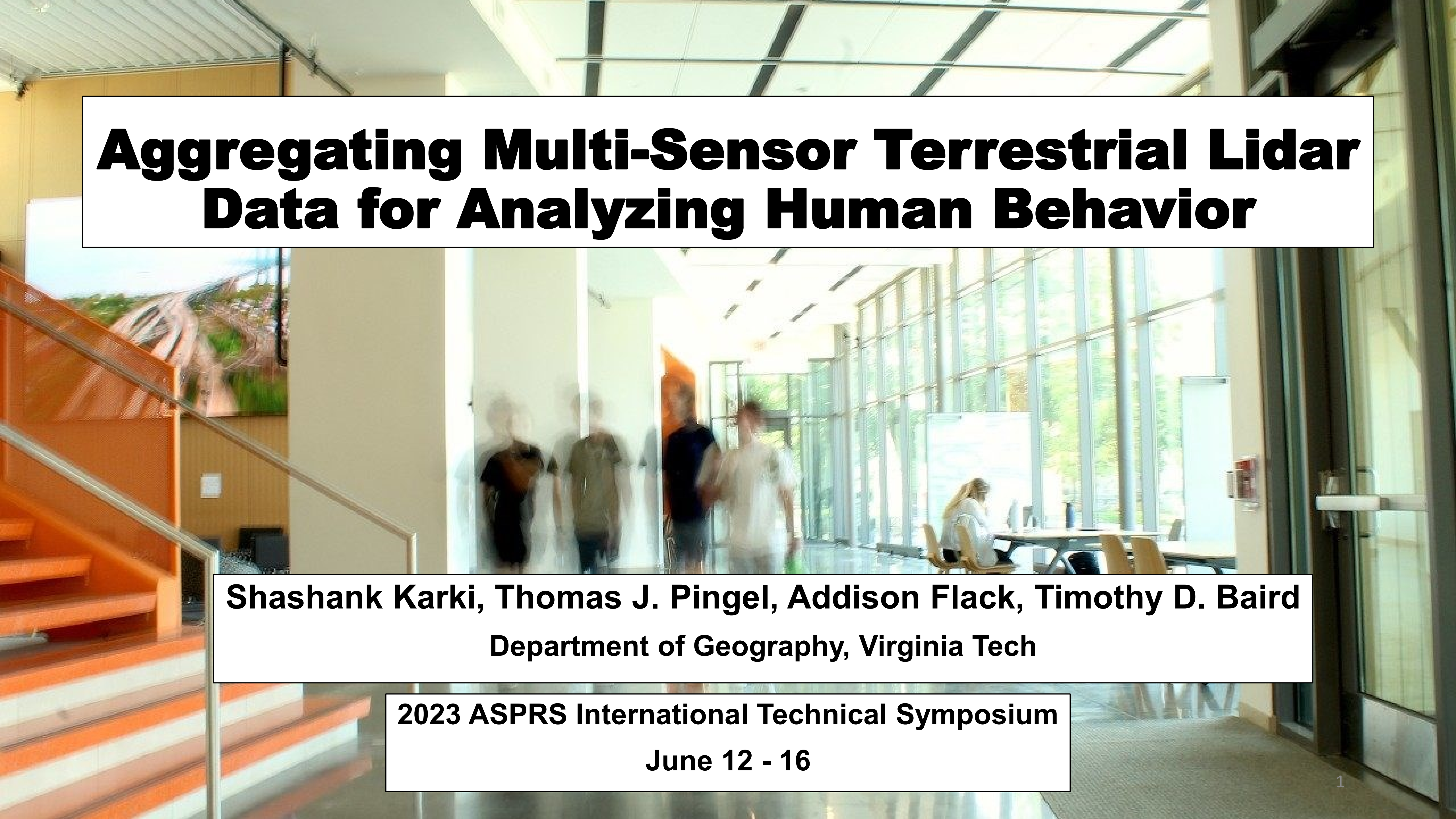

Aggregating Multi-Sensor Terrestrial Lidar Data for Analyzing Human Behavior

Shashank Karki, Thomas J. Pingel, Addison Flack, Timothy D. Baird

Department of Geography, Virginia Tech

2023 ASPRS International Technical Symposium

June 12 - 16

Dynamic Digital Twins

High-resolution spatial models using Lidar-based Simultaneous Localization and Mapping **(SLAM) and** Structure from Motion **(SfM)**

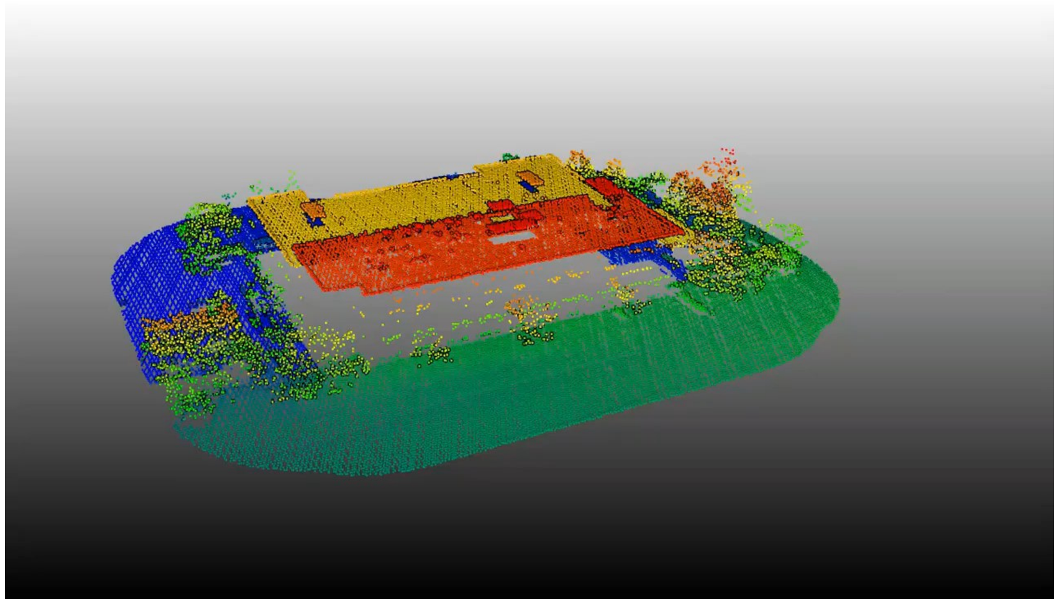

Figure 1. High resolution scan of GeoSLAM of a building showing multiple floors and details

They do not capture a key element of interest: **mapping human behavior and other moveable objects**

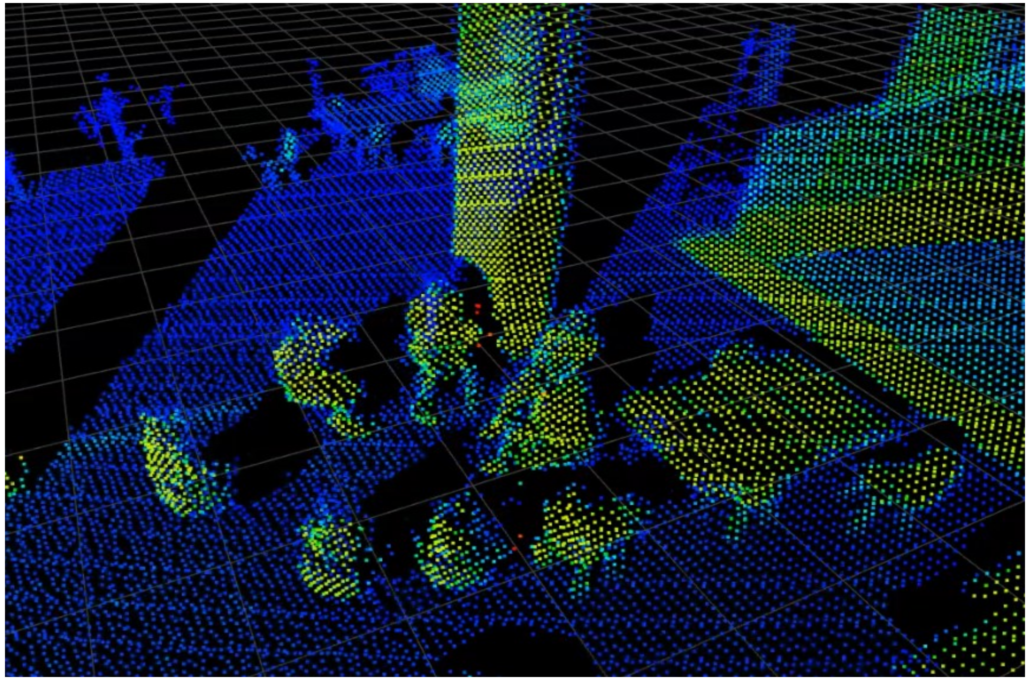

Figure 2. Humans being captured in the point clouds in lidar scan

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Indoor Remote Sensing

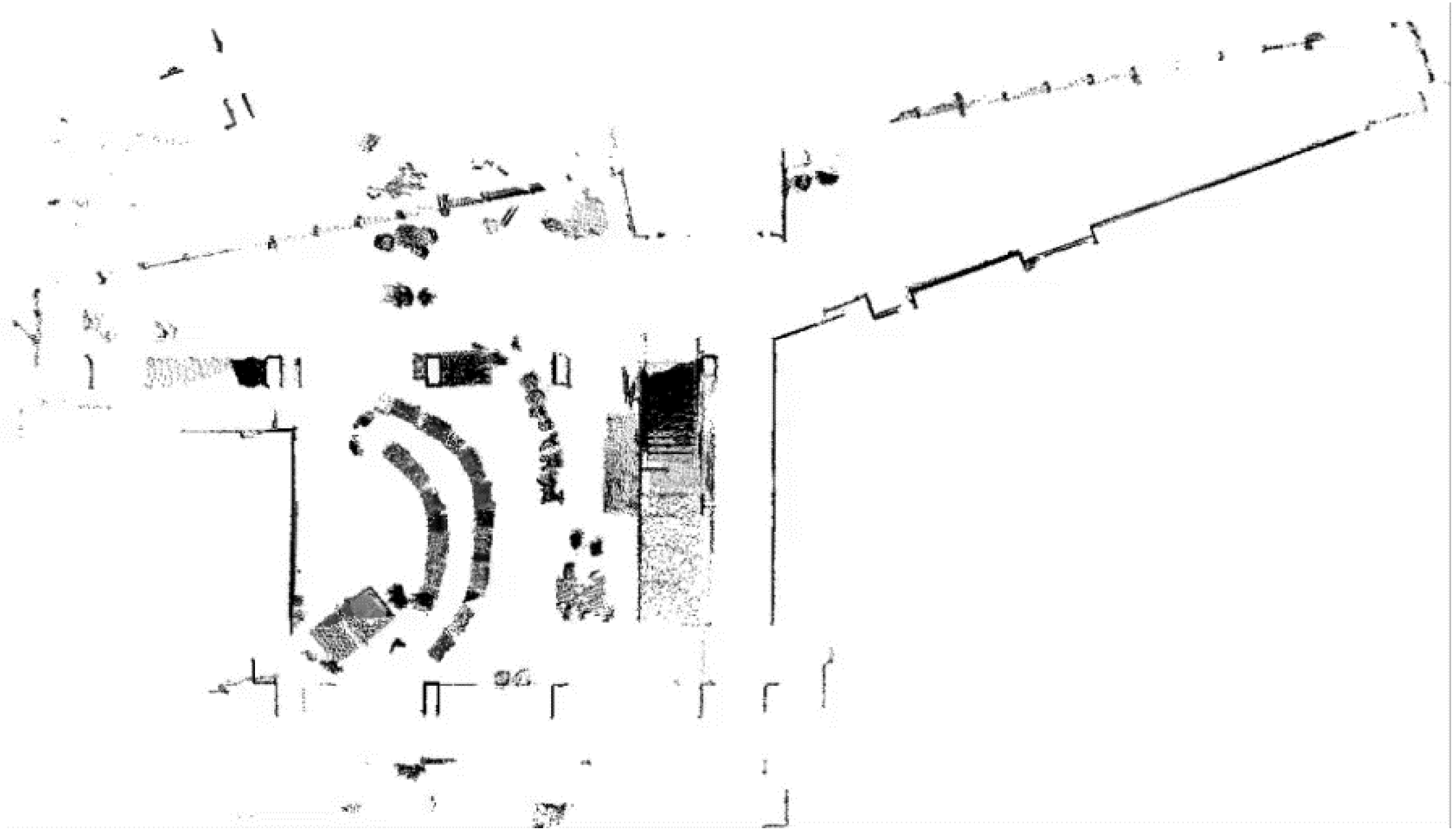

Figure 3. Animation created from lidar sensors

Building Ecology

How are meaningful places created?
How do they manifest over space and time?

How do patterns of use and interaction change in response to affordances and disturbance?

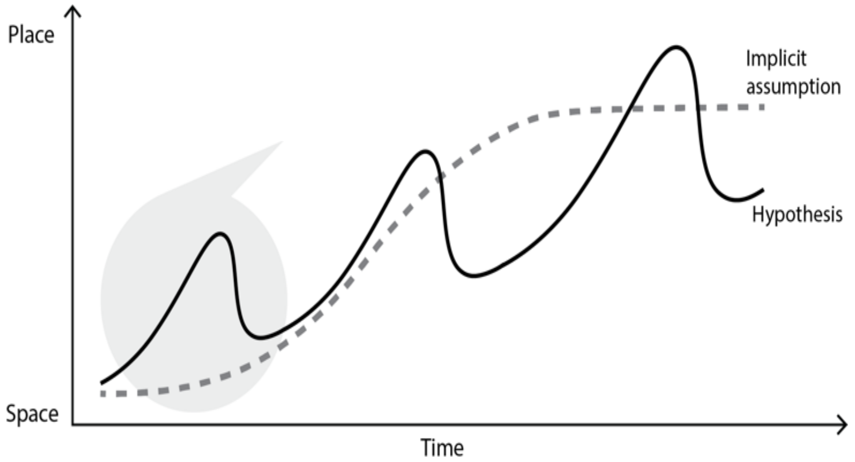

Figure 4. Graph showing how people create meaning to a space over time

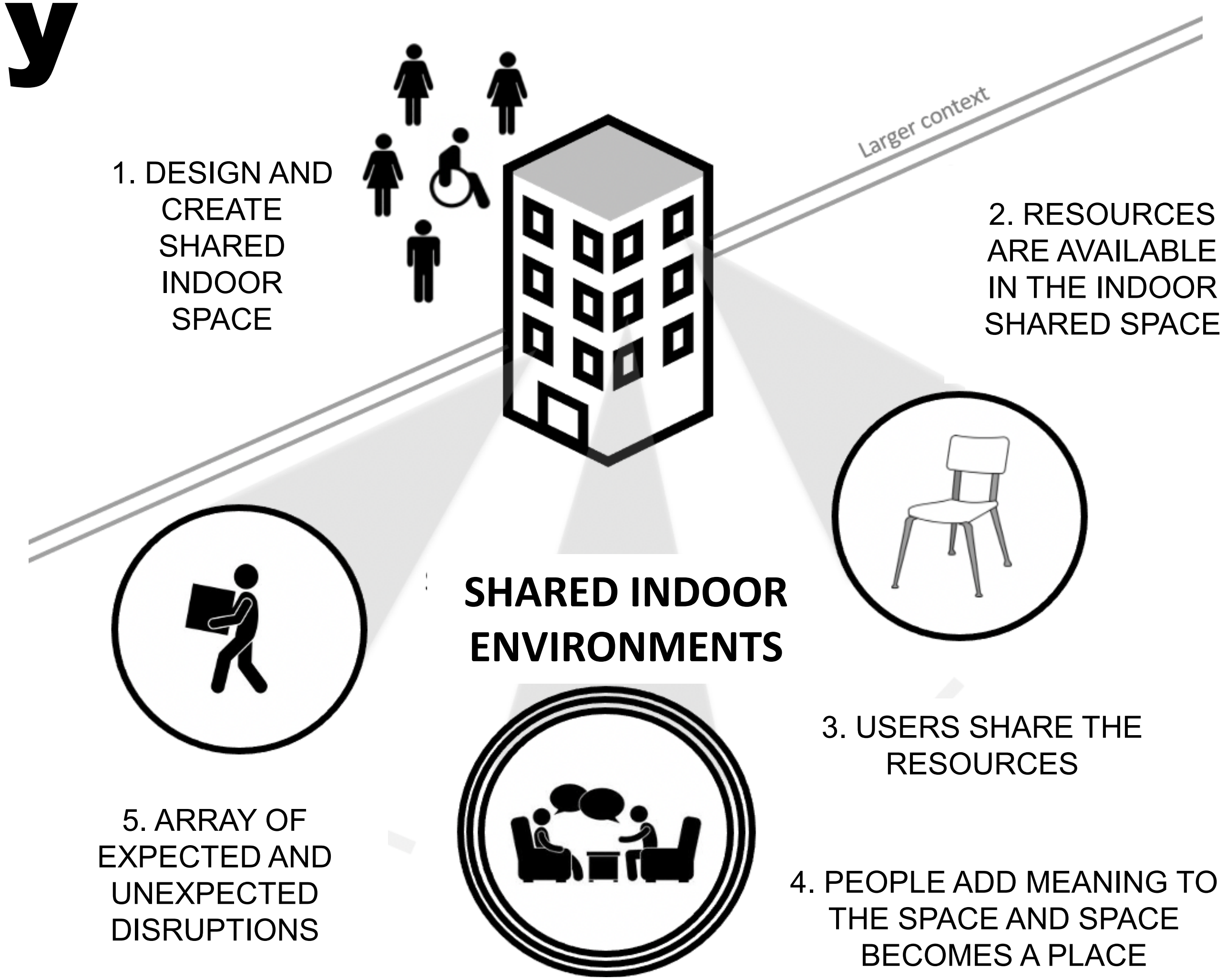

Figure 5. Schematic diagram of relationship between buildings, resources and people within buildings

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Study Area

- Capture the dynamic elements of a mixed-use building on the VT campus
- First floor of the Creativity and Innovation District (CID) at VT.
- CID is a residential and academic building with an area of 225,000 sq. feet.

Figure 6. CID lobby on a regular day with furniture and people using the space

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Lidar Sensors: Blickfeld Cube I

Figure 7. Blickfeld Cube

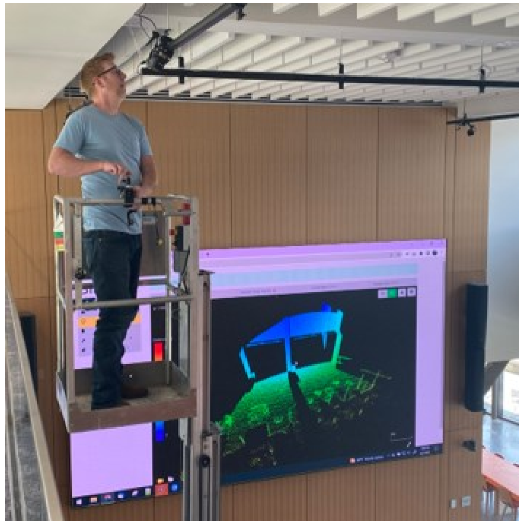

Figure 8. Lidar installation in CID Lobby

11 forward-facing lidar sensors continuously image the space.

<u>Each Blickfeld Cube transmits ~2 MB/s</u>

- 72° x 30° FOV, 2.4 Hz, 230 scanlines
- Transmits via Ethernet, Python decode
- Time sync with NTP / PTP
- 155 GB per day / 1.7 TB per day for all 11
- Models for outdoor use available

Using indoor coordinate reference system (Chen 2018, Chen and Clarke 2020) to co-locate the sensors and fuse them into a seamless stream.

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Near Earth Imaging Lab

Lidar perception software segments the stream into objects.

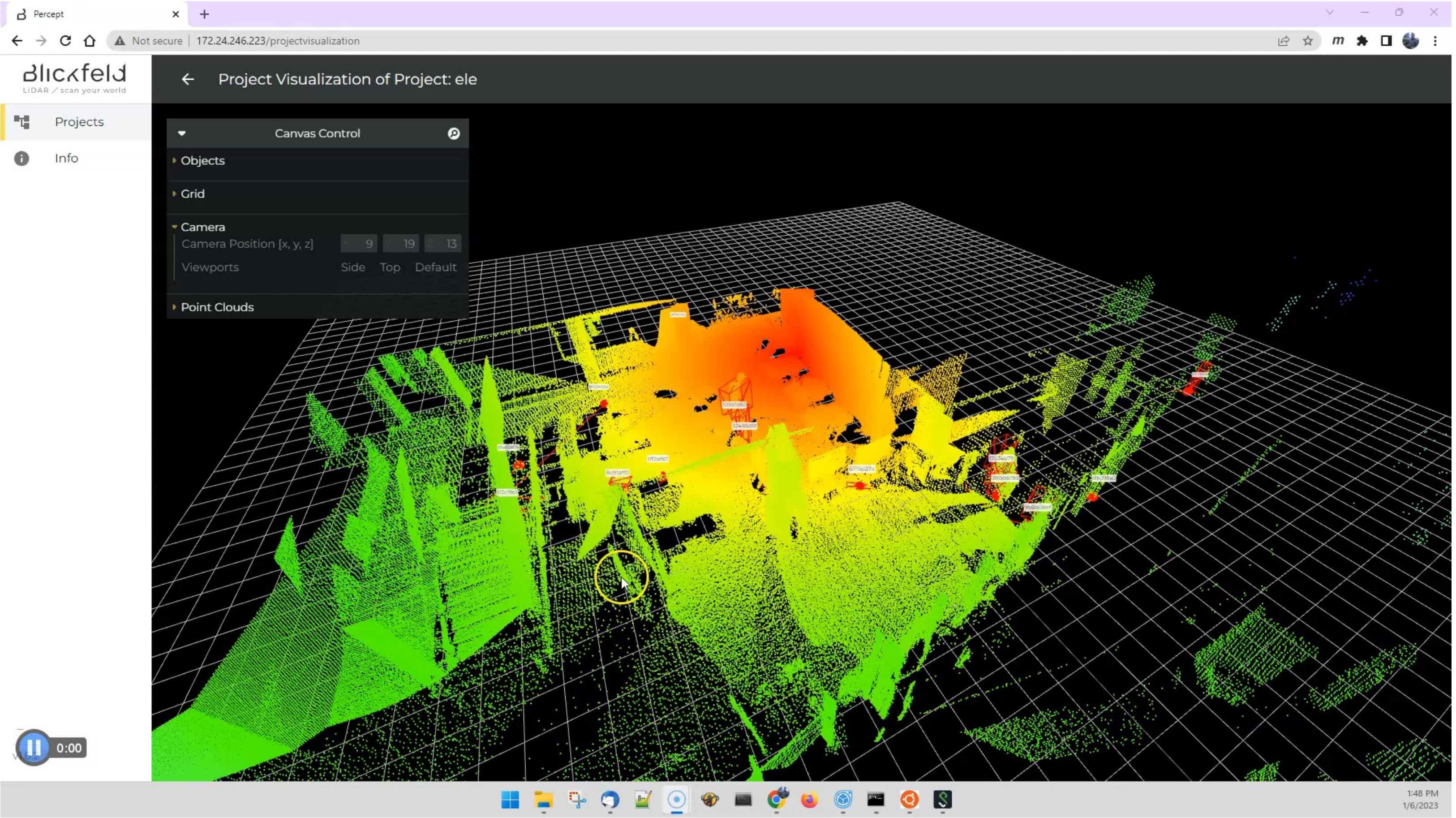

Figure 9. Video showing objects and people being detected in real-time by Blickfeld's Percept software in the lobby space. The vector-based logs include position and attributes (volume, speed, trajectory, etc.).

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Raw Data Management

1. Full 3D lidar point cloud
(0.1 Hz, 1500 KB; **13 GB / day**)

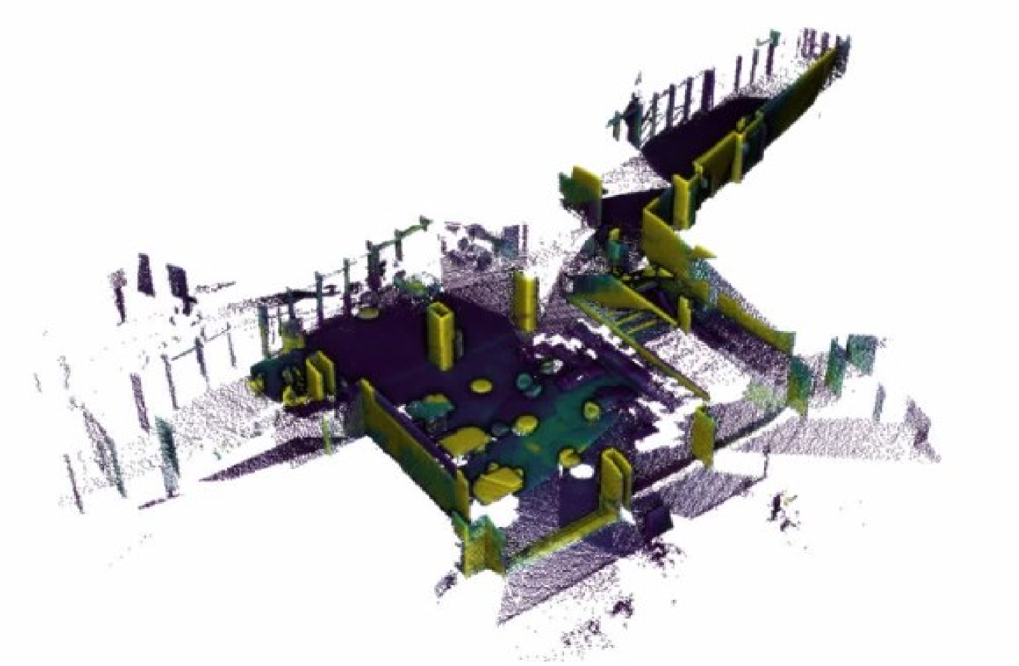


Figure 10. Point cloud visualization of assembly of point clouds from 11 sensors

2. Orthographic representation
(1 Hz, 5 cm, 50 KB; **8.6 GB & ~100 B pixels / day**)

Figure 11. Orthographic image generating removing a cluster of points for the floor

Data is aggregated into NetCDFs for analysis and visualizations for inspection and review.

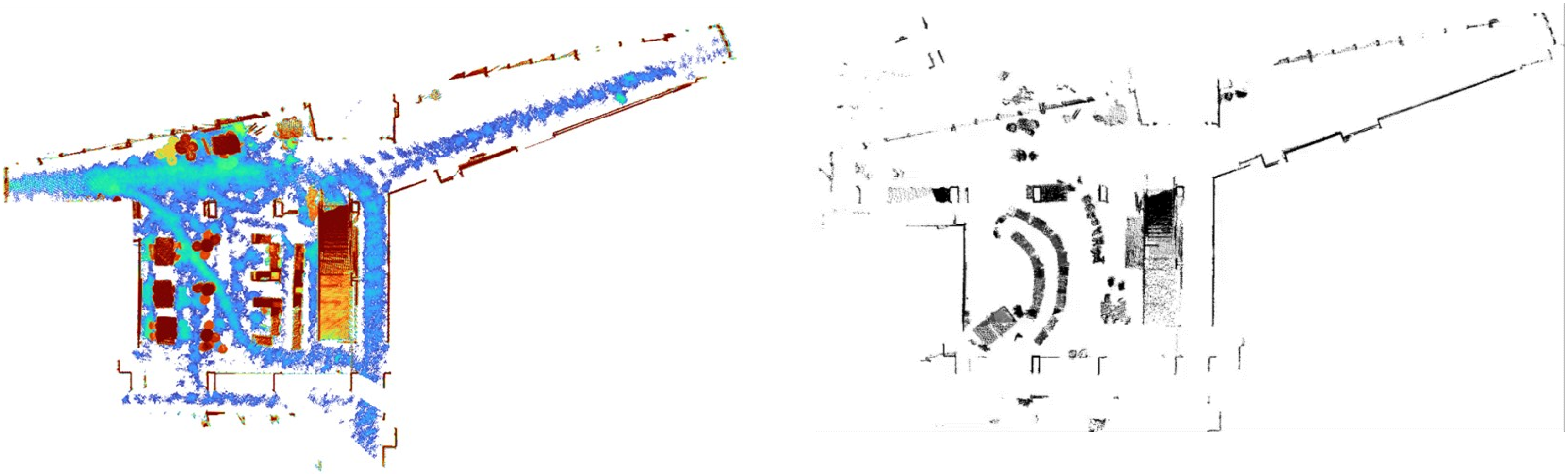


Figure 12. Hourly summary (left). Red shows non-moving objects (walls, furniture) and blue/green shows activity and Daily Animation (right)

These visualizations allow us to detect differences in activity over time.

Figure 13. Lobby space being occupied by students during Superbowl 2023 watch party

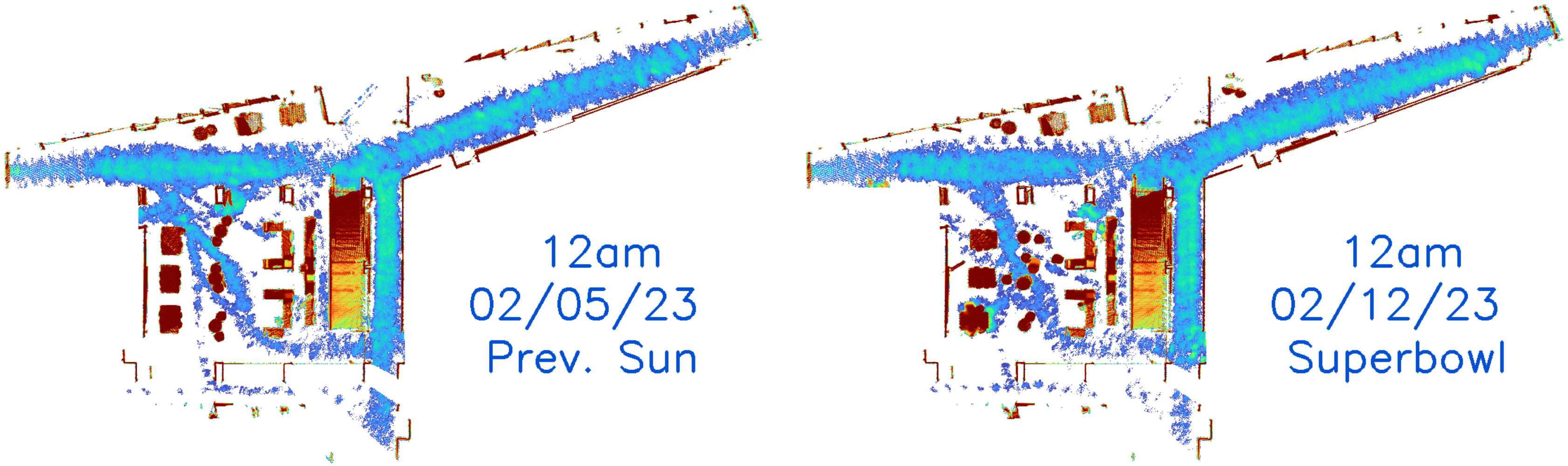
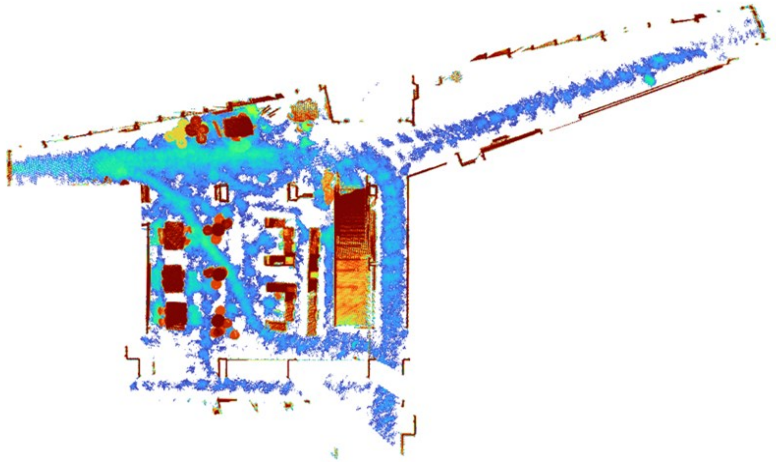


Figure 14. Comparison of occupancy and movement in the space on the Superbowl watch party with the previous Sunday

Small Multiples show monthly patterns.



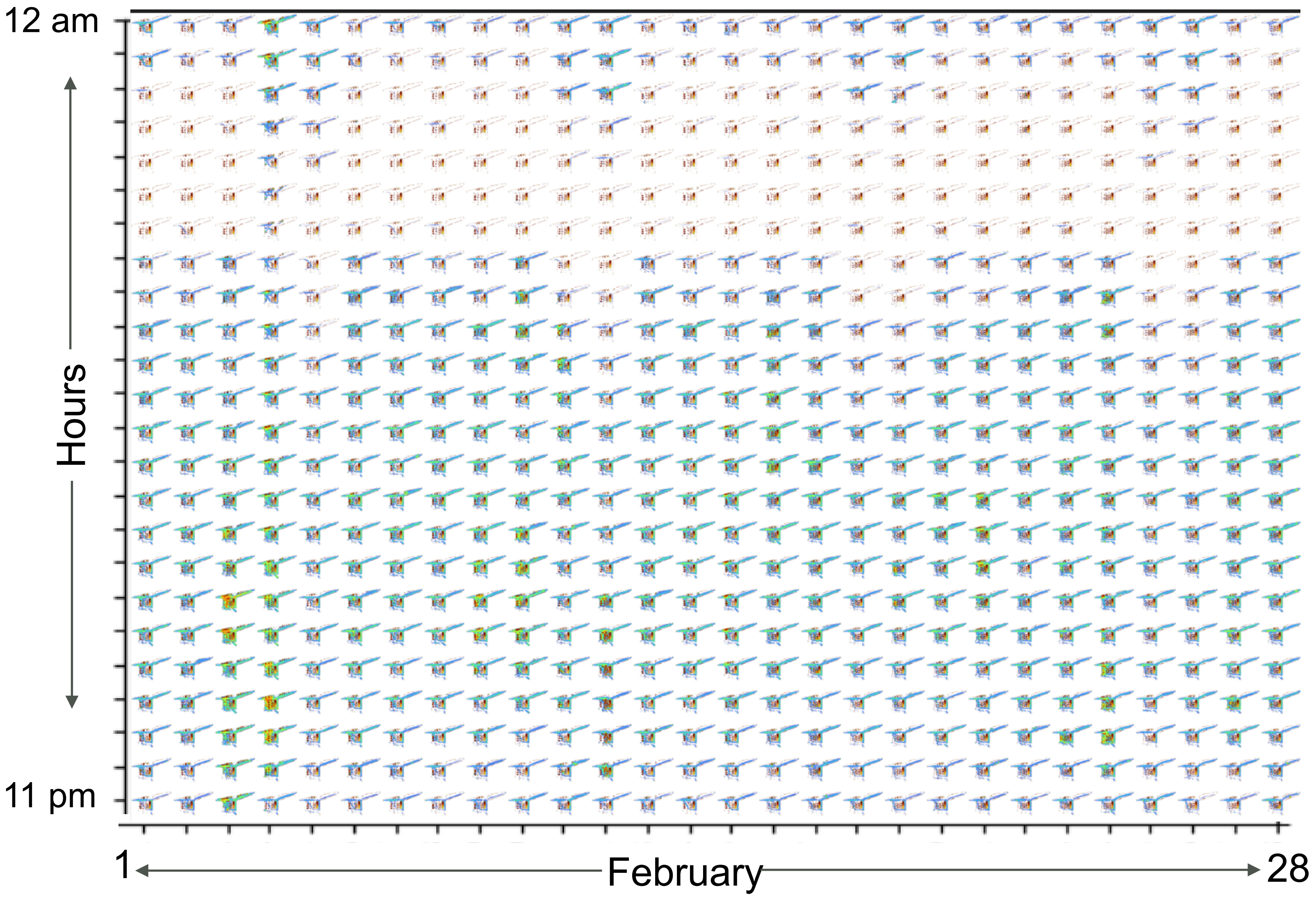


Figure 15. Activity patterns are visualized with hourly composites and monthly small multiples (Feb shown).

Perception software output lets us visualize and analyze individual behavior.

Logs are written out as JSON files.

Contains positional information, but also attributes such as velocity and volume.

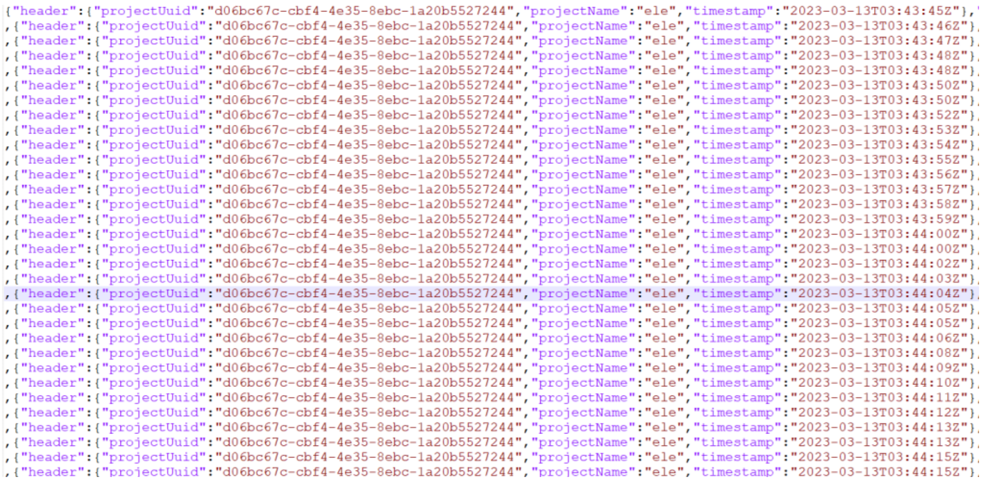


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Figure 16. Sample JSON data logged by Percept software

We use Python to convert the JSON files into a vector file.

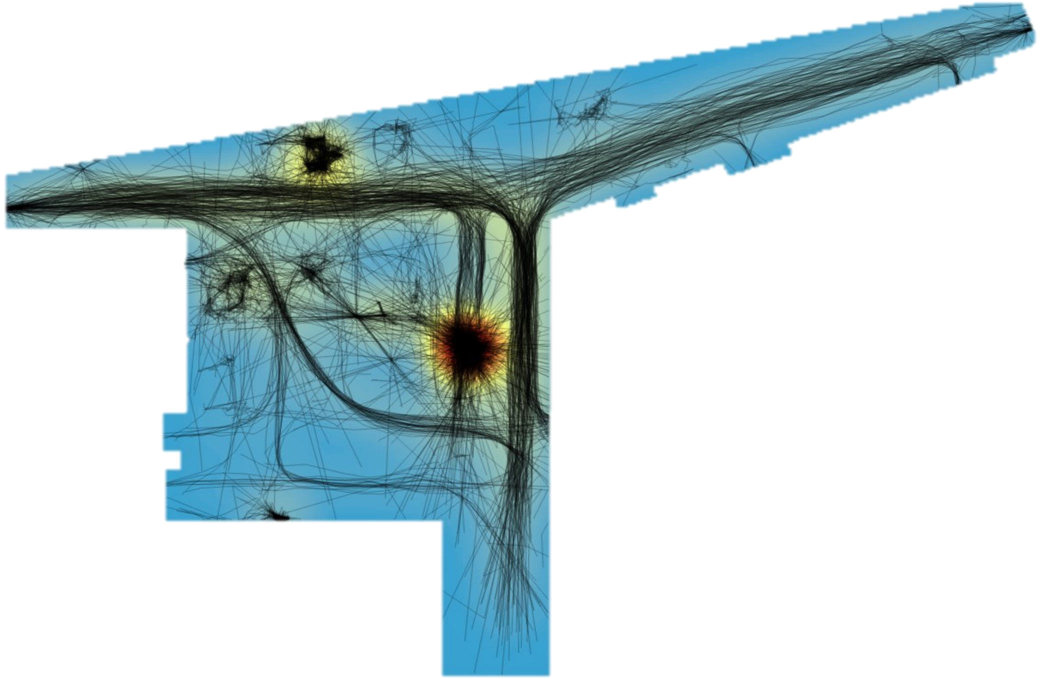

Figure 17. Visualization of Tracks generated from the JSON file

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Computer vision and AI-based video segmentation applied to raw lidar derivatives

Figure 18. A frame showing people and noise with OpenCV in a lidar stream animation. Green boxes represent people, and the blue boxes represents noise

Data Analysis: Daily Activity

- Overall intensity from all sensors represent the overall amount of occupation within the space
- The spatial average of the temporal average over an hour was calculated to determine the activity

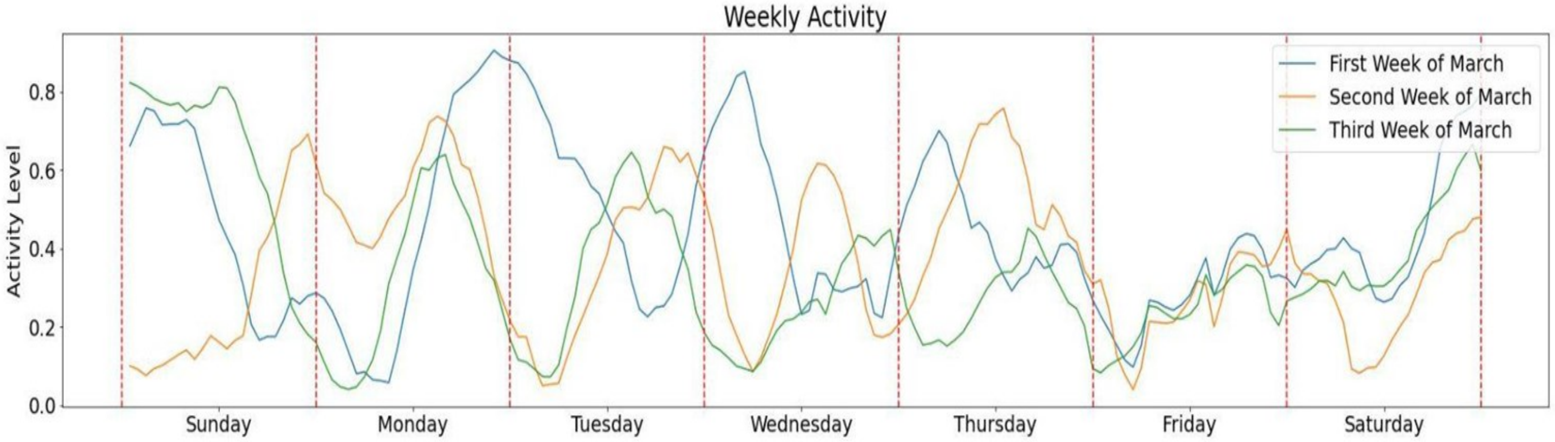

Figure 19. Line Plot showing the activity in the CID lobby for the first three weeks of March

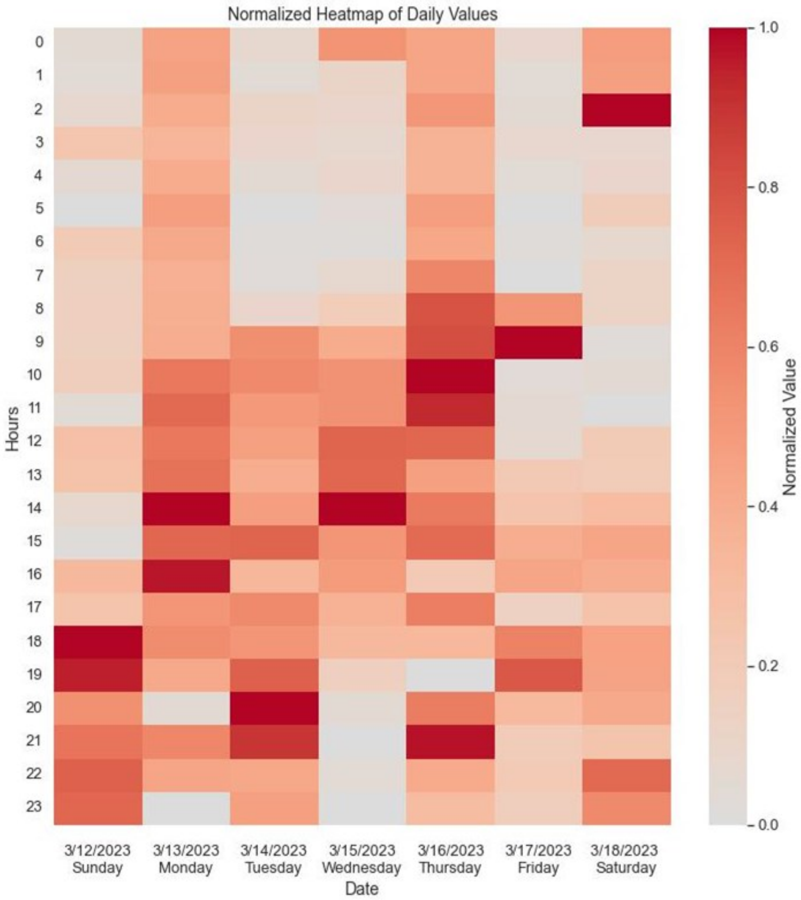

Figure 20. Heatmap showing activity level fluctuations for a week in March

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Data Analysis: Space Time Cube

Data at the hourly and daily levels were used for Space Time Cube analysis.

Trends and patterns can be identified such as the intensity and frequency of occupancy and movement in different spaces.

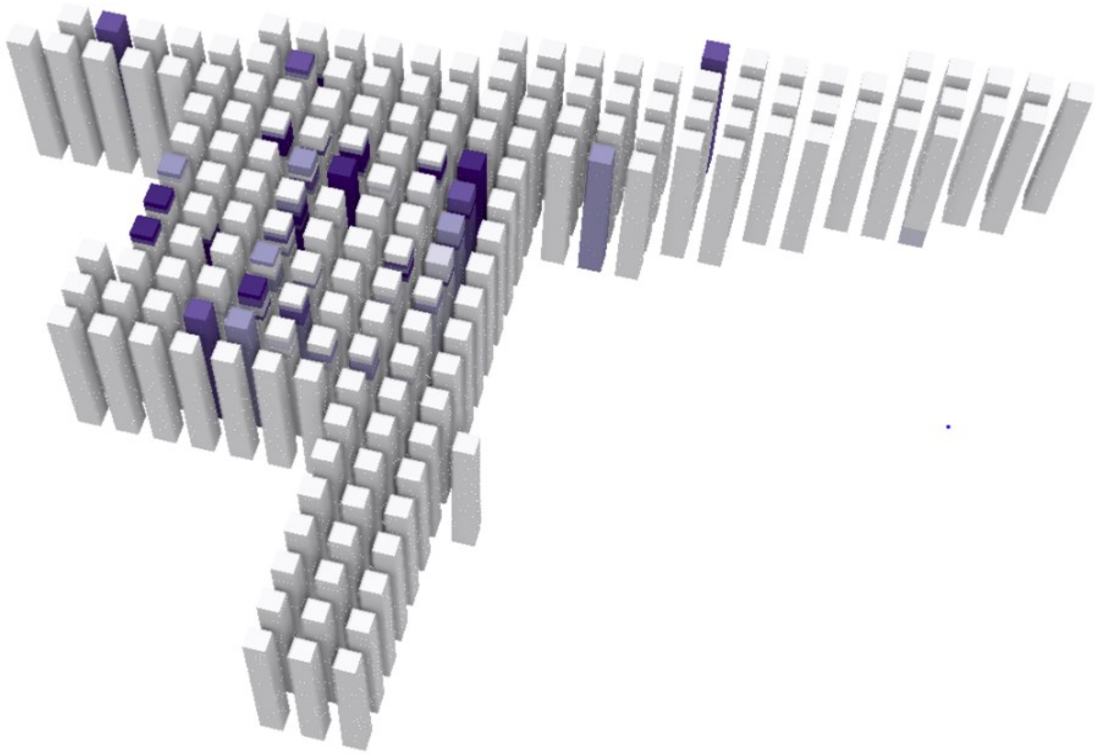

Figure 21. A 3D Visualization of a Space Time Cube charting the CID Building Space - There are 24 time slices representing the average movement over each hour of one day.

Building Model

- CAD-derived vector data
- Records of important resources (e.g., electrical outlets)
- Digital Calendar of Activity
- Photospheres
- Mobile lidar (GeoSLAM) scans

Figure 22. CAD drawing for the CID space

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Way Forward

Deployment of a network of microphones and a system to spatialize the sound data

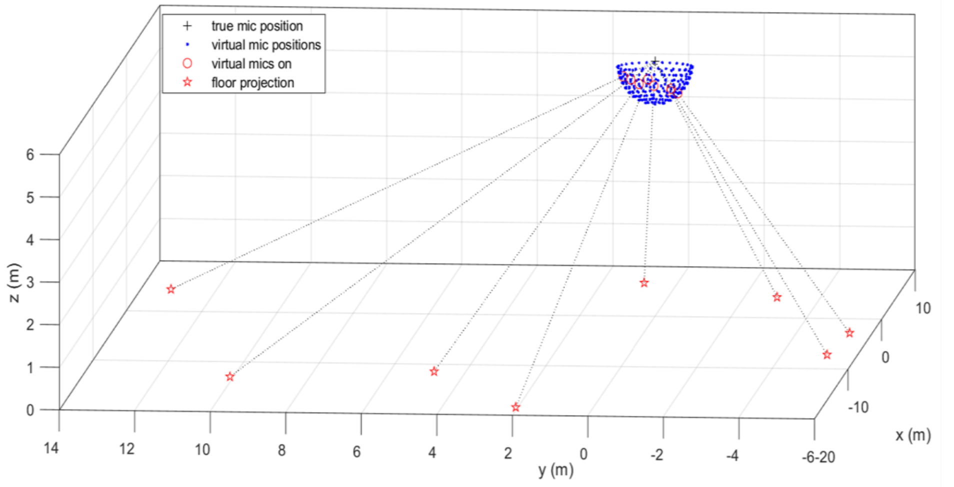


Figure 23. Sound data from a collection of microphones can be triangulated into position on a raster surface - Figure by Dr. Nicole Abaid

An ArcGIS Enterprise Base Deployment to host an ArcGIS Indoors server, with floor-plan functionality and indoor-based visualization.

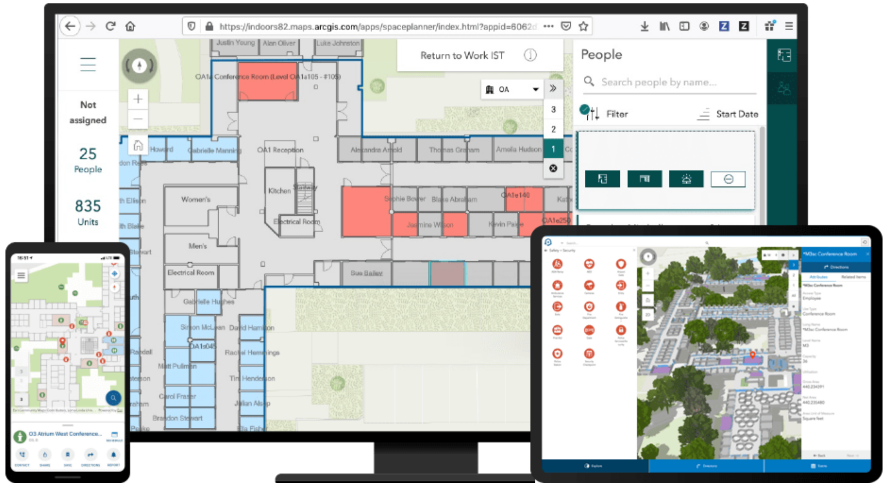


Figure 24. Image showing overview of ArcGIS Indoors. Source: [ArcGIS Indoors 2021 Webinar Series (esri.com)]

Applications

Design experiments and test hypotheses about indoor spaces

Continuous monitoring can help to identify and respond to potential hazards

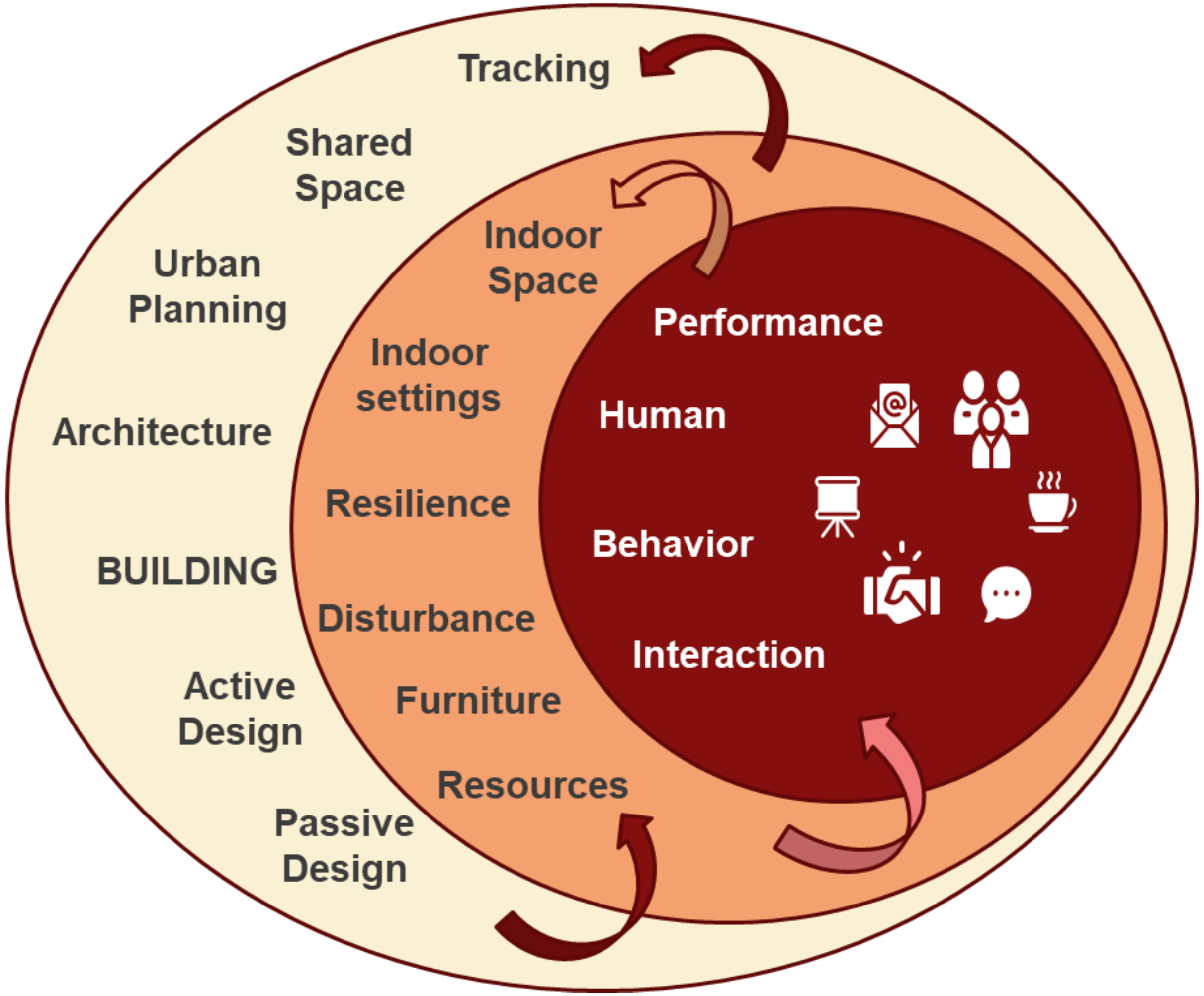
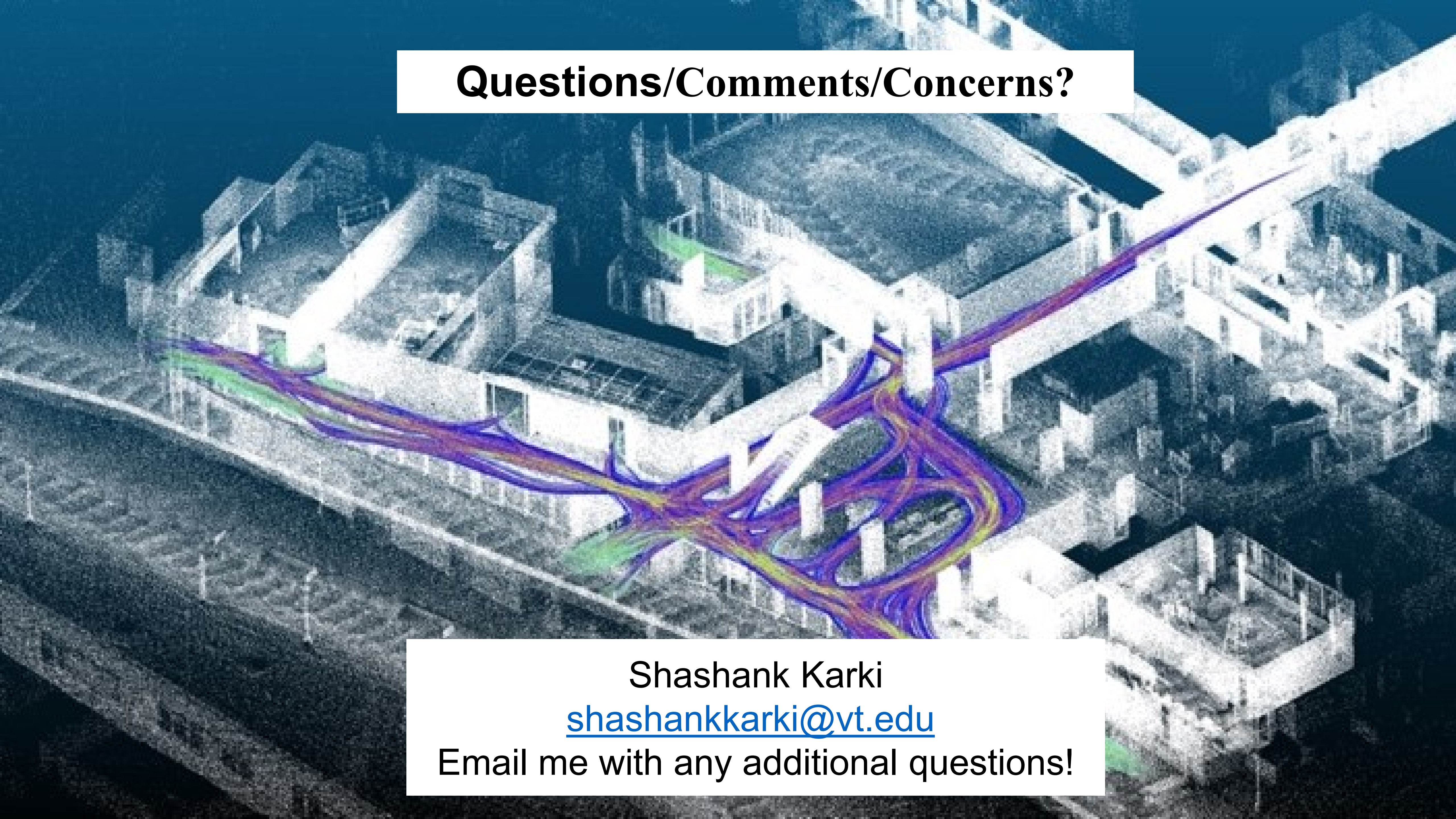


Figure 25. Schematic diagram showing the relationship between the layout of the building and human behavior



Questions/Comments/Concerns?

Shashank Karki
shashankkarki@vt.edu
Email me with any additional questions!