Towards a Route Planner Supporting Pedestrian Navigation in Hazard Exposed Urban Areas

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ABSTRACT

This study aims to design a route planner functionality that includes real-time context information from physical sensors and citizen observations to support pedestrian navigation in urban areas exposed to extreme heat and floods. Urban population is growing and people living in urban areas are especially exposed to heat and urban flooding, which are two of the anticipated effects of climate change. Route planning functionality can be of value to individual citizens, especially those with limited mobility, as well as for healthcare professionals and authorities who are responsible for crisis response and management. Although the route planner functionality is to be experimentally implemented in a specific tool with the use of broadly available web technologies and real time data, a major generic outcome is the framework that can be used to develop the functionality as part of a decision support tool of any kind.

Keywords

Pedestrian Navigation, Route Planning, Exposure To Heat, Exposure To Flood, Decision Support System.

INTRODUCTION

Route planning functionality has become a common element of various decision support and management systems dedicated for different purposes, including crisis response and management. Although many solutions exist (Bauer et al., 2010) and even more implementations have been undertaken, there are still challenges to be addressed for the development of route planner systems to support navigation in specific environmental conditions, such as heavy rain or snowy roads, and for specific target groups. Firstly, previously developed solutions have typically limited applicability due to either sophisticated methods or lack of easily available data and technology (e.g., Rußig and Bruns, 2017). As a result, some solutions exist only as proof of concept implementations limited to certain areas and specific conditions. Therefore, any attempt to make such solutions available is appreciated by practitioners. Secondly, although context-aware route planners have already been considered by scientists more than two decades ago (Abowd et al., 1999), they seldom employ recently collected context information or crowd-sourced real-time data (Rafidi, 2013). An exception, of course, is the broadly known Google Maps Traffic API that permits route planning based on road traffic. Nevertheless, Google Maps Traffic does not engage users for data collection since GPS positions are collected automatically from people using Google Maps apps on certain mobile devices.

Aim, research questions, and contribution

We call the pedestrian route planner we develop for WayFinder, and it constitutes part of the CitizenSensing web application (see below) that is available for the project's four partner cities: Norrköping in Sweden, Porto in

Portugal, Rotterdam in the Netherlands, and Trondheim in Norway. Our generic aim is to design a framework for map-based decision support tools that facilitate pedestrian navigation in hazard exposed urban areas. As hazards, we so far have included heat and pluvial flooding since these are the hazards identifyed by our participating stakeholders. Our long-term ambition is to include multiple types of climate – or environmental hazards. Furthermore, the primary assumption is to integrate a typical route-planning functionality with real-time environmental measurements and citizen observations. Our study is guided by three research questions (RQs):

(1) How can a pedestrian route planner system make use of real-time observations volunteered by citizens to support navigation in urban areas exposed to heat and inundation?

(2) How can a pedestrian route plannermake use of real-time context information about environmental conditions such as climate parameters?

(3) How are the interactive functions and content of a pedestrian route planner to be designed?

By addressing these three research questions, our contribution to the field of information systems for crisis response and management are both conceptual and operational suggestions on how a route-planning functionality to support pedestrian navigation in hazard exposed urban areas can be designed and implemented. We also formalize some development steps to further facilitate other similar implementations in information systems for crisis response and management of any kind.

RELATED RESEARCH AND CONTEXT

Route planners

Route planners, based on the classic Dijkstra algorithm (1959) or on its derivatives and more sophisticated methods (Bauer et al., 2010), are commonly used for military purposes (e.g., Björkbom et al., 2013), fleet management, as well as in applications for other civil use such as scenic route planners (Teslya, N., 2014; Gavalas et al., 2017; Novack et al., 2018), bicycle route planners (Hochmair, 2004), and wayfinding and navigation in specific places (Arenghi, 2018) or during specific events (Yin et al., 2019). Route planners work as separate decision support tools and serve as part of complex systems, e.g., geospatial technologies used in crisis and emergency management such as traffic evacuation (Tan and Chan, 2008). Then, a route planner can constitute part of a common operational picture (COP) or a situation awareness system to be used either in a portable device by a mobile emergency unit, or in a wall display in a command room. However, no matter what their main purposes are, route planners have one feature in common, they all suggest routes based on multivariate optimization, taking into account specific conditions that concern directly the route to be passed (route length, time distance) and the environment (physical context) the route is to pass by (e.g., land cover, terrain steepness, climate conditions, population density, noise). The information about the environment can concern its present state, as well as its historical characteristics or forecasts for the future.

Pedestrian navigation in exposed areas

Pedestrian routing has its specific set of challenges and opportunities. One of such is the necessity of including detailed sidewalks data in routing algorithms and the problems algorithms have to model the possibility of traversing parks and plazas (Andreev et al., 2015). Another challenge is accessibility/inaccessibility of locations due to, for example, steepness or stairs, particularly important for routing algorithm for users with walking disabilities (Holone et al., 2007). Regarding opportunities, the use of photos can facilitate wayfinding in unusual situations where the user has to walk through a specific gate or along a certain path. In these cases, photographs can provide information and reassurance to support the navigation decision (Beeharee and Steed, 2006). A large body of scientific literature reports on studies by architects and urban planners on mapping areas that are either recommended or excluded for pedestrians or other public space users during specific extreme events (e.g., Martins et al., 2016; Melnikov et al., 2017; Rußig and Bruns, 2017), including outdoor thermal comfort (Yoshida et al., 2019) and pluvial flooding (Russo et al., 2013).

Heat is a risk to human health and wellbeing, and heatwaves have been frequently addressed in urban climate adaptation studies, which however must be defined by thresholds that correspond to local weather conditions and their impact on human health and systems (Huttner et al., 2009). Hirschi et al. (2011) argue that extreme heat waves become more frequent and more intensive in Central Europe due to climate change. Therefore, getting insight into how people react on heat (what Yoshida et al., 2019, term 'thermal perception') along with their activities in public urban spaces helps architects and city planners to test their concepts and to design smarter and more liveable cities (Melnikov et al. (2017). For instance, Martins et al. (2016) suggested to integrate vegetation with strategically placed water fountains to improve the outdoor thermal comfort of pedestrians. However, extreme heat can occur over large geographic areas and can in combination with other factors such as humidity increase the risk of negative health impacts and death. Therefore, public urban spaces can be only partially adapted to extreme heat and citizens also require other support, especially vulnerable groups such as the elderly or children. Pedestrian navigation tools that facilitate planning daily activities during heat events serve as a good example of such (Rußig and Bruns, 2017).

During another extreme event type—urban flooding—the safety of citizens can be compromised when they are exposed to flows that exceed their ability to remain standing or to traverse flow paths (Russo et al., 2013). It happens if uncontrolled runoff flows on streets, creating a significant hazard for pedestrians. More frequently, pluvial flooding leads to less extreme situations, e.g., when a cloudburst or meltwater create flood conditions that block streets and sidewalks. Such conditions can become even worse, if there are snow and ice traces remaining on the streets. In such cases, pedestrian navigation tools can support citizens helping them to avoid inundated areas by displaying “blue spots” (Balstrøm and Crawford, 2018), i.e., modeled data on places where surface water accumulates. Since exposed areas might be larger than those shown by models, the tools can include real time data and observations.

The vast majority of prior studies on human exposure to extreme conditions, such as heat stress, are mostly based on already collected data (e.g., Rußig and Bruns, 2017). However, since hazard exposure conditions may change relatively quickly, it is of importance to assess the potential of real time observations and measurements and incorporate such information into a map based interactive tool that provides users with a typical routing system.

The Citizen Sensing project

A pedestrian route planner functionality is being designed under the umbrella of the Citizen Sensing project (http://citizensensing.eu/). The project’s main deliverable is a participatory risk management system that incorporates place-specific information and functions as an integrative platform for citizens and relevant organizations at different scales. The system is co-developed with stakeholders and consists of a database, a web app, a sensor network, and a web portal. The web app (Figure 1A) enables citizens to investigate real-time climate parameters derived from open access weather station networks in a certain area, act as sensors that report on critical parameters, and that obtain recommendations on how to behave during an extreme event. All reports are stored in the project’s database and can be examined through the web portal that has two instances: a simplified public version, and a password protected version (Figure 1B), enabling access to all collected data.

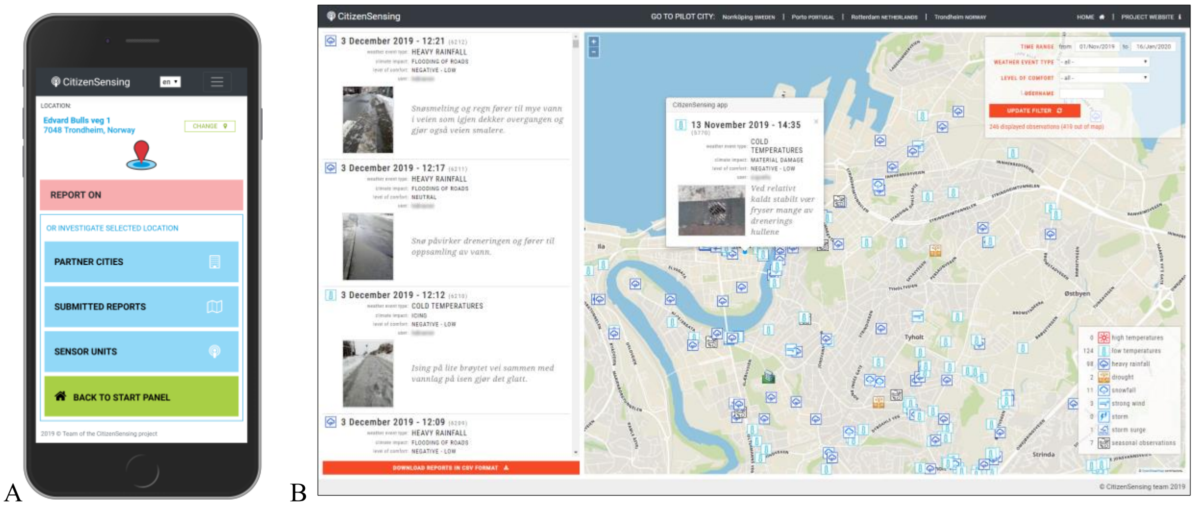


Figure 1. The CitizenSensing web app (A) enables citizens to investigate real-time climate parameters in a certain area, act as sensors reporting on critical parameters and obtain an advice on how to behave during an extreme event; whereas the CitizenSensing web portal (B) enables investigating user observations submitted to the project’s database (example shows submissions for the city of Trondheim, Norway)

The web app also features a pedestrian route planner functionality to provide added value to the app users. For instance, during a heat event, a citizen – or a visiting tourist – can use the app to report on how extreme heat affects them. Such engagement might be triggered by the fact that exposure or vulnerability mapping seldom “measures” how various hazards affect people. After reporting, the user obtains the recommendation to drink water (and where to get it), and is provided with the link to a map display which shows where to go to find cool places. Such a map display can be accessed regadless of the willingness to report on weather events and redirected to automatically if the climate parameters from the sensor network exceed critical values. Such a map display has been experimentally implemented as the pedestrian route planner "WayFinder" guiding users to the nearest park or other place with less asphalt and brick, and with more shadow and wind, or to a museum or other air conditioned public building.

PASSIVE AND ACTIVE ROUTE PLANNER FRAMEWORK

The concept of a passive route planner

A passive system integrates a typical routing system with background information; however, the routing system in itself is not context-aware. Although context information, such as auxiliary thematic overlays, real-time sensor data with climate parameters, and citizen observations can be provided in the tool, it is not taken into account by the routing algorithms (Figure 2). The system is referred to as passive because it only displays information without "actively" using it to calculate an optimized route. Therefore, the way how provided information is merged into a meaningful message depends on the interpretation by the user, and thus, depends on user skills and experience.

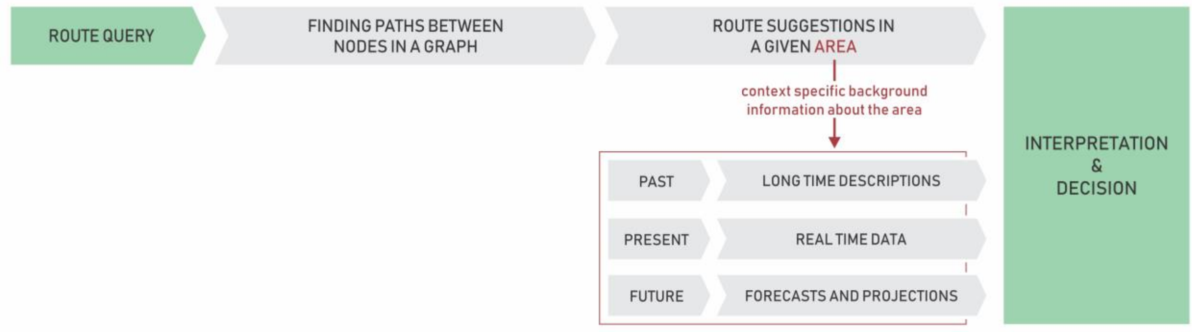


Figure 2. The pipeline in a passive routing system

A passive route planner benefits from including crowd-sourced real-time observations (see RQ1), by displaying them directly as map markers on a map display along with the calculated route suggestions or by processing them and displaying the resulting data as, e.g., a kernel density estimation map. When it comes to equipping the tool with real-time and up-to-date contextual information about environmental conditions (RQ2), a passive system displays such information as thematic overlays, allowing users to be aware of real time environmental conditions. Finally, the design of the functionality and the content of a passive system (RQ3), depends on user tasks and planned use scenarios.

A good example of passive route planners are common operational picture tools supporting situational awareness. Such tools, typically complex and multicomponent, provide route planning functionality along with background information depending on the target users' needs and requirements.

The concept of an active route planner

An active system differs substantially from a passive one. Here, routing algorithms include context-specific information that, similar to the passive approach, can concern past or present conditions, or can include forecasts. However, the active routing system, "actively" incorporates auxiliary information and optimizes route calculation taking into account local conditions (Figure 3). As a result, although the user is provided with suggestions, the user engagement and interpretation are significantly reduced.

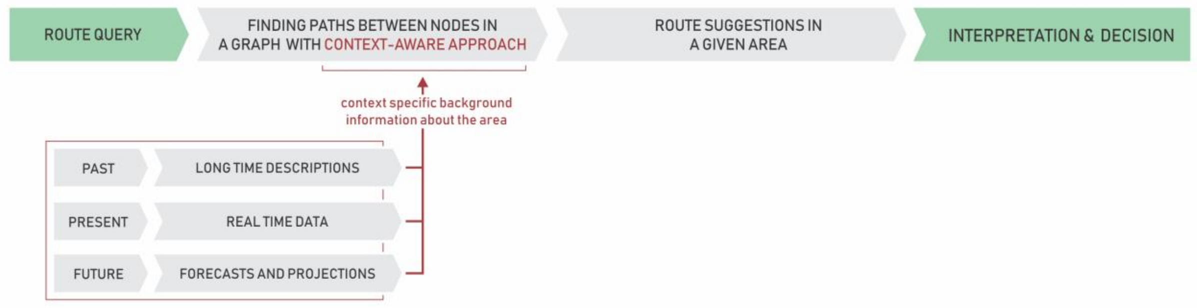


Figure 3. The pipeline in an active routing system

An active route planner benefits from including real-time crowd-generated observations (RQ1) by incorporating them directly in routing algorithms. When it comes to equipping the tool with real-time and up-to-date context information about environmental conditions (RQ2), an active system also includes such information in routing calculations. The functionality and the content of passive system (RQ3) can be extensively limited and simplified as the system provides users with ready-to-use solutions.

There are a number of studies that exemplify the concept of an active routing system. Nurgazy (2019) investigated a pollution-based route planning and presented CAVISAP, a context aware visualization of air pollution with IOT platforms. In turn, Rußig and Bruns (2017) proposed an approach to reduce heat stress for individuals by creating a decision support system that computes heat-optimal paths to locations as well as the optimal points in time to perform a desired action. Although their system “actively” considers available context information, users can decide for themselves whether the trade-off between additional distance and heat stress reduction is acceptable. Another example of the active approach is a routing cost function that helps to evaluate a number of trips (origin–destination pairs) in terms of their attractiveness according to specific criteria, e.g., more “social”, greener, and quieter than the respective shortest routes (Novack et al., 2018). Finally, real-time trip planning with the crowd (Rafidi, 2013) also exemplifies an active approach by giving travelers a quick and convenient travel planning assistance based on crowd-powered trip planning.

PRELIMINARY RESULTS

The route planner WayFinder has so far been developed as a passive system and experimentally implemented in the CitizenSensing web application (see Figure 1A), while an active version is currently under development. Therefore, in this work-in-progress article, we report on the outcomes of our conceptual investigations (i.e., on the framework briefly presented in the previous section) and, in this section, on the current passive system. The active extension is briefly sketched out in the two use case scenarios and in the discussion section along with the plans for the future.

Proof-of-concept implementation

Technical details

The WayFinder protype system has been developed in JavaScript and TypeScript using the Angular web framework, a front-end web application platform. WayFinder uses Google Maps API for a route planner functionality supporting pedestrian navigation. It also uses the data stored in the CitizenSensing project’s database. The data comprises real time measurements from weather station networks and voluntarily generated information on selected weather events (high temperatures, low temperatures, heavy rainfall, drought, snowfall, strong wind, storm, storm surge, and seasonal observations) as well as information regarding how those events affect citizens and environment, along with image files and textual descriptions.

The architecture of the CitizenSensing system is presented in Figure 4. We used JavaScript to develop the system since it has become the most common technology in modern web development. Numerous JavaScript free libraries make the web design and development process easy and quick. The CitizenSensing server-side architecture (back-end) has been impleneted in JavaScript using Node.js in combination with the Express.js framework. In turn, the system’s web application (front-end) has been developed with Angular and Google Maps API has been used for the mapping functionality. The routing mechanism is so far based on Google Maps API; nevertheless, there are other routing libraries such as Leaflet Routing Machine or OpenLayers Routing Machine that we consider to use in our application and will be tested along with the progress in the active routing system.

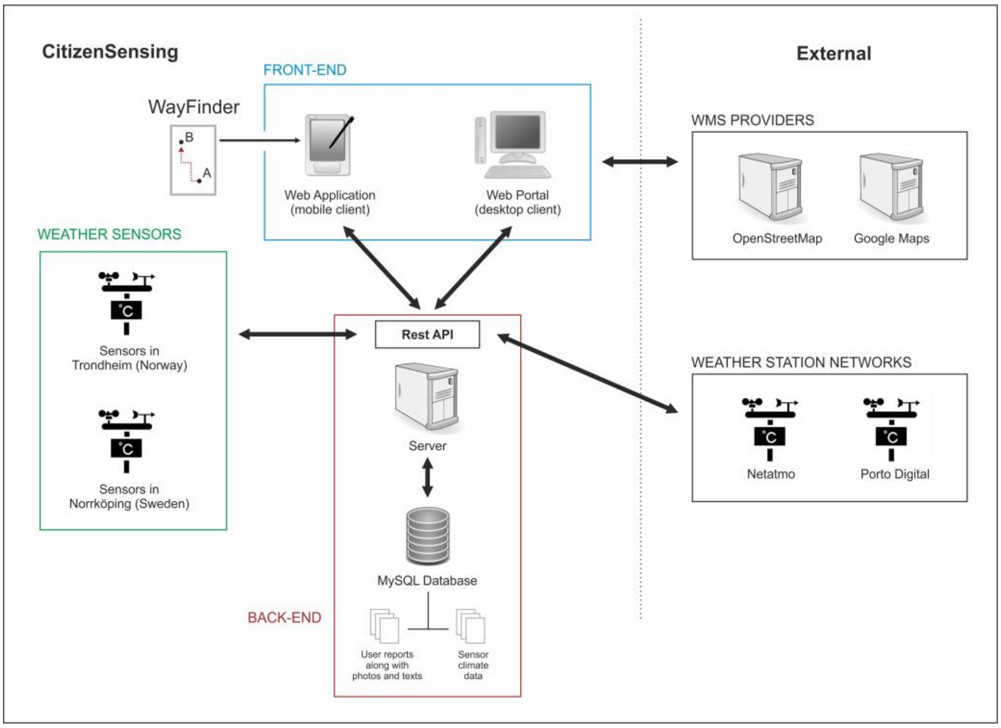


Figure 4. CitizenSensing architecture

WayFinder makes use of past and real time data. Currently, we do not plan to use forecasts neither in the passive nor in the active version. Regarding historical data, WayFinder incorporates blue spots modeling for Trondheim and urban heat island data for Norrköping and Porto. The data is stored in the CitizenSensing project's database. In the following section, we report on the collection of real time data as well as on the decisions regarding the functionalities implemented in the WayFinder system.

Weather station networks to gather context specific real time measurements

There is a growing body of scientific research regarding terrestrial or remote methods that enable collecting real time measurements. Volunteered geographic information plays a specific role in this context since with the advent of private weather station networks, more high-resolution data are now available within cities to better analyze various weather events such as extreme heat or cold (Seebacher et al., 2019). In our study, we make use of such voluntarily collected climate parameters (i.e., air temperature, pressure, and humidity) gathered from an open access weather station network. Additionally, we have also integrated data from a weather station network administrated by a municipal initiative (Porto), and from a few weather stations established in Norrköping and Trondheim as part of the CitizenSensing project.

Climate parameters are collected for the partner cities every half hour and presented on the application's map display as map markers. The markers are color-coded based on the temperature parameter. Additionally, we use a Javascript library with the ordinary kriging algorithm[1] to calculate, every half hour, a statistical surface with interpolated air temperature. The surface is displayed in the web application as a raster thematic overlay together with the map markers. Figure 5 shows the markers for the city of Norrköping along with the raster overlay. The color-coding of the markers and the raster overlay is experimental and will evolve along with the tool development.

[1] https://www.npmjs.com/package/@sakitam-gis/kriging

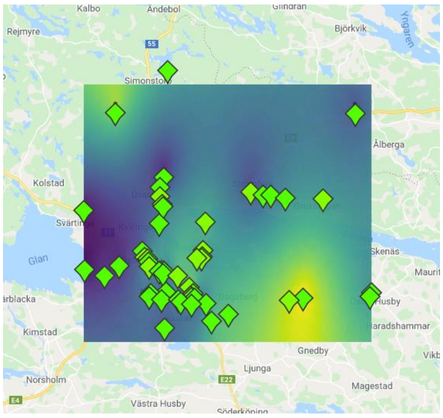


Figure 5. Map markers represent a subset of a weather station network for the city of Norrköping; the raster overlay has been generated based on measured air temperature

Citizen science and participatory mapping to gather context specific real time observations

The CitizenSensing web application primarily enables users to report on their observations. Collected data on ongoing weather events and their effects are next displayed in the web application and in the web portal (Figure 1B). The primary aim of displaying collected data on maps is to increase awareness by triggering citizen engagement. However, we also make use of collected data, especially those real time, to support users in their pedestrian navigation during a heat event and, in particular, if a pluvial flooding occurs. The latter case is of special interest to us since open access weather station networks do not provide real time "measurements" on flooded areas. Therefore, voluntarily reported observations of real time blue spots as those included in the screenshot from the web portal presented in Figure 6 can significantly facilitate selecting unflooded walking paths.

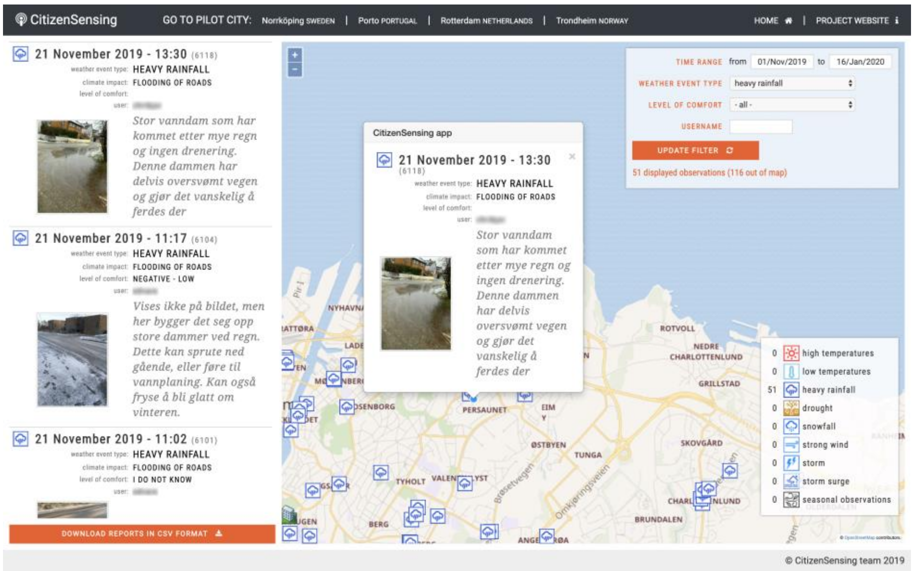


Figure 6. A reporting on a heavy rainfall that occurred on November 21, 2019 in Trondheim that resulted in inundated streets and sidewalks

Real time observations are so far used "passively" as a background overlay for optimized routing suggestions. In the next attempt, voluntarily reported data will be "actively" incorporated into routing algorithms. However, with such an approach, not the whole content of reports can be directly incorporated into routing algorithms. For instance, textual and graphical annotations need to be first "transcribed" into variables that can be next used by routing algorithms. Textual annotations need to be checked for words / phrases that suggest avoiding specific areas. Next, such words / phrases are to be granted scores that can be incorporated in the routing algorithms. In turn, image recognition methods need to be used to detect inundated / exposed to sunlight areas that should be avoided in the routing algorithms.

Functionalities

If a route planner is to provide users with final route suggestions with no extra information or with very limited auxiliary content, then the WayFinder's map display can be simple and equipped with basic interactive functions. However, since the passive system aims to show routing options along with background information, it is necessary to equip the tool with necessary interaction techniques.

In its current passive version, the WayFinder prototype's map display presents a user position (if a client location is enabled) and a number of target POIs from a predefined list of objects (park, cafe, museum, library, supermarket) within an arbitrarily set distance threshold (as for today it is 1 km). These settings can be easily customized and the current parameters have been set as a proof of concept. The target POIs can be selected and then, a shortest route suggestion is being displayed between the user position and the selected POI along with a route length tag. The suggested path can be modified by adding waypoints that can be dragged by the user across the street network. Of value to such modification is access to auxiliary overlays, i.e., users can enable map layers with markers showing real time temperature, markers showing submitted observations on high temperature and heavy rainfall, and a raster overlay with air temperatures interpolated from real time measurements. Moreover, three of the partner cities have own specific thematic overlays: an urban heat island map is available for Norrköping, heat zone mapping for Porto, and for Trondheim – a blue spots mapping.

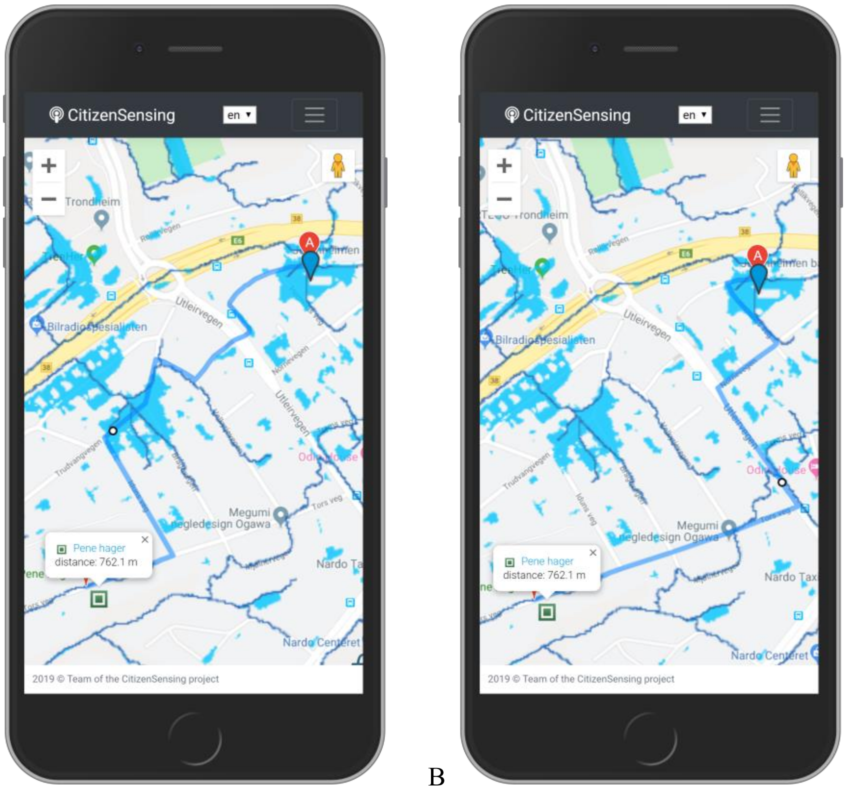
As the study is still in progress, more sophisticated geographic visualization techniques are also under consideration to make the passive system usable and useful. For example, route suggestions, apart from the map display, can also be presented in an adjacent visual component that shows them as cross-sections of specific attribute space such as terrain steepness, temperature, or noise.

Use case scenarios: child care and tourism

We exemplify the WayFinder functionality with two use case scenarios. The first case concerns decision support for child care staff during inundation, while the second case illustrates how WayFinder can support tourists in the urban area during a heat event.

Case 1: Planning daily activities for children in a kindergarten in the city of Trondheim, Norway

In the Norwegian context, kindergarten personnel are encouraged to arrange outdoor activities regardless of weather conditions. There are of course certain constraints if extreme weather events occur; nevertheless, the threshold for considering weather conditions as unsuitable for taking children for outdoor activities might be considered as less restrictive than in other countries. As a result, rainy weather is not an obstacle for kindergarten personnel to organized outdoor activities for the children. However, even if such practices are common, it does not mean that proper planning and safety issues are neglected. As there is a long tradition is Norway to organize outdoor activities, inhabitants know how to prepare equipment and appropriate clothing. In this particular case, the WayFinder would offer support by optimizing a walking route to get to a specific place if water accumulates in low-laying places in the nearby area due to, for instance, melting snow. In this specific case, the WayFinder display suggests a walking path along with a thematic overlay that shows a blue spots mapping (Balstrøm and Crawford, 2018). Users can see the shortest path (Figure 7A) and manipulate it if necessary (Figure 7B), for instance in case the presented path crosses inundated areas, e.g., due to melting snow and ice or resulting from a heavy rainfall preceding the walking trip.



A B

Figure 7. WayFinder suggests a walking path (A) where users can take into account the blue spots mapping and modify the path (B) to avoid areas that are shown as being inundated

An active extension of this routing system would include the blue spot maps directly in the routing algorithm. The algorithm would also include voluntarily collected citizen observations about water flow. Additionally, the active version could enable the child care personnel to supply spatially explicit information in relation to observations of local impacts, such as validating existing data overlays, submitting information or uploading images on additional flooded areas, or annotating textual information that supports other citizens or child care professionals to select safer routes, avoid specific places or plan for different pathways on their trip.

Case 2: Supporting tourists in the city of Norrköping, Sweden

Temperature based routing approaches to mitigate heat stress in daily activities have been presented by Rußig and Bruns (2017) and have the potential to enable heat sensitive groups to avoid urban heat islands. This is in particular relevant for groups that lack local knowledge, such as tourists. Our second example would imply that a group of visitors in the city of Norrköping is planning a walking trip through the city. The group is not prepared for the extreme heat development that occurs in the inner city during the early afternoon. The group of tourists uses the WayFinder in this case either to locate the nearest place that offers shade, such as a city park and a freshwater fountain, or to locate indoor air conditioning in a place where the visitors can wait for a train, such as a café at the railway station. WayFinder displays the closest route to such a selected location (Figure 8A) with a thematic overlay showing urban heat island effect, so that the user can manipulate the route in case it leads through an area with increased risk for heat. As a result, a modified route can lead along the river as in Figure 8B.

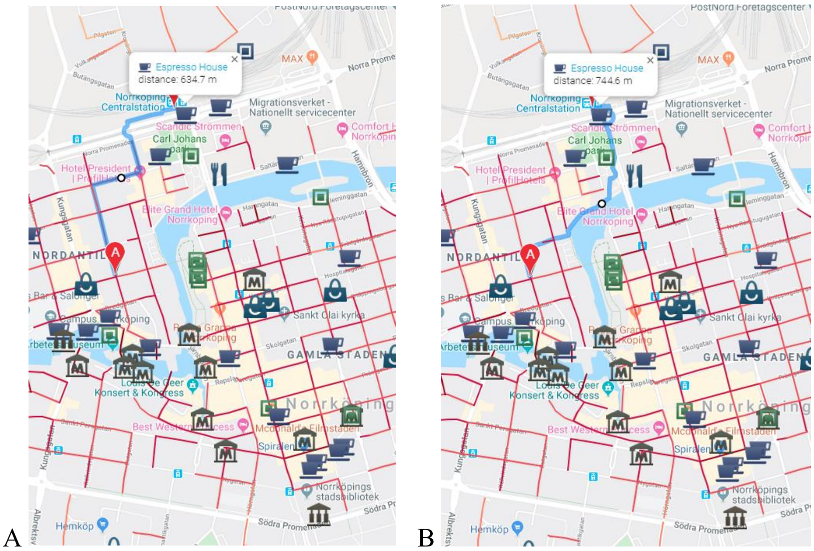


Figure 8. WayFinder suggests a walking path from the place A to the Espresso House at the railway station in Norrköping, Sweden (A), or users can take into account the urban heat island effect and modify the route to a cooler walk along the river (B)

An active version of this routing system would include the data on the urban heat island effect directly in the routing algorithm. The algorithm would also include real time temperature measurements and voluntarily collected citizen observations. An active system, after displaying optimized routing suggestions, could further enable users to add information regarding local heat islands – either validating given information, adding more spatially explicit information to the map, annotate with either images or text. This type of information could further include suggestions for adaptive action, such as where to reach a shaded park area, cool down in a fountain, or providing additional examples of activities that can be conducted in the city during heat waves.

DISCUSSION AND CONCLUSION

Table 1 juxtaposes the features of the two conceptual route planner frameworks for pedestrian navigation with regard to the three research questions. If a pedestrian route planner system is to be developed with the passive routing framework, then the benefit from including real-time weather observations volunteered by citizens (RQ1) concerns displaying them along with route suggestions. Then, if the observations concern (extreme) air temperature, such information can help to modify the suggested route by adding waypoints that enable the user to avoid areas exposed to extreme heat (extreme temperatures measured by specific weather station units). Similar, "automatized" mechanism, can be implemented in an active routing system, as in the study by Rußig and Bruns, (2017). With regard to urban flooding, to the best of our knowledge, there is no accessible observation network that provides real time data on inundated areas.

Table 1. Passive vs active route planner framework

Short RQ	Passive routing system	Active routing system
RQ1: How can a pedestrian route planner system make use of real-time observations volunteered by citizens?	Can display such information along with route suggestions	Can include such information in context-aware routing algorithms and also, to a minor extent, display it along with route suggestions
RQ2: How can a pedestrian route planner system make use of real-time context information about environmental conditions?	Can display such information along with route suggestions	Can include such information in context-aware routing algorithms and also, to a minor extent, display it along with route suggestions
RQ3: How are the interactive functions and content of a pedestrian route planner be designed?	Content-rich approach with extensive functionality	Simplified content and limited interactive functions

The essential shortcoming of including voluntarily contributed real time climate data in a routing system is the validity of such data. This is the critical limitation of the system. Firstly, there is no control over how citizens perform their volunteer observations, whether their private weather stations are properly calibrated and deployed in proper places, and whether the provided data are real. Secondly, the stations are typically deployed in inhabited areas so uninhabited areas such as parks or city green areas are often not covered by weather station networks. Therefore, for example, a statistical surface with interpolated air temperature is biased as there are no, or very few, recordings in potential cooler areas such as in parks. Such issues impede making use of real time weather observations, especially if the system is to be developed with an active framework. Then, all nuances need to be included in the algorithms since any outlier may lead to false route suggestions. One solution can be the use of historical climate data, for instance, on heat records to validate measured data. Several of these methodological challenges have been identified in the scientific literature (e.g., Resch, 2013).

Crowd-generated real-time observations on weather events and their impacts on human beings and environment (RQ2) can be used in a similar way as the information gathered from voluntarily administered weather stations (see Table 1). Thus, the advantages as well as shortcomings are similar to the previously described. For example, the primary limitation is an uneven distribution of reported observations, with a possible lack of data for certain areas. In these cases, data on historical events such as floods can help determine areas that should be avoided. However, there are two basic differences. Contrary to the data from weather stations, citizen observations can provide direct information about inundated areas, which can be either displayed or included in the routing algorithms. The second difference concerns the data format. While private weather stations collect specific climate parameters, usually, air temperature, humidity and pressure, crowd-sourced real-time observations can encompass not only standardized answers, but also comments and photos. While these can provide significantly more information, they might require verification. Particularly challenging is the inclusion of comments and photos directly in routing algorithms as proper techniques need to be employed to translate qualitative description into quantitative results (Srnka and Koeszegi, 2007) to be included in the algorithm formulas.

As such, the third RQ, focusing on the functionality of route planner systems, is the most challenging. Generally, the functionality of a passive system depends on user capabilities. The tool can provide users with available information and can be equipped with various interaction techniques. However, it is the user who determines whether the tool is not cognitively overloaded (Bunch and Lloyd, 2006) and to what extent the provided functionality is comprehensible. In turn, if the route planner is developed based on an active routing framework, citizen observations are incorporated in the route calculations. A successful functionality then depends on the algorithms being able to provide the user with a smart final routing suggestion without necessarily offering any additional background information. In practice, of course, such information can be conveyed; nevertheless, as already incorporated during the algorithmization stage, does not need to be considered so attentively by the users.

With the progress in web technologies, more and more sophisticated solutions are available for routing multivariate optimization. The bottleneck is access to reliable and freely available real-time volunteered weather data covering large geographic areas that can be incorporated in route planners supporting pedestrian navigation in hazard exposed urban areas.

REFERENCES

Abowd, G. D., Dey, A. K., Brown, P. J., Davies, N., Smith, M. and Steggles, P. (1999) Towards a better understanding of context and context-awareness, *International Symposium on Handheld and Ubiquitous Computing*, 304-307, Springer, Berlin, Heidelberg.

Andreev, S., Dibbelt, J., Nöllenburg, M., Pajor, T. and Wagner, D. (2015). Towards Realistic Pedestrian Route Planning, *15th Workshop on Algorithmic Approaches for Transportation Modelling, Optimization, and Systems (ATMOS 2015)*. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik.

Arenghi, A., Belometti, S., Brignoli, F., Fogli, D., Gentilin, F. and Plebani, N. (2018) Unibs4all: a mobile application for accessible wayfinding and navigation in an urban university campus. *Proceedings of the 4th EAI International Conference on Smart Objects and Technologies for Social Good*, 124-129, ACM.

Balstrøm, T. and Crawford, D. (2018) Arc-Malstrøm: A 1D hydrologic screening method for stormwater assessments based on geometric networks. *Computers & Geosciences*, 116, 64-73.

Bauer, R., Delling, D., Sanders, P., Schieferdecker, D., Schultes, D. and Wagner, D. (2010) Combining hierarchical and goal-directed speed-up techniques for dijkstra's algorithm, *ACM Journal of Experimental Algorithmics*, 15, 2.1-2.31.

Beeharee, A. K. and Steed, A. (2006) A Natural Wayfinding - Exploiting Photos in Pedestrian Navigation Systems, *MobileHCI '06: Proceedings of the 8th conference on Humancomputer interaction with mobile devices and services*, 81–88, New York, NY, USA, ACM Press.

Björkbom, M., Timonen, J., Yiğitler, H., Kaltiokallio, O., García, J. M. V., Myrsky, M. ... and Virrankoski, R. (2013) Localization services for online common operational picture and situation awareness, *IEEE Access*, 1, 742-757.

Bunch, R. L. and Lloyd, R. E. (2006) The cognitive load of geographic information, *The Professional Geographer*, 58, 2, 209-220.

Dijkstra, E. W. (1959) A note on two problems in connexion with graphs, *Numerische Mathematik*, 1, 269-271.

Gavalas, D., Kasapakis, V., Konstantopoulos, C., Pantziou, G. and Vathis, N. (2017) Scenic route planning for tourists, *Personal and Ubiquitous Computing*, 21, 1, 137-155.

Hirschi, M., Seneviratne, S. I., Alexandrov, V., Boberg, F., Boroneant, C., Christensen, O. B. ... and Stepanek, P. (2011) Observational evidence for soil-moisture impact on hot extremes in southeastern Europe, *Nature Geoscience*, 4, 1, 17.

Hochmair, H. (2004) Decision support for bicycle route planning in urban environments, *Proceedings of the 7th AGILE Conference on Geographic Information Science*, 697-706, Heraklion: Crete University Press.

Holone, H., Misund, G. and Holmstedt, H. (2007) Users are doing it for themselves: Pedestrian navigation with user generated content, *The 2007 International Conference on Next Generation Mobile Applications, Services and Technologies, NGMAST 2007*, 91–99, IEEE.

Huttner, S., Bruse, M., Dostal, P. and Katzschner, A. (2009) Strategies for mitigating thermal heat stress in central European cities: The project Klimes, *7th International Conference on Urban Climate ICUC-7*, Vol. 29.

Martins, T. A. L., Adolphe, L., Bonhomme, M., Bonneaud, F., Faraut, S., Ginestet, S., Michel, C. and Guyard, W. (2016) Impact of Urban Cool Island measures on outdoor climate and pedestrian comfort: simulations for a new district of Toulouse, France, *Sustainable Cities and Society*, 26, 9-26.

Melnikov, V., Krzhizhanovskaya, V. V. and Sloot, P. M. (2017) Models of pedestrian adaptive behaviour in hot outdoor public spaces, *Procedia Computer Science*, 108, 185-194.

Novack, T., Wang, Z. and Zipf, A. (2018) A system for generating customized pleasant pedestrian routes based on OpenStreetMap data, *Sensors*, 18, 11, 3794.

Nurgazy, M. (2019) *CAVISAP: Context-Aware Visualization of Air Pollution with IoT Platforms*, Master's thesis, Luleå University of Technology.

Rafidi, J. (2013) Real-time trip planning with the crowd, *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, 2743-2748, ACM.

Resch, B. (2013) People as sensors and collective sensing-contextual observations complementing geo-sensor network measurements, *Progress in location-based services*, 391-406, Springer: Berlin, Heidelberg.

Russo, B., Gómez, M. and Macchione, F. (2013) Pedestrian hazard criteria for flooded urban areas, *Natural hazards*, 69, 1, 251-265.

Rußig, J. and Bruns, J. (2017) Reducing individual heat stress through path planning, *GI_Forum*, 1, 327-340.

Seebacher, D., Miller, M., Polk, T., Fuchs, J. and Keim, D. A. (2019) Visual Analytics of Volunteered Geographic Information: Detection and Investigation of Urban Heat Islands, *IEEE Computer Graphics and Applications*, 39, 5, 83-95.

Srnka, K. J. and Koeszegi, S. T. (2007) From words to numbers: how to transform qualitative data into meaningful quantitative results, *Schmalenbach Business Review*, 59, 1, 29-57.

Tan, G. and Chan, G. (2008) Crisis Management Simulation: Traffic Evacuation, *Second Asia International Conference on Modelling & Simulation (AMS)*, 696-701, IEEE.

Teslya, N. (2014) Web mapping service for mobile tourist guide, *Proceedings of 15th Conference of Open Innovations Association FRUCT*, 135-143, IEEE.

Yin, Y., Xia, J., Li, Y., Xu, W. and Yu, L. (2019) Group-wise itinerary planning in temporary mobile social network, *IEEE Access*, 7, 83682-83693.

Yoshidaa, T., Yamagataa, Y. and Murakamia, D. (2019) Individual level heat risk evaluation using GPS towards smart navigation system, *Proceedings of the 29th International Cartographic Conference*, 2, 152.