Comparative Study of Urban Sensing Modalities for Curb Cut Surveys

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Abstract

In this project, we investigate the potential for new sensing modalities to help drive progress on streetscahep accessibility by reproducing a geographic section of a major data collection exercise - the Broadway Curb Cut Survey - using updated technologies. We compare three data collection methods: (i) a smartphone-based field survey with user-generated photos and curb cut locations; (ii) the mass-market 3D imaging device 'Structure Sensor'; and (iii) a 360-degree LiDAR scanner. Post-processing of the point cloud data on Broadway curb cuts is conducted, physical measurements are extracted, and a web-map is constructed to make data on accessibility problems easily accessible to decision-makers. Challenges identified include measurement of slope angles and accurate geo-location of the curbs. Having refined the methods through field testing, our work demonstrates the feasibility of 3D imaging to acquire useful information on physical properties of city streets - including slope width and steepness, presence of bumps and drops, and potholing. Such sensing methods may also help alleviate behavioral constraints to crowd-sourcing of accessibility data. Based on stakeholder requirements and our evaluation of the data collection methods, we propose the creation of a smartphone application that would combine survey methods with 3D imagery.

1. Introduction

1.1 Streetscape accessibility

People who use a wheelchair or have a mobility impairment number more than 100,000 in New York, and yet despite their numbers, the city very often fails this group (for People with Disabilities MOPD, 2017). Advocacy organizations have long complained that sidewalks and street crossings pose mobility obstacles that put their members in physical danger or impede their movement. Indeed, the city has faced major lawsuits for failing to maintain the curb cuts that wheelchair users rely on. In this study, we explore the potential for urban sensing modalities to address this problem.

The use of sensors within and across a city such as New York offers rapidly expanding possibilities to generate data on urban challenges such as wheelchair accessibility. Streetscape accessibility is an inherently physical and three-dimensional phenomenon for which elevation and slope, structural properties such as cracking of concrete, and design considerations such as orientation of cross-walks with regard to traffic are all relevant. These dimensions of the challenge make it amenable to urban data collection approaches, from GIS-based surveying with human input to 3D imaging using LiDAR. Moreover, streetscape accessibility is a challenge conditioned by limited budgets of organisations such as the city's Department of Transport. Given the high costs of traditional data collection methods such as sending teams of surveyors to street corners, substantial benefit could be attained from sensing modalities that harness volunteer manpower to acquire data. Expected

deployment of 3D imaging technologies in the 2019 release of the iPhone provides another motivation (Webb, 2017).

1.2 ADA standards

Recognizing the importance of accessible streets to wheelchair users and others with mobility impairments, the Americans with Disabilities Act (ADA) sets out detailed standards for Departments of Transport as well as building owners to abide by (www.ada.gov). A key provision in the ADA concerns curb cuts. Where sidewalks meet an intersection, or a pedestrian crossing exists, the ADA mandates that the sidewalk surface be cut away in a smooth ramp that leads to the street with suitable width and a sufficiently shallow incline. However, while the ADA is widely recognized as a legislative advance, disability rights groups complain that it goes un-implemented, with many street corners posing insuperable obstacles to their users. Wheelchair users or the visually impaired can be blocked or endangered by, among other things: sudden drop-offs, crumbling and uneven concrete, curb cuts that lead directly into oncoming traffic at the center of an intersection. The ADA also mandates detectable warnings such as stripes or bumps in the curb ramp surface, which are frequently lacking or eroded.

1.3 State of accessibility in NYC

Responding to legal pressure, the Manhattan Borough President in 2014 organized a survey of curb cuts along Broadway (MBPO, 2015). Requiring one year to complete, the Broadway Curb Cut Survey detailed the presence and condition of safety features along the 53-kilometer street. Forty trained volunteers measured ramps at over 100 intersections on Broadway, and their efforts are captured within the Broadway Curb Cut Survey Dataset on the NYC OpenData platform. The survey, which was highly labor intensive to produce, offers a thorough picture of the accessibility status of a major urban thoroughfare.

The survey revealed that approximately 80% of the city's curb cuts do not meet ADA standards. This is despite some $243 million being spent over a 15-year period on sidewalk accessibility (Hogan, 2017). Of 1,209 curb cuts surveyed, 28% were too steep, 60% were uneven where the cut meets the street, and 24% had crumbling concrete. Of particular concern to the visually impaired, nearly 90% lacked detectable warning features such as bumps or textured stripes.

Pressure to address the issue has come from civil society groups, notably a major lawsuit from the Eastern Paralyzed Veterans Association, which resulted in a 2002 settlement in which the city endeavored (albeit without binding timelines or monitoring) to upgrade curb cuts to ADA compliance (Hogan, op cit).

2. Previous work

A growing research literature addresses the physical form of city streets using sensing technologies. Previous studies at TU Delft employed a photogrammetry algorithm from UMG to measure street geometries (Aarsen, 2015). For our work, we similarly considering applying Structure from Motion (SfM) algorithms to images collected at the study site, but concluded that other methods suit the project requirements better. Curb detection methods that fuse 3D Lidar and imagery data for Autonomous Land Vehicles (ALV) are achieving

advances in precise navigation of urban environments (Tan et al., 2014). Detection of mobility challenges has also been addressed through computer vision applied to Google Street View imagery, achieving detection of missing curb cuts through a pipeline of computer-assisted human input (Kotaro Hara, 2014).

Complementing these sensing approaches are recent efforts to harness the potential of crowdsourcing - especially as facilitated by widespread smartphone use - to fill information gaps on urban accessibility. Specialized disability-focused crowdsourcing efforts include WheelMap, a Berlin-based non-profit with international operations, and J'Accede, a French non-profit initiative. These and similar UK and US-based initiatives have built communities of volunteers who upload user-generated information on restaurant, public building or transit accessibility. Despite success and recognition, these crowdsourcing initiatives have attracted fewer users than commercial crowd-sourced resources such as TripAdvisor and Yelp (Captain, 2017). Given multiple demands on volunteers' time, a key consideration to build larger crowdsourcing communities is to reduce the time required for data collection.

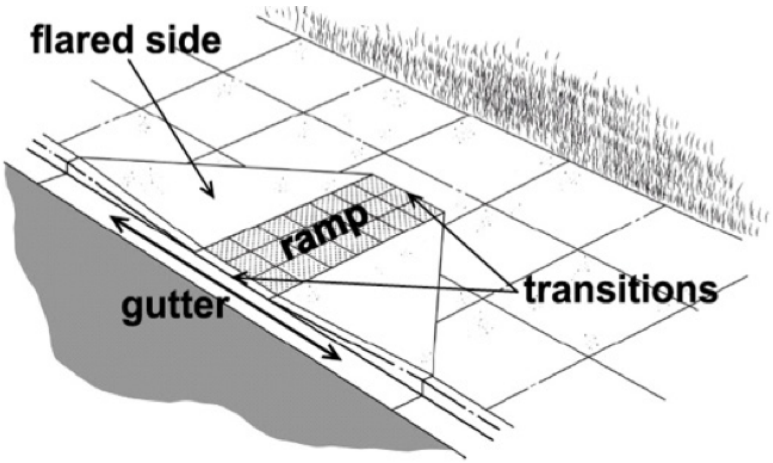

Figure 1: ADA Curb-Cut Requirements

3. Methodology

In this study, we reproduce a section of the Broadway Curb Cut survey using three data collection methods. Through these innovative data techniques, we evaluate the potential role of smartphone-based surveying and 3D imagery to produce useful information on urban accessibility. The smartphone-based survey is conducted between Union Square and 26th Street, while the Structure Sensor and LiDAR scan are deployed for one specific intersection: Broadway and 26th Street.

3.1 Data requirements

Data collection requirements were defined with the needs of three stakeholder groups - the DOT, city political stakeholders such as the Manhattan Borough President, and disability advocacy groups - in mind. These

stakeholders share the strategic goal of improving accessibility of NYC streets. Functional requirements for a data collection method to support them in this goal included (i) adequate data quality; (ii) low cost; (iii) speed and ease of use; and (iv) suitability for crowd-sourcing.

Considering these requirements, we identified priority data points to collect for each curb inspected. Table 1 lists these data points ands their corresponding ADA requirements. The data points are considered the minimal viable data requirements needed to assess curb accessibility at a given location. The data collection methods will be evaluated for their ability to collect these data points while considering the functional requirements listed above. In terms of data quality, the method must be able to collect useable measurements for the items listed - including slope (in geometric degrees) and physical measurements of width and height. For attributes slope or ramp width, standard error of up to 5% is considered tolerable (in light of the large

Attribute	ADA requirement
Slope	0.08
Width	36 inches
Lip measurement	Zero (flush to street)
Position with regard to intersection	No hazardous positions (center-cuts)
Detectable warning	Stripes or bumps

Table 1: Data collection: Priority attributes to measure

number of curbs to be surveyed and limited budget). For attributes such as whether a curb cut leads into a hazardous part of the intersection, inputs are qualitative and require human input. Location accuracy is important since each curb must be locatable for remedial works.

3.2 Data collection methods

With these requirements under consideration, data collection was conducted through three methods: (i) smartphone-based survey; (ii) Structure Sensor; and (iii) LiDAR scanner.

(i) Smartphone-based survey

A survey tool was built using ESRI Survey123 software. The tool comprised 12 questions in a web-based survey form. Publicly available on the internet, the tool may be utilized by anyone with a smartphone, allowing multiple team members to gather data independently. Data is entered for each curb inspected by a team member, making use of smartphone GPS and measurements using a tape measure. A photo is taken of each curb cut. The survey tool may be viewed at http://bit.ly/2I85t5Z.

Construction of the survey questions required several iterations of field testing. Challenges included:

- **Strict measurement definitions required.** Physical measurements for lip / bump height and ramp width proved, in initial field testing, to be ambiguous. The team agreed on standardized definitions for the measurements. For lip / bump height, it was agreed to measure height at maximum point of the drop from sidewalk to street - since the maximum height determines the difficulty faced by wheelchair users.
- **Condition classification scheme**. For ease of interpretation by decision-makers the team opted to include an 'overall condition' attributes based on an ordinal scale from 0 to 5. At first, subjective judgment about what constitutes categories such as 'good' or 'very poor' raised concerns over data

consistency, assuming multiple team members conducting the survey. To resolve this, a classification scheme was introduced with decision rules for inclusion of a curb in a given category.

- **Challenge of slope angle measurement.** A best effort was made to generate measurements of slope angle. This comprised measuring height from street to maximum elevation of sidewalk using a tape measure. Combined with a measurement of ramp length, simple Pythagorean geometry allowed the extraction of the angle of ramp elevation. However, measuring elevation by tape measure proved difficult. Team members were not confident in the reliability of this method and hence of the manual slope angle measurements generated.
- **Location accuracy**. Field testing revealed major problems with using iPhone GPS. The survey instrument was constructed for the user to hit 'locate', at which point the phone GPS would record longitude and latitude coordinates, attaching this to the curb record. However, in post-processing, curbs ended up 50 meters from their true. Given that typical 4-year intersections have 8 curb cuts, and complicated intersections with mid-street elevated sidewalk may have 12 or more, this degree of inaccuracy is not tolerable. New fields were introduced to allow for manual snapping of curbs to their true location. The fields were: (i) cross street; and (ii) crossing orientation [north-south or east-west].

Having refined the survey tool, curb cuts were surveyed between 26th St and Union Square.

Condition Classification Scheme	
1 - Very incompliant	High lip, cracking, potholes, steepness (3+)
2 - Multiple incompliances	High lip, cracking, potholes, steepness (2+)
3 - One incompliance	High lip, cracking, potholes, steepness (1)
4 - Good	Some steepness or cracking
5 - Very good	No cracking or lip, smooth ramp

Figure 2: Condition classification scheme: overall curb condition ratings

(ii) Structure Sensor

Structure Sensor is a mass market infrared sensor manufactured by Occipital. Retailing at $300, Structure Sensor is oriented towards several 3D sensing use cases, including interior design (capture of room interior dimensions), health (capture of body dimensions), and 3D model creation for gaming and software enthusiasts (capture of small items, such as models or figurines, at close range). The device is a sensor only, and requires connection to an iPad with a available memory to process the raw signal captured by the sensor. Several SDK apps are available based on existing use cases. After tested several, the Capture package was selected due to its medium range and ease of use.

The sensor with Capture package was first calibrated to ensure alignment between the iPhone camera image and the infrared range data. At our selected site, the Structure Sensor was used to scan curb cuts for which our measurements - including ramp width, lip height and slope - were required.

Specifications:

- Infrared structured light projector, uniform infrared LEDs
- Range: 40cm ˜ 350cm
- Precision: 0.5mm at 40cm (0.15%), 30mm at 3m (1%)
- Field of View: Horizontal: 58 degrees, Vertical: 45 degrees

- Resolution: VGA (640 x 480)
- Weight: 95g

Figure 3: Structure Sensor attached to iPad

(iii) LiDAR scanner

The Leica P40 LiDAR Scanner is a high quality device suitable for structural engineering applications where 3D imaging at high precision is required. As a ground-mounted device, it requires time to deploy in a specific outdoor location. As distinct from Structure Sensor, the P40 is a full assembly device that can capture, compute and generate files by itself.

The scanner does a 360 degree scan centered from where it stands. In our work, we deployed the P40 to the Broadway - 26th Street intersection and conducted a scan. The scan covered the targeted curb, although this was only a tiny portion of the overall scanned data, which captured the surrounding buildings in great detail. We cut area of interest out, measured the curb dimensions in points cloud.

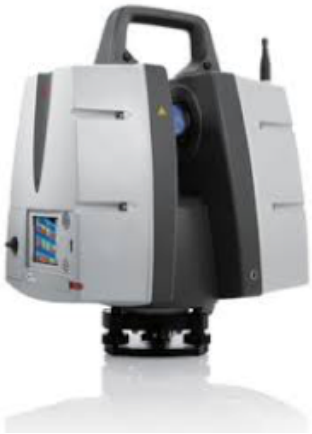

Figure 4: Leica Lidar Scanner P40

Specifications:

- Range: 0.4m ˜ 470m (accuracy: 1.2 mm + 10 ppm)
- 3D position accuracy: 8” vertical 3 mm at 50 m; 6 mm at 100 m
- Dimensions (D × W × H) : 238 mm × 358 mm × 395 mm

- Resolution: 4 megapixels per each 17° × 17° colour image; 700 megapixels for panoramic image
- Weight: 12.25 kg

3.3 Post-Processing

The survey data was exported as a Shapefile for data exploration in Python and visualization in ArcGIS. Symbology was used to generate intuitive outputs for decision-makers, such as a map output with curbs color coded by overall condition classification (from '1 / very poor' in red to '5 / very good' in green) and other attributes (such as excessive lip / bump measurement shown with polygon markers). Bar charts and pie charts were generated to show basic descriptive statistics of the curbs.

The Structure Sensor and P40 data was exported in point cloud form and manipulated with CloudCompare software. For the laser scanner, the point cloud captured the whole street scene including surrounding building facades in extremely high detail. The area of interest (curb dimensions) was extracted. Based upon this smaller area, CloudCompare was used to generate physical measurements. Using our priority data point scheme, measurements were generated for ramp width, lip / bump height, and other data points including slope elevation.

Due to GPS location inaccuracy, a necessary post-processing step was to manually move each Geodatabase record (corresponding to a single curb cut) to its true location. This was done in ArcGIS using the Move tool, based upon the street intersection and curb cut orientation attributes. This step was time-consuming, prompting us to consider methods to automate the process (see discussion below).

4. Results

4.1 Survey Results

Out of 42 curb cuts surveyed, the survey pinpointed many with poor or very poor condition, and other newly renovated curbs classed as 'very good', with the mean condition rating for Union Square to 26th St being 3.7. Fully one-quarter of the curbs surveyed had a lip / bump measurement of more than 1 inch, signaling a failure of ADA compliance on this measure alone.

The visualizations give a clear picture of where ADA-uncompliant curbs are located across this stretch of Broadway. For each uncompliant curb, decision-makers may pull up a photo from the Geodatabase. To facilitate data visualization, a web map was created using ESRI software. The web map is available at http://bit.ly/2w8mmZk. The map includes 'bookmarks' allowing the user to navigate to several key landmarks along the survey route, including the Flatiron Building and the key study site of Broadway and 26th Street. Color-coded condition ratings visualize the curb cut quality. Users can query the curb cut measurements by clicking on any individual point; an intended extension would be to make the photo of each curb accessible by clicking on it.

4.2 Scan Results

The 3D scanning methods both succeeded in generating the required data points as specified in Table 1. For our test curb cut on the south-west corner of Broadway and 26th, the Structure Sensor and P40 both

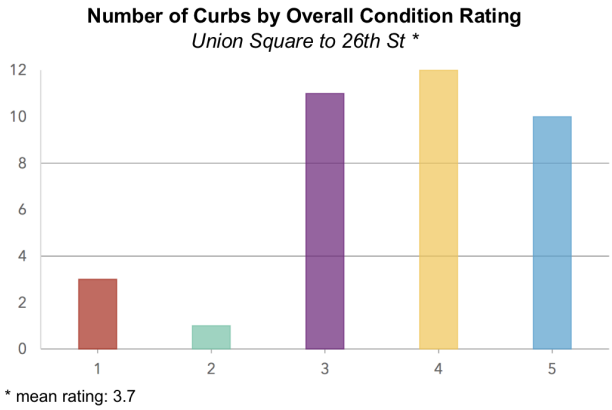

Figure 5:

Figure 6: Output from Geodatabase: Visualization of overall condition rating plus example photos

acquired comparable ramp width measurements. Compared with the hand-measured width of 42 inches, both methods were judged to have satisfactory data quality on this simple lateral measurement.

As noted above, acquiring slope angle measurements posed a challenge when measuring by hand, but excessive slope steepness is a serious issue where ADA compliance is concerned. Both scan methods successfully generated slope measurements. Structure Sensor measured the slope at 16.5 degrees, while the angle extracted from the P40 point cloud was 17.5 degrees. As observed from field measurements, the ramp in question was of excessive steepness. (The ADA specifies maximum acceptable slope angle of 10%.) While the team did not deploy high-accuracy surveying techniques necessary to reality-check the slope measurements with complete accuracy, the scan output was judged highly encouraging for generating easily extracted and robust slope measurements.

Figure 7: Photo Image of Inspected Curb - Structure Sensor

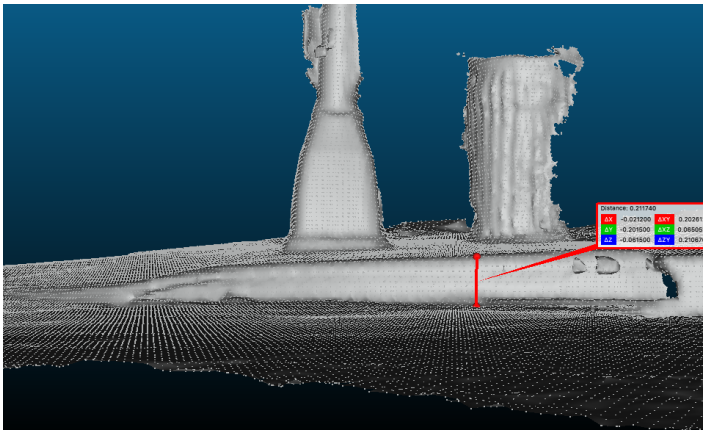

Figure 8: Ramp Height - Structure Sensor

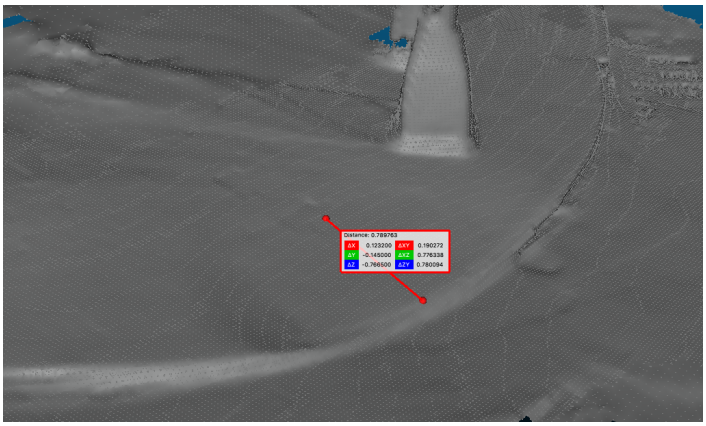

Figure 9: Ramp Slope Length - Structure Sensor

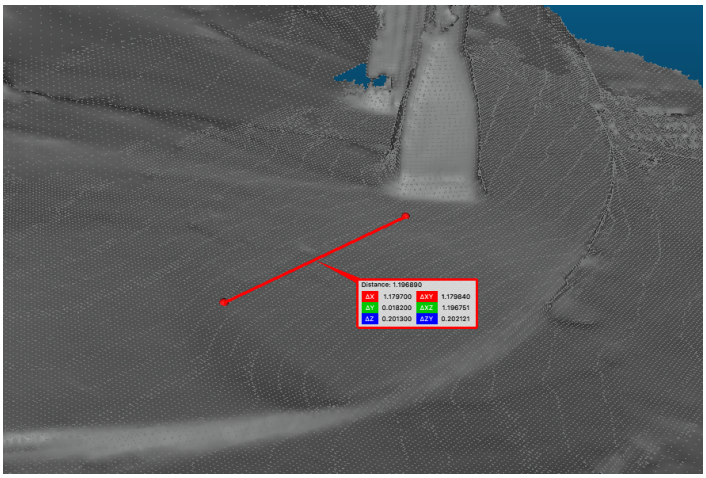

Figure 10: Ramp Width - Structure Sensor

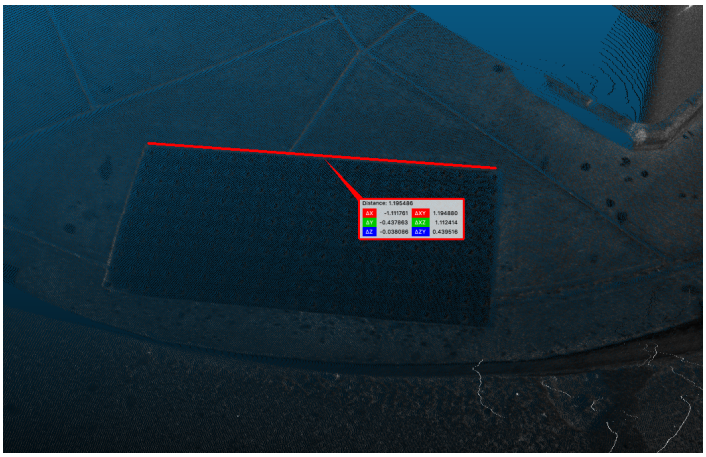

Figure 11: Ramp Width - Lidar Scanner

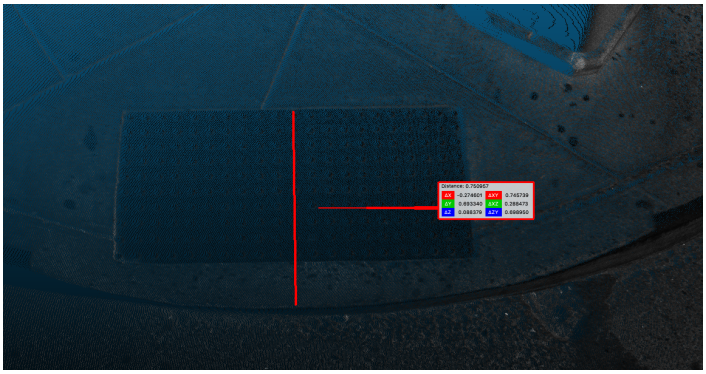

Figure 12: Ramp Slope Length - Lidar Scanner

5. Discussion

This work combined a smartphone-based survey using geolocation, photos and manual data entry together with two 3D imaging technologies. The results allow conclusions to be drawn about the relative merits of

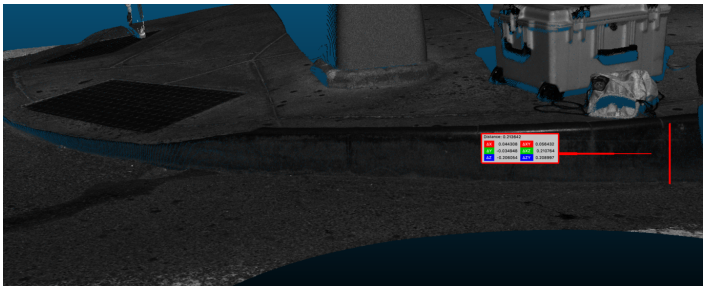

Figure 13: Ramp Height - Lidar Scanner

these approaches for our strategic goal: enabling better data collection on streetscape accessibility to drive improvements that benefit wheelchair users and the mobility impaired.

5.1 Comparison of Methods

Table 2 summarizes the methods' performance against our criteria of time, cost, ease of use and data quality. Methods differed substantially in their cost, with the LiDAR scanner generating extremely high quality outputs but at a prohibitive cost. While equipment cost is low for a smartphone-based method, at present this does not allow for 3D imaging. As such, while a great deal of useful data is generated, the most cost-efficient method does not allow for accurate slope measurements or for extraction of additional measurements during post-processing.

	Time	Equipment Cost	Training	Software	Accuracy	Storage
Smartphone survey	2 mins	$10	Low	Survey123	Depends	100 KB
Structure Sensor	5 mins	$300	Low	Canvas and other options	Good	2-3 MB
LiDAR scanner	60 mins (charge, set up, scan)	$100000+		Cyclone	Extremely high	1 2 GB

Table 2: Comparison Table of Curb Inspection Methods

5.2 Lessons from methods comparison

The comparison led to several conclusions:

1. Smartphone survey method achieves large proportion of data collection needs, but remains time-consuming. Using our current data collection instrument with all the questions included, up to 12 minutes is required to capture measurements for a single intersection. Field testing led us to conclude that the time requirements remain onerous where volunteer-led data collection is concerned. A priority in refining the tool should be to reduce the time requirement per intersection.

2. LiDAR scanner is of highest, but excessive, quality; while data quality from the low-cost Structure Sensor is sufficient for our needs. The device records points density at one million points per second. During post-processing, the superior quality of the point could for our target curb cuts was clearly apparent, when compared with Structure Sensor. However, the point density is far above requirements. Moreover, the Structure Sensor provided a sufficiently detailed point cloud to extract our required measurements at the necessary data quality. As such, Structure Sensor is our preferred 3D image acquisition method. Given its cost benefit and presumed similarity to the devices that may ship in 2019 iPhones, the technology is considered highly suitable for crowd-sourced street imagery in future.

3. The smartphone survey is not currently suitable for crowd-sourcing purposes. While conducting the smartphone-based survey, team members noted a self-conscious feeling that accompanied taking physical measurements. The process required crouching or bending down to foot level, extending a tape measure, and recording the dimensions noted. In a busy streetscape, there was a risk of tripping up pedestrians with the tape measure. Moreover, the measurements were time-consuming: for an intersection with 8 curb cuts it required at least 12 minutes. By contrast, taking smartphone photos produced little feeling of self-consciousness.

4. Three-dimensional sensors may help overcome behavioral constraints among crowd-sourcing volunteers. It was noted that 3D sensing technologies in smartphones may help volunteers overcome the behavioral constraint induced by feeling awkward when using a tape measure. Moreover, rapid acquisition of 3D images may help reduce the crucial time-per-observation criterion. Since physical measurements can be extracted during post-processing, a survey instrument incorporating 3D imaging could reduce the number of data points required - potentially limiting these to location fields, the 3D scan, and the minimum necessary qualitative fields where subjective judgment is required (such as overall curb condition, presence of detectable warning, and danger factor of curb cut location). Moreover, replacing hand measurements with 3D sensing could make it possible for wheelchair users to participate in data acquisition.

5. Good weather is required for 3D sensing. Field testing revealed that rainy days invalidate 3D scans of curbs. Puddles are recorded as physical surface, rendering the slope angle and lip / bump measurement inaccurate.

6. Query functionality realises significant value from sensor-acquired data. The ability to query the survey results through ArcGIS and a web map interface realized significant value. In our work, end users may call up photos of specific curbs based on a geographic region of interest, or any query term combining the attributes under consideration (examples include showing all curbs with crumbling concrete value "severe", all curbs with condition "very poor", or all curbs on a specific stretch of Broadway with no detectable warnings for the visually impaired). It was noted that 3D scans could be attached to the same Geodatabase structure. Through use of standardized 3D viewing platforms such as SketchFab, DOT or advocacy group users could view 3D representations of the curbs under question and conduct further exploration of their physical form such as extracting new measurements or verifying measurements from a printed report prior to sending field staff to make repairs.

7. 3D imagery may improve data credibility. After team members surveyed 40+ curb cuts using tape measures and photos, repetitiveness of the task led to a desire to speed things up by using rules of thumb such as estimating ramp width based on visual recollection for specific types of ramp slab. It was noted that quality of measurements made by hand may suffer as the number of curbs surveyed rises. Final data quality may suffer from credibility issues if volunteers are known to stray from the instructions. While 3D imaging

brings its own challenges - such as partial scans in cases where a pedestrian or street furniture obstructed the view - we noted advantages. Extracting measurements from 3D scans circumvents the tendency of volunteers to cut corners, and may increase the trust that decision-makers place in the resulting measurements. Besides providing great vision aid for inspections, 3D models can be easily converted to Computer Aided Drawings (CAD) which is popular used in engineering world.

8. GPS inaccuracy is a key operational constraint. Coordinates generated from smartphone GPS are not usable for placing curb cut records on a map. To conduct future curb cut surveys in an organizational context, volunteers could be equipped with accurate GPS devices. For crowd-sourced efforts, manual entry of cross-street and curb orientation is a workable solution, albeit adding to post-processing time.

6. Recommendation and preliminary design for 3D-enabled smartphone app

Our study leads to the following recommendation: develop a smartphone app for 3D-enabled collection of streetscape accessibility data, combining survey methodology with 3D scan capability.

Preliminary design for the app is shown in Figure 13. The design responds to the following design criteria: (i) benefit from anticipated deployment of Structure Sensor-style technology in smartphones from 2019; (ii) minimize time requirement per curb cut; (iii) incorporate the required measurement data and qualitative data; (iv) facilitate the merging of information from multiple users into a queryable Geodatabase; and (v) overcome GPS location constraints through snapping of curbs to their position on each intersection.

The smartphone app interface would resemble the Survey123 instrument developed for this project. Users would have an additional option to capture 3D imagery at each curb cut that they inspect. The 3D imagery component would allow the number of data points entered manually to be reduced, eliminating use of tape measures on street corners.

In light of GPS location problems with smartphone data and to minimize post-processing time, the app should automatically snap curb records to a representation of their location. A proposed method is to use the Google Maps API to locate the intersection dimensions, and place curb cuts according to their cross street and orientation.

A visualization interface should be developed allowing simple queries of the resulting Geodatabase. Alternatively, the data could be exported as a Shapefile for use in ArcGIS or QGIS alongside other datasets. We note that the method could equally be extended to other urban accessibility problems for which 3D imagery adds value. Wheelchair users are unlikely to use tape measures to confirm lack of turning space in movie theater corridors; and the slope measurement problems noted above mean they are unlikely to record objective evidence of excessive ramp slope at public libraries, hospitals, schools, airports or other categories of building. A crowd-sourcing effort using the architecture described here may add significant value to data generation, helping draw attention to these barriers and pressure organizations into making the necessary investments to become ADA compliant.

7. Conclusions

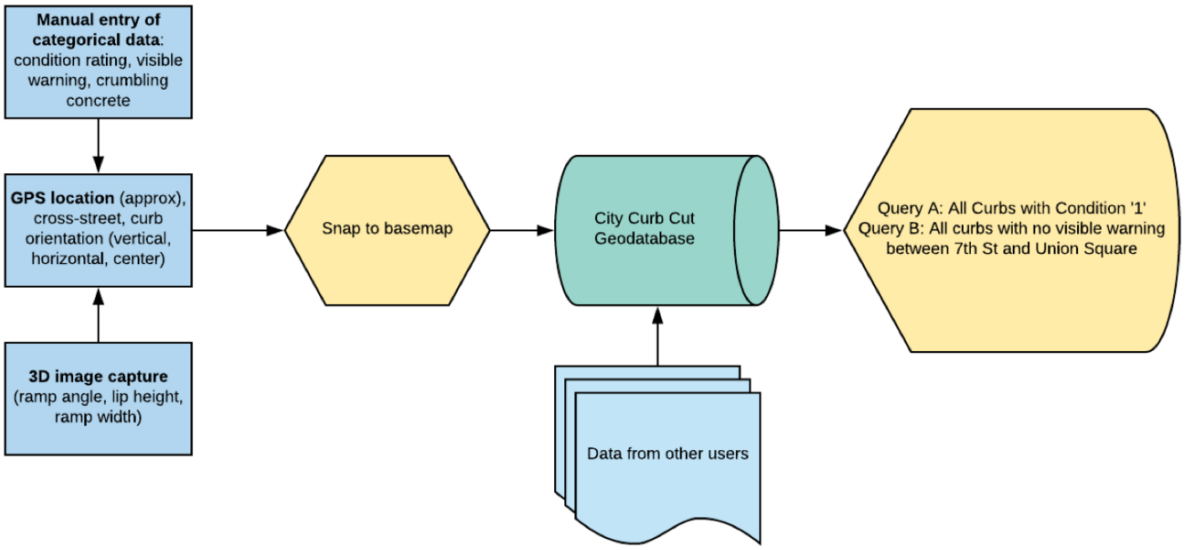

Figure 14: Proposed App Model: 3D-Enabled Crowdsourcing of Accessibility Data

Wheelchair users and the visually impaired face physical obstacles on city streets that inhibit their movement and place them in danger. Our review of the Broadway Curb Cut Survey, one of the most prominent data collection efforts to address this issue, underscores the costliness of producing data on the issue. To simply map out ADA compliance on a single New York City street required 40 volunteers and a year of time. Our work reviews this process and explores how new sensing technologies could expedite the process in future. Generating more data on the simple question of whether curb cuts are too steep, crumbling, or lack detectable warnings is crucial to drive progress on the issue - since without this information, agencies face no accountability to deliver their promise of better accessibility and DOT managers are un-informed about where investments are needed.

Our field work establishes the viability of using 3D sensing technologies to generate accessibility data. We defined a data schema based on the minimum required data points needed by key stakeholders in urban accessibility, and set data quality requirements based on stakeholder needs. The P40 LiDAR scanner produced better quality point cloud data, but the mass market Structure Sensor - currently retailing at $300 and representative of technology likely to be in the rear cameras of smartphones from 2019 - met all of our data quality requirements. Slope, width, and lip / bump measurements were successfully extracted from the Structure Sensor point clouds.

Having pressured the city to increase its attention to street accessibility through past lawsuits, disability advocacy groups can be expected to maintain pressure in future - especially given the continued extreme gap between ADA requirements and actual sidewalk ramp conditions in New York and other cities. 3D sensing combined with smartphone survey methods offers an opportunity to advocacy groups, and the city departments they aim to pressure, to build stronger operational awareness of accessibility conditions, and step up progress towards closing the compliance gap. To this end, we recommend creation of a smartphone app based on survey methodology but incorporating 3D scans.

The advantages of 3D sensing, observed in this work, could extend to other accessibility challenges beyond

sidewalks. 3D scans of the urban built environment have credibility that simple text-based reporting may lack. For instance, a crowd-sourced effort sponsored by a disability non-profit might focus on entrance ramps to cinemas. Citizen engagement may be facilitated by smartphone capabilities whereas taking physical measurements would be deemed unusual behavior in public space. A user-generated 3D scan could be shared (through web methods such as SketchFab) with cinema management, providing objective evidence that ADA requirements, such as maximum ramp slope or minimum turning space in corridors, have been violated. Combining 3D scans with Geodatabase architecture can allow for powerful evidence to accumulate, helping to drive change on urban accessibility that would not otherwise be possible.

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Robert Moore David Jacobs Jon E. Froehlich Kotaro Hara, Jin Sun. 2.1 Accessibility standards Recognizing the importance of accessible streets to wheelchair users and others with mobility impairments, the Americans with Disabilities Act (ADA) sets out detailed standards for Departments of Transport as well as building owners to abide by. A key provision in the ADA concerns curb cuts. Where sidewalks meet an intersection, or a pedestrian crossing exists, the ADA mandates that the sidewalk surface be cut away in a smooth ramp that leads to the street with suitable width and a sufficiently shallow incline. However, while the ADA is widely recognized as a legislative advance, disability rights groups complain that it goes un-implemented, with many street corners posing insuperable obstacles to their users. Wheelchair users or the visually impaired can be blocked or endangered by, among other things: sudden drop-offs, crumbling and uneven concrete, curb cuts that lead directly into oncoming traffic at the center of an intersection. The ADA also mandates detectable warnings such as stripes or bumps in the curb ramp surface, which are frequently lacking or eroded. 2.2 State of accessibility in NYC Responding to legal pressure, the Manhattan Borough President in 2014 organized a survey of curb cuts along Broadway. Requiring one year to complete, the Broadway Curb Cut Survey detailed the presence and condition of safety features along the 53-kilometer street. Forty trained volunteers measured ramps at over 100 intersections on Broadway, and their efforts are captured within the Broadway Curb Cut Survey Dataset on the NYC OpenData platform. The survey, which was highly labor intensive to produce, offers a thorough picture of the accessibility status of a major urban thoroughfare. The survey revealed that approximately 80the city's curb cuts do not meet ADA standards. This is despite some $243millionbeingspentovera15 - yearperiodonsidewalkaccessibility(Hogan2017).Of1,209curbcutssurveyed,28thecutmeetsthestreet,and24concerntothev$
$especiallyasfacilitatedbywidespreadsmartphoneuse-tofillinformationgapsonurbanaccessibility.Specializeddisability-$
$focusedcrowdsourcingeffortsincludeWheelMap,aBerlin - basednon - profitwithinternationaloperations,andJ'Accede,aFrenchnon-profitinitiative.TheseandsimilarUKandUS-$
$basedinitiativeshavebuiltcommunitiesofvolunteerswhouploaduser-generatedinformationonrestaurant,publicbuilding$
$sourcedresourcessuchasTripAdvisorandYelp(Captain2017).Givenmultipledemandsonvolunteers'time,akeyconsiderati$

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