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Public Participation GIS for sustainable urban mobility planning: methods, applications and challenges

Abstract: Sustainable mobility planning is a new approach to planning, and as such it requires new methods of public participation, data collection and data aggregation. In the article we present an overview of Public Participation GIS (PPGIS) methods with potential use in sustainable urban mobility planning. We present the methods using examples from two recent case studies conducted in Polish cities of Poznań and Łodź. Sustainable urban mobility planning is a cyclical process, and each stage has different data and participatory requirements. Consequently, we situate the PPGIS methods in appropriate stages of planning, based on potential benefits they may bring into the planning process. We discuss key issues related to participant recruitment and provide guidelines for planners interested in implementing methods presented in the paper. The article outlines future research directions stressing the need for systematic case study evaluation.

Keywords: PPGIS, mobility planning, sustainable mobility, travel survey, crowdsourcing, SUMP (Sustainable Urban Mobility Plan)

Introduction

In recent years sustainability-oriented approach to mobility planning has been gaining broader attention among both researchers and policy-makers. It is related to meeting sustainable development goals, which include reducing greenhouse gas (GHG) emissions and improving quality of life of urban dwellers. The focus of transportation planning is increasingly shifting from meeting demand of motorized travel, to promoting non-motorized travel modes and reducing travel demand. This change of focus, together with increasing complexity of transportation systems, creates the need for new data sources and ways of engaging local communities in mobility planning.

Sustainable mobility planning

The concept of sustainable mobility is rooted in the definition of sustainable development, as proposed by 1987 UN "Our Common Future" report, in that "it meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations World Commission on Environment and Development 1987, p. 16). Sustainable mobility seeks ways to meet citizens' demand for transportation while adhering to the principles of sustainable development. In contrary to formerly dominating approaches, sustainable mobility planning is based on presumption that public policy-makers should not only meet the current demand for transportation but are also encouraged to actively shape the magnitude and structure of that demand (Banister 2008, Rodrigue et al. 2013, US Federal Highway Administration 2012, German Road and Transport Research Association 2013). Because of its focus on change and different set of goals than previous approaches to transportation planning, sustainable mobility has been described as a new paradigm in planning (Banister 2008).

One of the main goals in the new paradigm is reducing amount of car travel in cities motivated by global (e.g. greenhouse gas emissions and fossil fuel dependency) and local (e.g. air and noise pollution, risk of injuries, lack of physical activity) impacts on environment and health. The reduction of car travel may be achieved, among others, through a modal shift toward walking, cycling and public transportation, as well as through reducing demand by increasing proximity of services and other land use changes (Banister 2008). Motorized travel reduction has recently become one of main goals of international transportation policies. European Commission's 2011 White Paper on Transport sets a goal to "halve the use of 'conventionally fueled' cars in urban transport by 2030; phase them out in cities by 2050; and achieve essentially CO2-free city logistics in major urban centres by 2030" (European Commission [EC] 2011, p.11). Other initiatives focus on promoting modal shift to public transportation and emission free modes such as cycling and walking. For instance, more than 50 European municipalities have signed the Charter of Brussels which "set[s] a target of at least 15% for the share of cycling in the modal split of trips for the year 2020 and of further growth if this target already is achieved" (European Cycling Federation 2009). Focus on modal shift is not limited to Europe. Numerous cities in the United States have adopted policies aimed at promoting the use of public transportation and non-emission modes. Examples include, but are not limited to, New York City, Portland, San Francisco, and Los Angeles.

New paradigm in planning requires new policy schemes and concepts. One of such new schemes is a Sustainable Urban Mobility Plan (SUMP) concept proposed by the European Union. Its goal is stated as "improving the accessibility of urban areas and providing high-quality and sustainable mobility and transport to, through and within the urban areas". (EC 2013, p. 2) Apart from the EU-proposed tool, European countries have established their own schemes of sustainable mobility planning, such as French 'Plan de déplacements urbains' or British 'Local Transport Plans'. Compared to traditional approaches to transportation planning, sustainable mobility planning offers an integrative and change-oriented approach. The focus is shifted from traffic and infrastructure management, to goals related to minimizing impact on global environment, improving quality of local environment, increasing accessibility and changing mobility patterns. All relevant travel modes are taken into account and transportation planning is integrated with land-use policies. Such approach requires clear definition of targets and monitoring them with appropriate data, as well as participatory formulation and implementation as a mean to ensure its acceptance and support (Ibid., p. 5).

The integrative approach situates SUMPs at the intersection of planning paradigms. In order to determine possible outcomes of the policy instruments, it requires the use of generalized evidence on the factors influencing mobility patterns and travel mode choice, as well as locality-specific facts such as population distribution, demographic prognoses, traffic patterns, and state of infrastructure. The evidence base should also include data about the end-users of the transportation system: their mobility patterns, causes of trips, attitudes and preferences towards alternative solutions (GPSM 2013, p. 15). The focus on people, their behaviours and quality of life, situates end-user requirements and perceptions as a central source of data for sustainable mobility planning. It creates necessity to collect, analyse and aggregate user-provided subjective data on quality of transportation services, infrastructure, as well as perceptions of street and neighborhood quality. On the other hand, change-oriented sustainable mobility policies usually require strong public and political support (Banister 2008). Stakeholder involvement is therefore a key component of mobility planning process. In such participatory approach, the end-users are not only a source of information but also exercise some level of decision-making power. This may take form of activities such as: defining the areas of intervention (both spatial and subject-related), setting policy goals, choosing policy solutions or deciding on details of intervention activities. Inclusion of the public in policy-making intends not only to produce optimal policy choices but also secure social support and empower local communities. Public involvement in sustainable mobility is necessary in order for the public to understand and support changes, and to follow with behavioral change such as modal shift. According to Banister (2008), achieving these objectives requires developing new forms of communication between experts and citizens.

Different approaches to planning, when applied independently to the same problem may produce markedly different outcomes. For instance, the evidence used by policy-makers may be in conflict with citizens' views on the nature of and solutions to a problem. One of the examples is the case of traffic management, where many solutions appealing to the public (such as additional supply of road infrastructure to accommodate the excess of the demand) may not always find their justification in scientific evidence. Similarly, the introduction of participatory decision-making may also produce outcomes that may be seen as suboptimal from a technocratic point of view, but are justified by other factors (e.g. social or political consensus facilitating their future implementation). The new and integrative requirements of sustainable mobility planning may require new methods of data collection and public participation. They also suggest flexibility and care in adopting methods originating from different approaches, and appropriating them to various planning stages and specific needs of decision-makers.

Data collection and public participation methods currently used in mobility planning have several limitations. User-specific data that are obtained using traditional survey methods, such as Pen and Pencil Interview (PAPI), Computer-aided Telephone Interview (CATI) and Computer-aided Web Interview (CAWI), have limited ability to properly accommodate geographical component of the data, the aspect that is crucial for mobility planning. PAPI methods allow for use of maps in data collection, but their scalability to large number of participants is limited, and integration with digital data sets is costly and time-consuming. CATI and CAWI techniques facilitate the creation of electronic spatial datasets, but generally lack the ability to define geographic objects in different ways than collecting addresses, postal codes or other pre-defined spatial units. Traditionally used public participation methods also seem to fall short of meeting SUMP requirements. Mobility planning at the scale of metropolitan areas requires involvement of large groups of participants, which is difficult to achieve in public participation methods that require physical presence at specific time in specific place. Typically used participation methods such as public meetings may also not be very effective in terms of gathering local knowledge of users, and building support for planning initiatives (Innes and Booher, 2004). Recent developments in geospatial technologies and online communication have created potential to overcome these limitations. New practices of spatially-explicit communication and data collection in urban and environmental planning have emerged. Such practices have been described under umbrella terms of Participatory or Public Participation Geographic Information Systems (PGIS/PPGIS) (Sieber 2006, Jankowski 2009, Brown, Kyttä 2014).

Public participation GIS

Talen (2000) suggested that geographical information systems (GIS) should be used to supplement data sources available for urban planners with perspectives of local community members. Such a bottom-up approach to GIS allows residents to directly contribute to data bases available for planners. In a similar vein Kyttä and colleagues (e.g. Kahila and Kyttä, 2009) envisioned *softGIS* as a “bridge-builder” between planners and residents. In softGIS, geographical data are contributed by participants along with other social survey data such as socio-demographic and attitudinal variables, using online survey tools such as *geo-questionnaires* (Jankowski et al. 2015). PPGIS tools have been used to collect such data in a variety of contexts ranging from environmental management to mobility planning (for a recent review see Brown, Kyttä 2014). A broad variety of data types may be collected using such techniques, ranging from mobility patterns, to evaluations of environmental quality and development preferences (Brown and Raymond 2014, Brown, Kyttä 2014, Kahila-Tani et al. 2015, Jankowski et al. 2015, Bąkowska et al. – in this volume). More detailed description of geo-questionnaires and types of data collected with their use is provided in following sections of the article.

Geo-questionnaires are best suited to collect data that may serve as sources of *crowd wisdom* (Surowiecki 2005, Brabham 2009). By allowing independent contributions from large and diverse groups of participants, this kind of PPGIS allows for creating high quality data that may bring valuable knowledge to planners (Brown 2014). Furthermore, data is collected in digital form and may be processed in GIS environment, allowing for its aggregation and integration with other data sources in a way accessible to planners (Talen 2000, Kahila, Kyttä 2009, Brown 2014, Kahila-Tani et al. 2015). Besides creating valuable data sets, PPGIS has also potential to improve quality of public participation in planning, by fostering such social actions and qualities as deliberation, mutual learning, and trust. PPGIS is originally rooted in critiques of geographical information systems as inadequately representing perspectives of local communities and interests of the disadvantaged members of the society (e.g. Pickles 1996, Sieber 2006) and has been used by grassroots organizations to bring forward their goals. Thanks to integration with online communication tools, PPGIS may bring about deliberative qualities to mobility planning and serve as a venue for e-participation. Argumentation maps (Rinner 2001) or *geo-discussions* allow participants to engage in online discussion supported with interactive maps and geographical data. Online deliberative functions may be coupled with analytical functions, allowing participants to form informed opinions and increase quality of decision-making (Nyerges, Aguirre 2011). If employed properly, PPGIS may thus help local governments fulfill the requirements for SUMPs by strengthening the active role of citizens in mobility planning.

This article aims at providing an overview of ways in which PPGIS methods can support sustainable urban mobility planning. The overview is based on case studies conducted in two cities in Poland (Poznań and Łódź) and supplemented with several examples from other countries. First we present the PPGIS methods and the case studies. Then, we outline a range of mobility-related data that can be collected with PPGIS, and ways of engaging urban dwellers in mobility planning with online techniques. We situate the techniques within the recommended SUMP formulation processes, and discuss potential benefits related to their use. We close the article discussing challenges related to PPGIS implementation and provide recommendations for mobility planning practitioners.

Case studies and PPGIS methods

Case studies

The content of the article is based on case studies conducted in two Polish cities – Łódź and Poznań – as a part of a research and development project. The project aims at developing PPGIS tools to support urban and metropolitan planning and decision-making. The data presented in the paper come from two particular case studies.

The first case study conducted in Łódź (population ca 700,000) aimed at consulting with the public a draft project of sustainable public transportation model. The main goals of data collection were to identify parts of the city with low rating of public transportation services; to single out locations with problems and issues related to the use of public transportation (e.g. uncomfortable interchanges); to establish locations of transport infrastructure (e.g. 'park and ride' facilities) suggested by the public; and to collect general suggestions for public transportation service improvements. The spatial extent of the survey was the City of Łodź encompassing the total area of 293.25 km^2. The survey was conducted between 28th February 2016 and 14th march 2016. During that time 2387 users of Łódź public transportation system filled out a survey. Participant recruitment was open and voluntary and information about the survey was advertised on posters at bus and tram stops, as well as in local and social media outlets. The data collection was carried out entirely online through a geo-questionnaire. The recipients of survey results were the City of Łódź Office of City Development (pol. Biuro Rozwoju Miasta Urzędu Miasta Łodzi) and the Transportation and Road Management Authority (Zarząd Dróg i Transportu w Łodzi). The recipients took an active part in formulating survey questions along with the research team.

The second case study was conducted in Poznań (population ca 540,000). The case study aimed at updating a "local needs map" as part of the *Integrated Program for Renewal and Development of Downtown Poznan for the years 2014–2030*. The program and the case study area involved 5 downtown neighborhoods encompassing the area of 1680 ha, inhabited by 122,500 people. The study was conducted in two stages. The first stage employed a geo-questionnaire to diagnose problems perceived and experienced by the residents and users of Poznań downtown and its objectives were to examine residents' mobility patterns; and to evaluate living conditions in the area in terms of security, accessibility and infrastructure maintenance. The data collection lasted between 14th and 31st of March 2016. During that time 709 residents participated in the survey. In the second stage, the study applied a geo-discussion to collect residents' proposal for infrastructural improvements in Poznań downtown. The second stage was carried out between 17th and 29th April 2016. During that time 169 participants contributed their proposals and commented on proposals contributed by others. The recipients of the results collated into a "local needs map" were the City of Poznań Office for Revitalization and Project Coordination and elected members of five city neighborhood councils. The main goal of the case study was to inform the future infrastructural investment in Poznań downtown with residents' input.

Both case studies employed PPGIS crowdsourcing and participatory methodologies to provide public input into urban planning policies and to guide local government spending. The topics were situated at the intersection of downtown renewal and public transportation planning. Therefore, they did not constitute a comprehensive and integrated Sustainable Urban Mobility Plan. Nevertheless, the methods and techniques utilized are applicable in SUMPs formulation, which we elaborate upon in the following sections. To broaden the scope of the article, and to provide a more comprehensive perspective on PPGIS applicability for sustainable urban mobility, we also present examples of cases that are not part of the two case studies.

PPGIS methods: geo-questionnaire and geo-discussion

The case studies employed two distinct PPGIS methods: a geo-questionnaire and a geo-discussion. A geo-questionnaire is an online questionnaire that is coupled with an interactive map. It enables collecting three types of data: geographical features, attribute data linked with geographical features, and data without an explicit spatial reference (Jankowski et al. 2015). The geographical features are contributed by participants or selected from features presented on a map. Depending on the geo-questionnaire design, geographical features may be represented as points, lines or polygons, and linked with one or more contextual questions. In a use case example illustrated in Fig. 1, participants are asked to mark their residential locations with a point feature and answer single-choice contextual questions. In a use case example in Fig. 2, participants are asked to draw polygon features representing areas poorly served by public transportation, and to provide reasons for such evaluation in an open-ended question. The method is similar to and builds upon methods used previously by Brown (e.g. Brown, Weber 2011), Kyttä (e.g. Kahila, Kyttä 2009, Kahila-Tani et al. 2015), Chaix and their co-authors (Chaix et al. 2012).

A geo-discussion is a Web application that integrates an online structured discussion forum with an interactive map. It allows participants to contribute geographical features and link them with discussion threads. The geo-discussion has several functions that are typical for online discussions, such as adding new threads, commenting on threads added by other participants, subscribing to posts and threads, adding positive and negative reactions, attaching files, and sorting and searching posts. The map module allows participants to run simple map searches and offers navigation functions such as zooming in and out, toggling between map layers, and retrieving attributes of geographical features presented on map. The exemplary use case illustrated in Fig. 3 presents a geo-discussion page, in which a user can browse through threads and comments added by other participants. In this case, threads represent proposals for infrastructure improvements in downtown Poznań. Design of geo-discussions builds upon pre-

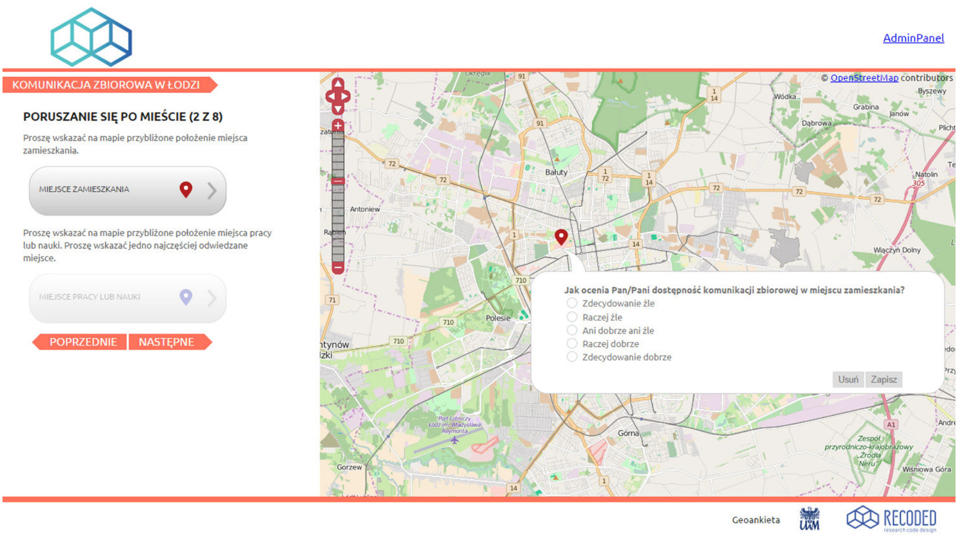

Fig. 1. Example of geo-questionnaire page from the Łódź case study. The respondents are asked to mark approximate location of their place of residence using a point feature. The single-choice contextual question refers to rating the quality of public transport at the place of residence

Source: geo-questionnaire application used in the case study.

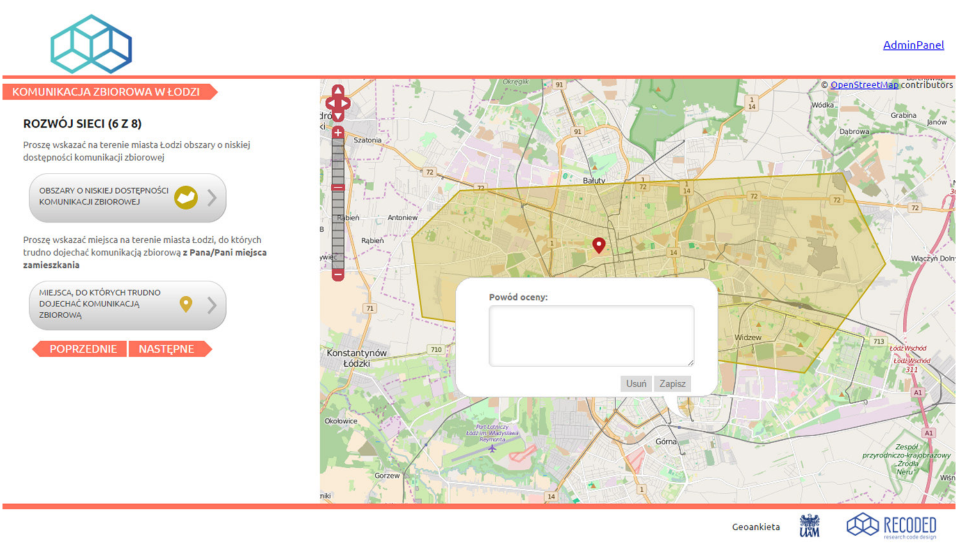

Fig. 2. Example of geo-questionnaire page from Łódź case study. The respondents are asked to indicate areas with poor access to public transportation using a polygon feature. The open-ended contextual question refers to perceived reasons for poor accessibility

Source: geo-questionnaire application used in the case study.

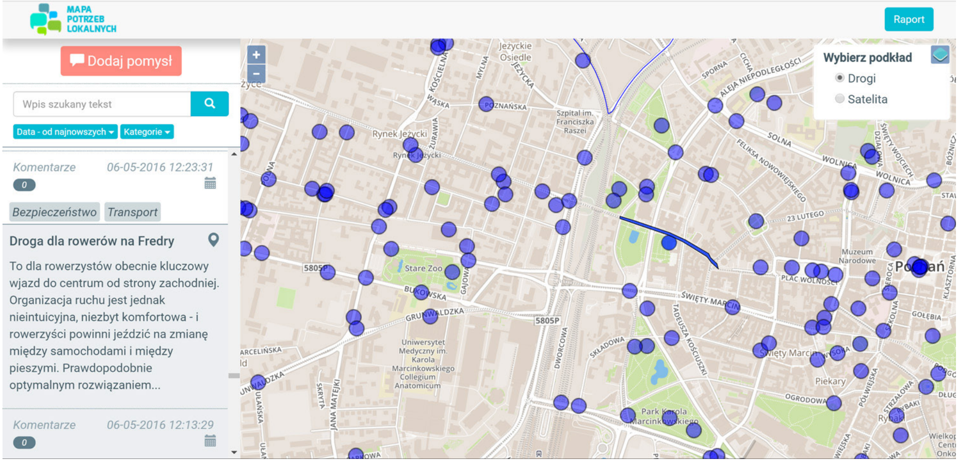

Fig. 3. Example of geo-discussion page from Poznań case study. The locations represent infrastructure improvements in downtown area proposed by participants. Highlighted line segment in the center of the map view is a proposed improvement of bicycle route with a detailed description of proposed course of action (left-hand panel)
Source: geo-discussion application used in the case study.

vious research and development by Rinner et al. (Rinner 2001, Rinner and Bird 2009) and others (e.g. Hall, Leahy 2008).

Geo-questionnaires and geo-discussions share certain characteristics, such as online mode of work and use of interactive maps, but they have several defining characteristics and may serve different purposes. First, geo-questionnaires typically allow for independent contribution of data, in which participants do not see contributions of others, while geo-discussions allow participants to view and comment on contributions of others. Second, geo-questionnaires allow for one-way communication, in which participants contribute the data that subsequently are aggregated, analyzed and integrated with other data sets by analysts or planners. Geo-discussions in turn allow for multi-way communication between multiple users at a time e.g. residents and planners. In general, geo-questionnaire may be seen as mainly data collection method, while geo-discussion is an online communication tool. Therefore, the use of both PPGIS methods in planning might serve different purposes and be related to different planning stages. The methods may be used separately (as in the Łódź case study) or combined in a sequential process (as in the Poznań case study).

PPGIS in sustainable mobility planning

Stages of sustainable mobility planning

Sustainable mobility planning is envisioned as a multi-stage process aimed at continuous and cyclical improvement (European Platform on Sustainable Urban

Mobility Plans [EPSUMP] 2014). Each of its stages has different goals and may require different data sources. In a similar vein, Horelli (2002) describes participatory planning as a cycle, with different participatory tools appropriate at different phases of planning. In this section we outline main phases of sustainable mobility planning and describe their basic data and participation requirements. According to Brown and Kyttä (2014), effective integration of PPGIS into planning is closely linked to the purpose the methods are supposed to serve in the planning cycle. Thus, in following sections we situate PPGIS in relation to different stages and goals of SUMP.

1. At the initial stage of *diagnosis and goal-setting*, both qualitative and quantitative data can be used to identify shortcomings of the analyzed system and set general goals of the policy. The information about the possible fields of improvement can be either obtained from objective measurements that are compared to predefined norms (as is the case of air pollution or noise level) or from subjective evaluation of end-users (e.g. perceived quality of public transport or conditions for cycling). Key inputs at this stage include analysis of current mobility patterns (e.g. mode shares, route selection, key origins and destinations, and traffic volumes), as well as end-user needs, preferences, and evaluations.
2. At the stage of *generating solutions and choosing suitable intervention activities*, all knowledge that could be used to predict future behavior of the end-users and forecast the future state of the transportation system can contribute to selection of the optimal set of instruments. This can include generalized knowledge of human mobility behavior (e.g. the determinants of mode or route choices) or localized and qualitative research that could be used to generate and test different policy scenarios (e.g. focus group interviews, questionnaires using purposive sampling). The solutions can be proposed and developed by citizens in the course of crowdsourcing or participatory process. In order to improve the sustainability of generated solutions and legitimacy of decisions, this stage requires collaborative engagement of residents and institutional users.
3. Moreover, there is a certain set of data that can be used as indicators in *monitoring the results of the policy*. For the data sources to be used in the form of indicator, it has to comply to the requirements of efficient indicators, i.e. '*have the capability (sensitivity) of detecting relevant changes in sustainability (...), in a time-based way (allowing a frequent update in order to monitor evolution)*' (Gillis et al. 2016). This requirement favors data that is collected regularly and according to a standard methodology, that would allow for comparison between different points in time. It can take form of repeated diagnosis (e.g. at several points in time of the implementation period of the policy) or a specifically-designed set of inquiries designed to monitor implementation progress. At the *implementation* phase, participatory approaches to design (e.g. geodesign – see other papers in this volume) may be especially warranted, for instance in order to improve quality of design with local user knowledge, as well as to support the sustainability of interventions.

Mobility patterns

One of the most important data inputs for mobility planning pertains to mobility patterns of the residents. Apart from measuring the amount of traffic, mobility patterns may be described in qualitative terms, e.g. by trip purpose or travel mode. Data on mobility patterns can be analyzed in aggregated manner to reveal mass phenomena or individually, to obtain in-depth information about single users' travel patterns and the motivation behind them. The knowledge obtained this way, can be used to learn about the causes of specific spatial behavior (e.g. the choice of mode or route), determine the areas in need of intervention, or facilitate forecasting the possible outcomes of policies. One of the classical techniques to collect mobility pattern data is 'mobility journal', which (depending on a variant used) requires the participant either to note down every trip made during specific period of time (e.g. 24 hours) or recall all the trips made in some time interval in the past. Those techniques, if used with random sampling, may be used to estimate modal split in a given region, city or neighborhood. PPGIS may be used to supplement the data derived from travel surveys. In geo-questionnaire, participants can mark locations of visited places or draw personal trip routes on a map. Each of the markings may be associated with contextual questions regarding e.g. trip purpose, visit frequency, travel modes, as well as more subjective topics such as estimated travel time, perceived connection quality, or reasons behind mode choice. Geo-questionnaire may thus supplement traditional travel diaries with user-generated spatial data and rich attribute data.

Attitudes and social marketing

Changing the existing mode shares and mobility patterns in order to reduce the use of motorized travel modes is one of the primary goals of sustainable mobility (Banister, 2008). Among the factors of such change are social norms and individual attitudes and preferences (Bamberg 2012). Such attitudes and norms may be changed within sustainable mobility policies by targeted social and individual marketing campaigns (Anable 2005, Banister 2008, Haustein, Hunecke 2013). Such campaigns require knowledge of current preferences of residents with regard to travel modes and behavioral changes. Social marketing campaigns rely on segmentation techniques, in which target groups and their specific need are identified (Haustein, Hunecke 2013). Geo-questionnaires allow combining social survey questions about mobility- and lifestyle- related attitudes with observed mobility patterns and evaluation. They can facilitate spatially-sensitive social marketing campaigns that are targeted not only to specific groups of population, but also to specific areas. Spatially-sensitive approach may take into account the latent demand for alternative travel modes, e.g. by identifying areas with high demand among residents for using specific travel modes, but lacking an appropriate infrastructure and hence exhibiting low levels of usage.

Modeling mode choices

The stage of *generating solutions* in sustainable mobility planning, among other inputs, requires generalized knowledge of the determinants of mobility behavior such as mode choice and route choice. Geo-questionnaire data may facilitate research on mobility behavior at individual, neighborhood and city levels. It allows integrating data on geographical patterns of mobility with socio-demographics, attitudes as well as GIS-based characteristics of environmental quality and urban structural characteristics. PPGIS-sourced data have been used so far to model mode choice between low-emission and fastest travel modes (Salonen et al. 2014), mobility patterns of children (Broberg et al. 2013) and adults (Haybatollahi et al. 2015), as well as travel-related health outcomes (Chaix et al. 2012). Aside from contributing generalizable evidence about factors and outcomes of urban mobility, geo-questionnaires may also be used to identify locally specific factors of behavior, thus helping policy-makers to target them with infrastructural or social interventions.

The use of geo-questionnaires allows mitigating some of the caveats of aggregated approaches to modeling mobility-related behavior. One of such caveats is Modifiable Areal Unit Problem (MAUP), which is related to travel analysis on data aggregated to traffic analysis zones (TAZs), districts or other arbitrarily set spatial units. In geo-questionnaire, responses have individual spatial footprints, and don't have to be aggregated. PPGIS may also help to alleviate some problems related to uncertain geographical context (Kwan 2012). In most studies on the influence of environmental characteristics on people's behavior, the "true" spatial context is unknown, and thus results are biased. The use of geo-questionnaires could alleviate some of the issues by, for instance, collecting data on route outlines, places visited, and thus allowing to formulate more detailed activity spaces. Such level of geographical detail in geo-questionnaire data allows to quantify mobility styles: i.e. identify and delineate segments of population with specific characteristics of their mobility patterns (i.e. travel modes, distances travelled, and activity space extent), which may supplement segmentations based on attitudinal and socio-demographics data in spatially-sensitive social marketing campaigns aiming at behavioral changes (Prillwitz, Barr 2011).

PPGIS in quality evaluation

PPGIS is especially well-suited to capture subjective evaluation of end-users, for the *diagnosis and goal-setting* stage of sustainable urban mobility planning. The data may be used to identify shortcomings of the analyzed system and set goals for policies. PPGIS strength lies in taking geographical perspective, which allows identifying specific areas and locations that require improvements. One of the ways of measuring user evaluations is through asking questions with answers in Likert-like or other rating scale format. Answers to these questions may be then geocoded to residential or workplace locations, or attributed to specific geographical objects, such as destinations or regions.

To capture an overall evaluation of public transportation accessibility in the case study in Łódź, we asked participants to answer a single question "How would you evaluate public transportation accessibility in your residential location?" The answers were provided on a Likert-like scale with five options: very poorly, rather poorly, neither poorly nor well, rather well, very well. The answers were then coded numerically (from 1 to 5) and geocoded to residential locations provided by participants. Such geocoding allows for cartographic presentation and spatial statistical analysis, thus helping to identify areas with need of improvement (Fig. 4). The geo-questionnaire also featured more specific diagnostic questions, such as distance to bus stops, quality of bus stops, number of lines, frequency of departures etc. The questions may also pertain to other aspects of transportation infrastructure or to neighborhood and street quality, which are also important aspect of sustainable mobility on their own right (Banister 2008).

PPGIS also allows for a different type of evaluation, in which participants mark or draw geographical objects (e.g. points, lines or polygons) that represent evaluated locations. The evaluations may be negative, allowing to identify inadequate, unsafe or otherwise problematic locations, or positive, for instance

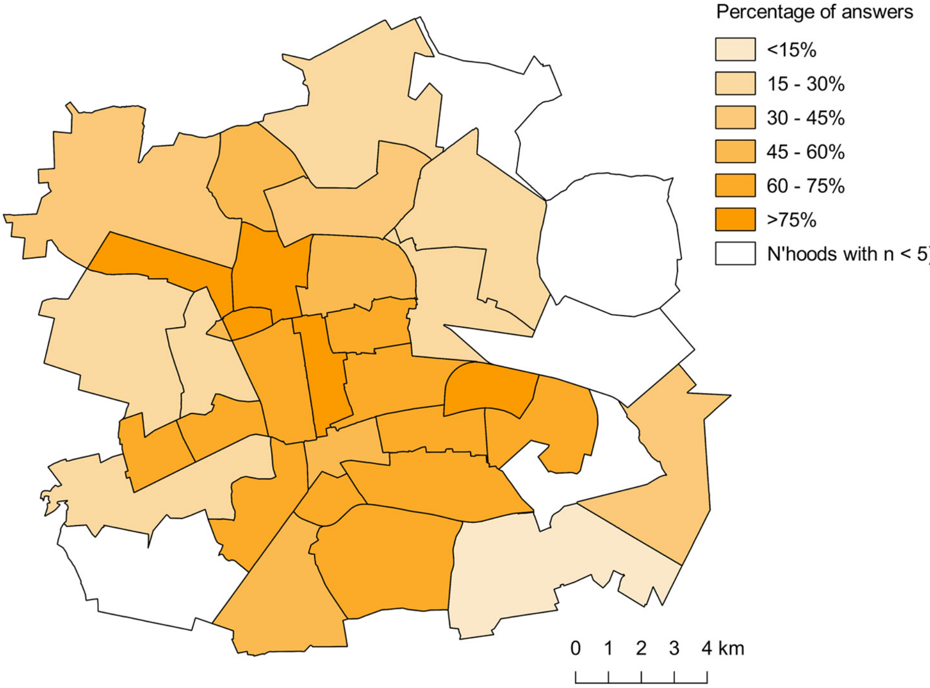

Fig. 4. Evaluation of public transport accessibility at the place of residence: percentage of positive ("very well" and "rather well") responses to question "How would you evaluate public transportation accessibility in your residential location?" in neighborhoods of the City of Łódź. Spatial units with n < 5 are rendered in white

Source: neighborhood boundaries provided by the City of Łódź; thematic data collected in the case study.

pointing out to qualities that should be preserved. Depending on the setting of specific geo-questionnaire, each location may be accompanied by a set of questions allowing to provide details of the evaluation (e.g. Fig. 2). In the Łódź case study, we employed this method to identify areas with poor access to public transportation within the city (Fig. 5).

This approach is akin to *bottom-up GIS* proposed by Talen (2000) and is at the heart of *softGIS* methodology developed by Kyttä and colleagues (e.g. Kahila, Kyttä 2009). In softGIS, perceived environmental quality is attributed to specific locations and its measurement aims at capturing *affordances*. Affordances are perceived opportunities and restrictions concerning person's actions in a given environment that may have physical, emotional or socio-cultural dimensions (Kyttä, Kahila, Broberg 2011). The concept of affordances is well-suited to mobility planning, as it may help to identify opportunities and restrictions to using specific travel modes (e.g. cycling and walking) in urban environment from a unique user perspective. Thus, it provides opportunity to account for individual differences between users and their preferences, which may be overlooked by normative infrastructure audits. PPGIS not only captures such aspects of infra-

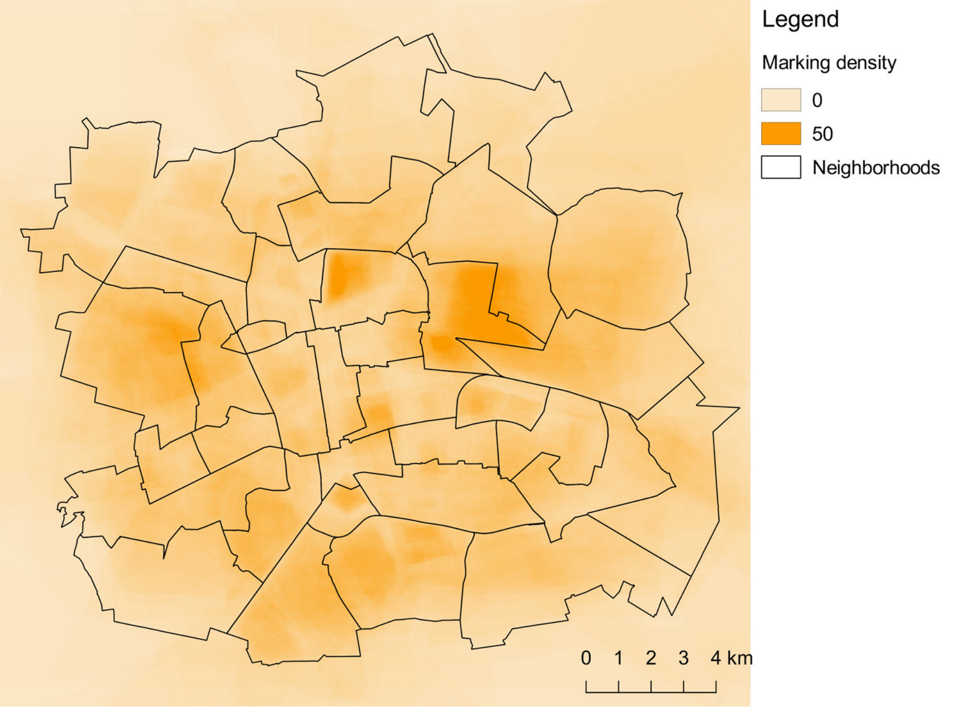

Fig. 5. PPGIS evaluation of public transport accessibility: aggregation of geographical objects (polygons) sketched by participants as an answer to question "Please mark areas with poor access to public transportation"

Source: neighborhood boundaries provided by the City of Łódź; thematic data collected in the case study.

structure quality as design flaws, but also discerns less tangible characteristics such as perceived comfort, safety or aesthetic attractiveness, as well as social and emotional affordances. Therefore, it is a source of data previously unavailable but potentially valuable to mobility planners. The list of measured aspects of quality might be derived in a bottom-up fashion, from participants answering broadly phrased open-ended questions, or as a closed list of issues based on theory or special areas of focused decision-making points of view (e.g. Rantanen, Kahila 2009). The questions might be highly focused, targeted at specific areas of improvement – depending on the needs of planners and decision-makers.

According to Brown (2014) aggregated PPGIS contributions may represent a form of *crowd wisdom*. Basic requirements for quality crowdsourced data include a large number and diversity of participants, independent way of contributing knowledge and expressing views, and appropriate aggregation of the contributions. Aggregation of contributions is performed with GIS rasterization algorithms followed by map algebra operations. Points and lines may be aggregated using simple density or kernel density estimation functions (Alessa et al. 2008). Polygons are aggregated using a series of map algebraic operations (Jankowski et al. 2015). Participant contributions may be also analyzed individually for instance by examination of answers to contextual questions. Such a disaggregated analysis is performed in desktop or Web GIS environment (e.g. Kahila-Tani et al. 2015) and may also be presented in synthesized form as a qualitative summary. According to Talen (2000) there is a trade-off between individual and aggregated approaches. On the one hand, individual viewpoints and affordances of respondents (i.e. *disaggregation*) provide planners with insights into subjective preferences and provide urban designers with empathy for end-user needs. On the other hand, even though presentation and analysis of aggregated responses (e.g. *collective aggregation*) compromises the depth of individual perspective, it may be more usable at the planning level, less labor intensive, and easier to integrate with other GIS data sets. Experience from the presented case studies suggests a two-step sequential approach:

1. *Collective aggregation*, in which all answers are aggregated in relevant categories, allows identifying a general pattern and clusters.
2. *Disaggregation*, in which researchers pool the content of individual answers pertaining to relevant clusters, to obtain details and learn about subjective perceptions provided by participants

In the Łódź case study we collected locations of problematic public transportation transfer points (Fig. 6). The participants contributed 1654 problematic locations. In most cases, the marked up points clustered around the main transfer locations. First, we aggregated the points using kernel density algorithm (*Heatmap* plugin in QGIS 2.14). Second, we identified the areas of high density markings by isolating the areas of density above a certain threshold. Figure 6 presents a group of clusters in Łódź city center, along with their names and numbers of markings constituting a cluster.

In the Poznań case study we collected the locations of places evaluated negatively with regard to mobility (Fig. 7). The participants contributed 308 loca-

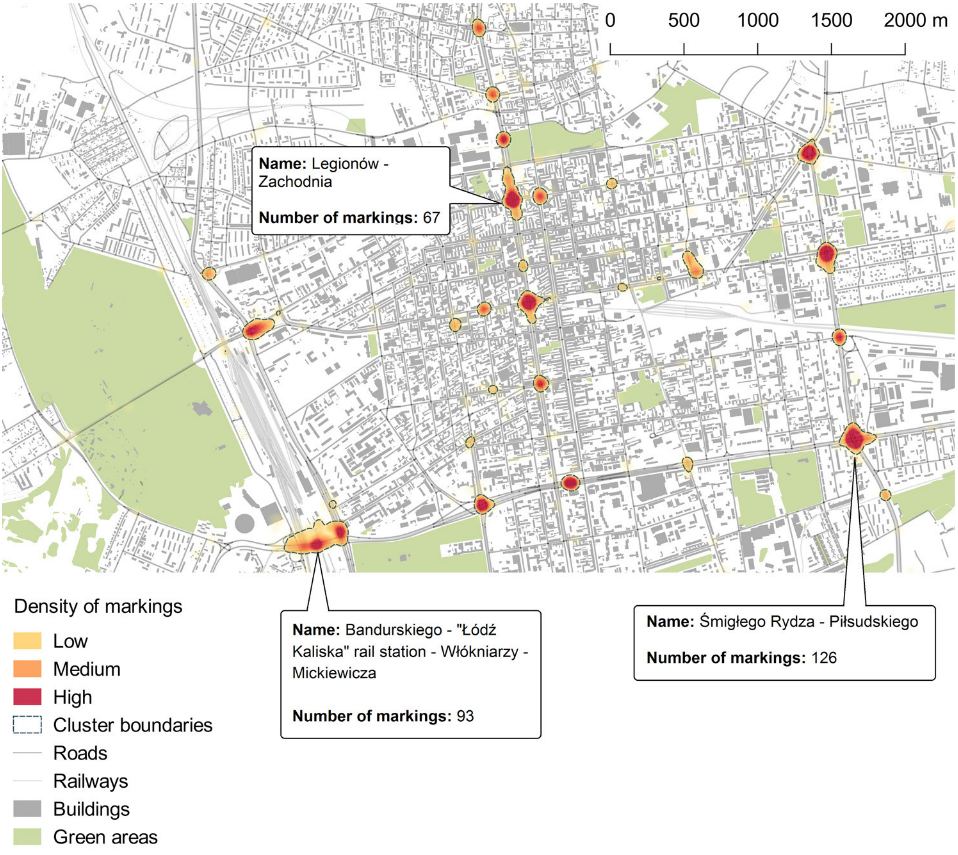

Fig. 6. Kernel density map and clusters of markings about locations in which respondents experienced “problems with changing buses and trams” (the Łódź case study)
Sources: topographic data © OpenStreetMap contributors; thematic data collected in the case study.

tions. Similarly to the Łódź case study, we aggregated the points using kernel density algorithm (*Heatmap* plugin in QGIS 2.14), and then identified the areas of high density markings by outlining the areas of density above a threshold. We identified 17 clusters of problematic locations. In this study, the locations were attributed with answers to open-ended questions about details of the evaluation and ideas for intervention that would alleviate the experienced problems. Figure 7 presents a group of clusters in Poznań city center, along with names, numbers of markings, and summaries of open-ended answers.

Experiences from the case studies suggest that the two-step analysis is best performed using point features. A difficulty related to lines and polygons is due to a possibility of a single feature contributing to more than one cluster, whereas point features can usually be assigned to specific locations without ambiguity. Hence, using points is recommended. Clusters identified in the first step (collective aggregation) may be used for scoping activities and selecting candidate locations for priority interventions, and results of disaggregated anal-

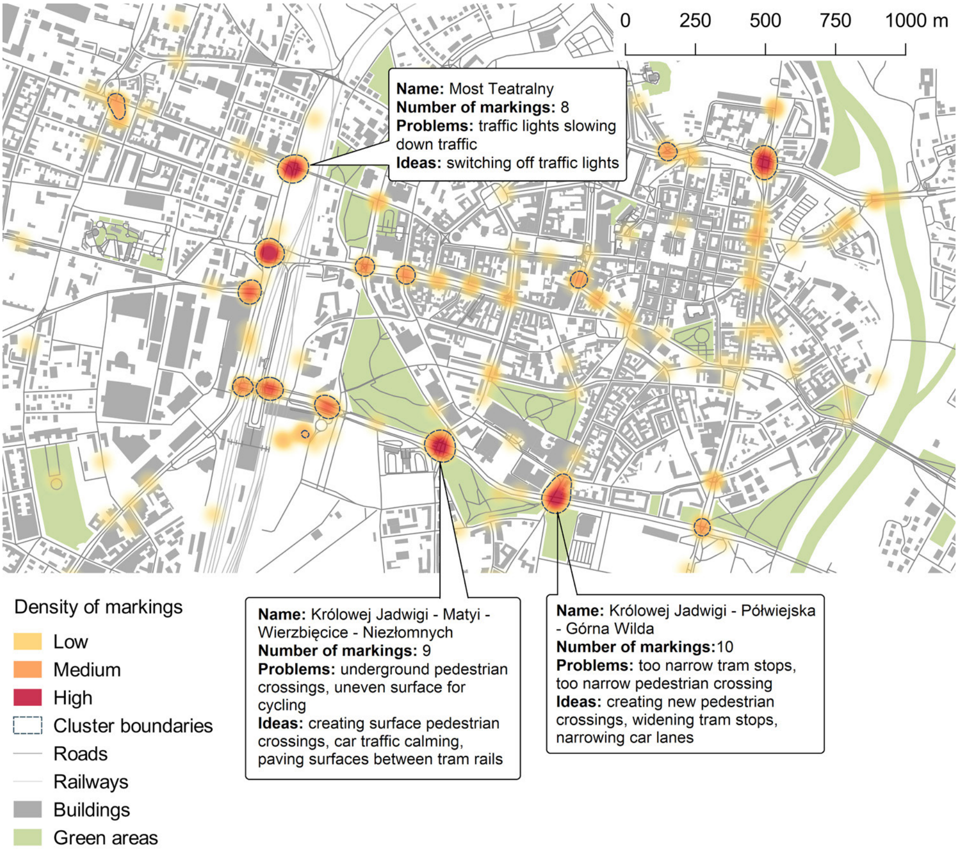

Fig. 7. Kernel density map and clusters of markings identifying the locations in which respondents negatively evaluated mobility conditions, along with summaries of answers to contextual questions. The markings denote places such as intersections, road segments, or public transportation stops (the Poznań case study)
Sources: topographic data © OpenStreetMap contributors; thematic data collected in the case study.

ysis (second step) may be used for detailed design of the interventions at the implementation phase.

PPGIS in generating solutions and making decisions

After diagnosis and quality evaluation, next steps in sustainable urban mobility planning involve generating solutions, creating policies and choosing specific activities. Public input in those phases may be contributed through a variety of PPGIS tools and configurations in what Talen (2000) described as *prescription* phase. Public participation GIS may be well suited to support gathering ideas or proposals on infrastructure improvements and changes, as well as their locations. The content of these proposals may for instance relate to new parking places, cycling routes, traffic calming projects etc. Such proposals are different in character from requests described in previous section in that their implementation may require making non-trivial choices of their characteristics and locations, and there may be conflicting viewpoints among the participants. Such public input may be gathered in a variety of PPGIS settings.

In one setting, participants propose locations and characteristics of mobility-related facilities. In this setting it might be appropriate to adopt a crowdsourcing mechanism, in which multiple independent contributions from a large group of participants are aggregated to identify a desirable outcome (Brabham 2009). To meet *crowd wisdom* requirements, contributions must be made independently (i.e. participants cannot see or be influenced by contributions of others) by a large and diverse group of participants (Brown 2014). Geo-questionnaires have been used for crowdsourcing in a numerous case studies, predominantly in environmental management (Brown 2014).

In the Łódź case study, a geo-questionnaire was used to crowdsource locations for park-and-ride stations (Fig. 8). The data collection and aggregation procedure

Fig. 8. Kernel density map and clusters of "park-and-ride" sites proposed by the participants of travel survey in the Łódź case study
Sources: topographic data © OpenStreetMap contributors; thematic data collected in the case study.

was similar to that of diagnosis: individual point locations were aggregated, clusters identified, and in the last step, disaggregated contributions were pooled to provide details. The advantage of this approach is taking into account a perspective of the "silent minority" and a potential to arrive at a solution that takes into account a collective aggregation of local knowledge. There are also disadvantages to this method: selecting optimal location may be subject to constraints that are unknown to participants, e.g. infrastructural, environmental or related to land ownership. Furthermore, preferences for certain locations of some participants may be in conflict with preferences of other participants, especially in case of developments that potentially harm livability of other residents (e.g. location of ring roads that generate noise in residential areas).

The issue of conflicting *development preferences* may be addressed by preference questions, in which participants mark locations (or areas) where development is not acceptable or where current function should be preserved. In this setting, a crowdsourcing principle is also applied: the outcome is an aggregation of independent contributions from a large and diverse group, but aggregation is performed differently. Contributions pointing out the areas where development is desirable are aggregated together with contributions concerning the areas where development is undesirable. Such a procedure has been used to identify the development preferences of residents in a local land use plan in Poznań (Jankowski et al. 2015). A similar approach can be used to gauge potential for preference conflict. Such *compatibility mapping* has been used in land use management at regional (Brown, Raymond 2014), and city scales (Kahila-Tani et al. 2015). Mapping development preferences may not be related to mobility *per se*, but is a valuable input to land-use policies aiming at urban densification, for instance allowing to identify areas, in which infill development is the least opposed by residents (e.g. Kahila-Tani et al. 2015).

PPGIS applications using crowdsourcing processes have high potential in providing valuable *task outcomes* of public participation, i.e. outcomes that lead to effective decision-making, high quality and sustainability of decisions (Jankowski and Nyerges, 2003). However, they may fall short of bringing about *social outcomes* of participation, such as building trust, long-lasting relationships and mitigating conflict (Halvorsen 2001, Innes, Booher 2004, Brown, Chin 2013). The PPGIS setting, in which contributions are made independently and then aggregated, lacks important deliberative qualities. Participation through geo-questionnaires is a one-way process, from residents to decision-makers, and despite its convenience, efficiency, and relatively low cognitive effort required of participants, it may lack depth and not lead to higher levels of civic engagement. In sustainable mobility planning, significant changes in travel behavior and public spending are often prescribed, and such changes require strong public and political acceptability. According to Banister (2008, p. 79) the scope of public discourse should be enlarged and stakeholders should be empowered through an interactive and participatory process. Sustainable mobility planning thus requires deeper stakeholder involvement in processes of discussion, decision-making and implementation.

Deliberative qualities may be supported by another PPGIS setting, in which *geo-discussions* are used to stage public debate between stakeholders. In such a setting, contributions of participants are usually not independent (i.e. participants can view and react to contributions by others), and there is a two-way communication among participants. In the case study of *Map of local needs* in Poznań, we implemented a geo-discussion tool to gather proposals for improvements in infrastructure, as part of Poznań's downtown renewal program. The case study employed geo-questionnaire in *diagnosis* stage, and a geo-discussion in *prescription* phase. The proposals were related to eight topics, one of which was labeled as "transportation". Mobility related proposals concerned for instance bicycle lanes, bicycle racks, parking spaces, and traffic calming projects. In Poznań case study, 169 residents took part in geo-discussion, while 709 residents provided data in a geo-questionnaire. Similar pattern of participation in the two PPGIS methods emerged in another case study of local land use planning in Poznań described by Jankowski et al. (2015). In that study 128 people took part in a geo-discussion and 1087 people contributed data through a geo-questionnaire. The differences in participation rates suggest that participation in geo-discussion is more challenging to participants, as it may require more time and cognitive effort. At the same time, deliberative features of geo-questionnaires create the potential for deeper collaboration, communication, and valuable social outcomes. However, these hypothetical benefits remain to be investigated empirically.

In the Poznań case study, participants formulated their proposals based on the report from *diagnosis* part, their local knowledge, as well as their assumptions on outcomes of the proposals. They could also question proposals contributed by others, but there were no additional data sets available and discussion was not assisted by experts. Nyerges and Aguirre (2011) describe and evaluate a PPGIS use case in regional transportation planning in Seattle metro area, which employed an analytic-deliberative approach. The PPGIS setting involved a multi-step process, in which online discussions were coupled with data collection and analysis. Nearly 200 participants engaged over a month in online activities including mapping and discussion of their daily travel itineraries, discussing concerns related to Seattle area transportation system, reviewing factors of improvement, discussing and creating transportation improvement packages, as well as discussing and voting on recommended packages. Similarly to geo-discussion, the deliberation concerned a prescribed course of action, but it also allowed participants to review and question available data, how analyses were done, as well as assumptions made by other participants and experts. Such a setting addresses limitations of other PPGIS configurations related to lack of appropriate knowledge about constraints, conditions and costs of proposed interventions. It has potential to engage participants in a more profound manner and thus contribute to their empowerment. However, achieving a meaningful participation of large and diverse groups of stakeholders is also demanding and wider application of analytic-deliberative PPGIS still remains a challenge.

Integrating PPGIS into planning process

Participant selection and recruitment

Based on a literature review and the evaluation of presented case studies we identified two key aspects of PPGIS design for successful application in sustainable mobility planning. The first aspect is related to appropriate integration of PPGIS methods and data into the phases of mobility planning cycle. The second aspect concerns participant selection and recruitment, and its implications on communication and data quality.

In diagnostic activities of the *initiation* and *evaluation* phases of mobility planning, geo-questionnaires are an appropriate tool for mapping current mobility patterns and identifying mobility-related attitudes. In this phase, the contributions should be made independently by large and diverse group of participants recruited with random sampling from the general public. Socio-demographic representativeness is crucial for gathering reliable figures that summarize mobility patterns, such as modal splits due to individual variables influencing mode choice and other facets of mobility behavior. It is also crucial for analysis of attitudes towards specific travel modes or policy interventions, especially if the results are meant to be used in quantitative analysis. Mapping mobility patterns also requires proportional spatial distribution of participants in relation to spatial distribution of residents, as *spatial bias* is likely to influence the data (Czepkiewicz et al. 2016). Mapping mobility patterns also poses high requirements in terms of sample sizes in order to obtain the sufficient number of participants in each spatial unit of analysis, such as TAZs or neighborhoods. Meeting sampling requirements with online geo-questionnaire is challenging, because of high non-participation bias related to the lack of internet access, browsing skills, and willingness to participate among the less educated segments of the population (Czepkiewicz et al. 2016).

Sampling requirements are somewhat relaxed in another type of diagnostic activity at initial stages of planning, in which PPGIS is used to identify locations with positive or negative evaluations of environmental quality. Large and diverse groups of participants are still required to meet crowdsourcing criteria, but the effect of bias is less critical than in mapping mobility patterns. In other words, errors in estimating modal split or travel demand may bring greater uncertainties to decision-making process, than wrongly identifying locations that are perceived as uncomfortable or unsafe by residents. Relatively large sample sizes are required to reliably aggregate contributions of geographical data. Brown and Reed (2009) suggest that 300 should be a minimum target number of respondents of such mapping, but this figure is likely to be also a function of PPGIS design and the extent of study area. Spatial bias also plays a role in diagnostic mapping. First, the markings represent local knowledge of participants derived from their own experience (Rantanen, Kahila 2009), and its quality may be related to their familiarity with the study area, which is typically higher for locations closer to the place of residence than elsewhere (Brown and Reed 2009). Contrary to mapping mobility patterns, diagnostic mapping does not necessarily need to target a general population. Purposive and quota sampling targeting specific groups of users may also be warranted. For instance, mobility planners may be interested in identifying locations that are negatively perceived by cyclists, to improve them in an effort to promote the use of bicycle as a travel mode. Crowdsourcing locations and characteristics of infrastructure improvements with geo-questionnaire have similar sampling requirements as in the case of diagnostic mapping. Spatial bias is of interest here, as residents of certain locations are likely to favor infrastructure that would improve their own mobility and livability, and not necessarily be optimal in the context of a whole study area (Swobodzinski, Jankowski 2015).

Sampling issues are the key in applying PPGIS in urban planning practice if data quality and meaningful contribution is the main concern (Brown, Kyttä 2014). The use of CAWI on the Web in either PC or mobile versions are still challenging in terms of achieving satisfactory response rates and demographic representativeness. Even if it possible to collect large samples with relatively low cost, representativeness may be compromised for several reasons. One is related to non-response bias resulting from low mapping or Web browsing skills, as described in Czepkiewicz et al. (2016). This is especially relevant in more demanding mapping tasks such as delineating routes and areas. This pitfall might be partially alleviated by CAPI in either workshop or lab setting (e.g. Chaix et al. 2012) or door-to-door data collection. Geo-questionnaires can also be potentially used to collect data in public space by using tablets and other mobile devices.

Despite its importance for data quality and its role as common evaluation criterion of public participation (Brown, Chin 2013), sample representativeness is not always valued or strived for by urban planners. Voluntary sampling settings are often preferred, because of its inclusive character (e.g. Kahila-Tani et al. 2015). Voluntary sampling may be indeed appropriate in some activities at late decision-making stages. When focus is shifted from data collection to collaboration and deliberation, statistical representativeness is no longer necessary. However, group of participants should still meet certain requirements in order to achieve diverse and meaningful discussion. According to Nyerges and Aguirre (2011), experts, decision-makers, and other important stakeholders should take part along with members of the general public. They also point out that participants should represent a variety of views, values, interests and geographical regions. Spatial bias is also of interest, as participants inhabiting specific locations may have different views on issues at hand, e.g. due to how the proposed changes would affect their own mobility patterns and livability (Nyerges, Aguirre 2011). In an analytic-deliberative setting, quota sampling or purposive selection may be preferable. However, one of the biggest challenges to participation in such a cognitively demanding process lies in attracting diverse participants and achieving high level of engagement.

PPGIS methods may also be used as part of public outreach process in *implementation phase*. Residents may, for instance, engage in deciding the details of implementation within an already defined project scope, such as suggesting locations of bike-share stations or details of a traffic calming project. Such PPGIS applications may help create ownership over the activities among the public, and thus improve their sustainability (e.g. Sadik-Khan 2016). In such settings, open and voluntary sampling appears to be the most appropriate, as special interest and involvement of participants in a given project may lead to positive outcomes. It also important to note, that we do not propose that PPGIS methods substitute other data collection, modeling and participation methods. In our view, well-known methods such as travel diaries, surveys, field observation, traffic modelling, group workshops or public meetings, should rather be complemented with PPGIS methods, thus improving data quality and diversity, and extending public outreach to those who do not participate in face-to-face meetings.

There is a high potential to use PPGIS in sustainable urban mobility planning and related planning activities in Poland. Sparked, among other reasons, by European Union requirements for structural funding, the increasing number of cities and metropolitan areas is implementing mobility plans and policies focused on cycling and public transportation. There is also a growing interest among municipalities to implement comprehensive SUMPs recommended by the European Commission, even though the lack of funding is perceived as a barrier among mid-sized cities (PAP 2015).

Recent decade in Poland has been marked by the heightened activity of urban movements (Domaradzka 2015), who challenged local governments to step-up public participation in planning and apply high standards of planning practice (e.g. cyclists' associations demanding the adoption of cycling infrastructure standard). Urban planners and decision-makers, who are willing to strengthen public participation processes in mobility planning with PPGIS methods may thus find a supportive environment among activists, who often closely collaborate with city officials. On the other hand, the increase of civic activity among urban dwellers may also results in the amplification of conflicts between the groups of residents with different mobility styles and needs (e.g. resulting from travel mode choice habits), and mobility planning in such controversial issues as parking spaces or traffic calming, may be politically challenging. In such a context, very important is the appropriate integration of PPGIS methods into planning process and care in recruiting participant, interpreting data, and presenting results.

Conclusions and future research directions

In the article we have provided an overview of public participation GIS methods in mobility planning using recent case studies in two Polish cities. We have presented numerous potential benefits that PPGIS methods may bring to planners developing sustainable urban mobility plans. We have situated the methods in stages of plan development and implementation, and provided guidelines for participant recruitment. In addition to issues related to data quality, methods of data analysis, and participant recruitment, future research should focus on benefits and advantages of PPGIS methods as perceived by mobility planners and decision-makers, and in comparison with traditional methods. The use of data collection and public participation methods brings about some costs, which are most likely covered with public money, and the perspective of planners and local authorities is key in assessing PPGIS quality (Ganapati 2010, Czepkiewicz, Snabb 2013). The methods must also advance social goals and provide value to participants representing a broader set of stakeholders and general public. Anecdotal evidence of PPGIS benefits in mobility planning is relatively easy to find (e.g. Sadik-Khan 2016), but there is dearth of systematic evaluations. Kahila-Tani et al. (2015) evaluated PPGIS in master planning process in Helsinki from the perspective of planners. Other evaluations have focused on data quality and such aspects as meeting crowdsourcing requirements (Brown, 2014), spatial accuracy (Brown 2012), and internal validity (Jankowski et al. 2015). The challenges in implementing PPGIS in practice might be, however, less related to data quality per se, but more to perception of its usability by planners. Future research directions include case study research and systematic empirical evaluation of PPGIS usability in specific PPGIS configurations in sustainable mobility planning. Researchers should focus on PPGIS evaluation from multiple perspectives: those of participants, mobility planners, and decision-makers.

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