WheelieMap: An Exploratory System for Qualitative Reports of Inaccessibility in the Built Environment

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ABSTRACT
The built environment remains a persistent accessibility challenge for people with mobility impairments. Whilst platforms to report these inaccessible locations exist, the underlying documentation processes are verbose, time-consuming and fail to effectively communicate the barrier at hand. We propose WheelieMap, a platform which uses the motion of manual wheelchair users to support the identification and documentation of potentially problematic locations. WheelieMap captures and segments device video footage and GPS as evidence of the problematic space, which can then be shared with both other people with disabilities and the relevant authorities. We document the use of the WheelieMap prototype by both manual wheelchair users and planning experts through semi-structured interviews. The qualitative findings revealed this approach to be the most viable route for documenting inaccessibility, compared to the existing alternatives. We also offer guidance on how to design and develop similar community driven reporting and annotation systems in the accessibility setting.

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Accessibility; Disability; Mapping; Town Planning.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI).

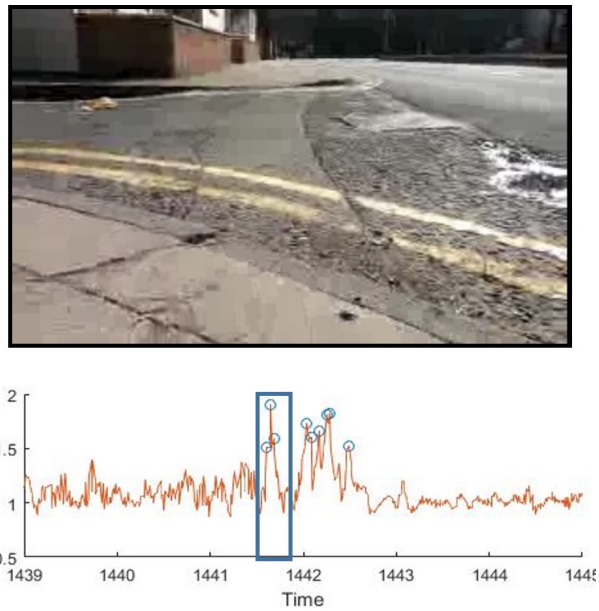

Figure 1: In this location, WheelieMap has identified a 'rough' dropped kerb, by finding the highest local peak in the accelerometer data. This is a potential accessibility barrier, being both a general 'trip hazard' and also requiring a manual wheelchair user to lift their chair to clear it.

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INTRODUCTION

Mobility remains a challenge for a broad range of people with disabilities. It is well recognized that the underlying cause is the nature of the built environment [3,10,18]; for instance, stepped surfaces are inaccessible to most wheelchair users, whilst uneven surfaces can present a hazard for people with a wide range of mobility impairments, especially those related to age. The result is that many people with disabilities are relatively excluded from society and the workplace, due the difficulty or relative impossibility of accessing a given location.

In urban spaces that have evolved over a number of years (and mostly prior to anti-discrimination legislation against disabled people such as the UK Disability Discrimination Act (1995)), the determination of which barriers need to be addressed (and how) is an innately qualitative exercise. This is for three reasons. First, although it is true that some physical barriers are immediately evident (e.g. a step), many others are not immediately apparent, to the point of being counter-intuitive for those who do not directly experience them (for instance, the layout of a given space). Second, there is a reality that it is impractical for public authorities to address all barriers in the built environment, not least because of the effects of austerity: instead, they need to ration which barriers are to be addressed, and this involves considering the qualitative effects on different groups of people. Third, in the European Union at least, the introduction of the UN Convention on the Rights of Persons with Disabilities ("the UN CRPD") as EU law, mandates a qualitative approach – it is unlawful (especially in the UK under s.149 of the Equality Act (2010)) to simply apply a reductive building code and its heuristics to a public space (see e.g. [28] for evidence of this).

In this context, the mapping of inaccessibility is a form of empowerment. The more convincing the documentation of potential barriers, the greater opportunity for advocates on all sides to have a positive impact on the planning process, whilst a public authority can be empowered to proactively take better decisions. Appropriate accessibility documentation is therefore an essential ingredient in developing a more accessible built environment and minimizing the effect of already pre-existing barriers. Furthermore, whilst enabling long term improvements in planning should be the wider goal of such mapping, there are immediate benefits, in that someone with a disability can determine the most appropriate route (in line with their own specific abilities/concerns) to utilize before they travel, thereby allowing them to maximize their prospects of accessing the local community.

It is that latter concern which has driven existing community-driven accessibility mapping systems (hereon "CAMS"), such as Euan's Guide [29], AXSMap [30] and WheelMap [31]. Whilst important, these all suffer from severe limitations in respect of the accuracy of their descriptive labels and the range of locations covered, as well as a relative lack of effective user engagement. Nor have these systems been expressly designed to address the planning context and therefore have little emphasis upon changing the environment itself. This means that there is a limitation on how meaningful the underlying reports are: there is a real distinction between someone asserting there is a problem, and there being a verifiable documentation of it.

WheelieMap has been designed to explored the use of semi-automation, rapid sensor-driven annotation and direct video documentation to improve upon existing accessibility mapping solutions. We make three contributions. First the deployment of WheelieMap itself, together with an exploration with town-planners, demonstrates a viable new route towards developing community supported accessible mapping systems, emphasizing semi-automation using simple inertial sensors. Second, this paper also offers explicit guidance for the design of future accessibility systems within this space and thereby a substantial advance in the development of CAMS. Third, we also explain how our experience with WheelieMap can be used as a basis for developing other systems that enable people with disabilities to engage in transport related advocacy.

PREVIOUS ACCESSIBILITY MAPPING SYSTEMS

Before turning to the design of WheelieMap itself, it is important to overview what has gone before in the domain of accessibility mapping. There are three classes of systems: (i) automated (or semi-automated), (ii) expert driven and (iii) community driven (i.e. CAMS). WheelieMap draws upon elements of each type of system, with a view towards taking advantage of the opportunities provided by each approach.

Automated (or Semi-Automated): There have been some prior efforts aimed at developing AMS which use inertial sensing of one kind or another in order to assist with the documentation of barriers. WeGoTo [20] is a system which logs and documents inclination; this was tested using a single wheelchair user on a pre-determined route. The work in [26] also uses an accelerometer to detect incline, but suffers from the deficit of being in a laboratory setting. The prototype described in [19] attempts to document a broader range of problems, this time with a powered wheelchair (with an accuracy of 80% using a SVM), however this is also in a highly controlled setting which does not reflect the real world environment and thus is of limited utility.

Unfortunately, the evaluations of these systems are defective in two fundamental ways: they are not naturalistic (or ecologically valid) which means that the study's findings do not translate to realistic activity recognition problems [21] and they fail to use the appropriate leave-one-out metric of evaluation [9]. This means that there is a serious overestimation of performance and therefore no evidence that these systems are actually viable in respect of a real world deployment. More fundamentally, these systems make no express qualitative assessment: knowing where an obstacle is and determining the extent to which it is a problem are two entirely different things. However, the fact

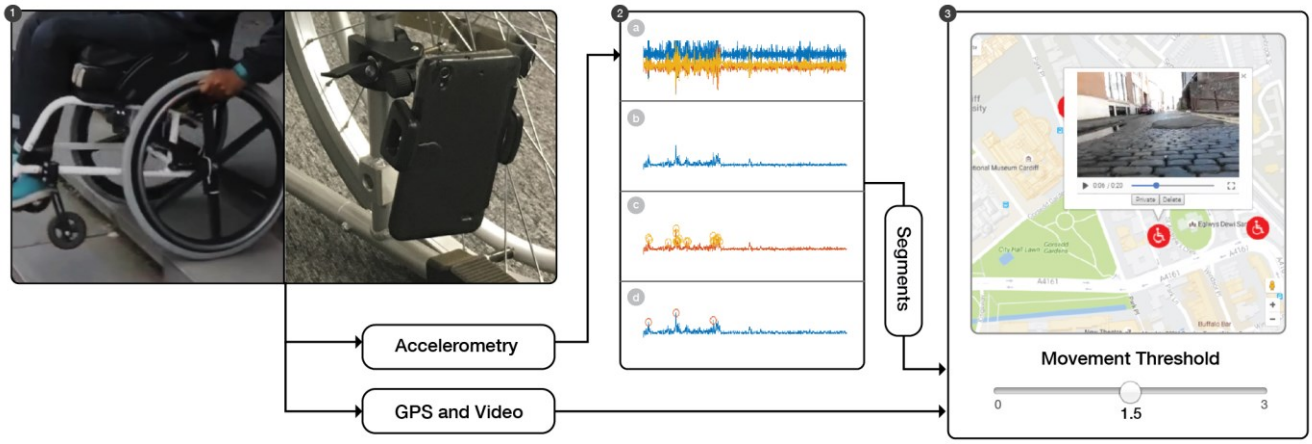

Figure 2: The overview of Wheeliemap. *Left:* The motion of the manual wheelchair user is recorded using GPS and an Accelerometer on a rear-facing smartphone. *Centre:* (a)The accelerometer data is (b) converted to Energy and smoothed, before (c) peaks are identified and a final step (d) eliminates peaks which are too close to one another. The video is cropped around these peaks into segments. *Right:* The editor interface of WheelieMap, where the video segments are plotted at their requisite locations. The user can review each video by clicking on the marker and choose to publish it (in which case the marker turns green) or delete it. They can also filter markers by energy threshold, allowing the user to make decisions based upon potential severity.

that other types of interaction (e.g. ADLs [5] or wheelchair stroke patterns [6]) can be detected using Human Activity Recognition methods suggests that a semi-automated approach could be effective, by detecting where a user might be encountering a problem and then inviting an annotation from the user.

Expert Driven: The most notable expert driven system is Disabled Go [32]. This involves a rigorous and expensive process of direct documentation by an expert of every feature in the built environment within a confined area (e.g. the local high street), performed by an expert assessor on behalf of the local authority. PhotoRoute [33] serves a similar, but discrete function: a venue can request a photo illustrated accessible route from an important landmark (e.g. a Train Station) to enable attendees to follow the most appropriate route. There have also been developments of other expert driven systems in the academic community, which are in effect interfaces for a map already generated by an expert user: two examples are RouteCheckr [27] which uses a modified Dijkstra's algorithm to determine the best route for an individual based upon their capabilities, whilst U-Access [24] operates on three specific groups "peripatetic (unaided mobility), aided mobility (mobility with the help of a cane, walker or crutches) and wheelchair users". Whilst expert-driven systems are effective for the routes and locations that they actually cover, they have the limitation of sparse coverage caused by the underlying expense of adopting them; in short, although these systems are useful on some occasions, they simply do not scale to provide adequate coverage outside of confined (but important) situations.

Community Driven (CAMS): There are a number of systems in existence which are community driven. In all of the cases we have been able to identify, they comprise a website, supported by a mobile app, wherein users provide qualitative information with respect location markers. These systems are typically constrained to locations which can be already found in Google Maps, for example Euan's guide [29] provides Likert ratings (between 1 and 5 stars) as well as a three page report that an annotator can complete (Wheelmap [31] is identical, asides the fact there is no separate three-page report functionality and the annotations are more extensive, with over 400,000 markers). AXS map [30] is similar, with the exception that all ratings are on a Likert basis on a few focused categories and the aim is to arrange 'mapathon's' where a large number of venues are annotated at the same time. In the academic literature, Holone et al [11], demonstrated that a collaborative approach towards identifying indoor barriers was possible using a qualitative rating system: however, this study was simulated by participants who did not have mobility impairments.

In respect of the outdoor built environment and urban space the existing systems have largely been deployed in controlled settings, as opposed in the wild. One interesting example of a prototype mPass [22] – a 'mashup' system which brings together expert reports and user reports from FourSquare, however there has been no direct evaluation of this system. SoNavNet [13] is a location-based social network (LBSN) designed to assist in the context of the built environment: the novel feature is that it enables user collaboration and communication in respect accessibility in a locale, rather than simply passively absorbing markers. The notable exception is the widely used FixMyStreet [34], which is a MySociety project aimed at general problems in the local community, but also serves as a platform for reporting some accessibility related problems (e.g. potholes). Complaints through this system are made via a simple webform, supported by text and (potentially) photographic evidence at

a given location marker, however there is no option to use video.

WHEELIEMAP

At present, it can be seen that there has been no truly successful implementation of an accessibility mapping system. Automatic approaches are not presently viable; expert driven systems are too costly and existing community driven approaches fail to provide actionable evidence which can be used to persuade decision makers to alter the existing environment. WheelieMap aims to address these concerns. It does so by combining semi-automation, video-based documentation and an accessible editing system. The result is to have a system that enables rapid engagement by an end user, whilst also providing effective documentation and evidence that can be persuasive in making change, thus addressing the limitations of prior art.

Value / Feature	Appropriate Disability Activism/Advocacy	Objectivity	Auditability	User Convenience	Anonymity and Privacy
Video Documentation	X	X	X		
Automatic Segmentation				X	
Mapping			X	X	
Rapid User Interface	X			X	
Camera Positioning					X

Table 1. This table summarises how the values and features (i.e. the realization of the values in the design of WheelieMap) intersect with one another.

The Overarching Design Principles (or Values)

Based upon (i) initial consultations with manual wheelchair users, (ii) prior art (as detailed above) and (iii) a consideration of the accessible planning process in the European Union (including the legal aspects thereof, namely Article 9 of the UN CRPD, which is to be operationalised by EC Directive 2015/0278), we developed the underlying design principles of WheelieMap. These principles are very much akin to 'values' in a Value Sensitive Design process [7]; they have shaped and driven the design and implementation of the WheelieMap system (and the qualitative evaluation will ultimately test both these values as well as our relative emphasis upon each of these). The value sensitive design process is consonant with the legal concerns, which in essence require a move from a heuristic type process (with an emphasis upon specific features) onto a holistic proportionality driven approach. We also explain how these specific concerns have been facilitated in the design of WheelieMap (see **Table 1** for a summary).

Appropriate Disability Activism/Advocacy: An overriding consideration is the need to ensure that the development of a system recognizes existing challenges in respect of disability rights. It is well known that people with disabilities are often excluded from activism as a result of their impairment group [12] and the competition between different groups [4] as well as by virtue of their circumstances, where organizations that purport to support people with disabilities are more concerned about being careful to maintain access to government funding and do not wish to "rock the boat" [16]. Furthermore, there is wider exclusion for people with disabilities in respect of party political processes, due to their general failure to align with disability rights [2]. It is of fundamental importance to take into account these barriers and past experiences, which means offering an inclusive and flexible approach, whilst also accounting for the competition between the needs of different groups of disabled people. This includes allowing people with disabilities to choose if they will be advocates or activists, or somewhere in between. The following four principles flow from this concern.

Objectivity: The impairments arising from a disability are individual in nature. A barrier which is insurmountable for one person is simply an inconvenience or discomfort for others (although it must not be forgotten that a repeated degree of discomfort can ultimately amount to a barrier, because it would likely reduce that person's inclination to fully explore their local community). For some people, these can also vary on a day to day basis, be it with the fluctuating nature of a condition, or the human support that the person is provided with. *Objectivity* is essential: a simple gathering of opinions has a limited practical use for an independent decision maker, because this can only really provide an egocentric view narrowly focused upon a given individual's impairment. The approach of WheelieMap facilitates this both through auditability and providing the opportunity for reflection, because our users can engage in a post-facto (and thus more dispassionate) consideration of the problem in question, rather than raising a concern in the moment, or a subsequent recollection of it.

Auditability: WheelieMap is designed to be substantially different from previous systems which have attempted to highlight challenges in the built environment: it is intended to actually help persuade the skeptical. This means moving away from the purely qualitative emphasis of other community based mapping systems discussed in the foregoing sections: instead, there is an emphasis upon auditability, in the sense that an independent outside observer can ultimately judge a video and determine for themselves if the issue presents an access barrier. The advantage of this approach is that it provides evidence which can be potentially actionable by an organisation (i.e. it

demonstrates the problem at hand), as well as allowing a person with an impairment the opportunity to determine for themselves if an obstacle is surmountable for them given their own condition and needs. It is also consonant with what has been widely recognized as good practice in Human Rights more generally [8,17] with international caselaw demonstrating that a video that accurately captures the circumstances at hand is extremely persuasive as legal evidence (See especially the US Supreme Court case of *Scott v. Harris*, 550 U.S. 372 (2007)). Whilst video has been hypothesized as an appropriate approach [23], there have been no investigations that actually test this in practice, or have succeeded in addressing this for the goal of documenting accessibility barriers.

User Convenience: In the design of WheelieMap, there is also a strong *emphasis upon convenience*. The user has a binary decision: publish or do not publish. This does not involve providing detailed reports on perceived problems and difficulties, nor does it require making a qualitative assessment as to one's personal inconvenience. It allows the dispassionate review of videos sometime after the events in question, rather than requiring the end user to disrupt the activity they are currently undertaking in order to document the issue in question. It also affords the user the choice of how much they engage with the system: they can use the map to focus on points of interest, or simply review all the videos generated by the system. There is also the option to filter videos on the basis of intensity; again affording the user a significant degree of control. It is reasonable to presume that a system which is efficient and effectively scaffolds the users experience in highlighting inaccessibility, will have the effect of enabling people who would otherwise not take part in advocacy and activism to do just that.

Anonymity and Privacy: Another concern which is emphasised in the system is *privacy (and anonymity)*. There is a significant emphasis upon choice: if a video contained private content, then the user need not publish it. (In respect of the privacy of others, in Europe under the ECHR regime this does not generally apply in public spaces and there is an overriding right to freedom of expression, see [14]). The consequence of this is that the system can be used safely by any user who is concerned about their privacy or the risk of being identified. Furthermore, the camera positioning (slightly angled towards the pavement) means that there are no identifiable close-ups of other people and the removal of audio from the video also protects anonymity. At the same time, the physical system is discreet. This is important for a system which is intended to support and assist with an activity which is not necessarily popular, as highlighting inaccessibility (and thereby impliedly the perceived incompetence of the local authority) has the potential to be perceived as antagonistic.

Technical Overview

WheelieMap has three components. It comprises a mobile application which records sensor, video and location (GPS) data for each session; a server that segments the video in an attempt to identify problematic locations and a web platform which allows end users to view and 'publish' videos. Collectively, this is intended to provide an end-to-end process (as summarised in **Figure 2**) for annotating videos and to highlight trouble spots.

The Mobile Application

The mobile application is simple. It has two features. The first is the recording function, which has been engineered to enable videos to be taken continuously without interruption and with highly accurate (~0.1s) synchronisation with the accelerometer data. To this authors' knowledge, there was no custom Android application which can collect this data over a sustained period of time. Secondly, the application also provides a facility for uploading the video and sensor data (over WiFi) for completed sessions. The smartphone is mounted to the wheelchair using a commodity clamp (which costs £10) and mounts to all known manual wheelchairs. The camera is set to face the rear of the wheelchair.

The Video Segmentation Algorithm

The aim of the design is to favour Recall over Precision, given the relative ease of removing irrelevant videos: this is a common and well-recognised approach in respect of semi-automated activity recognitions systems. The algorithm comprises three steps: (i) **Generation of Segments.** This is achieved by computing the (smoothed) Energy (E) of the accelerometer data, which is the Euclidian Distance. We then identifying all peaks in the data. (ii) **Segment elimination.** Simply selecting each peak that emerges would produce an inordinately large number of videos. To address this, we threshold at 1.5G. We then merge remaining peaks that are close to one another iteratively, until there are no points that are within 3 seconds of one another, preserving the peaks of the highest energy level). The intention is to avoid a series of videos that show the same event. (iii) **Segment extraction.** A video of 20 seconds in length is centered on each point identified, along with its GPS co-ordinates (after noise filtering). This video is then 'sped up' by a factor of two, making a 10 second video as an output.

Although this approach is not expected to capture every possible accessibility barrier, events of a high energy would be expected to indicate significant problems. It also has the advantage of centering the video on the event that has been presumably identified. Because we retain the energy value at each point, our user interface can adjust for the degree of energy and therefore balance between precision and recall in line with the taste of each user, thereby allowing a degree of customizability, and in turn, the support of a broad range of user needs. This approach is appropriate for an exploratory system, in that it casts a wider net than a final production system might be expected to achieve, especially given that it was not appropriate or possible to determine *a priori* what a specific detection system should focus on. Future work, with a more complete implementation aimed at a longer term deployment, would provide features that address

confounding circumstances (e.g. not to record events when someone is using public transport by utilizing an explicit activity recognition system such as in [25]).

The User Interface

WheelieMap provides an exploratory user interface for interacting with the videos generated by the system. The idea is to afford a simple, yet visual, interaction with the segmented videos. Each becomes a (red) marker on a map, with an info-window displaying the video of the interaction which triggered the event in question. There is a toggle button to publish the video to the map (i.e. make it public or private); if a video is made public, then the icon representing it in the editor will change to green.

It is important to briefly observe how this design provides the affordances set out at the beginning of this section. The simplicity of the interface, with the centrality of video affords the key design concerns (i.e. the emphasis on video, convenience and objectivity), likewise with control. The slider at the base of the screen allows for users to adjust the energy threshold at which videos are displayed. This is intended to be a simple user interface which removes all the complexities that arise when compared with alternative systems. The intention is to enable the user to engage with the system on their own terms; one person might wish to review every video; others will wish to be selective.

STUDY DESIGN

This is a qualitative investigation in two parts, reflecting the fact that there are two different stakeholder groups: the manual wheelchair users themselves and the people (town planners) responsible for responding to the system in question. This work focusses upon the values and principles for designing a CAMS system; as such, the data reported here is purely qualitative. For an extended account that includes quantitative results, the interested reader can access them in the first author's PhD thesis [15].

Manual Wheelchair Users: Four experienced (i.e. greater than two years) manual wheelchair users (W1-W4) were recruited through a snowball sampling approach. All participants lived in the same local community and knew the area extensively. An Android smartphone running the WheelieMap mobile application was mounted to the lower-rear of the participants manual wheelchair. WheelieMap, continuously captured video from the rear facing camera, time coded motion data from the device's 3-axis accelerometer and GPS co-ordinates. Participants were asked to trial the application in a wholly naturalistic manner, taking it on the typical routes they would take through the built environment e.g. their commute to work; or travelling to meet friends for coffee. (For ethical reasons, we did not impose a particular route, because doing so could encourage someone to risk injury by attempting something that is outside of their comfort zone.) However, the resulting routes, being in a European city, involved a substantial degree of variety in respect of the terrain traversed (which is not necessarily found in US-centric locations).

Town Planners: To explore the potential benefits of WheelieMap to support incident report sensemaking by build environment professionals, we met with five town planners (P5-P9) to demonstrate the experiential incident reports and gather feedback on their impressions of the system. Each session lasted 30-45 minutes, in which the planners could explore the WheelieMap reports to play back videos and read the reflection statements of the reporting users. Our town planners had a range of experience in disability rights: four had been involved in matters that involved disabilities issues, whilst two regarded it as their area of specific expertise.

Data analysis: The interviews were audio recorded and transcribed. Thematic analysis [1] was used in order to organise the data into themes and subthemes; this approach was used for its flexibility and rigor in finding patterns within qualitative data. Our factual findings are therefore driven by the underlying data itself, rather than our a-priori design principles and values.

RESULTS

Video as a Documentation Tool

Given the emphasis upon video as being critical to the system, it is unsurprising this emerged as a major theme from our analysis. This issue attracted a significant amount of discussion from our participants and it was agreed by all participants that the use of video was a highly effective way of documenting the problems at hand, especially when considered against the fact that the alternative systems simply presented subjective qualitative ratings. For example, W1 explained the advantages:

> "Close to where I live there's a bus stop and the bus stop has no curb at all. If we have a system like this, I could take a picture or video of it and then when I get off the bus and there is no curb, I could challenge either the bus company or the council to come and pull the curbs in that place. The more information you have the better you can advocate, you see? Like only sending text messages asking or writing letters [is not sufficient; by contrast] adding things like videos and whatsoever, it brings more evidence to support your case."

This advantage was echoed by our planning participants; with P5 explaining that unlike other community evidence, this went beyond *"something that was kind of notional or you standing in the street",* thus endorsing the objective approach of video. P7 stated that: *"it would point to potential solutions, it would suggest whether the problem was more difficult to fix than just filling in a pothole".* Relative to a photograph, P7 further observed that this system has an advantage in that you can see the action, for instance *"if you see a video of a wheelchair user [..] having to really far around than where there was a dropped curb",* then the nature of the issue is obvious. The most direct account was by P8 noting that the video combined with the map was particularly effective:

> "It is visual, so you can actually see, much better than a photograph or a thousand words, so this obviously gives you an area on that street and you can click on it and that gives you a video of the condition. … [furthermore] "pictures or a video are a lot better than actually written word, as everyone has a different opinion. When they come to read a report, for instance I could write something, and say this road surface or the footpath is of a poor condition, its got no dropped curb, etc. But you can't actually quantify that until you actually see, so I think a Video is quite good."

P9 was also supportive, raising the point that the video could sometimes assist in capturing a wider context:

> "I think it is very important that you can see what is happening around, why he necessarily had to go across a road at an angle, rather than straight across."

However, some participants were concerned that a video might not always capture everything. P6 observed that it is possible that the video would be effective, presuming that the *"council IT systems do not block videos";* perhaps more pertinently, he added that it is not always initiative to grasp the issue at hand:

> "So if you were to watch a particular video, one particular officer might not identify the issue immediately. … if someone receives the video, they look at it and then they might say I didn't see a problem there, but if it is written and it says there is a problem with this particular curb on X Drive, then it would just be a lot more helpful. … You could argue conversely that is more accessible because not everyone would be receptive to a video. So you offer it in several different modes."

W4 indicated that they would like a *"brief sentence"* to capture an event along with a rating, as did W1; both also wanted to know about the nature of the wheelchair user who captured the video, with it being observed that the nature of the impairment has a significant impact. Moreover, the detailed documentation provided by the participants when exploring videos in the first part of the study amply demonstrates the willingness of them to provide this further information about accessibility barriers, implying that there was little or no motivation barrier on their part.

The existence of the map was found to be generally useful and important in assisting with the documentation process. W1 explained that "*the map definitely helps because it tells you, you know exactly what happens and it gives you more control over and more understanding of what is happening."*, which was a view point echoed by our planning participants; for instance, P7 stated that he *"appreciated that it is mapped, as the problems are tied to a location".*

Capturing the *Right* Video

Some of the concerns about the video raised in the foregoing theme seems to have arisen from the accuracy of the system itself and the decision to position the camera behind the chair. Whilst all our participants endorsed the approach of video, the wheelchair user participants did express concrete limitations in respect of the configuration used in WheelieMap. It was indicated that they would prefer a forward facing camera instead, with W2 explaining that *"Because it's a rear-view camera, you don't see what's in front of you"* and furthermore that he would prefer a 360-degree view so that he could make a full assessment of the environment. W3 expanded upon the issue of interpreting videos, explaining that the existing approach presents some intellectual difficulty in identifying the nature of the hazard:

> "Because other people are going to be looking at these videos, aren't they, to decide whether they can... I must admit, watching them back, it is a bit more difficult to work out. You're only seeing once it's already happened, if you know what I mean."

It was also agreed amongst our participants that ramps were particularly problematic with our current configuration, because of the perspective of the camera made it difficult to discern. W1 stated that he did not *"know when the floor is flat or if you're going up a slope or something like that ... because we only captured the data from a chair perspective [rather than a] view which is a little bit more external to the wheelchair.",* whilst W4 also expressed that sometimes *"it's a bit hard to see gradient or camber from a video".*

Our wheelchair user participants had varied views on how accurate the system was. W3 took the view that the system was highly accurate in what the system identified, stating that he thought "*they [the video's] were all good"* and that *"the good thing is that it's highlighting that it's showing a different range of terrain";* however, he did indicate that it would be interesting to capture somewhat more subtle features, such as *"Things like sometimes trees come right out onto the pavement and really narrow your path. Like railings, they can sort of really narrow your pavement space, so I guess extra little bits like that as well"* W2 considered that the system had a degree of overfitting, in that it would produce too many videos in a given setting. *"Yes. I would say that these two videos are actually right next to each other. It's just video one after the other, so it may be useful but I don't think you need both of them."* However, the broad nature of the system generally meant that it captured the most serious issues from the viewpoint of our participants.

From the planning perspective, P6, P7 & P8 observed that a video cannot be the basis of decision in respect of a specific artifact or feature, because this would require a 'site visit'. This has an interesting consequence for accuracy, because the system effectively accords with the original philosophy of being a mechanism for highlighting potential problems:

> "… What I am thinking is that someone from the council will have to do a site visit, so does it have to be accurate, maybe not. … The most likely thing is that one person would go and visit multiple sites [within a confined area] doing their own appraising"

However, P5 considered that the system would be a *"strong piece of evidence"*, especially in respect of *"neighbourhood plans"* and in *"highlighting where the hotspots are".* In this broader context, the planners were also keen to understand the wider range of barriers, seeing the system as a

particularly mechanism for generating a broader perspective as P7 explained:

> "planning wouldn't be putting in dropped kerbs, nor would they be fixing potholes, but they would be doing more long term visioning and plans and saying this area frequently features on this website, it has got a lot of problems reported with it, how can we change this in the long term, what can we do to make this junction easier, it would be more the concern of highways"

Part of this issue is the different contexts to planning: most work in this space was described by the planners to be reactive, i.e. in response to a given application to make a development. P6 and P5 were particularly keen to emphasise that the temporal aspect of when the information was generated is important; plans are made irregularly (and in the words of P5), if you *'miss the boat'* on neighbourhood planning, then the system is bound to have less influence. From the planners perspective then, the question of when is therefore more important than the inherent accuracy of the system.

The Nature of CAMS Activism and Advocacy

We now move to the broader question, namely how WheelieMap could assist with the advocacy process, taking into account the existing barriers. All of our wheelchair user participants had not used alternative CAMS systems. Impliedly these tools (e.g. [30–32]) were largely academic, at least insofar as this group was concerned; they were simply unaware that they existed. This speaks to an underlying knowledge barrier, with W2 emphasising (in common with W3 & W4) that *"[it is] something that I didn't know where to start or how to do it before"*, but if there were to be a supportive community, *"[they] would be happy to join them"*. W3 went further and observed that if there were to be an effective system, then it would be already well known in the community of wheelchair users:

> "Because we play wheelchair basketball, so I think it's something that word would get around fairly quickly then because you would naturally talk to your teammates and things like that about, you know, "There's this website," or, "There's this app that you can use. I think if it became a bit more well-known in these different areas, I think it could potentially then pick up quite quickly and hopefully get a lot of people on board and using it."

Whilst such a finding would be expected with respect to academic prototypes, the reality is that many of the systems identified in the background setting are widely deployed. Another perceived barrier to using pre-existing CAMS was time. This is perhaps inevitable with respect to disability rights; people with disabilities already have difficulties and barriers which mean that essential activities, like work and study, often take more time. W1 was particularly keen to emphasise that time – and the perception of effort – was important to his previous disinclination to engage in disability activism or advocacy around transport barriers:

> "No, other factors that really prevented me is also the fact that I didn't really find the time to do those things. ... Now that I'll be having a little bit of time, I think I'm going to start looking into those things again from fresh eyes."

There is also a wider point that the nature of the disabilities of our participants, including their past experiences, impacted upon the general views of on how they would approach activism. According to W1, who was originally from a developing country, the contrast between the UK and his previous experience fundamentally shaped his viewpoints on accessibility activism:

> "We still have to fight for certain things here but it's not with the commitment, it doesn't affect you the way it affects you where you in a country where those things are not really that advanced. … Here there are things that I can maybe not ignore but not really pay that much attention, but back home they were just 'in my face' and I could not but act. … there are already certain things that are in place that we take here for granted that are not the same back home. Like I remember when I did spend one year in university, we never had a disabled toilet over there. … I didn't even know until I came here that we could have disabled toilets."

W3 made a similar observation, noting that he would *"I just get on with it and make do."* The further issue, most directly expressed by W3 (but also implied by W2 and W4) was the attitude towards activism and this being a negative concept. W3 observed that not engaging with activism was *"just the classic British way"*, but when pressed on in the issue (the interviewer asked if the position was spun around to emphasise advocacy instead), he was more positive:

> It's the perception, like if it's seen as in a more positive way to give feedback like this, like that's how I could see this as being good. Rather than telling people what's wrong, like you said, it's that platform almost to say, "How are things? Is there anything that could be done better?" Do you know what I mean? It's that throwing a nicer spin on it, I guess.

For W4, the discomfort from advocacy arose from the barriers of explaining this issue to people who were not wheelchair users themselves:

> "Occasionally obviously if I had a bad time I'd say, "Ah, I tried to go this way today and it was a massive fail." My friends would say, "That's really unfortunate." But I'm quite good at making everything a laugh, to be honest. I only really talk about that sort of thing with other people in wheelchairs because they know what it's like."

The views of the planners also coincided with that of W3 and W4, in that activism would not be necessary (or impliedly appropriate) as a means for addressing accessibility barriers in the built environment. P8 was particularly concerned to emphasise the limitations of existing reports on accessibility, observing that:

> "any tool that helps with providing access information is a massive plus, everyone has their own idea how good or bad things are, how good a surface is, some people might say that surface is uneven, whereas someone else might say that surface is fine, I don't see any issues. It is very much in that person's head what they think is an access issue."

As such, pre-existing activism driven approaches have not been so appropriate or effective. More fundamentally, they are unnecessary, indeed public authorities actually want and need more appropriate information, as P6 explained, that due to severe funding cuts *"The Council would just want, you know, the least work as possible. They would want to see that the money is the most effectively spent in the most pertinent location. Something like this would work very well in a village because it is quite small, it would be win win really"*. P7 observed that *"the planners are kind of like the mediators, they are the ones who facilitate the discussion and ultimately make then decision … this would be for the planners to get a strategic overview of where the problems occur"*. P5 took the view that enhancing inclusivity and accessibility was a *"very gradual process of raising awareness"* and that this was a challenge to integrate into an existing planning workflow due to stronger external pressures, including a emphasis *upon "box ticking"*; indeed this was a fundamentally different process to what planners had been trained in. P7 further observed that in respect of a specific scheme, there is actually a legal obligation for the planners to respond to all representations from the local community, which also minimizes the need for activism; the planners are in a certain way a captive audience.

There was a further point raised by P9, that certain national level schemes are focused on particular timescales. For example, with respect to cycling routes:

> "The way it works is that the local authority gets the funding to develop and improve those national cycling routes. Once they have got the funding … they have got to do it. In terms of the timescale, it has got to be done within the year"

This means that there is a need to obtain the information in a rapid fashion that coincides with the particular scheme at hand, thereby making a digital system that can achieve this particularly desirable.

WheelieMap as a Tool for Disability Inclusion

The general approach and ethos behind WheelieMap was found to promote disability inclusion. There was an agreement amongst our Wheelchair User Participants that the system was easy to use, with W2 stating that *"I quite liked how it's designed. It seems quite simple, you just click on the logo and then watch a video."* The map was also highly beneficial – as W1 observed, it *"gives you more control over and more understanding of what is happening."*. Indeed, both W1 and W4 observed that the nature of the system was so persuasive to the effect that it enabled them to intellectualize the possibility of activism as being something that they themselves could perform, as W4 explained:

> "No. I had a quick look, like the sort of wheelchair access apps, that sort of thing. But I've never really found anything which is particularly useful. I've never found anything like this, for example. And so I just kind of stopped looking, I guess."

An appealing aspect of the system was its altruistic nature, as W3 explained:

> "In terms of helping other people out, you know, if I knew somebody that had a bit more of a severe disability, this system could help them and other people could feed into it to say, "This area might not be so good but have a look over here."

W4 also appreciated the fact that the system (presuming regular enough usage) would particularly assist with transient inaccessibility, especially with respect to: *"the little things like parking on the kerb, or bin bags, you look at it Thursday and think, 'obviously someone can get past that. You can walk past that easily.'"*. In other words, they recognise the temporal nature of the problems and how this particularly applies to people with impairments beyond wheelchair users, indeed W4 the explained that that brings forth and assists with empathy in respect of the counter-intuitive nature of the barriers that this group face:

> "I think it would be really good to sort of show the general public things that they otherwise wouldn't think of. Not through them being nasty or whatever, just because, obviously if you don't experience something yourself, you just don't think about it sometimes. This terrain would be really easy to walk along; you don't actually realise what it would be like for someone in a wheelchair, or in a pram or something maybe. And obviously if people actually realised that, maybe they would also want to be involved in an activism project, that sort of thing."

This was a position also endorsed by our planners. P7 echoed this position, observing that the approach of the system *"describes more easily what the problems are, because you are a non-wheelchair user, you wouldn't see a problem with that"*, compared to a paper report.

These features imply that WheelieMap has the potential to develop and sustain a following in a way that previous systems have not, due to the inclusive and broad approach which it facilitates.

DISCUSSION

This discussion is in two parts. In the first, each design decision is considered in turn and tied to its underpinning values. In the second, the wider findings and concerns that emerged as a 'higher level' concerns that have a broader set of implications for designing systems that support disability advocacy in the space of transport more widely.

The Design of WheelieMap and Future CAMS

The overarching design and values of WheelieMap, especially with respect to the higher-level choices made. However, some of the subtler choices might be reconsidered in the development of a future CAMS system, thereby affording a more appropriate tensioning of the underlying values and design choices.

Video Documentation: For the concerns that the videos captured directly, this approach was regarded by planners and wheelchair users alike as to be highly effective. The reasons raised by our participants accorded with the values of *objectivity* and *authentication*: the fact that someone could see the nature of the problem for themselves and experience it in a manner which creates empathy with the concern in question is an advance on the bare assertions of

inaccessibility promoted by pre-existing CAMS systems. However, there was a need for further information to assist with the interpretation of videos, so it was clear as to the problem that was being reported, as well as to assist in identifying subtler accessibility barriers.

Camera Positioning: Whilst the use of video in and of itself was found to be appropriate, there was a concern raises across the wheelchair user participants that the positioning of the camera was inappropriate, be it the proposal for it to be forward facing, or to capture a wider field of video. The purpose of locating the camera facing downwards behind the Wheelchair was to protect *privacy*, both of the user and of others. Given the proliferation of cameras in wider society engaged in surveillance, together with the safeguards of allowing the user to publish, it might be that we struck the wrong balance between *privacy* and the human right of freedom of expression (and in turn, effective *disability advocacy*). In other words, future systems, subject to the autonomy of the user, should place a greater emphasis upon the right to accessibility, and concern themselves less with the privacy concerns of the designers.

Automatic Segmentation: The concept of segmenting videos was well received by the planners who desired efficiency, albeit slightly longer videos. Moreover, this approach enhanced *ease of use* with respect to documenting accessibility barriers. However, the approach adopted within the system was perhaps too restrictive: users should be given more autonomy in accessing their own videos and publishing entire journeys if they wish to do so. This does raise the issue of ensuring *privacy*, because such an approach may mean that users publish videos without directly inspecting them, so some further assistance would have to be developed or provided to address this potential concern.

Rapid User Interface: The ease of use of WheelieMap was one of the core features, having been derived from a concern that previous CAMS systems were not concomitant with the need of *user convenience*. Whilst the failings of the other systems were found to be true (especially with respect to the surprise of our wheelchair user participants that these even existed), it is likely that we have overemphasized *ease of use*, with our participants being more willing to participate to a greater extent if wider benefits were provided (such as supporting route-planning, or genuinely changing the planning process). With respect to planners, the simplicity and economy of an interface for them was of the utmost importance, but again, this required the design of their interface to be embedded with the practice of the planning process. WheelieMap is an advance on these issues, but a future incarnation would benefit from different interfaces for these differing sets of needs.

Mapping*:* The use of mapping in general was found to be appropriate. At the same time, the specific concerns raised by planners means that there is a need to construct a mapping interface that affords to their particular needs and concerns. The fundamental design decision of video mapping should not be changed, but there is a need to adapt it going forwards to the nuances of the participant groups.

A Wider Picture

The investigation of WheelieMap also raised a number of pragmatic concerns about designing systems that intersect with public authorities in the sphere of accessible transit. These findings provide new opportunities, both in respect of the development of CAMS systems, and beyond them.

Learning from Immersive Experiences: The objective of CAMS is to communicate the barriers, challenges and views of the community: however, this underpins a wider question, namely how these systems ought to communicate the problems at hand. Our overall finding is that to be persuasive, the most effective evidence of inaccessibility needs to be inherently immersive and this can often be achieved using a video driven approach. Pre-existing CAMS promoted abstraction and categorization over rich experiential reflections. This contrasted with our realistic portrayal which in turn allowed planners to empathize with the wheelchair users, but also accurately understand the extent and nature of the barriers from their perspective.

Integrating CAMS with a wider Planning Process: Predominantly CAMS have been used to capture and archive evidence from the community. While the planners could see the value in these resources, the prospect of using the experiential videos to support discussion in community engagement was immensely appealing. There is a need for more integration between CAMS (which simply reports problems) and the reactive and rhythmic nature of the planning process - for genuine change to happen, this dialogue is essential. More specifically, our qualitative findings suggest that this can be realized by structuring data collection and annotation activities to address specific events in the planning process, rather than making it a general data collection 'free for all'. This is a fundamentally different design direction and approach compared to what has previously been followed in respect to the development of accessibility mapping systems.

Collaborate to Advocate: The discussion from our participants in respect of CAMS implies a fundamental rethink of the approach taken towards disability rights, especially in respect of the rejection of more aggressive activism approaches which have dominated disability rights. It is a shift away from activism to a more reflective advocacy driven approach. This turns the approach of addressing barriers on their head, by focusing on collaboration with organisations (in this case planning authorities) rather than the typical demands of activism. Such an approach is concomitant with avoiding the wider risks of 'rocking the boat' associated with disability advocacy for service user organisations [16]. Designers of future CAMS (and other systems aimed at advancing the rights of people with disabilities) should consider emphasising visibility of the barriers, whilst also implementing the 'soft' and 'subtle' approach of advocacy rather than activism. Although our

participant's experiences are constrained to CAMS, it is reasonable to assume that this principle would apply to other systems which seek to further the rights of people with disabilities going forwards.

CONCLUSION

This paper has presented WheelieMap as an exploratory tool for understanding how to develop more effective and appropriate CAMS systems. We have demonstrated that a simple approach based upon automatically segmented video is a substantial improvement upon previous methodologies, being viable for both planners and manual wheelchair users alike. In turn, this means that the underlying values of appropriate disability advocacy, objectivity, auditability, user convenience have been found to be essential in the design of future systems, whilst leaving open the emphasis to be placed on anonymity and privacy. The exploration with WheelieMap has also identified that a 'soft' approach towards promoting the mobility rights of disabled people is the most appropriate. This is because it addresses the potential discomfort of wheelchair users of being seen as activists and in any event, direct activism seems to counterproductive when the prevailing circumstances lend themselves to a more collaborative and inclusive approach. At the same time, future efforts will need to carefully account for and manage the disparate viewpoints and goals of those who collect and utilize the data, as well as focusing upon the need to develop and retain a community which is willing and able to engage in the regular data collection and annotation needed for any CAMS to be successful.

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