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On-Site and Remote Crowdsourcing of Accessibility Data for People with Mobility Impairments: A Case Study in Zurich's District 1

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ABSTRACT

Collecting accurate accessibility data systematically for pathways is a time-consuming task that typically requires expert knowledge. However, it is a prerequisite to enable reliable and trustworthy accessible routing. The development of Capture & Go, a mobile application to report barriers for people with mobility impairments, facilitates the on-site collection of crowdsourced accessibility data. Several other mapping tools contain accessibility data, although they have not been developed explicitly for this purpose. In contrast to Capture & Go, they allow data collection to be performed remotely. Using quantitative and qualitative approaches, we analyzed several such applications and examined their efficiency in capturing barriers in a case study of District 1 in Zurich. The remotely collected data was compared to the data of the barriers captured on-site using Capture & Go. Overall, the remote tools were less efficient than Capture & Go in terms of effort, coverage, and accuracy of the barriers, as well as usability.

Keywords: Accessibility, Barriers, Crowdsourcing, Data collection, Empirical study, Mobility impairments, On-Site, Performance, Remote, Routing

INTRODUCTION

Finding a path from A to B is a challenge that everyone occasionally meets, if not regularly. While route planners, such as Google Maps (Google, 2022), exist to help find the right way, it is frustrating if one encounters an unexpected obstacle that hinders the passage. People with mobility impairments, i.e., wheelchair users, often face this challenge. Standard route planners cannot ensure users that a calculated route is accessible. Hence, there is a need for further development in the area of accessible routing (Darvishy *et al.*, 2022). The first step in achieving reliable accessible routing is to gather information about existing barriers on a route. In 2022, Capture & Go was developed to enable non-experts to easily report barriers for people with mobility impairments on-site (InIT, 2022). Users can efficiently capture barriers with the application when encountering them on their way. By crowdsourcing the data collection, the barriers are supposed to be up-to-date and comprehensive.

An alleged disadvantage of Capture & Go is the requirement to be on-site to capture barriers. For the city of Zurich, a number of other remote tools can be used to gather accessibility data in an alternative way, including government-generated maps, commercial products and open-source maps. Although these tools are not specifically developed for the purpose of collecting accessibility data, they can provide the means to extract information about potential barriers. This empirical study analyzes the effectiveness of these remote tools for the collection of accessibility data, and compares them to the on-site data collection approach of Capture & Go in a case study for District 1 in Zurich (Switzerland).

RELATED WORK

The environmental challenges of wayfinding for people with mobility impairments are described in research that evaluates the frequency and the various types of barriers that wheelchair users encounter daily (Meyers *et al.*, 2002). Accessible routing aims to find the most suitable way for a person with a mobility impairment, taking into account any barriers on the way. To compute such routes, all potential barriers must be captured beforehand. Projects such as StreetComplete (Zwick, 2022) or GoMap! (Cogswell, 2020) facilitate the tagging of data points in OpenStreetMap; however, they are not suitable to cover all of the many accessibility problems that exist.

Recent research has demonstrated the need for personalization of accessibility routing, with the necessity of collecting specific accessibility data first (Darvishy *et al.*, 2022). Accordingly, some projects focus on the remote labeling of accessibility problems, for example, Project Sidewalk (Saha *et al.*, 2019), where users can identify barriers using Google StreetView images. To capture barriers when encountering them on-site, solutions such as AccesComplete (Stoll, 2020) and Capture & Go (InIT, 2022) have been developed. The projects AccessMap (Bolten, 2019) and path-Nav (Sinagra, 2019) even go a step further and enable the calculation of accessible routes. Both of these projects allow for route customization based on the individual needs of the users. Such projects are constrained by the limited availability of open-source accessibility data and the resulting routes that are not truly accessible (Darvishy *et al.*, 2022).

METHODOLOGY

To analyze the collection of new barriers and the verification of already reported barriers, two types of methods were carried out. For both approaches, the data collected by Capture & Go served as the ground truth for analyzing the performance of the remote tools.

For the first method, the data was collected on-site with Capture & Go in Zurich's District 1, followed by the verification of a sample of barriers by the remote tools. Each tool was used to identify the previously collected barriers and verify the measurements. For the second method, the order was reversed; a random street, that was previously unfamiliar to the authors, was chosen outside of District 1. The remote tools were consulted to see how many barriers were found on the street with each tool. Then, these barriers were verified on-site using Capture & Go. Additional barriers not found in any of the remote tools were also recorded in Capture & Go.

Performance was evaluated by calculating the finding rate, measurability rate, and accuracy of the barriers. Only found barriers accounted for the rate of measurability. Their relative accuracy to the ground truth (collected by Capture & Go) was determined using relative errors. The calculations differ for each type of barriers, as they vary in the measurement data. For gates, bollards, others, cycle barriers, blocks and planters, the accuracy was determined by the measured passage difference between barriers. The accuracy in kerbs was calculated from the height difference related to the height of the ground truth, whereas cross drains used the width differences. Stairs have multiple relative error results: one for the number of steps and one for the average height of a step. The mean of both error results was calculated to express the accuracy of the stair measurements. For problematic ways, accuracy was calculated from the difference in degree (for cross or running slopes) or the match of the type of surface.

The second method compares the coverage and falsely determined barriers (false positives) of the remote tools. The percentage of ground truth barriers that have been found by the remote tools account for the coverage. On the other hand, barriers found to be inaccessible by the remote tools, but not Capture & Go, make up the false positive rate.

Capture & Go

In 2022, the InIT Institute of Applied Information Technology (ZHAW School of Engineering; 2022) developed the application "Capture & Go". Capture & Go enables users to report and view barriers for people with mobility impairments. Users can select the location of a barrier, indicate the type of barrier, and add further information, for example, a picture or description (Fig. 1). After its creation and review, the barrier is added to OpenStreetMap (OSM, 2022a), and becomes visible to other users. Ten different types of barriers can be captured: gates, blockages, cycle barriers, bollards, stairs, planters, kerbs, problematic ways (i.e., surfaces and slopes), cross drains, and "other" (e.g., construction sites). Each barrier type requires different types of information to be entered by the user, for example, step height and step count for the type "stairs".

The on-site collection of barriers was performed using a smartphone having Capture & Go and an incline measuring app installed. A folding ruler/measuring tape, a wooden beam with length ticks, a small kerb measuring wood piece, a city map and a pen were used during data collection. Information, such as start time of barrier recording and time when finished, was automatically added to a barrier by the smartphone app. In addition to noting and measuring a barrier, at least one picture was taken for each recorded barrier which turned out to be helpful for remote verification. For our analysis, all captured barriers for District 1 were extracted from the database in order to perform the calculations for coverage and accuracy. The verification of barriers of the chosen street followed the same procedure.

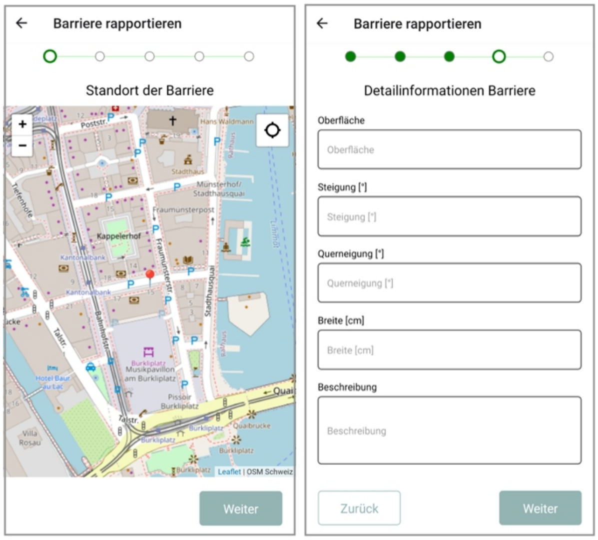

Figure 1: The screen for locating the barrier and the screen to enter details about a barrier in Capture & Go. (InIT, 2022).

OpenStreetMap

With the goal of providing free geographic data, OpenStreetMap is an initiative based on crowdsourcing (OSM, 2022b). The data of OSM is structured into data points (nodes, ways, and relations) which can be tagged and labeled with different values/attributes that describe it (OSM, 2022c). The tags, values, and any other information regarding the data points are documented in the corresponding Wiki pages (OSM, 2022c). OpenStreetMap can be accessed in the browser and offers different tools such as zooming, searching for a specific location, and changing the map layer (OSM, 2022a). As previously mentioned, the goal of Capture & Go is to add accessibility data to OpenStreetMap. Nonetheless, some of the data entered by OSM users already provide information about possible barriers. For example, a node tagged as a kerb with the associated value "raised", declares that the kerb is higher than 3 cm and therefore not accessible for the average wheelchair user (OSM, 2022c).

From the collection of barriers with Capture & Go, a sample that covers all barrier types except bollards was verified (as bollards cannot be found on OSM). The Capture & Go data provides exact OSM coordinates. Once the coordinates had been entered in OSM, the query feature was used to highlight paths/nodes in the radius of a chosen point. The barrier was determined based on the selection. If it existed, the entry was compared to its counterpart in Capture & Go.

For the barrier collection on an unfamiliar street, the chosen street was "traversed" on OSM by dragging the map. The query tool was used to highlight possible points of interest. If a barrier was found, its information was manually added to the data. Time-related information, such as time to find a barrier and time to report the barrier, was measured by using a stopwatch and manually documented.

Infra3D

A more immersive approach is the tool Infra3D developed by iNovitas (2022c). By offering a geo-referenced 3D image database, the user can navigate through high-resolution three-dimensional imagery. Infra3D has the option of choosing a view on a given path, that is, either a road, tram track, or footpath. Furthermore, a 360° view is provided from the center of the vehicle; the front view is defined by the direction of travel (0°), the right rear view by approximately 120°, and the left rear view by approximately 240°. The contrast slider and zoom function allow for a better sight of a particular barrier. Furthermore, the Infra3D Web Client (iNovitas AG, 2022a) provides several measurement and analysis tools, for example, to measure distances or areas (iNovitas AG, 2022b).

Similar to the OSM verification, coordinates can be directly entered into Infra3D, although its accuracy is not always guaranteed. For precise location-finding, OSM was used to determine the exact location of the barrier. The location was compared and adjusted on the Infra3D map, which uses OSM as the underlying structure. Different angles were used to further determine the exact location of the barrier. In addition, images captured with Capture & Go were sometimes used to verify the barrier with the 3D image. With the exception of barriers located at inaccessible locations for the Infra3D car, all barrier types could possibly be found. Measurements were carried out in a zoomed-in view of the barrier. Using the distance measurement tool, two points were fixated and the distance between them was calculated. For the incline measurements, additional options of viewing the horizontal and vertical distance were used to calculate the incline manually.

For the remote collection, the street was navigated with arrows on the user interface or paths on the map to find potential new barriers. Similar to OSM, time-related data was manually measured with a stopwatch.

Zürich Virtuell

The city of Zurich provides a "digital twin" of Zurich - the interactive map Zürich Virtuell (Stadt Zürich, 2022b). Similar to Infra3D, they offer a 3D model of the city and measurement tools. Although Zürich Virtuell does not provide 3D imagery, objects such as houses and trees are placed as true-to-scale models (Stadt Zürich, 2022a). Furthermore, the map includes an accurate digital elevation model and the data is part of the Open Government Data, which can be used for free (Stadt Zürich, 2022c).

Compared with OSM and Infra3D, Zürich Virtuell does not rely on coordinates for navigation; instead, street names can be entered in the search bar. Because the ground truth data only supplies coordinates for the exact location, the streets of the barriers to be verified were determined with OSM and entered in Zürich Virtuell. Dragging and turning the map allowed for a suitable view of the street. The measuring process was similar to that in Infra3D, fixing two points on the map to determine the inclined distance, as well as the vertical and horizontal distance. The latter information was used to determine the incline and a separate stopwatch handled the time data. In addition to problematic ways, planters are the only other barrier type determinable by the remote tool. Planters are shown on the map as virtual trees with its data attached.

The remote collection of the chosen street was carried out by traversing the street by dragging and turning the map and measuring it as explained in the previous paragraph. No additional navigation options are available in Zürich Virtuell.

Baustellenliste Zürich

The main problem with the above-mentioned tools is that they are snapshots of the city. Temporary barriers are unlikely to be found on these maps. To this end, the list of current construction sites in Zurich can be used for the analysis of temporary barriers (Stadt Zürich, 2022a). The construction sites are sorted by street names with the duration of the construction work indicated. In addition, all construction sites can be viewed on a map (Stadt Zürich, 2022b) in order to see which part of the street is blocked.

As the German name suggests (Baustellenliste means "list of construction sites"), the remote tool may be used to verify the presence of construction sites, which are listed in Capture & Go as barrier type "other". The GPS coordinates used by Capture & Go could not be directly searched for in the official Baustellenliste of the City of Zurich; as with Zürich Virtuell, only street names may be used to identify a barrier. For this reason, the street name where the given barrier was located was first identified through OSM; then, it could be compared to the list in the Baustellenliste or entered into the search function of the map.

For the collection of barriers on an unfamiliar road, the name of the selected road was checked against the list of street names in the construction list, and then visually identified on the map. Alternatively, construction sites could be directly looked up on the map.

RESULTS

On-Site Collection & Remote Verification

After removing invalid time entries (entries with a reporting time of less than 3 seconds), Capture & Go shows 1154 barriers reported over District 1. As seen in Table 1, barriers of type "problematic way" and "stair" are predominant, followed by cross drains and kerbs. At the lower end, only a handful of gates, bollards, cycle barriers, and planters have been reported. The overall average time to report a barrier was 32 seconds. The analysis showed a slightly higher number for the average median time of 45 seconds. The numbers shown in Table 1 do not account for the time needed to find the barrier (i.e., walking and spotting time), and only represent the time used to determine and report details of a barrier and to take a picture. On-site experience has shown, however, that spotting a barrier is very fast and can normally be performed more or less in real time while walking.

In the subsequent analysis, the data has been cleaned of outliers (upper 10%) resulting in 1075 remaining barriers for the verification. After that, for

Table 1. Barriers for District 1.

Barrier type	Total reporting time	Number of barriers	Mean reporting time per barrier	Median reporting time per barrier
gate	00:01:02	2	00:00:31	00:00:31
bollard	00:06:29	6	00:01:05	00:01:00
kerb	00:48:10	89	00:00:32	00:00:25
stair	02:31:26	237	00:00:38	00:00:32
other	00:17:49	24	00:00:45	00:00:35
cycle_barrier	00:02:40	2	00:01:20	00:01:20
block	00:31:19	50	00:00:38	00:00:31
planter	00:01:57	1	00:01:57	00:01:57
problematic_way	04:48:51	599	00:00:29	00:00:23
cross_drain	01:07:47	144	00:00:28	00:00:20
all	10:17:30	1154	00:00:32	00:00:45

Table 2. Verification results (1/2).

			OSM			Infra3D		
Barrier type	Barriers total	Sample size	Barriers found	Barriers measurable	Average relative error	Barriers found	Barriers measurable	Average relative error
gate	2	2	2	0	-	1	1	50.00%
bollard	6	6	-	-	-	5	5	58.01%
kerb	82	30	9	0	-	29	25	70.69%
stair	221	30	20	6	0.00%	22	9	21.39%
- number of steps	206	27	5	5	0.00%	8	8	10.53%
- height of steps	206	27	0	0	-	9	9	53.08%
- wheelchair ramp	221	30	5	5	0.00%	9	9	0.00%
other	21	21	-	-	-	1	1	0.00%
cycle_barrier	2	2	0	0	-	0	0	-
block	49	30	9	1	10.00%	12	11	3.38%
planter	1	1	0	0	-	1	1	5.66%
problematic_way	563	56	56	55	43.81%	47	47	39.30%
- surface	563	56	55	55	45.45%	47	47	44.68%
- running slope	264	27	12	12	51.61%	18	18	25.12%
- cross slope	313	30	-	-	-	26	26	40.51%
cross_drain	128	30	30	0	-	30	30	22.50%
all	1075	208	126	62	17.94%	148	130	30.10%

each category of barrier, a random sample was obtained. The sample consisted of either 10% of the data or at least 30 samples, if the data for the category was not large enough. The exceptions were barriers of type gate, bollard, other, cycle barrier, and planter, where all the data was used because of the few reported barriers. This sample data was then verified using the remote tools (see Table 2 and Table 3). To compare the accuracy of the individual measurements, the barrier types "stair" and "problematic ways" are split up by their kind of measurement.

It was found that OSM provided little comparable data: only 62 (29.81%) of the barriers reported in Capture & Go could be verified in OSM. Nevertheless, all sample gate and cross drain barriers could be found, although OSM

Table 3. Verification results (2/2).

Barrier type	Barriers total	Sample size	Zürich Virtuell			Baustellenliste Zürich		
			Barriers found	Barriers measurable	Average relative error	Barriers found	Barriers measurable	Average relative error
gate	2	2	-	-	-	-	-	-
bollard	6	6	-	-	-	-	-	-
kerb	82	30	-	-	-	-	-	-
stair	221	30	-	-	-	-	-	-
- number of steps	206	27	-	-	-	-	-	-
- height of steps	206	27	-	-	-	-	-	-
- wheelchair ramp	221	30	-	-	-	-	-	-
other	21	21	-	-	-	0%	0%	-
cycle_barrier	2	2	-	-	-	-	-	-
block	49	30	-	-	-	0%	0%	-
planter	1	1	1	1	316.98%	-	-	-
problematic_way	563	56	55	53	33.77%	-	-	-
- surface	563	56	-	-	-	-	-	-
- running slope	264	27	27	27	21.39%	-	-	-
- cross slope	313	30	29	29	45.00%	-	-	-
cross_drain	128	30	-	-	-	-	-	-
all	1075	208	56	54	175.38%	0	0	-

did not include their width measurements. However, cycle barriers and planters could not be verified by OSM, as they were not present in the OSM data. Overall, with OSM we were able to find approximately half of the sample barriers, with measurements for 62 of the found 126 barriers (49.21%) and an error rate of 21.55%.

Infra3D showed a different picture, as we were able to detect 148 of the 208 sample barriers (71.15%) and measure 130 of them (87.84%). Nonetheless, the overall error rate (29.66%) was similar to that of OSM. For almost all barrier types, if a barrier was found, it could also be measured most of the time. However, not all streets of District 1 were covered in Infra3D, so even if a barrier could be seen in the imagery, we were not always able to view it well enough in order to measure it. One such example is the barrier type "stair", where only 9 of 22 (40.91%) of the sample barriers could be measured.

Zürich Virtuell produced high detection results for the two barrier types "planter" and "problematic ways", by finding almost all sample barriers. Nonetheless, across all barrier types, only 56 of the 208 barriers (26.92%) were found. The overall error rate was very high at 104.28%, due to the inaccurate measurement of the single planter. The average error rate for problematic ways (running and cross slopes) was 33.77%.

Finally, the list of construction sites for the City of Zurich was not useful for finding any construction barriers, as none of the construction sites reported with Capture & Go could be found on the list.

Remote Collection & On-Site Verification

The selected road outside of District 1 was first traversed virtually using all remote tools, and subsequently in person with Capture & Go, resulting in a total of 120 barriers. Tables 4 and 5 show the results for each of the tools. There were 26 barriers detected by OSM, 6 by Zürich Virtuell, 27 by Infra3D,

Table 4. Remote collection results (1/2).

	OSM		Zürich Virtuell	
Barrier type	Number of barriers	Mean reporting time per barrier	Number of barriers	Mean time per barrier
gate	0	-	0	-
bollard	0	-	0	-
kerb	1	00:00:44	0	-
stair	2	00:00:58	0	-
other	1	00:00:17	0	-
cycle_barrier	0	-	0	-
block	8	00:00:32	0	-
planter	1	00:00:31	2	00:02:02
problematic_way	0	-	4	00:01:29
cross_drain	13	00:00:27	0	-
all	26	0:00:31	6	0:01:40

and 61 by Capture & Go. No barriers were encountered in the list of construction sites for Zurich; therefore, we excluded this tool from further analysis. Problematic ways and cross drains were by far the most commonly found types of barriers. No cycle barriers nor bollards were encountered with any of the tools. With Capture & Go, the mean reporting time needed was lowest at 19 seconds, followed by OSM at 31 seconds. At the other end was Zürich Virtuell, taking almost 2 minutes to calculate barrier details on average.

Table 6 shows the percentage of barriers covered by the remote tools. Of the 61 barriers reported with Capture & Go, only 17 barriers (27.87%) were found in OSM, and only 19 (31.15%) were found in Infra3D. With Zürich Virtuell, 14 of the barriers (22.95%) were identified. By combining all remote tools, 33 barriers were identified, accounting for a total coverage of 54.10%. In OSM, 11 of 26 barriers could not be found on-site (false positives). With Zürich Virtuell, 3 barriers were falsely reported, and with Infra3D, 10 false positives were found, resulting in 23 falsely determined (unique) barriers for the combination of all tools.

In Table 7, the coverage of each tool can be seen; split into the respective barrier types. Overall, the combination of all remote tools was successful in finding all stairs and all cross drains but only 16 of 37 (43.24%) of the problematic ways. Gates, kerbs, and barriers of type "other" were not found by any remote tool.

CONCLUSION AND FUTURE WORK

In conclusion, the remote tools were not appropriate replacements for Capture & Go. Regarding coverage of (types of) barriers, Capture & Go remains the most suitable application, followed by Infra3D. Infra3D provides an environment that makes remote data collection more similar to on-site collection, but is not as effective as Capture & Go. Even though some types of barriers can be measured quite well remotely, without having verified them on-site, the measurements would not be sufficiently accurate. The exceptions

Table 5. Remote collection results (2/2).

Barrier type	Infra3D		Capture & Go	
	Number of barriers	Mean reporting time per barrier	Number of barriers	Mean reporting time per barrier
gate	0	-	1	00:00:33
bollard	0	-	0	-
kerb	0	-	4	00:00:30
stair	2	00:01:24	2	00:00:58
other	4	00:00:54	2	00:00:31
cycle_barrier	0	-	0	-
block	2	00:01:16	0	-
planter	1	00:00:51	0	-
problematic_way	7	00:01:14	37	00:00:15
cross_drain	11	00:00:36	15	00:00:16
all	27	00:00:56	61	00:00:19

Table 6. Remote tool coverage.

Tools	Ground truth barriers found by tool	Recall	True positives	False positives	Precision
OSM	17	27.87%	15	11	57.69%
Zürich Virtuell	14	37.84%	3	3	50.00%
Infra3D	19	31.15%	17	10	62.96%
All tools combined	33	54.10%	20	23	46.51%

Table 7. Coverage by type.

Barrier	Total number of barriers	Barriers found			
		OSM	Zürich Virtuell	Infra3D	All tools combined
gate	1	0	-	0	0
bollard	0	-	-	0	0
kerb	4	0	-	0	0
stair	2	2	-	2	2
- number of steps	2	1	-	1	1
- height of step	2	0	-	0	0
- wheelchair ramp	2	2	-	1	2
other	2	0	-	0	0
cycle_barrier	0	0	-	0	0
block	0	0	-	0	0
planter	0	0	0	0	0
problematic_way	37	0	14	4	16
- surface	5	0	0	2	2
- cross slope	30	-	12	1	13
- running slope	3	0	2	1	2
cross drain	15	15	-	13	15

are tram tracks, which could be directly translated from OSM to cross drains with a universal width of 4 cm. With regard to the effectiveness of the reporting and verification of barriers of all types, on-site data collection cannot be fully replaced by remote data collection (yet).

The results have shown that capturing barriers on-site with apps such as Capture & Go are feasible within a reasonable time and with reasonable effort, at least for smaller compact cities like Zurich. To achieve sufficient coverage and accuracy of accessibility data, systematic on-site data collection (e.g., crowdsourcing) is inevitable. Although capturing barriers with Capture & Go is easy and intuitive, instructions on how to capture barriers are important in order to obtain consistent barrier data. Providing thresholds for measurements could help users, especially those who are not familiar with mobility impairments, to identify barriers. Moreover, the development of algorithms for the automatic extraction of accessibility data could improve the efficiency of remotely collecting accessibility data.

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