Effective PPGIS in spatial decision-making: reflecting participant priorities by illustrating the implications of their choices

DOI:
10.1111/tgis.12888

Effective PPGIS in spatial decision-making: reflecting participant priorities by illustrating the implications of their choices

Denwood, T.[1]*, Huck, J.J.[1], and Lindley, S.[1]

[1] MCGIS, Department of Geography, University of Manchester, UK

* timna.denwood@postgrad.manchester.ac.uk

Acknowledgements

Timna Denwood acknowledges financial support from EPSRC (EP/L016141/1) through the Power Networks Centre for Doctoral Training. The authors would like to thank the residents of Barra who contributed openly and generously to this study, with particular thanks to Euan Scott.

The software presented here makes grateful use of the Open Source Libraries: 'Leaflet' (https://github.com/Leaflet/Leaflet), 'proj4js' (https://github.com/proj4js/proj4js) and 'javascript-astar' (https://github.com/bgrins/javascript-astar). Both interfaces use a modified version of the Ordnance Survey 'Terrain 5' dataset obtained by EDINA Digital Service (https://digimap.edina.ac.uk/webhelp/os/data_information/os_products/os_terrain5_contours.htm).

Author Credits

Denwood: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Writing - Original Draft, Visualisation. Huck: Conceptualization, Methodology, Software, Writing - Review & Editing, Supervision, Funding acquisition. Lindley: Conceptualization, Methodology, Writing - Review & Editing, Supervision.

Declarations of Interest

None.

Abstract

The use of local knowledge adds value to the decision-making process, for which Public Participatory GIS (PPGIS) are widely deployed. However, there are often issues in the way that PPGIS are designed, particularly with respect to the type of spatial representation used. We propose 'informed interfaces' as a novel approach to PPGIS interface design, to ensure the system can effectively reflect the interests, priorities and values of participants in case-specific spatial decision-making. This paper introduces the concept before demonstrating the benefits of the approach using two examples of informed interfaces through an illustrative UK case study. Evidence was gathered from three face-to-face workshops and five multi-participant online usability tests, revealing that participants felt more confident in the datasets they produced using the informed interfaces. The results also confirm that informed interfaces hold the potential to provide richer, more veracious datasets for improved decision-making, revealing new insights into local perspectives.

Keywords: PPGIS, Participatory Mapping, Interface, Representation, Public Participation

1.0 Introduction

The development and use of any Geographical Information System (GIS) is a socio-technical process. GIS is not merely a method for translating spatial data into cartographic form but a representation of the connections, patterns and relationships between people and their environment (Obermeyer, 1995). In the early phases of development, traditional GIS were criticised as being elitist. Inconsistent access rights, financial barriers and top-down methodologies imposing external perspectives on local problems led to not only a distrust in the practice, but also produced ineffective outcomes (Craig & Elwood, 1998, Sawicki & Craig, 1996; Weiner et al., 1995; Rundstrom, 1995; Harris et al., 1995).

As a reaction to these criticisms, more democratic GIS techniques evolved in order to better acknowledge the social, epistemological and power implications the process may have (Elwood, 2006). The focus shifted towards providing marginalised communities with a voice, using an integration of place-based, non-expert knowledge to aid in addressing issues such as complex land use disputes (Brown & Kyttä, 2018; Radil & Jiao, 2016; Kar et al., 2016 & McCall & Dunn, 2012). Public Participatory Geographical Information Systems (PPGIS) encompass a wide array of practices in which social groups and individuals can participate in GIS-based spatial analysis, planning, knowledge production and decision-making (Elwood, 2006). PPGIS can be used to compile and present spatial data from a broad range of stakeholders in order to represent individual (or group) interests and priorities (Anderson et al., 2009). It is widely agreed that the inclusion of public, non-expert views in decision-making allows for a better understanding of the way people interact with the space around them and consequently enables more robust decisions to be made (Anderson et al., 2009; Evans & Waters, 2007). Accordingly, PPGIS are often used as part of Spatial Decision Support Systems

(SDSS) or other multi-method data collection approaches to obtain public perceptions (Keenan & Jankowski, 2019).

Including members of the public in GIS-based decision-making processes, brings both benefits and challenges. Barriers to the effective use of PPGIS include digital divides between those who can and cannot access the internet or computer technologies (Gottwald et al., 2016); participation inequalities in how much those who can participate actually contribute (Haklay, 2016); and data-related issues, e.g. quality, credibility and the effectiveness of representations (Huck et al., 2018). Despite progression in the field since the mid-1990s, Elwood (2006) argued that participatory forms of GIS still fall foul of the same limitations and criticisms as their predecessors, such as issues around representation and inclusion. Whilst further technological advances have since taken place and the limitations in the field often acknowledged, little has been done to address them (Radil & Anderson, 2019; Brown & Kyttä, 2018 & Robinson et al., 2017). As Blackstock et al. (2006) indicated, the validity of public involvement of any type depends on credible, accountable and transparent methods which connect individuals and groups to the decision-making process. In PPGIS, this requires the use of an appropriate interface, to enable the most effective transfer of information between the target population and the researchers or decision-makers.

1.1 Representation in PPGIS

Many PPGIS interface examples in the literature use spatial primitives (normally basic points and polygons) to simplify complex social and geographic features into readable and replicable formats. Brown (2012) suggests that using point-based data collection is the simplest way to collect spatial data whilst yielding the highest response rates, reduced levels of bias and greatest participation. However, the uncritical use of basic spatial units such as points, can in some circumstances offer a poor representation of the complex relationships between people and place compared to other units (Huck et al., 2018). Representing human opinion more effectively on a map requires a shift from the normative approach of collecting data based on simple points and polygons, to considering more specialised spatial units and associated interfaces (e.g. the interfaces presented by Huck et al., 2014; Evans & Waters, 2007). Such spatial units are designed to generate information which is better representative of the specific question at hand, as opposed to being predicated on convenience, convention and availability. With the technological advances that have taken place since the millennium, it hardly seems appropriate that the interfaces used in PPGIS should not have advanced simultaneously. Whilst it is often acknowledged in the literature that these traditional approaches are unsatisfactory, their use remains common practice in research and decision-making (Brown & Kyttä, 2018; Robinson et al., 2017; Huck et al., 2014 & Goodchild, 2011). The continued use of spatial primitives in PPGIS has been described as the *"Hammer of Participatory GIS"* (Huck et al., 2018:5), referring to Maslow's 'Law of the Hammer' (*if the only tool you have is a hammer, you'll treat everything as if it's a nail*; Maslow, 1966). This analogy highlights an over-reliance on familiar tools and techniques for the collection of nuanced and complex data, instead of ensuring that the question being asked is what influences the nature of representation used (Huck et al., 2018).

It is vital that the interface used in PPGIS reflects the values and priorities of both the participants and of the researchers or decision-makers. As such, new techniques in spatial representation are emerging that greatly expand the possibilities for both researcher and participant, and which are critical for ensuring the public is engaging with PPGIS in a meaningful way (Godwin and Stasko, 2017; Huck et al., 2014). It is also important to ensure the questions asked with PPGIS can reasonably be expected to be answered by members of the general public, without requiring advanced analytical assessment. For example, as part of an energy infrastructure project, we might wish to gather public opinion on the location of a potential new wind turbine. We cannot reasonably expect the public to have the depth of knowledge and spatial thinking skills to identify a location from which a proposed turbine might be visible, or at least to be able to do that accurately. Neither can we expect them to have a detailed understanding of the many complex factors that determine the suitability of a location for a wind turbine. Such expectations might be one of the reasons that target audiences feel poorly qualified to comment in these sorts of decision-making consultations, and therefore do not participate (Firestone et al., 2020). In such situations, participants can benefit from the support of an underlying algorithm to provide contextual information or guide the user in a way that better reflects the real world situation.

1.2 Research Aim

To address the reliance on simple spatial primitives in PPGIS, this research considers how the type of representation used might enable participants to engage more effectively in the decision-making process. Specifically, we ask the question:

How might PPGIS interfaces be designed in a way that better supports the researcher (in the question they are asking) as well as the participant (in the answers they are giving)?

In answering this question we introduce and demonstrate the concept of 'informed interfaces' in PPGIS: purpose built systems that utilise underlying algorithms to provide case-specific, contextual information that supports and informs both the participant in making their choice, and the decision-maker or researcher in interpreting the resulting dataset. Such interfaces are commonplace in traditional GIS, yet rarely seen in PPGIS where the focus is on members of the general public providing their views on spatially explicit questions to support the decision-making process (as opposed to specific groups of stakeholders). Whilst there are numerous factors that influence the success of PPGIS such as geodesign (e.g. Burnett, 2020) or sampling design (e.g. Brown 2017), this research focuses on spatial representations and seeks to encourage the use of more considered spatial units to progress the field of PPGIS. The objective is to encourage the use of more informed interfaces to improve the veracity and value of data collected from the general public, as well as progress the field of PPGIS through more effective spatial representation.

2.0 Methods

We demonstrate the potential of informed interfaces through two examples: the first of which relates to the visual impact of wind turbines and the second to designing footpaths, using the isles of Barra and Vatersay, Outer Hebrides, UK as a case study. This section begins by detailing the case study, before explaining the interfaces designed and how they were assessed through both face-to-face focus groups and a remote usability study.

2.1 Case Study

The isles of Barra and Vatersay (Figure 1) have an area of approximately 70 km^2 and a population of around 1,300 (CNE Siar, 2011). The interior geography of Barra and Vatersay (two islands joined by a short causeway) consists of machair (low-lying grassy plains), uninhabited hills and lochs, with the population residing in hamlets and crofts along the coast. This location offers a unique opportunity to explore the use of informed interfaces in PPGIS as the residents have recently produced a Local Energy Plan enabling existing and future energy needs to be assessed, opening up further opportunities to obtain local views (Local Energy

Scotland, 2018). The plan identifies electricity production and active transport as two key areas of concern, largely due to the remote location of the isles, which makes importing fuels both challenging and expensive.

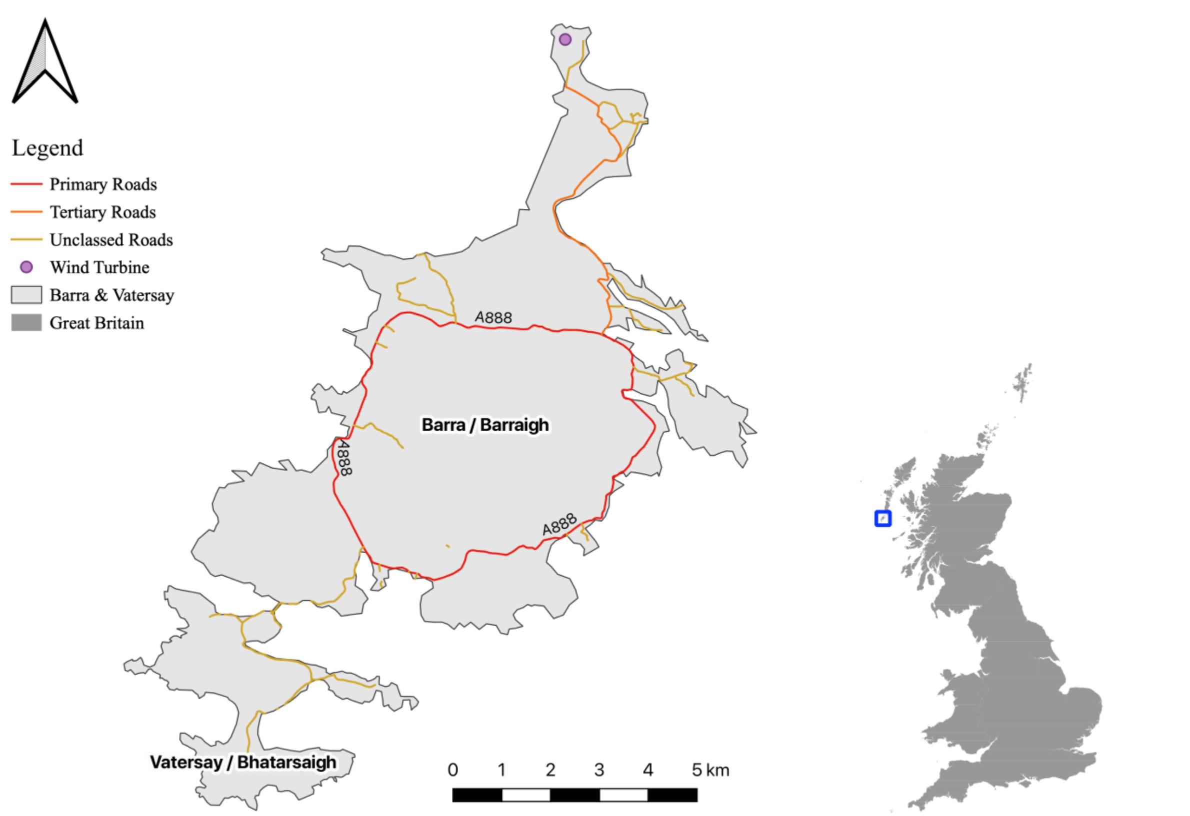

Figure 1 The isles of Barra and Vatersay, Outer Hebrides, UK

2.2 Informed Interfaces

The algorithms underlying the two 'informed interfaces' used in this research are widely available in traditional GIS packages, but are not normally used as part of web-based PPGIS. To ensure transparency in the data collection process, both interfaces are available online at https://gitlab.com/.../informed-interfaces. This not only gives those taking part in the research the opportunity to see exactly how their data are being collected (therefore increasing transparency and trust in the process) but also enables the tools to be integrated into research with only minor alterations i.e. the parameters of the algorithm or location.

2.2.1 Using Viewsheds as an Informed Interface

The first interface uses viewsheds (a visibility structure that represents all visible points from the selected viewpoint) as a spatial unit; calculated and drawn in real-time in response to clicks on the map (Kaučič & Zalik, 2002). The viewshed indicates all of the locations from which a 50m tall wind turbine would be visible to an individual standing at the click location (with eye level set at 2m above the ground, a 360° field of view and a maximum visible distance of 5km). As participants click on multiple locations from which they would *not* wish to be able to see a turbine (e.g. their house, or a hill summit with a 'nice view'), the map will then be populated with a cumulative viewshed delineating the areas in which a turbine should not therefore be placed in order to meet the desires of that individual participant. Asking participants to specify locations from where they would not wish to see a turbine is a question to which they can reasonably be expected to be able to answer without further information being provided. This contrasts with more traditional approaches to planning-based PPGIS, which have asked participants to identify locations they view as suitable or unsuitable for a wind turbine, or choosing from already designated areas (e.g. Huck et al. 2014 and Mekonnen & Gorsevski, 2015 respectively). These are complex decisions for which a non-expert cannot be expected to provide an informed response. The approach presented here, however, is able to facilitate the asking of questions that better reflect how participants think they would experience the installation in real life, and also provides them with contextual information about the implications of their decisions (because they can see the viewshed as they add locations to the map, and choose to accept or reject them accordingly).

Within the interface, multiple viewsheds can be added to the same map, resulting in a composite viewshed of all of the locations at which each participant would not wish to see wind turbines, i.e. as a composite of viewsheds for homes, vantage points and other significant locations where seeing the turbine would have a negative impact for that participant (as shown in Figure 2). Over multiple viewsheds and users, an inverse suitability surface is generated, with the areas containing the fewest viewsheds - or none at all - being the most acceptable to the participants.

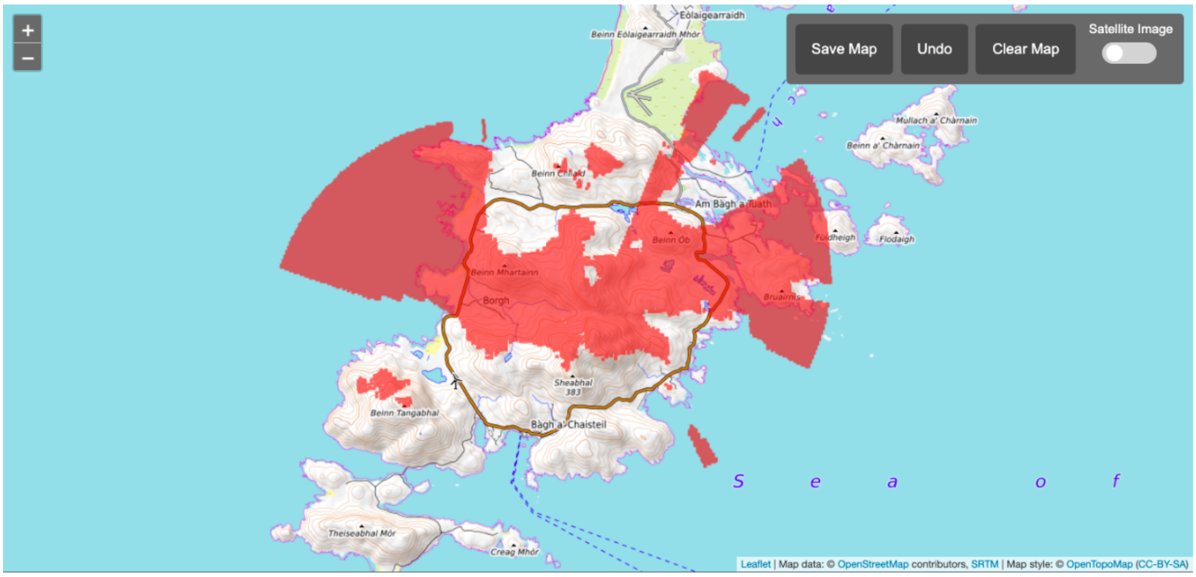

Figure 2 Screenshot of the informed interface using viewsheds, with the red denoting areas considered unacceptable locations

In this way, both the participant and the decision-maker gain a more comprehensive view of the expected visual impact of a wind turbine without increasing the level of effort or technical skill required. The use of the informed interface, together with a reframed question, means that the participant is more empowered to provide meaningful answers. In this case participants are asked the considerably more straightforward task of entering known point locations which denote places to shield from view (e.g. homes) as opposed to being asked to accurately assess point locations where turbines would be invisible from those places. From the perspective of the researcher, the dataset provides a meaningful insight into the participants' views on spatial variations in the visual acceptability of a wind turbine development across the isles; as opposed to a collection of somewhat arbitrary points indicating understandably ill-informed opinions on where a wind turbine should or should not go. From the perspective of the participant, they are able to provide more informed locations in their answers, using the viewshed to understand the implications of their choice, and in doing so better understand the decisions that they are making. As such, the proposed interface is better suited to support the question being asked by giving participants the opportunity to make better-informed decisions, and generating a more robust and useful dataset for the researcher.

2.2.2 Using the A Algorithm as an Informed Interface*

The second interface uses a routing algorithm to generate least-cost paths between nodes (click locations) entered interactively by the participants to indicate where they would like to see new footpaths and pavements on the isles (Hart et al., 1968). The interface using the algorithm has the potential to improve support for participants by removing the need for detailed digitising and for making judgements about what might be a realistic route. In Gottwald et al.'s (2016) research into the usability of PPGIS among older adults, the drawing of a digital line proved to be such a major challenge that the tool was removed completely. The use of an informed interface removes this barrier, enabling participants to just select a start and end location should they wish, with the resultant route still being feasible. Additionally, by masking specific areas in the base-map, the routes are ensured to be physically feasible (avoiding water, steep slopes and other impassable obstacles). Elevation was selected for the underlying dataset as people tend to follow the easiest and most comfortable route when walking, avoiding sharp changes in elevation (Ciolek, 1978).

The use of simple digitised lines in PPGIS can also present challenges to the researcher with regard to aggregating and making sense of the data collected. One example derives from the challenges caused by the varied levels of generalisation that users might employ in representing their route choices. For example if multiple participants are trying to plot the same route between two points, it is unlikely they will draw exactly the same route, even if they intended to do so. One participant might just draw a straight line segment between the two locations, whereas another might draw a far more detailed path. There is then no way of knowing whether they both meant the same route and just had different time available to complete the survey, had different levels of skill, or drew the routes exactly as desired (both being intentionally different). This challenge arises from varying levels of generalisation both between lines that have been digitised by different users, and between multiple lines that have been digitised by the same user (Figure 3).

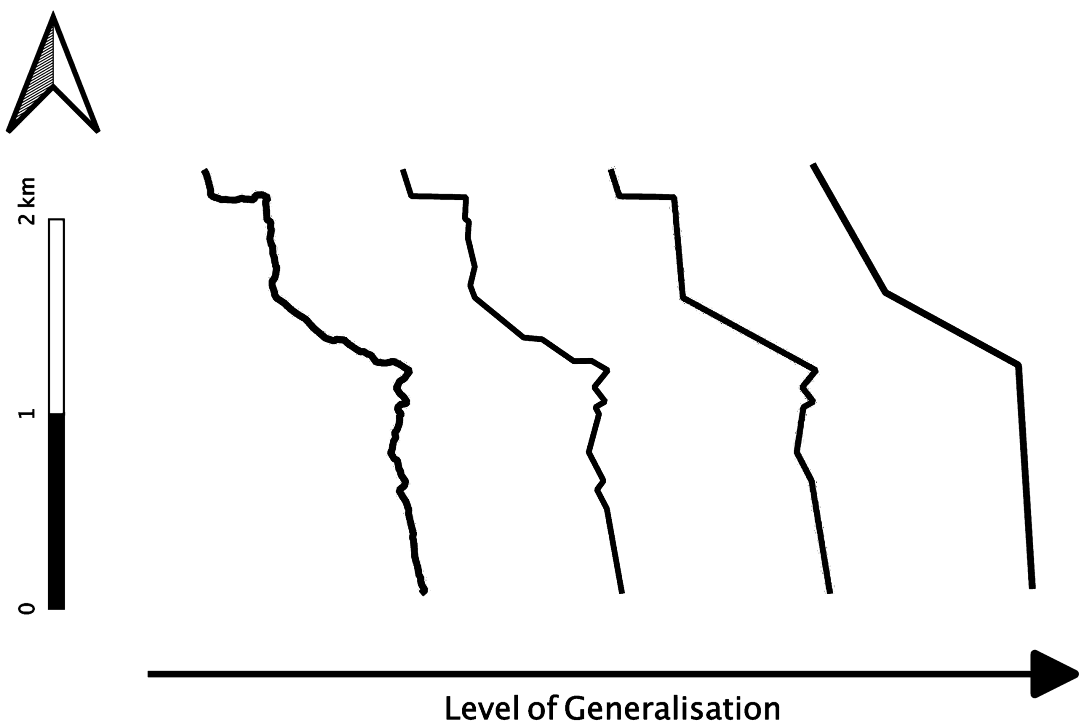

Figure 3 An illustration of a single line digitised with varying levels of generalisation

The A* algorithm is a widely used, heuristic-based method of finding the most efficient route across a network. Here, it is used to address the challenges found in line-based PPGIS by rejecting the traditional line digitisation model in which user-generated nodes are joined with straight edges. Instead it adopts one in which each node is joined to the next with a least-cost path, using an underlying elevation surface (Figure 4). The use of a routing algorithm means that the level of generalisation is standardised (to the spatial resolution of the DEM) across all users and routes. This standardised level of generalisation means that similar inputs will follow the same route, avoiding the need for path bundling, which can draw results away from their intended location (McGee & Dingliana, 2012). This also facilitates analysis using supervaluation, akin to the concept of 'desire lines' used by landscape architects, whereby paths are routed based on the lines on the ground caused by the greatest number of people walking there (Bates, 2017). Accordingly, the resulting paths avoid issues around comparability and representation, whilst permitting the user to maintain full control over the final route. As the interface standardises the level of generalisation in the resulting paths, it takes the onus for digitising quality away from the participant's individual mapping effort or skill and places it instead on the spatial resolution of the dataset. This enables collective knowledge to be presented in a clear and uniform manner to decision-makers. In this instance, the Ordnance Survey Terrain 5 DEM (2019) was resampled to a spatial resolution of 35m and converted into JSON using raster2js (Huck, 2019). This resampling allowed an acceptable compromise between granularity and processing speed, with a near-instantaneous calculation time for each user click.

Figure 4 Screenshot of the A* interface connecting multiple nodes (blue markers) with least-cost paths (red lines) based on elevation

As the algorithm highlights (in real-time) the least-cost path between locations, the user can edit the route by adding a greater or fewer number of nodes, in order to maintain full control over the final path. Accordingly, the influence of the algorithm on the resulting route is therefore inversely proportional to the level of detail described by the participant. Once a path has been drawn and saved on the map, it remains at a lower opacity so that the participant can view all of their submissions simultaneously. The use of the A* interface allows the participant to more effectively represent their ideas, whilst the standardisation of generalisation in the resulting routes makes processing easier for the researcher and the answer to the question being asked more meaningful and readily answered by the participant.

2.3 Data collection

Each of the informed interfaces were tested through both face-to-face workshops with residents of the isles, and remote usability testing with the general public. The details of which are presented below.

2.3.1 Face-to-face workshops

In response to the challenges around transport and energy infrastructure highlighted in the Local Energy Plan, two distinct questions were developed:

1. From which locations would you not wish to be able to see a wind turbine on the isles of Barra and Vatersay?
2. Where would you like new footpaths or pavements to be developed on the isles of Barra and Vatersay?

Responses to these questions were collected at three facilitated workshops across the three main settlements on the isles in November 2019 with a researcher in attendance. Workshops were advertised to residents on a local social media group, in the local paper and with posters at the venues used. A total of 22 participants (c.2.3% of the eligible population on the isles) attended the local, in-person workshops, contributing 107 footpaths and 18 viewsheds. Over half of the participants identified as female (59%), and 73% of the participants were over 51 years of age. Participants were not compensated for their time or incentivised to participate. During these workshops, participants were asked the two spatial questions using the two interfaces and standard demographic data were also collected (including gender and age). Alongside the mapping element of the workshop, participants were required to add free text to explain their contribution and provide feedback on the interface, thus enabling qualitative and quantitative responses to be captured and analysed simultaneously. A workshop diary was kept to record additional data, however all of the quotes used in this paper are taken directly from the online participant comments.

2.3.2 Usability Testing

Two further interfaces using simple points and lines were developed to be used as a comparison to the informed interfaces, with all four hosted alongside two usability questionnaires. The new site and data collection format was beta tested on a group of 9 expert GIS users to ensure the interfaces and instructions were understandable and to locate any bugs, prior to the formal focus groups. Five focus groups were conducted in January 2021 via cloud-based video conferencing. A total of 37 participants attended the online focus groups, of which 51% identified as male, with 25% over the age of 51 years (Figure 5). Overall, 41% of focus group participants had some experience of public consultation and 78% were very familiar or experts with using a computer. Although a large number of participants had achieved an undergraduate degree or higher (81%) the largest proportion of participants did not consider themselves familiar with mapping (57%).

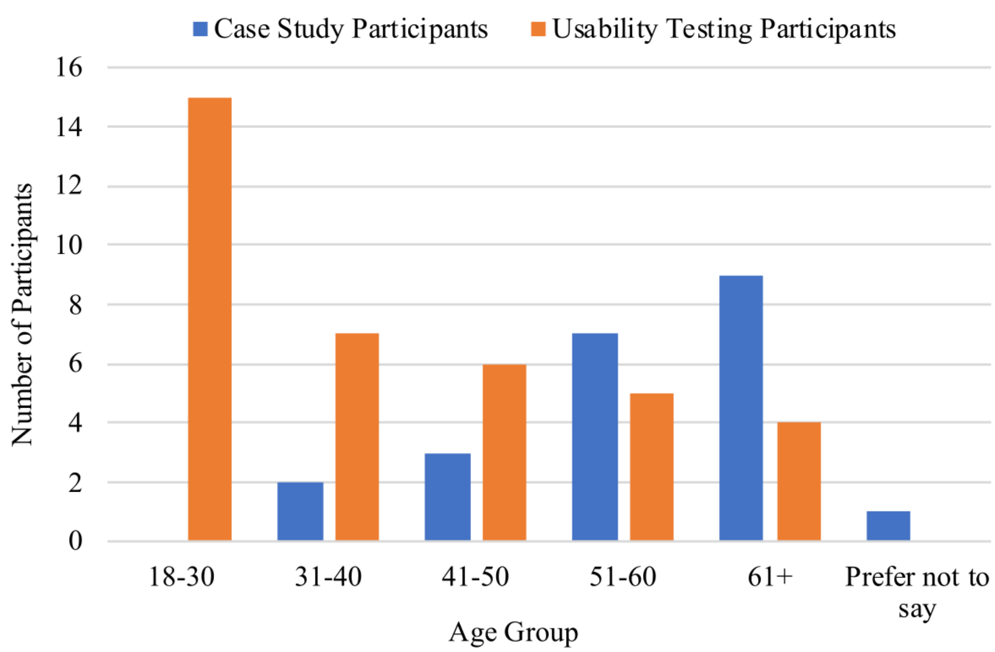

Figure 5 Age category for all participants who took part in the November 2019 workshops and January 2021 usability testing

The focus groups began with a short presentation outlining the research before participants were asked to complete the comparative map survey and subsequent questionnaires, in which the viewshed and A* routing interfaces would be directly compared to simple point and line-based interfaces respectively. For this study, the questions were re-framed to reflect the fact that participants did not live on the isles:

A. Design a new footpath route between Castlebay (green marker) and the airport (purple marker).
B. Imagine you live in one of the hamlets on Barra and enjoy the picturesque views from the inland areas of the isles, from where would you NOT like to see a wind turbine?

The order in which questions A and B were presented to each user were randomised, as was the order in which each interface for the relevant question was presented in order to control for fatigue bias. Each question (A or B) was accompanied by an instructions page, the two interfaces, and a questionnaire in order to gather feedback on their comparative qualities. Once again, participants were offered no incentive of compensation for taking part in the focus group. Standard demographic data were collected, with additional information collected on experience levels, i.e. education level obtained, computer experience, mapping experience and any past experience of participating in public consultations. The questionnaires set out a series of Likert scale questions asking participants to select which interface they preferred across twenty questions regarding mapping, effectiveness and representation, or whether they found them both the same (based on Ballatore et al., 2019). These were followed by four free text questions designed to collect more detailed feedback on the informed interface specifically. Whilst the spatial and textual data from the face-to-face workshops were both analysed, only the questionnaire responses were analysed from the usability study. This is because the mapping tasks in the usability study were hypothetical in nature and designed purely to ensure participants gave sufficient time to exploring the interfaces before assessing their usability in the questionnaires.

3.0 Results

This section presents the results from the case study workshop with local residents and from the separate usability study focus groups. The results regarding the viewshed interface are analysed first, followed by the results from the A* interface.

3.1 Viewshed Results: Case Study

The data collected using the viewshed interface are presented in Figure 6, with the darker areas indicating where a greater number of viewsheds are overlaid. The darker areas indicate where most participants would prefer not to see a turbine from the perspective of minimising visual intrusion at key points of interest.

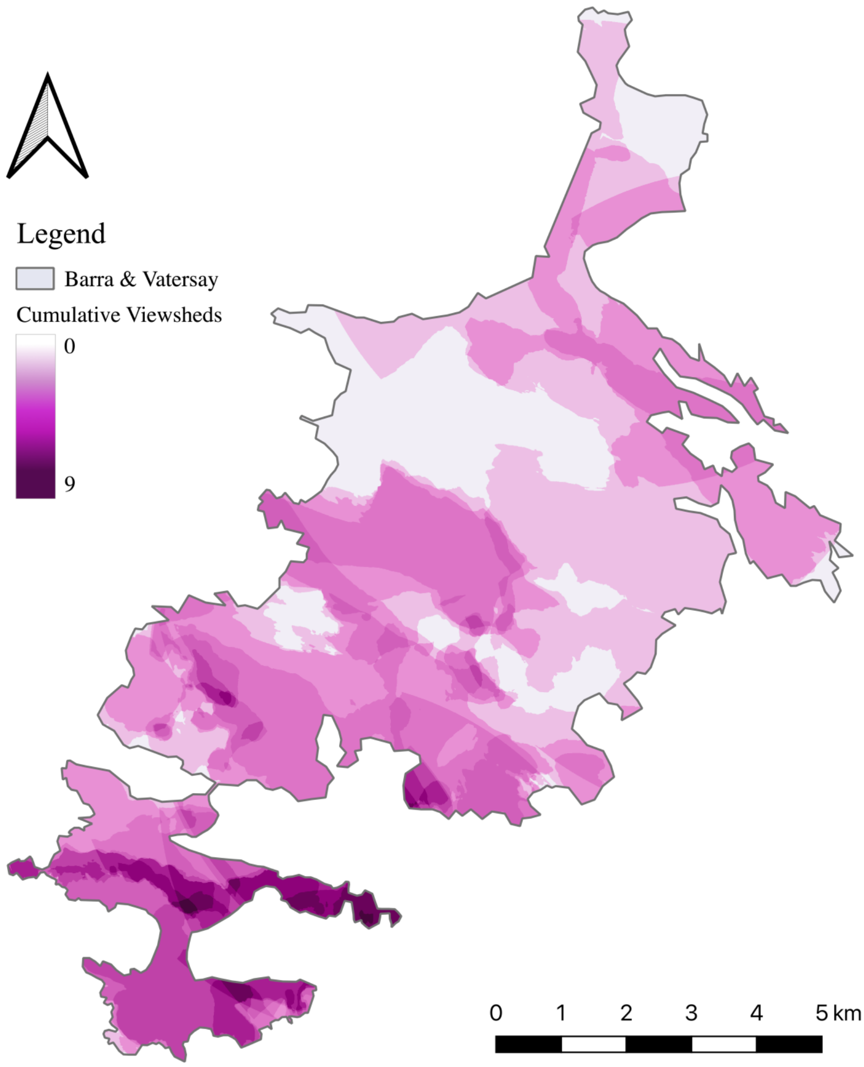

Figure 6 Cumulative viewshed formed from the 18 datasets collected from the residents of Barra and Vatersay

It is clear from Figure 6 that there was a strong preference for avoiding areas towards the south of the isles, predominantly on Vatersay and the more residential areas located towards the south of Barra. It is notable that locations in which a viewshed is absent (the grey areas in Figure 6) do not necessarily indicate areas where residents would explicitly *like* to see a turbine, but instead show locations from where residents are more ambivalent about turbines being visible. This knowledge can then enable decision-makers to identify areas that should cause least conflict in the planning process.

Due to the small size of the isles and known limitations of the current energy infrastructure, local residents have a relatively high level of knowledge of local electrical systems. This knowledge resulted in some participants adding further details on why certain areas were unsuitable, as opposed to reasons purely related to visibility as indicated in the qualitative feedback:

"Not got the infrastructure for a turbine on Vatersay." [Female, 51-60]

The viewshed interface was designed to identify where participants would *not* wish to see a turbine, based on the dominant public view given in the literature (i.e. that wind turbine visibility is undesirable, e.g. Wróżyński et al., 2016). However, the prevailing view on the isles appeared to be that the benefits of wind energy outweigh any perceived negative visual impact. Residents were therefore overwhelmingly in favour of having turbines regardless of location, and accordingly, many participants submitted no viewsheds whatsoever.

Whilst a number of participants did not contribute viewshed data, they still tested the interface and provided feedback. Participants found the tool easy to use, providing feedback such as:

"Very easy to use if you follow instructions." [Female, 31-40]

Participants also commented on specific benefits of the informed interface. One participant, for example, initially selected a high peak as a location from which they would not wish to see a turbine, however upon seeing that this would mean a significant area of the island would also be blocked out, changed their mind:

"I wouldn't actually mind being able to see the turbine if it meant we could make more energy on the island, I didn't expect it to be seen for so far though". [Male, 61+]

This example demonstrates how the informed interface can give participants a better understanding of the decisions that they are making. By being able to see the immediate impact of their choice and having the capacity to reassess based on the information provided by the viewshed, the participant has been able to present a more balanced and informed opinion. Additionally, it reduces the spatial accuracy problem associated with point-based PPGIS, as the viewshed represents the combined visual impact on the area rather than simply the pin-point location of the wind turbine.

3.2 Viewshed Results: Usability Testing

The results of the comparative usability test between the viewshed and point interfaces are presented in Figure 7. For the majority of questions relating to the functionality of the underlying web map, the two interfaces were found to be "*both the same*", as would be expected (as both were based on the same 'Leaflet' web map). However, 97% of participants found the informed (viewshed) interface better for decision making. The informed interface helped 84% of participants decide turbine locations and 92% agreed that it helped them understand more about locating a wind turbine more generally.

QUESTION	More so the viewshed tool	A little more the viewshed tool	They were both the same	A little more the points tool	More so the points tool	N/A
It is easy to zoom in and out on the map	0	0	32	2	1	2
It is easy to move to a new location on the map	2	0	28	5	1	1
I can add new features to the map easily	4	3	19	5	6	0
When I add something to the map, it takes effect immediately	0	0	25	6	6	0
Mistakes can be easily undone	0	0	28	6	2	1
I feel confident using the mapping tool	5	4	18	7	3	0
The mapping tool enables me to effectively achieve the set tasks	10	14	11	0	2	0
The mapping tool is reliable	4	3	23	4	2	1
It is easy to remember how to perform tasks	2	1	30	3	1	0
I feel confident exploring the mapping tool by trial and error	5	4	26	0	2	0
It is easy to understand what I have added to the map	7	4	14	5	7	0
It was easy to get my views across by using the mapping tool	14	6	13	2	2	0
The mapping tool helped me decide my answer to the question	26	5	5	0	1	0
I think this mapping tool is useful for informing decisions about locating a turbine	30	6	0	0	1	0
I understand more about locating a wind turbine from using this mapping tool	27	7	1	0	1	1

Figure 7 Participant responses to each question from part 1 of the usability testing questionnaire regarding the two wind turbine locating interfaces with bright blue squares indicating the most popular answers and red indicating the least

The free text questions gave participants the opportunity to add reasons for their answers, such as:

"Viewshed gives you a much better idea than guesswork about what is visible from where. Points give basically no info except remembering where I clicked." [Male, 18-30]

"I think the Viewshed tool made it easier to inform my mapping decisions as it allows me to see the context in which I was making a decision." [Male, 18-30]

Despite the positive reactions to the informed viewshed interface, some participants reported finding it more complicated:

"[The viewshed tool was] More complicated for the initial user but probably easier for a planner. And easier to show a group the collective implications of a turbine location, not just individual points." [Female, 18-30]

In contrast to the informed viewshed interface, participants reported finding the point-based tool ineffective by comparison. For example, two participants, neither of whom had any mapping experience, stated:

"The points tool was rather hard to use as I felt like I could just put points anywhere and everywhere without really understanding where they were going." [Male, 51-60]

"[The viewshed tool was] Easy to use. Good way to gather local opinions and work out any utterly unacceptable locations." [Female, 51-60]

There were no discernible differences in how participants found the usability of the informed interface based on their age, gender, mapping experience or computer experience.

3.3 A*Results: Case Study

Figure 8 presents the complete 'raw' dataset produced using the A* interface alongside the processed data demonstrating the potential network of footpaths and pavements. In Figure 8a the darker lines indicate where a greater number of participants desired the same paths to be located. These include areas that might be expected, such as the three main settlements, but also the centre of Barra and a particularly picturesque beach along the North coast.

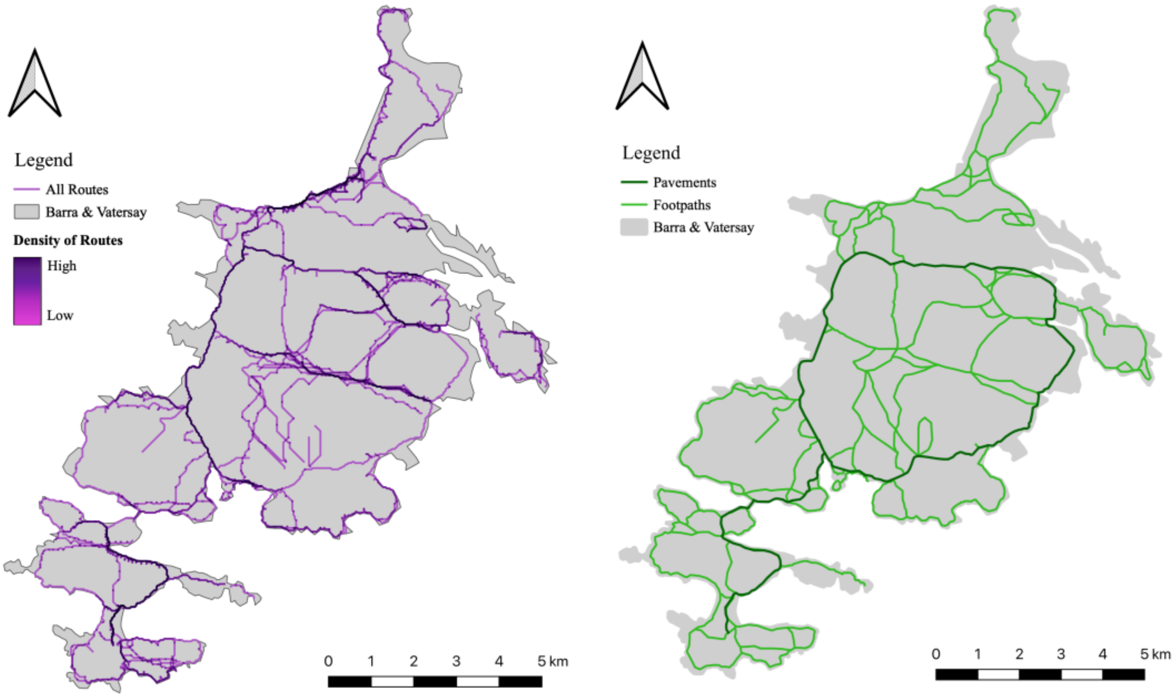

Figure 8 107 potential footpaths (totalling 541km) designed by residents of the isles of Barra and Vatersay, showing (a) the raw resulting paths and (b) the processed dataset of potential footpath and pavement networks

Again, qualitative feedback was obtained from the interface in addition to the routes themselves, with each new path requiring some comment or explanation in order to be saved to the database. The responses predominantly fell into two categories. Firstly, routes that participants wished to be made more accessible for their scenic value through the use of footpaths; and secondly an increase in pavements along the road for the purpose of safety and accessibility, for example:

"This is a traditional walk where people would cross the cliff from Claid to Aoligarry passing Dun Chliff and if so wish can carry on across Traigh Eais to Dun Scurrical." [Male, 61+]

"[Current road infrastructure is] busy, narrow, large vehicles, unsafe for anyone walking." [Female, 51-60]

Whilst Figure 8a shows the initial output for the decision-maker, it is clear the interface also met the requirements of the participants in answering the question, as they validated the claim that the interface was both usable and useful in the qualitative feedback, adding comments including:

"Like that it finds you the easiest route, very neat." [Female, 61+]

Based upon the raw geometric dataset and qualitative data provided by the online comments, the second map (Figure 8b) was produced illustrating a proposed path network, in which duplicates have been removed, loops have been closed, and classifications have been added to distinguish proposed pavements (i.e. concrete, raised and alongside a road) and footpaths. This proposed network comprises an increase of approximately 400% to the current network length, comprising the addition of 192km of new footpaths and 43km of new pavements, which cover approximately 40% of roads on the isles (including all primary roads).

The abundance of responses from even a small number of participants suggests that the interface was easy to use and effective for the task in hand, enabling those with no experience of route-planning to collectively create a new network of footpaths and pavements. For the decision-maker there are clear, realistic routes presented by residents from which new plans can be drawn without complications around generalisation, casting any doubt as to the reliability of the data.

3.4 A* Results: Usability Testing

As with the turbine example, participants largely preferred the informed (A*) interface for footpath routing (Figure 9; bright blue). However, in this case there was some variation in the extent of that preference, i.e. spread over a range of adjacent categories (light blue).

QUESTION	More so the A* tool	A little more the A* tool	They were both the same	A little more the lines tool	More so the lines tool	N/A
It is easy to zoom in and out on the map	0	0	35	0	0	2
It is easy to move to a new location on the map	0	5	30	1	0	1
I can add new features to the map easily	6	5	16	9	0	1
When I add something to the map, it takes effect immediately	1	4	28	4	0	0
Mistakes can be easily undone	0	0	32	4	1	0
I feel confident using the mapping tool	3	8	14	10	2	0
The mapping tool enables me to effectively achieve the set tasks	9	12	9	5	2	0
The mapping tool is reliable	6	7	20	2	2	0
It is easy to remember how to perform tasks	1	0	34	1	0	1
I feel confident exploring the mapping tool by trial and error	4	2	29	1	0	1
It is easy to understand what I have added to the map	8	8	18	1	2	0
It was easy to get my views across by using the mapping tool	9	10	8	8	1	1
The mapping tool helped me decide my answer to the question	14	13	8	1	0	1
I think this mapping tool is useful for informing decisions about footpath routing	19	11	5	1	0	1
I understand more about footpath routing from using this mapping tool	13	13	9	1	0	1

Figure 9 Participant responses to each question from part 1 of the usability testing questionnaire regarding the two footpath routing interfaces with bright blue squares indicating the most popular answers and red indicating the least

Although not found as straightforward to use as the viewshed interface, most participants felt the A* interface enabled them to achieve the set task effectively. There is a clear preference towards the informed interface when it comes to questions regarding decision-making with 81% identifying it as the most useful. For example 73% of participants found it helped them decide footpath routes; and 70% found they learned more about footpath routing from the A* than the line-based interface. Participants who preferred the informed (A*) interface commented:

"I found the A tool much easier as it allows you to see which route would be the least difficult and gives you a better sense of the way the land lies." [Female, 18-30]*

"A made life a lot easier rather than clicking loads of little lines" [Male, 51-60]*

Whilst over half of participants found the A* interface made their mapping decisions easier, this was not unanimous. Some preferred having control over the route taken instead of being drawn towards the easiest route based on elevation. Although feedback was more mixed, interface preference did not seem to be explained by age or experience. For example both of the below quotes are from two different 18-30 year old digital mapping experts:

"Made it more complicated. When I was trying to draw a path to follow contours round hills the A tool kept making me 'walk' slightly down then uphill again. This made my path look frustratingly inefficient." [Female, 18-30]*

"Definitely a positive to inform mapping decisions, it allows the user to see the wider context of where they are placing their footpaths, and it's quicker to map rather than mapping lots of individual points." [Male, 18-30]

Suggestions for developing the tool further included making the route draggable, giving the user a preview of the route to their mouse location before they click, and allowing the user to influence the underlying algorithm by adjusting a setting to make routes either 'faster' or 'easier', for example. It would appear that many of the difficulties found with using the informed A* interface came from the latter suggestion, in that participants did not feel that elevation was the most appropriate factor:

"Maybe add more control to the least cost bit, so it could be based on speed or distance not just the lay of the land" [Female, 51-60]

"Being able to drag the path to change slightly the path without changing the waypoints." [Male, 31-40]

Based on both the results from the multiple choice and free text questions, the informed interface has again proved more effective in supporting the decision-making process than the more conventional (lines) interface.

4.0 Discussion

This research has highlighted how the use of informed interfaces can produce more realistic and usable datasets in GIS-based spatial analysis, planning, knowledge production and decision-making. The analysis of the two case studies in the Outer Hebrides, UK, combined with the results from the usability study, indicate that the use of informed interfaces can benefit both the researcher and the participants. Our viewshed-based interface was shown to be more effective for guiding participants' decisions about where turbine views would not be desirable compared to an equivalent point-based interface. In turn, onward users of the dataset could be confident about obtaining a more considered, robust and fit-for-purpose dataset, i.e. to meet public consultation goals. Similarly, our A* informed routing interface was generally preferred over digitising paths with simple lines. By using least-cost paths between nodes as opposed to straight line segments, the skill-based barriers found by Gottwald et al., (2016) are reduced, placing the onus for data quality on the algorithm and background dataset rather than the assumed ability of the participant.

The uncritical use of spatial primitives has been widely criticised in the literature (Brown & Kyttä, 2018; Robinson et al., 2017; Huck et al., 2014 & Goodchild, 2011). Both of our 'informed interfaces' were therefore developed to support participants in answering the two specific questions posed, instead of allowing *'the Hammer of Participatory GIS'* to dictate the questions being asked (Huck et al., 2018). The informed interfaces empowered participants to feel more confident in the datasets they produced and their usefulness in the decision-making process. This distinction between the usefulness of informed interfaces compared to interfaces using spatial primitives became particularly apparent in the direct comparison in the usability studies. In asking appropriate questions coupled with the support of an informed interface, participants can be reasonably expected to answer complex spatial questions without prior technical knowledge on the subject. Such technical developments may provide an important link in the 'Chain of Trust' (Dwyer & Bidwell, 2019) through facilitating more meaningful community engagement processes and therefore helping to overcome some of the barriers suggested by Firestone et al. (2020).

Whilst still deemed most useful in the decision-making process, some participants did find the informed interfaces more complicated to use during the usability testing. This contrasted with the in-person workshops (which had the benefit of a researcher being present), during which no participants reported this same issue. Whilst the difference in age demographic of those who attended the in-person workshop and online focus group should be noted (with participants on the isles being notably older than those who attended online), there were no apparent connections between the degree to which participants found the interfaces more complicated and their demographic or mapping experience. This suggests the use of a more informed interface does not require additional training or effort from those who participate given a base-level of computer literacy. Indeed, much of the feedback for the A* interface, in fact, suggested that increasing the complexity would improve the interface. For example by displaying a ‘preview’ of the route as the participant moves the cursor around the map, removing the need to edit and redraw points; or by increasing the number of variables which control the underlying algorithm such as distance or speed so that participants can select their priority, giving further feedback to the decision-maker. As such, the balance between an interface being more complicated and more useful is difficult to define and will vary between participants and situations, so it is important for the wider social context of the research to be considered when designing the most suitable interface.

The engagement process is also important. Although instructions provided were similar in content and a facilitator was present, online focus group participants seemed reluctant to ask questions or seek assistance, preferring to leave any feedback about the tools in the online questionnaire. Conversely during the in-person workshops there was much greater interaction both between participants, and participants and the facilitator. This created an atmosphere of trust in which participants were more comfortable asking questions and seeking assistance to use or better understand the tool. This is despite the participants being predominantly older adults, which has presented challenges in similar PPGIS research (e.g. Gottwald et al., 2016).

The results from the in-person workshop data collection also demonstrate the types of additional insight that can be revealed by using informed interfaces, such as the thought process of participants changing their minds based on the immediate feedback from the viewshed interface. Equally, participants trusted the A* algorithm to take them along the easiest route. The algorithm was particularly beneficial for non-residents unfamiliar with the local terrain, but it helped to improve the data provided by all participants (whether local or not). The datasets obtained from the use of informed interfaces are intrinsically richer, as participants are presented with feedback on their decision in real-time, and then given the option to adjust or accept it accordingly.

The results from both informed interfaces demonstrated in this paper are overwhelmingly positive with regard to supporting participants in providing their answers and in turn giving the researcher more confidence in their validity of the resulting dataset without adding bias from intermediary steps in analysis. Despite this, there are certain limitations to the approach, such as the additional skill or funding required to design and develop the appropriate tools, as well as supporting participants in their use of the resulting interfaces. However, the two examples demonstrated in this paper give an indication of the potential of informed interfaces for empowering and engaging participants in consultative exercises. The interfaces provide a foundation for use in other visual impact or routing decisions, but are not limited to these areas.

5.0 Conclusion

This research sought to assess how PPGIS interfaces might be designed in a way that better supports the researcher (in the question they are asking) as well as the participant (in the answers they are giving). Through using conventional GIS tools as spatial units in two purpose-built web-based interfaces we demonstrate how participants can better answer the questions being asked and consequently produce richer, more veracious datasets. Although our examples are most directly relevant to visual impact and routing exercises, the fundamental principles apply more widely. For example, other applications in the wind industry could consider the integration of other conventional GIS tools into interfaces for PPGIS, for example as proxies for 'ice throw' or 'shadow flicker', whilst other forms of industrial development might include pollution plume dispersal or noise propagation. The advantages of informed interfaces have been evidenced by both rigorous usability testing as well as being demonstrated through a successful, in-person case study in the Outer Hebrides, UK. During each data collection stage, participants found the informed interfaces beneficial in their decision-making process, and enabled the production of datasets that were straight-forward to interpret for the researcher. The use of informed interfaces facilitated the collection of additional insights into local opinion that would not have been possible with more traditional interfaces. Additionally, participants were given an increased understanding of the question at hand with no additional effort or skill required.

We suggest that informed interfaces provide the foundation for a step change in the development of PPGIS, moving away from the traditional approaches that are known to be inadequate but remain largely unaddressed (Radil & Anderson, 2019; Brown & Kyttä, 2018; Huck et al., 2014). Informed interfaces hold the potential to improve and diversify spatial data representation, and therefore decision-makers' understanding of participants' views. Informed interfaces can also simultaneously increase the ability of participants to express their opinions, thus encouraging further participation and enhancing trust in participatory processes. Accordingly, the continued development of informed interfaces can both increase democratisation in the decision-making process and also progress the field of PPGIS by improving the potential veracity of the data collected. This research has demonstrated the potential in moving beyond the status quo, providing an indication of just what might be achieved by abandoning the '*Hammer of Participatory GIS*' once and for all.

References

Anderson, C., Beazley, K., & Boxall, J. (2009). Lessons for PPGIS from the application of a decision-support tool in the Nova Forest Alliance of Nova Scotia, Canada. *Journal of environmental management*, *90*(6), 2081-2089.

Ballatore, A., McClintock, W., Goldberg, G., & Kuhn, W. (2019). Towards a usability scale for participatory GIS. International Conference on Geographic Information Science (pp. 327-348). Springer, Cham.

Bates, C. (2017). Desire lines: walking in Woolwich. Walking through social research (pp. 55-69). Routledge.

Blackstock, K., Kirk, E., Chang, Y. C., & Davidson, G. (2006). Public Participation and Consultation in SEPA Regulatory Regimes (R50063PUR) Final Report. *Macaulay Institute*.

Brown, G., & Kyttä, M. (2018). Key issues and priorities in participatory mapping: Toward integration or increased specialization?. *Applied Geography*, *95*, 1-8.

Brown, G. (2017). A review of sampling effects and response bias in internet participatory mapping (PPGIS/PGIS/VGI). Transactions in GIS, 21(1), 39-56.

Brown, G. (2012). Public Participation GIS (PPGIS) for regional and environmental planning: Reflections on a decade of empirical research. *Journal of Urban and Regional Information Systems Association*, *25*(2), 7-18.

Burnett, C. M. (2020). Incorporating the participatory process in the design of geospatial support tools: Lessons learned from SeaSketch. Environmental Modelling & Software, 127, 104678.

Ciolek, M. T. (1978). Spatial behavior in pedestrian areas. Ekistics, 120-122.

Comhairle nan Eilean Siar, (2011) [Online]. 2011 Census Statistics Barra & Vatersay. https://www.cne-siar.gov.uk/media/5557/barra-and-vatersay-profile.pdf pg1-13 [Accessed 22/01/2020].

Craig, W. J., & Elwood, S. A. (1998). How and why community groups use maps and geographic information. *Cartography and Geographic Information Systems*, *25*(2), 95-104.

Dwyer, J., & Bidwell, D. (2019). Chains of trust: Energy justice, public engagement, and the first offshore wind farm in the United States. Energy Research & Social Science, 47, 166-176.

Elwood, S. (2006). Critical issues in participatory GIS: Deconstructions, reconstructions, and new research directions. *Transactions in GIS*, *10*(5), 693-708.

Evans, A. J. & Waters, T. (2007). Mapping Vernacular Geography: Web-based GIS tools for capturing "fuzzy" or "vague" entities. International Journal of Technology, Policy and Management, 7 (2), pp.1468-4322.

Firestone, J., Hirt, C., Bidwell, D., Gardner, M., & Dwyer, J. (2020). Faring well in offshore wind power siting? Trust, engagement and process fairness in the United States. Energy Research & Social Science, 62, 101393.

Godwin, A. and Stasko, J, T. (2017). Nodes, Paths, and Edges: Using Mental Maps to Augment Crime Data Analysis in Urban Spaces.

Goodchild, M. F. (2011). Formalizing place in geographic information systems. Communities, Neighborhoods, and Health 21-33. Springer New York.

Gottwald, S., Laatikainen, T. E., & Kyttä, M. (2016). Exploring the usability of PPGIS among older adults: Challenges and opportunities. *International Journal of Geographical Information Science*, *30*(12), 2321-2338.

Haklay, M. E. (2016). Why is participation inequality important?. Ubiquity Press.

Harris, T. M., Weiner, D., Warner, T. A., & Levin, R. (1995). Pursuing social goals through participatory geographic information systems. *Ground truth: the social implications of geographic information systems*, 196-222.

Hart, P. E., Nilsson, N. J., & Raphael, B. (1968). A formal basis for the heuristic determination of minimum cost paths. IEEE transactions on Systems Science and Cybernetics, 4(2), 100-107.

Huck, J., (2019) Raster2js. [Online] Available at https://github.com/jonnyhuck/raster-js . [Accessed 29.04.20]

Huck, J., Whyatt, J. D., Dixon, J., Sturgeon, B., Hocking, B., Davies, G., Jarman, N. & Bryan, D. (2018). Exploring Segregation and Sharing in Belfast: a PGIS approach. *Annals of the Association of American Geographers*.

Huck, J.J., Whyatt, J.D. and Coulton, P., (2014). Spraycan: A PPGIS for capturing imprecise notions of place. *Applied Geography*, *55*, pp.229-237.

Kar, B., Sieber, R., Haklay, M., & Ghose, R. (2016). Public participation GIS and participatory GIS in the era of GeoWeb. *The Cartographic Journal*, *53*(4), 296-299.

Keenan, P. B., & Jankowski, P. (2019). Spatial decision support systems: Three decades on. Decision Support Systems, 116, 64-76.

Kaučič, B., & Zalik, B. (2002). Comparison of viewshed algorithms on regular spaced points. Proceedings of the 18th spring conference on Computer graphics (pp. 177-183).

Local Energy Scotland, (2018). [Online]]Local energy plan for Barra and Vatersay. https://www.localenergy.scot/media/110393/barravatersay-lep-july-2018-final.pdf [Accessed 12.12.18].

Maslow, A. H. (1966). The psychology of science: A reconnaissance. New York: Harper & Row.

McCall, M. K., & Dunn, C. E. (2012). Geo-information tools for participatory spatial planning: Fulfilling the criteria for 'good' governance?. *Geoforum*, *43*(1), 81-94.

McGee, F., & Dingliana, J. (2012). An empirical study on the impact of edge bundling on user comprehension of graphs. Proceedings of the International Working Conference on Advanced Visual Interfaces (pp. 620-627).

Mekonnen, A. D., & Gorsevski, P. V. (2015). A web-based participatory GIS (PGIS) for offshore wind farm suitability within Lake Erie, Ohio. Renewable and Sustainable Energy Reviews, 41, 162-177.

Obermeyer, N. J. (1995). The hidden GIS technocracy. *Cartography and Geographic Information Systems*, *22*(1), 78-83

OS Terrain 5 [DTM] Scale 1:10,000 Updated January 2019, Ordnance Survey, GB. [Online] Available at https://www.ordnancesurvey.co.uk/business-government/products/terrain-5 Using: EDINA Digimap Service. [Downloaded 01.09.19]

Radil, S. M., & Anderson, M. B. (2019). Rethinking PGIS: Participatory or (post) political GIS?. Progress in Human Geography, 43(2), 195-213.

Radil, S. M., & Jiao, J. (2016). Public participatory GIS and the geography of inclusion. *The Professional Geographer*, *68*(2), 202-210.

Robinson, J. A., Block, D., & Rees, A. (2017). Community geography: Addressing barriers in public participation GIS. *The Cartographic Journal*, *54*(1), 5-13.

Rundstrom, R. A. (1995). GIS, indigenous peoples, and epistemological diversity. *Cartography and geographic information systems*, *22*(1), 45-57.

Sawicki, D. S., & Craig, W. J. (1996). The democratization of data: Bridging the gap for community groups. *Journal of the American Planning Association*, *62*(4), 512-523.

Weiner, D., Warner, T. A., Harris, T. M., & Levin, R. M. (1995). Apartheid representations in a digital landscape: GIS, remote sensing and local knowledge in Kiepersol, South Africa. *Cartography and Geographic Information Systems*, *22*(1), 30-44.

Wróżyński, R., Sojka, M., & Pyszny, K. (2016). The application of GIS and 3D graphic software to visual impact assessment of wind turbines. Renewable Energy, 96, 625-635.