Beyond the Clutter: 3D Sidewalk Auditing for Spatial Equity

Evaluating the Viability of Smartphone-Based Gaussian Splatting for 3D Sidewalk Modeling Against a LiDAR Benchmark

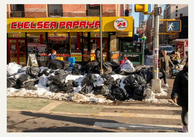
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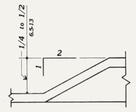
CENTER FOR SMART STREETSCAPES

BACKGROUND & PROBLEM

- Over 13% of U.S. adults **(approximately 36 million people)** live with a mobility disability (difficulty walking or climbing stairs), making sidewalk infrastructure a critical public health utility.
- Municipal audits demonstrate that **a majority of urban sidewalk corners contain unaddressed accessibility barriers**, such as non-compliant slopes or missing curb ramps.
- Under the 2010 ADA Standards for Accessible Design (§303 Changes in Level), vertical surface faults or displacements **≥0.5** in strictly violate federal regulations, creating severe trip hazards for wheelchair users, elderly pedestrians, and strollers.
- High-precision Mobile LiDAR systems require major capital investment **(≥$4k per unit)**, forcing cities to rely on reactive complaints that leave miles of pavement uninspected.
- Standard 3D scanning bakes temporary surface clutter (trash heaps, parked e-bikes, vendor stalls) directly into static geometry as false-positive structural defects.

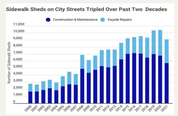

The image shows a severely cracked, lifted, and uneven NYC Sidewalk Surface.


Snow and trash bags pile up outside Chelsea Papaya, NYC.



ADA architectural requirements for a sidewalk or flooring surface


LiDAR Scanner



Tripling of NYC sidewalk sheds (2000–2021), demonstrating escalating temporary street clutter.

Prohibitive LiDAR Costs (≥ $4k) → Conflated Street Noise → Unaddressed Physical Barriers

THE INTERDISCIPLINARY PIPELINE BRIDGE

Community input defines what to measure, and engineering defines how well we can measure it.

- Our project used interview and survey data to help us target what sidewalk features to focus on and digitize, helping us ensure our technology is not only accurate but relevant to the barriers residents actually experience.
- Our social science data revealed a strong community need for garbage, large cracks, and uneven pavement to be addressed.
- We thus particularly emphasized such features when using both our methods during sidewalk scanning.


Harlem storefronts and buildings rendered by a LiDAR scan

TECHNICAL ENGINEERING WORKFLOW

LiDAR (Ground Truth):

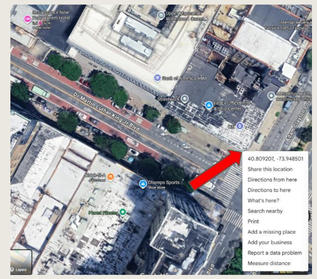
- Scan sidewalk segments with LiDAR sensor to obtain a raw point cloud (x, y, z)
- Import into CloudCompare; apply denoising to strip isolated/noisy points from real surface geometry
- Export cleaned point cloud as benchmark reference

Smartphone (3DGS):

- Record walkthrough video with MiSensorKit (iPhone)
- Split video into frames + camera pose JSON; process in Google Colab
- Generate point cloud and assign Gaussian "blobs" (shape, color, transparency), then splat to 2D for rendering
- Export smartphone-derived 3D model

Convergence:

- Align both point clouds in a shared coordinate frame
- Compare smartphone model against LiDAR benchmark for geometric accuracy (e.g., crack width)
- Feed validated results into ArcGIS for spatial mapping

Georeferencing being performed through the alignment of points from a LiDAR scan and the according coordinate system points found on Google Maps

OVERVIEW

Low-Cost Smartphone Data Capture | Dynamic Clutter Masking | Community Grounded Hazard Targets | LiDAR Precision Benchmarking

A low-cost smartphone scanning pipeline that erases temporary street clutter (like pedestrians) to accurately detect permanent sidewalk damage requiring city repair.



Dynamic object (pedestrian) identified, masked and removed from a frame of a sidewalk scan

HARLEM COMMUNITY SURVEY ASSESSMENT (N= 44)

88.6% Demand Government Action

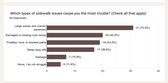
79.5% Perceive Spatial Inequity

70.5% Impacted by Concrete Cracks

- **Pedestrian Sample Profile:** 68% residents, 32% commuters (47% daily corridor–125th Street–walkers).
- **Transit Disruption:** 82% face navigation barriers; 59% encounter daily obstacles.
- **Vulnerable Demographics:** 19% live with disabilities that affect mobility 65% are parents/ caregivers.
- **Key Hazards:** Uneven Cracks (71%) > Damaged Ramps (46%) > Blocked Paths (43%) > Steep Drops (39%).







QUALITATIVE INTERCEPT INTERVIEWS & CODING FRAMEWORKS

Code	Focus	Prevalence	Key Finding
ROLE	Trip Purpose	Residents - 50% Worker - 25% Visiting - 12.5% Gym - 4.2%	Most individuals live in harlem.
Importance	Value of Sidewalk Quality to Individual	62.5% - high importance 29.2% - moderate importance 8.3% - low importance	Most pedestrians consider sidewalk quality a high priority issue.
Obstacle	Immobile Objects	50% complained about cracked and uneven sidewalks.	Only about 50% of people thing broken sidewalks is the main cause of their troubles.
Attitude	Mobile Objects	54% complained about trash and litter 29.2% - Crowds/people 20.8% - Dog feces 8.3% - Parked cars 8.3% - Constructions	Individuals were more concerned with immobile issues like trash and crowds then immobile issues.
Improvements	Ways to fix issues	58.3% - Better Sanitation 45.8% - Repavement 12.5% - More trash cans	Many individuals pointed out sanitation, repavement and community awareness as key solutions.
Trends	Change in quality	41.7% - Improved 37.5% - Stayed the same 20.8% - Worsened	Most people said it had improved.


Seraphine (top left), Julien (top right), Benjamin (bottom left), and Seraphine and Sophia (bottom right) engage in fieldwork

GIS SPATIAL TAXONOMY & DATA SCHEMA (ArcGIS Pro)

Category	Feature Class	Geometry	Key Attributes	Engineering Function
Static (*Permanent*)	Sidewalk_Segment	Polygon	Width_ft, Slope_Pct, Vertical_Offset_in, ADA_Compliant	Audits pavement integrity; flags vertical defects ≥ 0.5 in.
	Streetlight	Point	Asset_ID, Operational_Status	Catalogues municipal illumination assets.
	Trash_Bin	Point	Bin_ID, Capacity_L	Maps designated sanitation infrastructure.
	Bus_Stop	Point	Stop_ID, Shelter_Present	Evaluates pedestrian transit access areas.
Temporary (*Transient*)	Illegal Dumping	Polygon	Clutter_Type, Volume_Est_cu_ft	Guides dynamic loss masking and sanitation dispatch.
	Street_Vendor	Polygon	Kiosk_Type, Clear_Path_Width_ft	Quantifies temporary pathway bottlenecks.

Temporal Tracking (T_1 T_2)
Survey_Date: Timestamp of initial scan (T_1) vs. follow up scan (T_2)
Persistence_Flag:
0 (Temporary): Cleared by T_2 (filtered out as clutter).
1 (Permanent): Still present at T_2 (confirmed structural defect).
Defect_Delta_in (Δh): Measures if a crack grew or worsened over time ($\Delta h = h_{T2} - h_{T1}$)

DISCUSSION

Findings

- Smartphone-based 3DGS achieved comparable geometric accuracy to LiDAR at a fraction of the cost, making sidewalk auditing accessible without $4k+ equipment

Equity

- Because our method removes the cost barrier to auditing, communities unable to afford professional LiDAR surveys (or not prioritized by the city for one) can generate their own evidence-grade data
- This shifts sidewalk auditing from something only well-funded districts can access to something any resident with a smartphone can contribute to—directly addressing the mobility barriers faced by wheelchair users, elderly pedestrians, and caregivers

Limitations

- Smartphone accuracy still depends on lighting, distance, walking speed, and camera stability—less controlled than a dedicated LiDAR rig
- Google Colab did not always correctly mask and remove dynamic clutter, either incorrectly removing elements like a statue or failing to remove pedestrians
- Our sample size limits how confidently findings generalize citywide

Future Steps

- Deploy as a crowdsourced iPhone app so residents can scan and geotag defects directly, feeding underserved neighborhoods' data into the ArcGIS pipeline

"Sidewalk quality is important because they're the veins of our roads, and our roads lead us where we have to go." – Harlem Resident

REFERENCES

1.https://makeabilitylab.cs.washington.edu/media/publications/Saha_ProjectSidewalkAWebBasedCrowdsourcingToolForCollectingSidewalkAccessibilityDataAtScale_CHI2019.pdf

2.https://www.sciencedirect.com/science/article/abs/pii/S0968090X12001179

Image REFERENCES

Cracked sidewalk image: https://fkfirm.com/article/nyc-sidewalk-defects/

CHELSEAPAPAYA:https://metrostor.us/nyc-trash-revolution-progress-challenges-whats-next/

ADA SIDEWALK DIAGRAM: https://pages.uoregon.edu/ftepfer/access/ADAAGuplan/fig7d.html

SIDEWALK SHEDS: https://www.6sqft.com/the-number-of-sidewalk-sheds-in-nyc-has-tripled-over-past-two-decades/