Towards a Framework for Detecting Temporary Obstacles and Their Impact on Mobility for Diversely Disabled Users

Enka Blanchard[1,2,3(✉)], David Duvivier[1], Christophe Kolski[1], and Sophie Lepreux[1]

[1] Laboratoire d'Automatique, de Mécanique et d'Informatique industrielles et Humaines, UMR CNRS 8201, Université Polytechnique Hauts-de-France, Valenciennes, France
enka.blanchard@gmail.com
[2] Chaire d'Intelligence Spatiale, Université Polytechnique Hauts-de-France, Valenciennes, France
[3] Centre Internet et Société, UPR CNRS 2000, Paris, France

Abstract. While walking around a city, the temporary obstacles present on the sidewalk barely register in most people's minds. The reality for people with disabilities is quite different, whether it's a scooter left in the way, crowds that refuse to budge, or construction work loud enough to trigger somatic effects. While detecting permanent obstacles (e.g. wheelchair-inaccessible areas) is a relatively easy thing, detecting and addressing temporary obstacles is very difficult. The objective of this paper is to propose some first elements to build a framework aimed at detecting temporary obstacles for diversely disabled users. We point out several scientific and technical issues that pave the way to reach this goal and highlight the limits of existing approaches. We insist on three significant problems to overcome: incomplete models of the environment, limited availability of good-quality data, and absence of tailored algorithms . Taking inspiration from percolation theory, we propose some leads to solve the first two problems mentioned.

Keywords: Disabled mobilities · Percolation theory · Obstacles · Routing

1 Introduction and Problem Statement

If one is attentive while strolling around a city, one can notice a large variety of obstacles that don't initially come to mind: construction work with its loud noises and equipment left on the ground that we must sidestep, trash bins on the sidewalk, crowds and queues in front of pubs and shops... These obstacles (illustrated on Fig. 1) rarely register in the conscious mind of most pedestrians, as their impact is generally negligible. There is, however, one group on whom those obstacles can have a considerable impact: disabled people. To be precise,

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we are not using this term as shorthand for people with physical impairments or wheelchair users, who already have very varied approaches to mobility [19]. Instead we use it to denote anyone whose bodymind peculiarities[1] are not compatible with all environments, such as the following (non-exhaustive) list[2]:

- People with multiple chemical sensitivities, for whom various aerosols (smoke, perfumes, pollutants) can trigger intense short- and long-term adverse reactions [28].
- People with mobility impairments or lowered manoeuvrability for whom a physical obstacle can be impossible to go around (especially in a constrained environment like a sidewalk) [2].
- Blind people[3] who cannot generally perceive obstacles at a distance and plan their path, and who are especially at risk when it comes to floor irregularities [14,24].
- People with hyperacusis for whom loud noises can be painful, disorienting, and even act as a trigger for anxiety disorders [32].
- People with cognitive impairments who rely on specific landmarks and for whom a small change can prevent recognition and prevent them from reaching their destination [1,10,22].
- Agoraphobic and ochlophobic people for whom the presence of a crowd in a street can make it an impassable obstacle.

Previous work on disabled mobilities and spatialities has mostly focused on physical impairments and especially wheelchair users [2,7,13], albeit with some exceptions [10,24]. In all cases, however, a common finding is that many of the people concerned have restricted spatial habits (sometimes dependent on the availability of a companion). They tend to move in a discrete fashion, such as from home to workplace and back (with no stops in between), and rarely deviate from known routes to explore their environments (for example, one study on blind people found that 40% deviated from known routes less than once per week [24]).

There are many reasons for this reduced tendency to explore one's environments, including potentially higher intrinsic costs as well as safety considerations and stress factors. Intelligent Transportation Systems (ITS) can be of assistance in such contexts by providing accessible routes to one's destination for different transport modalities, sometimes with multiple routes [8,26]. However, most algorithms—whether online (during the trip) or offline (during the preparation phase)—rely on the assumption that the environment is known with reasonable

[1] The term *bodymind* is used in disability studies to accentuate the importance of corporeity (against an imagined detached mind). We choose to use peculiarities as the issues here are not always impairments, but rather incompatibilities between the bodymind and its environment. A classification of disabilities will not be attempted here as it is an endeavour fraught with difficulties [18].

[2] This list does not include the troubles caused by harassment and discrimination, which play a big role in disabled spatialities but are much harder to evaluate, and are thankfully not as frequent as the obstacles mentioned for most users [3,25].

[3] We use the term here as one chosen by the community to describe itself [20].

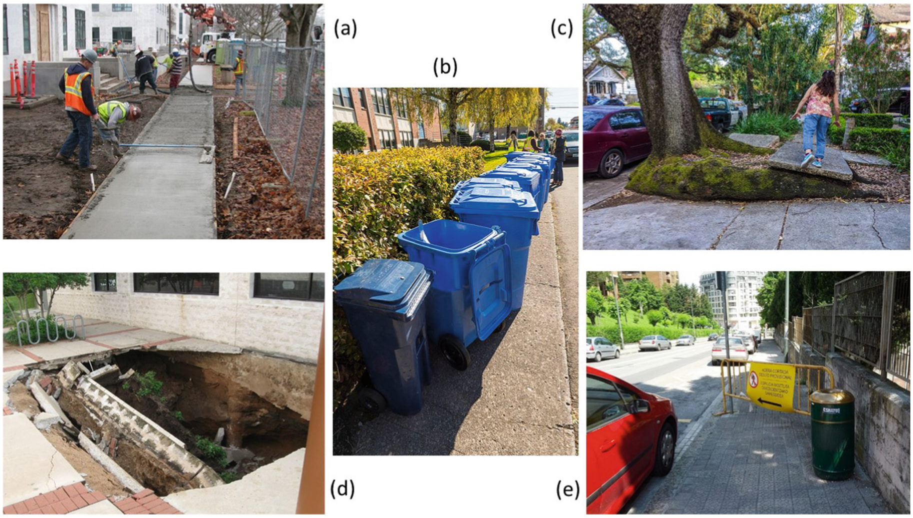

Fig. 1. Various kinds of temporary and semi-permanent obstacles. Images from Wikimedia Commons under CC-A licenses by the Oregon Department of Transportation (a and b), Bart Everson (c), En el nido (d), Eric Fischer (e).

accuracy. They might allow for rerouting in case of increased traffic, but are generally not optimised for cases where a significant proportion of the network can become suddenly unusable. This is where temporary obstacles create an issue, as their distributions—or even rough estimates—are generally not available, and require specific measurements methods, which we seek to address here. The main previous study that addressed some of the same issues did not take such temporary obstacles into account—and also collected limited data, based on questionnaires [33].

Using percolation theory [6] allows us to look at how the impact of temporary obstacles on disabled mobilities can differ from that of permanent obstacles and requires different solutions. If their density is high enough, moving around a city can become nigh-impossible, and this can be subject to threshold effects. Having good estimates of the prevalence and impact of temporary obstacles would be a useful tool, whether for informing policy-making or to evaluate spatial discriminations (or help disability advocacy groups). Knowing the obstacle distribution also makes it possible to use operations research tools to address path-planning with redundancies.

This paper is structured as follows. First, we give some background on the model and tools we use, before analysing why existing databases are not sufficient to get quantitative data. We then propose first ideas concerning a framework to measure and handle temporary obstacles, and finally discuss its limitations and potential extensions.

2 Graphs, Percolation and Criticality Effects

A common way to model transit networks (such as the ones in cities, whether they are road-based or rail-based) is to use graphs where each node is an intersection (or a terminus) and two nodes are joined by an edge if and only if there is a street between them (with no intersection in-between). The edges can potentially be weighted (to denote travel time, cost, or any other information). Then, two nodes are *connected* if one can go from one to the other and vice versa, and the graph is *connected* if this is true for any node pair. If the graph is not *connected*, then it can be split into a set of maximal *connected components* [15].

From a driving point of view, nearly all cities are made up of one connected component (that is, using one's car, one can go anywhere, even when taking into account one-way streets). Pedestrians can ignore one-way restrictions which simplifies matters. A pedestrian moving in a grid-like city can then be assimilated to a path between two nodes of $\mathbb{Z}^2$—points indexed by (x,y) integers. In such a case, even if one edge is removed from the graph, there are many similar paths with minimal differences (such as turning one street earlier).

Let's now consider a wheelchair user in San Francisco—which is mostly grid-like [4]. Unlike for most pedestrians, some streets are completely impassable (such as Greenwich Street which features stairs). Moreover, other streets can be impassable or too dangerous to be tried (such as Filbert street, with a slope of 31.5%). These, however, are permanent obstacles, and any frequent user (or anyone that prepares their trip) can plan to avoid the area. Moreover, they are sufficiently rare that they don't affect most trips in most cities.

Let's now add the constraint of temporary obstacles. As those cannot be known in advance (at least for now), a reasonable model is the one where each street has a constant probability of being impassable. Hence the following:

– take the graph G corresponding to the city;
– remove from the graph G any edges that are permanently impassable;
– for each remaining edge, keep it with probability p (or equivalently remove the edge from the graph with probability $1 - p$, corresponding to the probability of adding an impassable obstacle).

This brings us to percolation theory, which is dedicated to the study of such structures, of their connected components, and of the probability of being able to go from one point to another) [5]. One result from this field is of particular interest to us:

– There is a critical threshold p_c for many classes of graph—such as $\mathbb{Z}^2$, but also more general graphs that could be better models for non-grid cities.
– If $p < p_c$, the connected component around the starting point is exponentially small (in $p_c - p$).
– If $p > p_c$, there is one major connected component that corresponds to a constant proportion of the graph (which depends on p).

For our considerations, this means that there is a critical value for p, above which users can safely explore nearly all their environment, and under which they are stuck in a finite and small neighbourhood. Moreover, as illustrated on Fig. 2, this type of model can also allow us to compute not only the probability of finding a path between two points, but also the expected additional cost of detours. Additionally, this model can have an impact on users' spatial habits. If p is known for a city (and for a person, as the type of impassable obstacle varies widely), and is sufficiently above p_c, then the user can be secure in the hope that nothing wrong will happen on their trips. Whereas if it is below (or close to p_c), the user would have to plan backup solutions. Some disabled users may have a personal estimate (obtained from experience) of such probabilities, but these are generally not transferable from one place to another, meaning that travelling disabled people might be forced to use very conservative estimates just in case (and unnecessarily limit their activities).

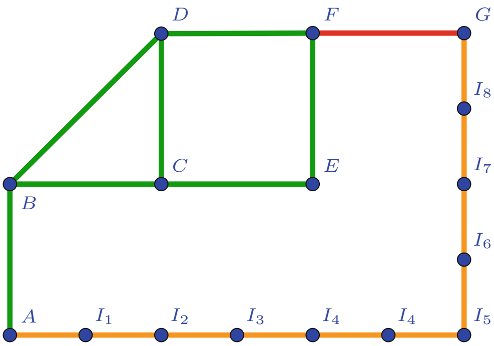

Fig. 2. An illustration of percolation in a small graph where we try to go from A to G. Let's assume that the red FG edge is often unavailable (for any reason) for a disabled user, with probability 0.5. Then a temporary obstacle on any orange edge is enough to prevent them from reaching our destination. Assuming that each non-red edge has a probability $p = 0.9$ of being usable, the probability of being stuck is 0.367 (a non-disabled user not affected by the red edge and with $p = 0.95$ would be stuck with probability 0.023). More importantly for the disabled user, no matter the path chosen, the probability of encountering an obstacle is at least 0.56, and in all but 1% of cases, this means having to take a long detour (more than two edges). This is a toy example as, due to the exponential nature of some of the behaviours, the difference is most visible on bigger graphs. (Color figure online)

Alas, as the next section shows, existing tools and databases are not sufficient to compute p. A central goal of the framework introduced in Sect. 4 is to create databases that can compute approximate values of p in various localities, while handling multiple models depending on the types of obstacles considered.

3 Existing Potential Solutions

Most of the potential sources for data on temporary obstacles come from intelligent transportation systems. Those sometimes integrate some rudimentary features for disabled mobilities (such as indicating the presence of elevators, or the accessibility of given public transit routes).However, this data is partial, and the objective functions that are used to compute or rank the paths are generally not able to take specificities of disabled users into consideration. Moreover, they can't be used directly to study the prevalence of temporary obstacles, as we will show below.

Google is the best-known provider and has two main services that could be useful in the measurement of temporary obstacles. The first is Google Maps in its satellite version, and the second is the Street View service, for which the coverage is not as complete, especially in the Global South [12]. A central concern in both sources is that due to their proprietary nature and limited transparency, it is not always feasible to get accurate metadata (temporally, the precision is at best at the month level). As such, it would be very hard to obtain a "snapshot" of a zone as it would necessarily be recomposed from multiple capture times (sometimes months apart), with unknown impacts stemming from the imprecision on when (time/day) the images were captured. Moreover, the satellite version is generally not precise enough for most temporary obstacles, and Street View is generally taken from the roadway, with a limited view of the sidewalk (especially when hidden by parked cars).

OpenStreetMap is a more promising tool as its open-database license allows users to easily create extensions, such as ones tailored for accessibility. As of January 2021, OSM's wiki shows the existence of 5 such extensions. Two of them—*GetThere* and *Accessibility layer in OSMS-WMS*—focus on making the map itself accessible (and are not maps of accessibility), and a third—*BiViMap*—is a map of points of interest for blind users, only available in German and mostly focused on German metropolitan areas. The last two—*Wheelmap* and *Wheelchair map*—are focused on wheelchair accessibility. They use existing OSM data plus additional user inputs to list accessible and inaccessible places. However, even a cursory visit to known locations (or comparisons with Google Street View history) show that some of the data has been obsolete for at least two years.

There have been attempts to create user-collected databases of obstacles, but they are a priori not able to address the problems of temporary obstacles. One central issue is the dynamic nature of the data collected. The obstacles can be either inherently ephemeral or require an intervention to be removed, and their temporal duration vary from minutes to weeks. Moreover, an obstacle is added when someone sees it, but might stay a long time before being removed from the database as users don't systematically report obstacles and no-one knows how many kilometres the user walked before reporting the obstacle (which would be needed to estimate the obstacle density). So if three obstacles are shown in one neighbourhood, it could correspond to three independent points reported over a week, each immediately reported and present for only a few hours, with no other obstacles ever being there. Or it could be a single person on a five-minute walk forced to deviate from their route three times. Collating dynamic data to have an idea of which percentage of the network is unavailable is not a priori solvable, even before getting into issues of manipulation, false-reporting and DoS attacks.

Some navigation software tools like Waze try to address temporary road obstacles such as accidents [23,31] by looking at slowdowns in the network, but they rely on a massive distributed sensor system (made up of all their users). They also rely on the relative simplicity of the data collected (location and speed) which is given with no direct cost to the user. Automatically identifying temporary obstacles might be at the edge of feasibility by detecting detours taken by certain people, but the system would need to guess the type of obstacle, and if it truly is an obstacle or if the user didn't simply cross the street to say hello to a friend. Moreover, there might not be the critical mass of users needed to obtain the information—even when discounting the fact that disabled users tend to go out less frequently.

Security camera networks and drones could be an eventual lead but their data is generally not made public, they are not available everywhere, and their use raises many privacy concerns and is often opposed by human-rights groups [30].

4 Proposal: A Framework for Detecting Temporary Obstacles in Mobility Contexts

The goal of this section is to provide a framework for the detection of temporary obstacles in mobility contexts. This type of detection has to be considered jointly with the detection of permanent obstacles. A central constraint is that we want an agnostic approach. That is, an approach which is not tailored to one disability but is as general as possible, to maximise the applicability and re-usability of the databases collected—although the characteristics of the eventual end-user will have to be taken into account to tailor the system to their needs. Figure 3 shows how a global view of how such systems could interact in the future, taking data from a variety of sources and feeding it into ITS.

In this approach, as suggested in Fig. 3, the bodymind peculiarities of the target user or group have to be defined and known by the support system. Indeed, they are necessary to identify the categories of obstacles to be detected; the obstacles are different, for instance, in the cases of agoraphobia, hyperacusis, or sensitivity to odours. One also has to keep in mind that many users have multiple categories of obstacles that affect them (e.g. hyperacusis and sensitivity to odours are often found together). This idea of groups reflects the fact that many disabled users are in many cases, for different personal, safety or health reasons, accompanied by one or several members of their social environment, which is sometimes referred to as the ecosystem [16,17]. This ecosystem is composed, for example, of family and/or professional caregivers, therapists, friends or colleagues, and this in relation to a set of activities to perform. It should be noted that the presence of one or more other people can in some cases help the person overcome certain types of obstacles, just as it can hinder in other situations.

The target user or group has in most cases objectives (e.g., go to a concert), habits (e.g., go through a park) and preferences (e.g., go through the main street rather than its parallel streets). Such characteristics have to be taken into account by the system with a view of personalisation/customisation [27,34].

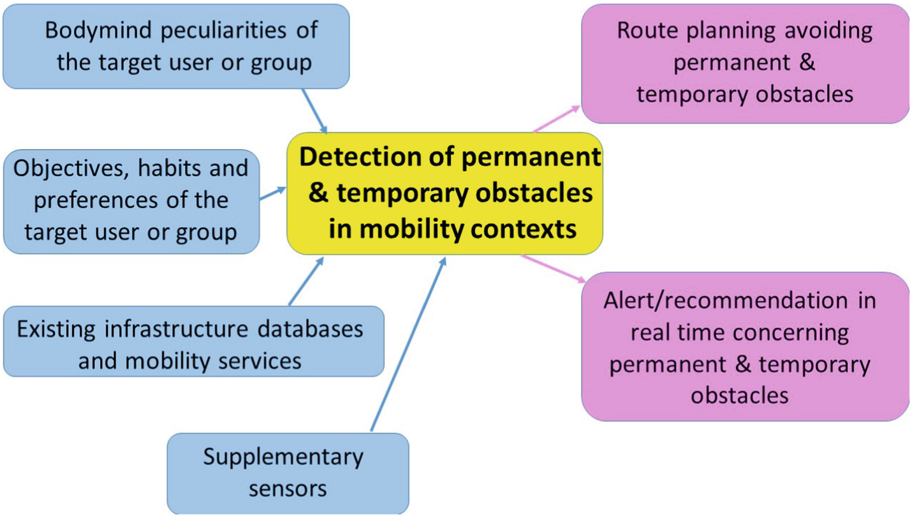

Fig. 3. Global view of the approach proposed allowing the detection of permanent and temporary obstacles, and its uses.

Concerning the obstacles to be detected, a specific work about how to categorise finely them into categories and sub-categories needs to be performed and may be object of further research. Globally speaking, they may be classified into two main categories:

– Permanent or semi-permanent obstacles, such as: broken elevators, missing curb cuts, illegally narrow sidewalks, high slopes, unmaintained pavement (or specific kinds of pavement), traffic lights not equipped with acoustic systems, street signs at head level...
– Temporary obstacles, such as: garbage cans or scooters on the sidewalks, invasive terraces (e.g. restaurant or bar terraces that extend in good weather), gatherings of people in the broadest sense (including queues spilling over onto the sidewalks, or groups of exuberant fans before or after games), animals leashed to posts on the sidewalk, loud roadworks—which can also emit MCS-triggering chemicals...

In order to model all the notions seen in this article, we wish to propose a class diagram in Fig. 4 that synthesises them and allows them to be related. In the model, the *Obstacle* element is linked to the detection mode. Thus it is possible to know by which means the obstacle is identified and thus to be able to associate a probability in time or to use machine learning on the prediction of this obstacle. The model shows two possible elements of detection, which are: information given by the user themself, or by automatic detection via sensors. As mentioned above, the obstacles are of two types. For example, a person who cannot walk on steep streets will set it as a constraint so steep streets will be considered a permanent obstacles and won't be offered during pathfinding.

This information is specific to them, it does not mean that it is an obstacle for other users. For this person, the obstacle is permanent. Another example concerning a person who often follows routine routes, with the same streets and the same sidewalks. In the case of work on the sidewalk or the installation of scaffolding, they would have to cross the road. For some of these users, this is very complicated and they might turn back. The system is there to help them in this difficult situation, either by anticipating and proposing another known route (link between *Recommendation* and *Trip*) or by assisting them in crossing the road (link between *Recommendation* and *Ecosystem*). This data-centric system could be complementary to the wayfinding-centric ones as [21].

Figure 3 leaves open the possibility of extracting data about possible ways and/or certain potential permanent, semi-permanent or temporary obstacles from existing databases and from mobility services. For instance, from entertainment, sport or transport databases, it is possible to deduce at what time there is a risk of gatherings of people in one or several streets and/or on a place. However, as said in Sect. 3, existing databases are not sufficient to obtain a working model that can optimise routing—in both route-planning and real-time recommendation—and provide guarantees.

A central missing element to feed these eventual models is the density of temporary obstacles—to obtain an approximate value for p. Before other approaches can be developed we can already imagine a rudimentary setup where one equips a device (such as a wheelchair) with a set of sensors and exhaustively covers a given locale, while registering all the obstacles they perceive (and capturing generic data to also allow later refinement and classification). Such a setup could potentially include:

- video capture, possibly from multiple angles (such as at wheel level to observe street quality);
- sound capture (or sound intensity measurement, for different frequencies);
- GPS to coordinate with map data;
- a manual clicker to add arbitrary points in the database, both for facilitating later classification and to add elements that are only perceived by the user operating the capture device;
- pollution or chemical sensors.

With such an apparatus, one could cover all streets of a neighbourhood at different times in a systematic way, thus avoiding the biases inherent in the options mentioned in Sect. 3. A practical implementation would still need to address multiple technical hurdles:

- There is the question of how the general database architecture should be organised to be most useful in different contexts. Just from the data-presentation side, there are advantages to having it as video, as a clickable map$\Longleftrightarrow$picture interface (as in Google Street View), or as a set of obstacle-events (viewable chronologically and geographically). With some work, all those formats should be convertible to each other (except potentially for the video source), but a first step before the practical realisation of any database

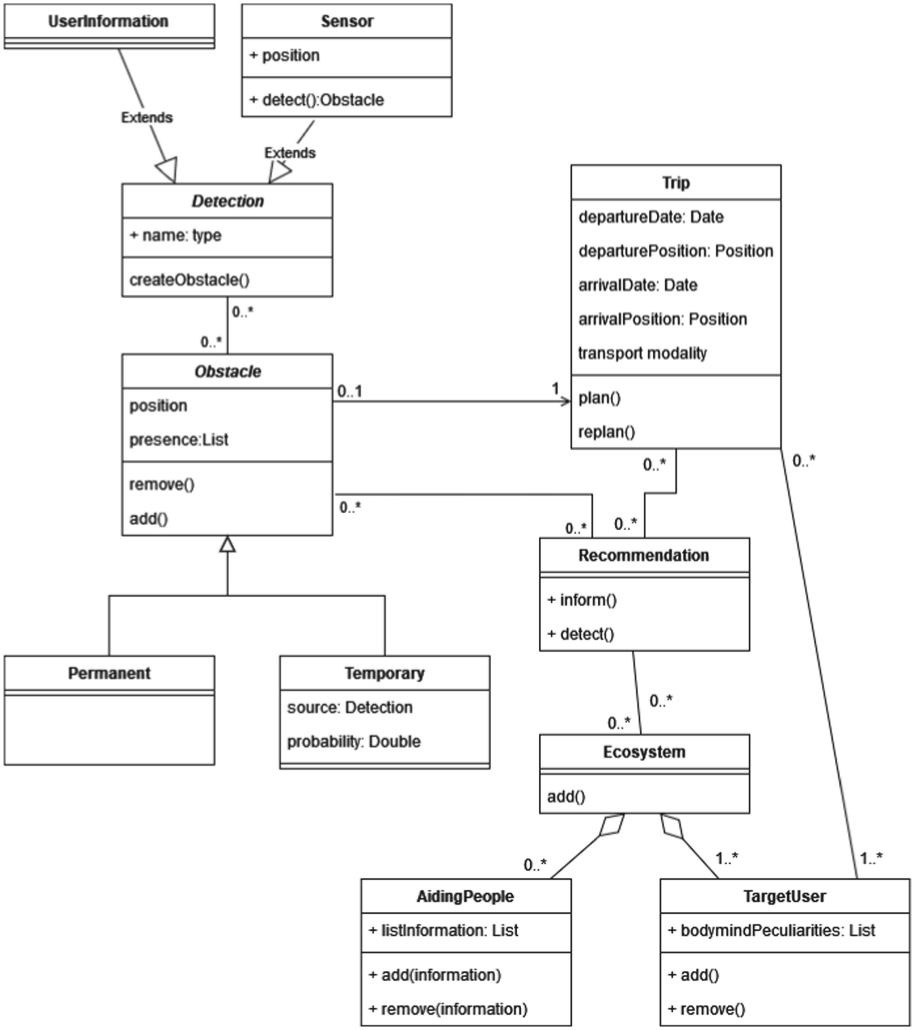

Fig. 4. UML classes diagram to model notions and the relations between them to provide the support system.

should be a reflection on the desired architecture (to privilege usability, interoperability, performance...).

- There is also, as mentioned above, the design of the obstacle classification system.
- Finally, the data collection procedure should alleviate privacy concerns, which are affected by various laws, and would be non-trivial, as previous work has shown [11].

5 Discussion

The proposal above gives a first lead as to how to determine the prevalence and cost of multiple kinds of temporary (and semi-temporary) obstacles. The goal is not to detect them in real-time for end-users but rather to integrate their statistical presence in our ways of thinking, especially for path-planning (although this work raises the question of how to best present these statistical obstacles to users and which interfaces to use to show alternative or redundant routes). We leave open multiple questions regarding both how to implement it and how to optimise it in practice.

A first subject concerns the temporal aspects of data gathering, with three questions arising. First, when capturing data for a single database, what would be the impact of the capture day and hour? For example, trash bins are often left outside and collected on given days. Similarly, electric scooters might be more frequently left on sidewalks in the evening, before they get picked up to get charged. Night-time capture (and corresponding temporary obstacles) nearly constitutes a different problem by itself. There are probably no good answers to this conundrum, but eventual data gathering endeavours will have to choose a temporal modality, and see how it affects the corresponding database. The second question is related, and concerns the weather and long-term temporal aspects, as certain obstacles are not the same in summer and winter—e.g. crowd behaviours on sidewalks or pavement quality when freezing. The third question is whether the database should include some repeated segments, to see the dynamic evolution of temporary obstacles. Ideally, each database would correspond to a single snapshot, which is made impossible due to the time necessary to capture the data. Although there are additional costs to capturing certain elements multiple times, it could also provide interesting data. How to best integrate such data and how to optimise the capture of the most interesting segments—for example, those with certain obstacles already present—is another complex question.

There are two technical elements worth looking into. First, if we assume that people in an area obtain information on the distribution of temporary obstacles, it would be useful to integrate the corresponding percolation models in routing algorithms. This would mean creating algorithms to handle multi-objective routing while maintaining a balance between the route redundancy, the length of eventual detours, and their probability (all depending on the users' constraints and risk profiles). Second, experience shows that a significant percentage of people working on improving accessibility are directly affected by various impairments. Most databases are not usable by blind users, especially visual ones (such as Google Street View), and the databases created in our context should be usable by all, which might require some new solutions.

There are also two questions on the social and geographical side. First, this article has introduced a framework for the study of temporary obstacles, and this could be useful for decision-making on urban questions. However, we did not address who should be the ones to implement such frameworks in practice (municipalities, NGOs, public advocacy associations), or how the framework, data and conclusions could be used (and whether they could have a negative impact). Moreover, the creation of such databases—with potentially semi-sensitive data on the privacy front—requires special considerations concerning both cybersecurity and updating/maintenance, with digital obsolescence being a growing concern [9,29], especially if undertaken by small NGOs without cybersecurity expertise. Second, the framework shown above is more adequate for urban/suburban environments and urban policy-making. If one seeks to adapt it to rural areas, what changes would be necessary?

Finally, two main open problems also remain:

– The framework allows for the capture of data for chemical sensitivities—and allergies—but the manner of capture remains a problem, as most commercially available equipment only allows the measurement of some proxies (such as particulate air pollution). How then to measure the various sources of chemical obstacles?
– What would be necessary to obtain a system that deals with temporary obstacles in real-time (such as certain routing services do for both traffic and speed cameras)?

6 Conclusion

We have shown the importance of temporary obstacles to disabled mobilities, and the difficulties in both keeping track of these obstacles and simply estimating their prevalence, and introduced some concepts from percolation theory to model their impact on disabled users. We have also discussed the interest in using a disability-agnostic approach that does not focus in advance on a specific impairment but captures as much as possible to be reusable by all who could benefit from it—with the ITS optimising for the user's eventual impairments. We've introduced some initial ideas on how to build a framework to detect and handle such temporary obstacles. They require further study on multiple fronts, from the sensor systems that should be used to the questions of interoperability between databases and services and the problem of user privacy and respect of existing legislations (such as GDPR).

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