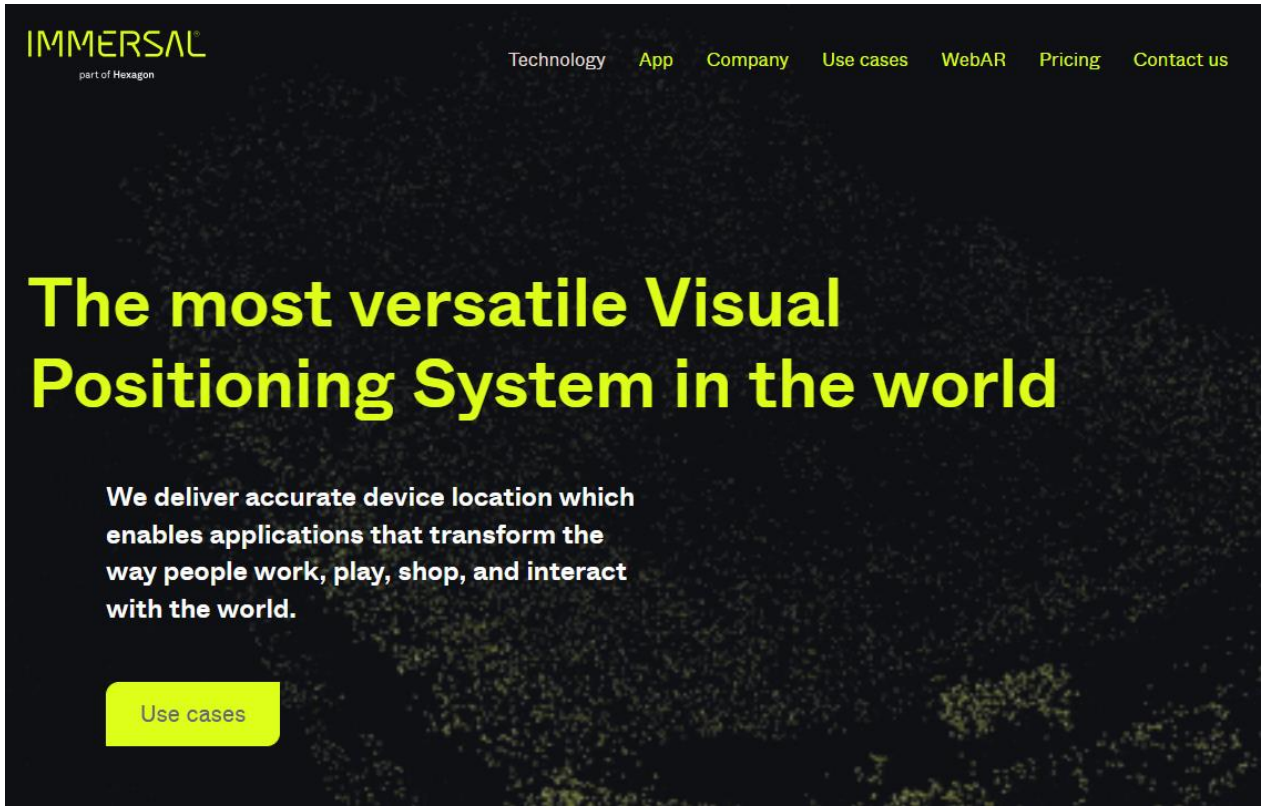
GNSS 2025: Building on 2024 Research

The Team is pursuing a comprehensive experiment design to establish point accuracy to explore the viability of VPS methods for professional purposes.

- **Establish Permanent Control Points**
  - Permanent, accessible markers at key locations on the GTI campus and in an urban canyon in downtown Chicago.
- **High-Resolution Base Maps**
  - Utilize high-resolution imagery from Planet's SkySat to minimize discrepancies and ensure precise visual alignment.
- **Enhanced Data Reliability**
  - Develop a robust framework for evaluating location-based applications in challenging environments.

Immersal vs. Google

- The advantage of Google VPS is its ubiquity and global coverage.
  - Presumably, ubiquity sacrifices some level of accuracy and point precision.
- Immersal is more customizable and requires area-specific data collection, but offers potentially higher cm-level positioning accuracy in urban canyons as well as greater customization.

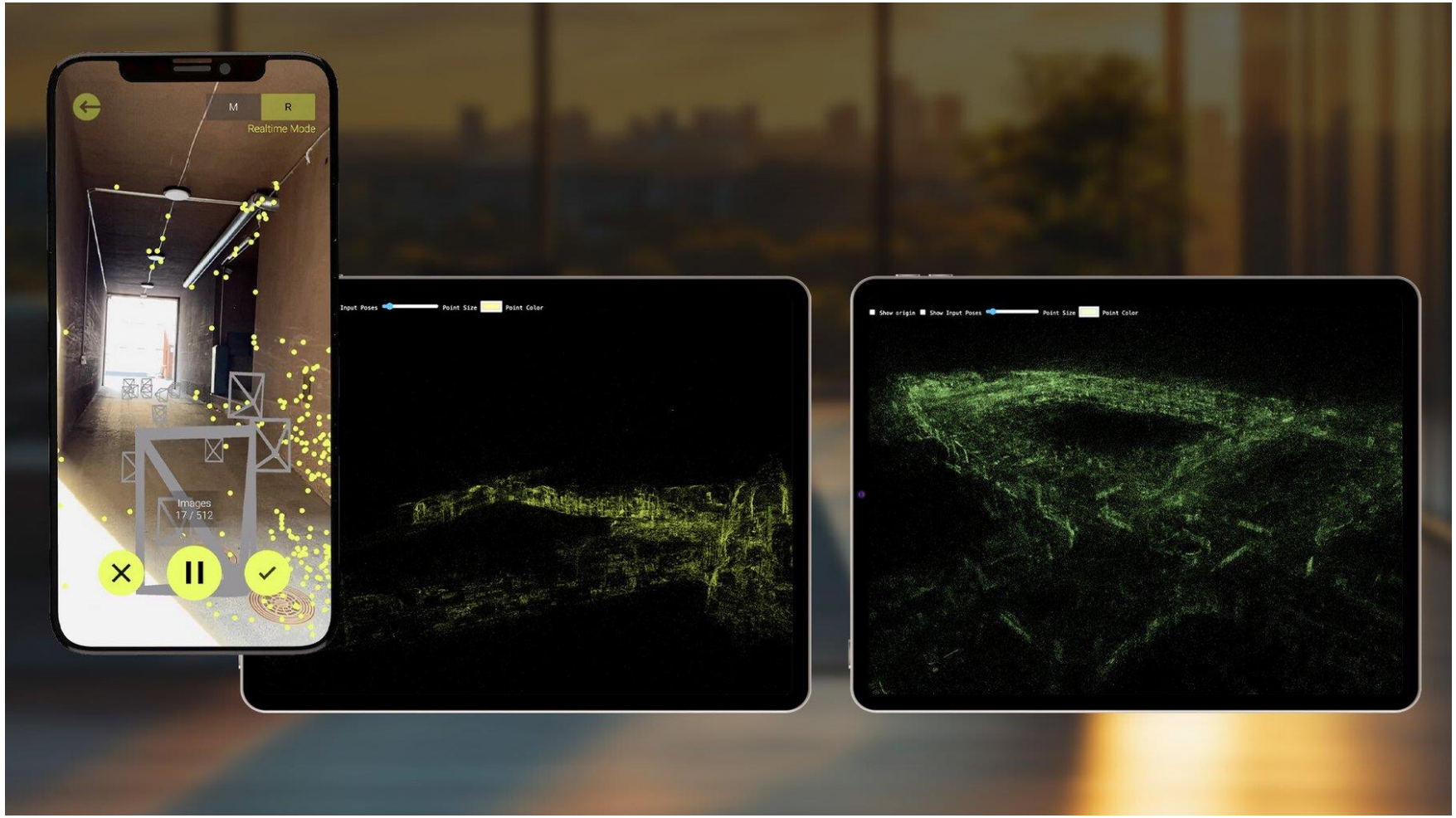


2025 Consortium Work

- **2025 Testing**
  - Contracted Immersal, a custom VPS platform
  - 3D data capture completed using Leica scanners, smartphones, and 360 cameras
  - Developed test app for fast visual positioning

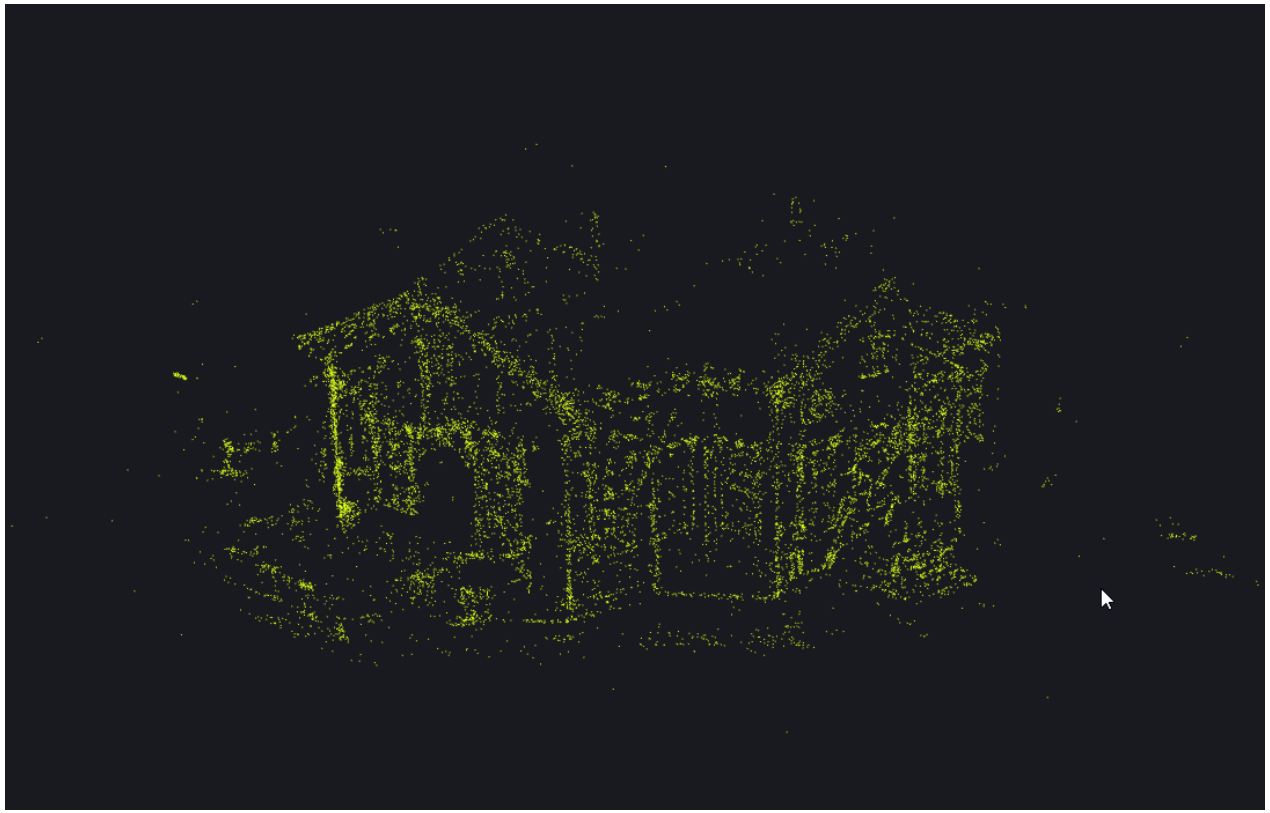
- **Additional features**
  - REST API for the Immersal Cloud Service for use with any device
  - Capable of mapping even large city-scale areas, both indoors and outdoors
  - Private/Public maps with sharing options
  - Tag and search maps with GPS coordinates
  - Point clouds and textured meshes of the mapped spaces available
  - Supports multiple maps at the same time in the same space

Immersal: Sample Map Rendering



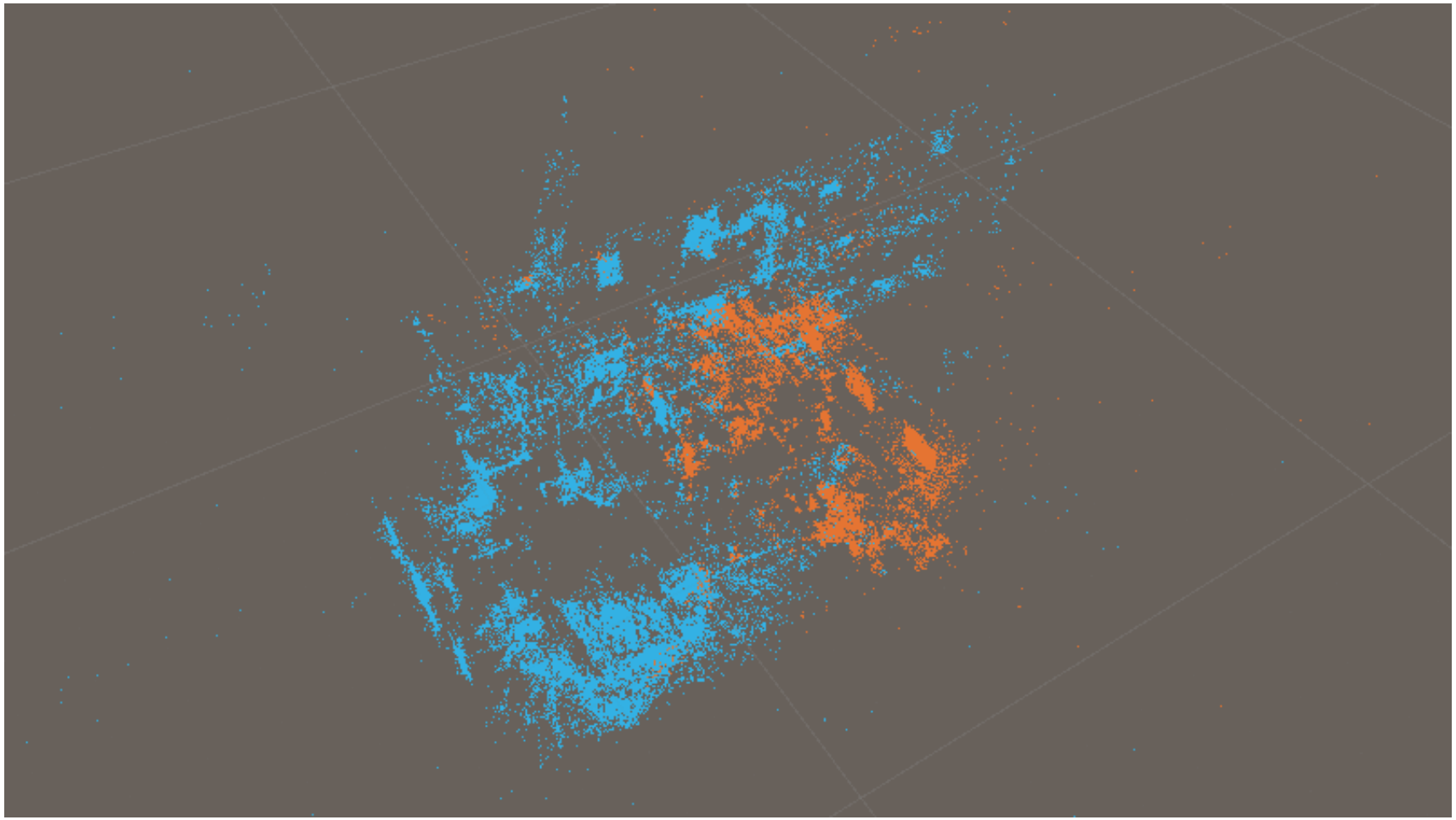
Immersal Mapper app creating a spatial map/point cloud from a phone scan.

Immersal: Sample Map Rendering



Public Immersal map viewer example (yellow point-cloud of a scene). Public maps can be shared for demos.

Immersal: Sample Map Rendering



Unity Multimap sample showing multiple Immersal maps (colored point clouds) in a single scene.

Immersal Mapping: Overview

- **1. Initial Mapping**
  - Capture imagery (360° or standard) of the environment.
    - GTI Energy, on campus, used a 360 camera to capture map data.
    - Mapping in downtown Chicago also complete.
  - Immersal processes the frames to detect visual features, match them across frames, and **build a local coordinate point cloud** (origin at capture start, units in meters).
- **2. Geospatial Alignment**
  - The local point cloud is **anchored to real-world coordinates** using GNSS readings, surveyed ground control points, or known reference features.
  - This process transforms the model into a **geo-referenced coordinate system** (e.g., WGS84, EPSG:4326).
- **3. Benefits of Geo-spatialization**
  - The map can be used across **multiple sessions, devices, and locations** without drift.
  - Enables hybrid workflows where VPS provides local precision and GNSS provides global position.
  - Allows integration into GIS systems, utility asset management platforms, or AR navigation services.

360 Video Capture

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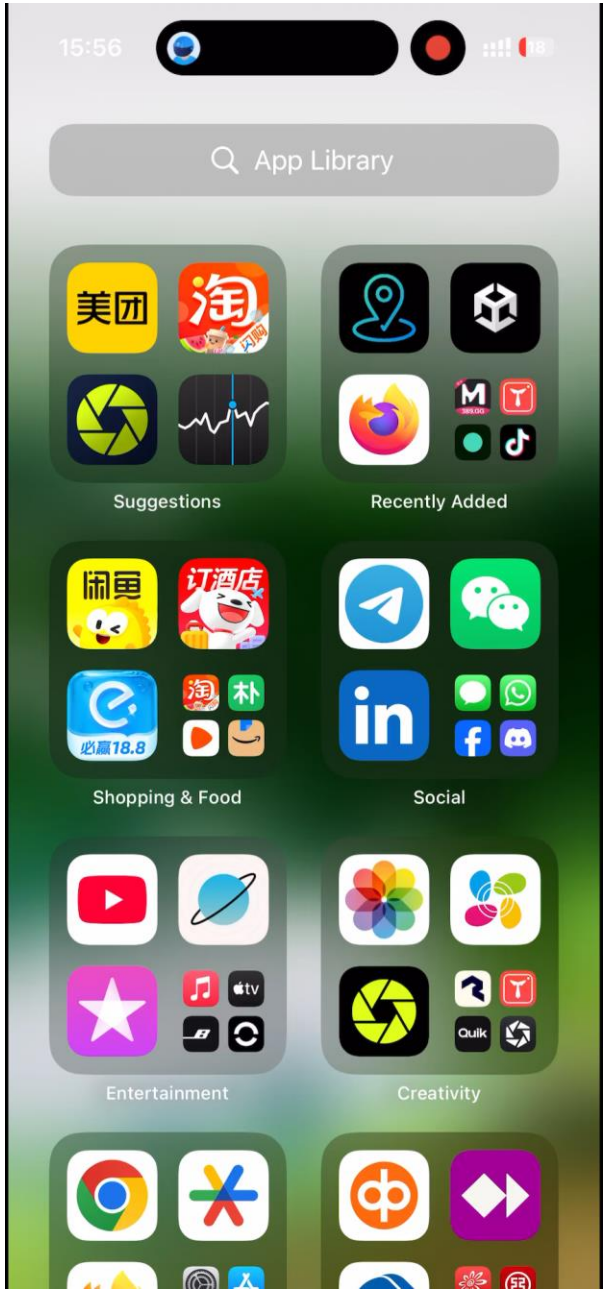
2025 Consortium Work

Re-Localization and Data Capture with Immersal

- **Initialization:** Load the previously created and geospatialized Immersal map into the development (dev) app.
- **Re-Localization**: The app uses the device camera to match live visual features against the stored map, determining precise position and orientation in real time.
- **Data Recording**: Once localized, the app can record local XYZ coordinates as well as geospatial lat/lon/altitude measurements
    - Subsequent research could focus on the viability of AR annotations with accurate geo-referencing tied to the map's coordinate system.
- **Operational Value**: Anchoring every new dataset to the same spatial reference frame enables repeatable, high-accuracy data capture in GNSS-degraded areas.



2025 Consortium Work: Test App

- Data capture shows tabular and mapped data captured by the Immersal dev app.
  - Subsequent testing this year will assess point accuracy relative to traditional GNSS methods.

Timestamp	Latitude	Longitude	Altitude
2025-08-03 16:44:14.873	30.635747	104.075444	486.311565
2025-08-03 16:44:17.309	30.635748	104.075444	486.317755
2025-08-03 16:44:19.093	30.635748	104.075444	486.340606
2025-08-03 16:44:20.713	30.635747	104.075443	486.350867
2025-08-03 16:44:22.017	30.635747	104.075442	486.335587
2025-08-03 16:44:23.483	30.635747	104.075443	486.320569
2025-08-03 16:44:24.816	30.635747	104.075443	486.323034
2025-08-03 16:44:26.349	30.635748	104.075444	486.334145
2025-08-03 16:44:27.782	30.635748	104.075444	486.363386
2025-08-03 16:44:29.051	30.635748	104.075443	486.291118
2025-08-03 16:44:30.340	30.635747	104.075443	486.276192
2025-08-03 16:44:32.088	30.635747	104.075443	486.317617
2025-08-03 16:44:33.923	30.635747	104.075443	486.347273
2025-08-03 16:44:34.856	30.635748	104.075444	486.332816
2025-08-03 16:44:36.074	30.635748	104.075443	486.26545
2025-08-03 16:44:37.509	30.635747	104.075443	486.286555
2025-08-03 16:44:38.975	30.635747	104.075443	486.346889

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Next Steps

- Finish monument setup in downtown Chicago.
  - GTI Energy monument network setup complete.
- Capture points using the Immersal dev app and the GTI Energy and Immersal maps.
  - Compare points recorded to monuments and control network established using GNSS methods to assess accuracy.
  - Analyze, map, and visualize results to determine future research steps.

VPS Research Areas

In addition to assessing positional accuracy, GTI Energy is planning to assess logistic viability for utility deployment. As such, the team is planning future research to address the known issues below.

- **Visual Data Drift**: Over time, differences between the captured map and the current environment (due to new construction, seasonal changes, or moved objects) can reduce feature-matching accuracy, leading to positional errors.
  - High-accuracy maps require periodic updates to remain valid, particularly in fast-changing urban areas.
- **Feature-Poor Environments**: Areas with repetitive textures (e.g., uniform building facades) or minimal visual detail can limit reliable localization.
- **Lighting and Weather Variability**: Shadows, glare, rain, or snow can obscure key features and degrade camera matching.

VPS Research Areas: Future Work

- Future work will seek to leverage similar localization workflows already proven in warehousing, logistics, and other controlled environments, adapting them to field utility operations.
- **Visual Data Drift**
  - Additional work is needed to understand map update frequency requirements.
    - Consider regular collection of imagery to refresh models more frequently.
    - Determine methods for prioritizing map updates for high-use areas and integrating them into routine field operations.
  - Add a secondary scan (LiDAR or high-res 3D) for additional reference and richer spatial awareness. **probable work focus next year.*
- **Feature-Poor Environments**: supplement mapping with LiDAR scans or GNSS constraints to improve reliability in feature-poor areas.
- **Lighting and Weather Variability**: target mapping during optimal conditions and train VPS with imagery from multiple lighting and weather scenarios.

Questions and Discussion

Interested in our work? Feel free to follow up and stay in touch!

Benjamin Alpert
balpert@gti.energy