Twist, Shift, or Stack?
Usability Analysis of Geospatial Interactions on a Tangible Tabletop

Catherine Emma Jones[1] and Valérie Maquil[2]
[1]*CVCE, Sanem, Luxembourg*
[2]*Luxembourg Institute of Science and Technology (LIST), Esch-sur-Alzette, Luxembourg*
catherine.jones@cvce.eu, valerie.maquil@list.lu

Keywords: Tangible User Interface, Cartography, Geospatial Information, Usability, Qualitative Study, User Study, Tangible Interfaces, TUI, Mapping, User Centred Design, Interactive Tabletops.

Abstract: Maps as learning, exploration and analysis tools have great power to aid understanding of complex phenomena and to instigate and engage discussion. To date, web-mapping platforms have largely contributed to the public availability of geospatial information. Tangible user interfaces (TUI) as an emerging class of interfaces, have a clear potential for improving collaboration around geospatial data, as well as increase geospatial understanding, but to realise this potential they must be easy and straightforward to learn and use. To date, there is a lack of research centred on human interactions with geospatial tangible applications. This paper reports on the results of an initial qualitative usability study carried with novice users on a geospatial tangible table. It discusses aspects related to cartographic elements, object manipulations, and offline interactions, to create an initial set of usability guidelines for geo-tangible tables.

1 INTRODUCTION

Maps as learning, exploration and analysis tools have power, aiding understanding of complex phenomena and to instigate and engage discussion for both novice and experts. If we are able to integrate maps within technology that facilitates discussion and collaboration there is even more potential for knowledge building and cross-disciplinary engagement.

Technological advances in the last decade transformed maps and geographic information (GI), bringing new technologies and methods for acquiring, processing and sharing GI (Goodchild, 2010). Most markedly, the now ubiquitous web-mapping applications based on the online "slippy map" API's (Bing Maps, Google Maps, OpenStreetMap) (Parsons 2013) have largely contributed to the public availability of geospatial information on web sites, services, and apps. These user friendly interfaces prove that simple intuitive interfaces adhering to usability principals (Jones and Weber, 2012) were a real breakthrough for widening access to GI. Such interfaces are one of the primary GI interaction tools for the lay person and have been widely adopted by National Mapping Agencies. This revolutionises in how GI is created and consumed, and presents new opportunities for design research. Turning from the over reliance on sophisticated and often complex interactions which alienate users and impairs knowledge construction and moving towards new geo- interfaces with users at the core, adding value by being fun and engaging (Fuhrmann, 2005; Hakley and Tobòn, 2003; Jones et al., 2009).

Tangible user interfaces (TUI) as an emerging class of interfaces (Ishii 1997), have a clear potential for improving collaboration with geospatial data. TUIs offer large representations that encourage collaborative working amalgamated with intuitive and tactile user interactions (MacEachren et al., 2005). The inherent knowledge of the physical objects, drawing upon familiar concepts of the physical world, helps to provide users with a feeling of intuitive directness (Djajadiningrat et al. 2004). TUIs are natural supports for collaboration; they enhance group productivity, by bringing users around a shared discussion space and supporting them in coordinating their actions using the physical objects (Hornecker and Buur, 2006). Moreover, applications available via tangible devices are inherently spatial, both literally and metaphorically (Marshall 2007).

These benefits have led to the implementation of a variety of geospatial TUI research scenarios, such

Jones C. and Maquil V..
Twist, Shift, or Stack? - Usability Analysis of Geospatial Interactions on a Tangible Tabletop.
DOI: 10.5220/0005377601700177
In *Proceedings of the 1st International Conference on Geographical Information Systems Theory, Applications and Management* (GISTAM-2015), pages 170-177
ISBN: 978-989-758-099-4

as urban planning (Maquil et al. 2007) or disaster management (MacEachren et al., 2005). TUIs have potential as novel collaborative learning environments for mapping applications but to realise this potential they must be straightforward to learn and use. Their functionality must be memorable and peripheral so users focus on knowledge construction.

There are relatively few usability studies related to mapping on tabletop interfaces. Research focuses on technical implementations at the expense of user research. The few existing studies have only marginally incorporated user centric approaches and testing, through use of questionnaires (Nagel et al., 2014) and a task-based approach (Scott et al..2010).

The study presented in this paper is novel in two aspects. First, it focusses on cartographic interactions on a tabletop. Second, it investigates the use of tangible objects for that purpose: our cartographic interactions are implemented by means of manipulations with physical objects. We explore the relationship between the user and the spatial interactions to determine the most intuitive and effective use of tangibles for geographic interactions such as zoom, pan and working with layers and their legends. The aim is to describe the results of an initial qualitative usability study to provide insights on how novice users interact with geospatial data through a tangible table.

2 ABOUT THE GEOSPATIAL TANGIBLE TABLE

The geospatial tangible table (Maquil et al., 2015) allows users to explore and analyse digital maps projected onto a tabletop. Interactions with the map are carried out using physical objects that are placed, shifted, and twisted on the tabletop. The rounded tabletop is sized 150x105cm, with an interactive surface of 120x75cm (see Figure 1).

Figure 1: Digital maps on the tangible table.

The system was developed in 2013-14 in an iterative approach. The digital maps were created in the context of sustainable freight transport in North Western Europe, from the Interreg IVb Weastflows project. The aim was to develop a new technological solution for supporting face-to-face collaboration of multiple stakeholders in order to identify future opportunities for sustainable and more efficient supply chains, an inherently geographical problem.

In multiple iterations we designed a series of basic geospatial interactions, that we progressively extended by more advanced interactions. While the system with all the interactions, as well as the software architecture has been reported elsewhere (Maquil et al., 2015), the basic spatial interactions are described below (see Figure 2):

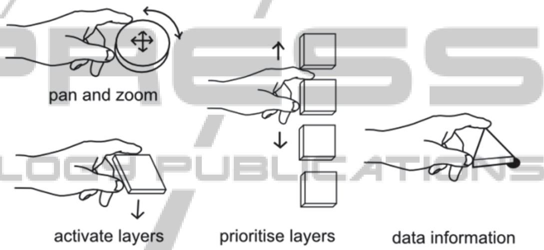

Figure 2: Basic cartographic interactions implemented with tangible objects.

Panning: By dragging the circular object across the table, the map view is moved in the same direction. When lifted and dropped at another location, no panning is performed.

Zooming: The same circular object is rotated to the right to zoom in and to the left to zoom out.

Activate Layers: A set of square objects represent different geographical data layers. To activate the layer, the object is placed anywhere on the map. The legend is then visualized in a box displayed on the right of the placed object. When the object is removed from the table, the layer is deactivated.

Prioritise Layers: The vertical position of each layer object determines the order the layers are drawn. Layer objects nearest the bottom of the table are drawn first, while layers lying at the top are drawn last – hence may occlude any layers underneath.

Data Information: A triangular object shows a black dot at one of its corners. This dot can be placed on any graphical element. When the object remains in a same position for 500ms, a description is opened next to the graphical element, removing the object closes the window.

3 EXPERIMENT METHODOLOGY

A qualitative approach was used to collect user interaction data describing an enriched view of the participants' perspective of the tangible geospatial interface. The study combined participant observation (video and observer) together with the Think Aloud protocol (ISO/TR 16982:2002). The experiment had 6 tasks, taking about 30 minutes. The tasks were designed around the basic cartographic interactions patterns a new user would be expected to learn (zoom, pan, adding layers, rearranging layers, working with legends and interpreting thematic maps). Complexity of tasks increased as users completed the work sheet. The tasks had the following themes:

- Locating Luxembourg and its greater region (zoom, pan & adding data layer).
- Adding multiple data layers
- Working with different information and prioritising it (zoom, pan, switching data on and off, rearranging layers to create visual hierarchy)
- Interpreting meaning from the map (using legends, working with the info tool)
- Working with thematic maps and different layers (zoom, pan, working with layers and legends).

A pilot experiment was conducted to test the protocol for consistency, errors and timeliness. Prior to commencing, participants were provided with an information sheet outlining what they would be doing and why, given the opportunity to ask questions, informed about collected data and how it would be used, asked to sign a consent form and complete a brief general IT questionnaire to gauge computer literacy and experience with GIS. An experiment room was set up, comprising of the TUI, objects, a camera and seating for observers (see Figure 3). For each experiment the objects were set in the same place and order. Participants were only provided with the task sheet.

Eight participants (N=8) were recruited. There were two pre-requisites: a) participants must never have used a TUI before and b) they must be comfortable Thinking Aloud in English. An equal mix of genders participated (4 females and 4 males) with an aged between 20 and 45. All were familiar with online mapping websites such as Google Maps (3 frequent and 5 occasional users).

No testers routinely used desktop GIS although 2 participants have used it: 1 described himself as a novice with less than 1 years' experience, the other as an intermediate user with 1 to 3 years' experience). All participants were IT literate with 4 participants stating they have experience in application development.

Figure 3: Setup of the experiment room and initial position of the objects.

There are many debates on the number of users required for usability testing. The number of recommended users range from 5 (Landauer and Nielsen 1993), 10-20 (Faulkner 2003) to 10 +/-2 (Hwang and Salvendy 2010), justifying our sample size, there are diminishing returns for discovering additional issues.

4 ANALYSIS OF RESULTS

The purpose of our analysis was to understand issues associated with ease of learning and ease of use. In mid-term perspective, the results of this analysis should provide input for an iterative research revealing insight into the learnability and intuitiveness of tangible mapping interfaces.

4.1 Getting Started: Making a Basic Map with One Data Layer

Participants created a map, of one geographic boundary, adding data for European country borders onto the table to create their first, albeit simple, vector map of Europe. To complete the task, which all participants did, they had to place the correct object on the table. They were uncertain how to start. At first they showed confusion, bemusement and wonder, *"How do I start this?"* (P2). Four participants were observed shrugging shoulders and/or waving hands or arms before either exploring the objects or touching the table. After their initial perplexity, users explored the table using prior knowledge of other types of technology. Wondering how to start, P7 touches the table, shrugs and says *"… am I supposed to click on something?"*. P2 first attempted a vertical stroke down the table with the exclamation *"OK, nothing happens…"* where as P4 waggles the fingers on the table and says, "*it seems to me I should switch something*".

All users were surprised by and hesitant to use the objects to create their map, believing that the identification of the correct object was, *"a lucky shot, I guess!"* (P1). Users unfamiliar with such interaction objects, initially explored the objects intently: scanning the objects, selecting one, examining it by turning them around or upside down.

4.2 Zoom and Pan

The next stage in the task sheet was to zoom to a specific Country. In this case, we asked participants to zoom to Luxembourg, recreating an example map view. Experience with prior technology influenced how participants investigated this interaction. On their first attempt, all participants used the familiar touch interactions common to mobile and tablet. We observed vertical swipes of the table from top to bottom (P1, P2) pinching thumb and forefinger together (P2), using middle finger and forefinger pinch to try and zoom (P3), touching the table by moving two hands towards each other (see Figure 4).

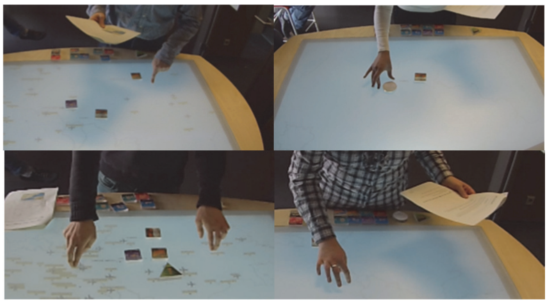

Figure 4: First zoom and pan attempts with hand gestures: (a) vertical swipe (b) pinching (c) using two hands (d) middle and forefinger.

Panning, more than zoom, was the most intuitive and easy to learn. Once the object was correctly identified, all participants picked it up and dragged it. Five participants took less than 10 seconds to work out the functionality. To stop panning, participants instinctively moved the object off the table. The zoom functionality was less obvious and more difficult to identify. We observed six participants zooming when using the object to pan. This was unintentional and unexpected because as they panned, the object twisted a little causing the map to change scale. This functionality led to confusion and frustration, "*it zooms but I don't know why?*" (P2) or "*I have no idea how to zoom, sometimes it works a bit*" (P3). Twisting the object was not always the most intuitive action as the functionality was hidden.

4.3 Working with Several Data Layers

The next task was to create a map with five different data layers, switching on the reference map and then to develop a visual hierarchy of the layers by prioritising their displayed order.

All participants added new layers with ease and confidence. P2, for instance, describes it as being "*straightforward*". They adopted the same procedure, consisting of 1) reading the labels of the objects lying on the border of the table, 2) grasping the required object and 3) putting it onto the interactive surface.

There were two distinct approaches to completing this task. Four of the participants repeat this procedure in a quick fashion until all layer objects were lying on the table and their information displayed. The remaining four carefully explored the displayed information after having placed an object on the surface. E.g. P2, who immediately reads and analyses the legend after placing the object. Then she tries to identify the information on the map, and finally uses the zoom to view more detail: *"at this zoom level it is not very legible… but if I zoom in I suppose I will be able to see more… ok, yes"*.

All participants hesitated on where to place layer objects on the table, assuming they had to be placed in the area of interest. This was also observed during the first map creation. Participants placed objects at arms-length, just below the optical centre of the map. Additional confusion arose as some layers required several seconds to load, there was no feedback to tell the users data was refreshing. For instance, P4 takes the road object from the border, *"Let's create a map with roads"*, and first makes a movement to place it inside UK, but then places it west of UK, inside the sea, waits a short moment, while looking at the map. Nothing is displayed, so he lifts it again. *"Maybe I should place it on the ground somewhere"*, and places it inside France.

Switching on the reference map, labelled full map on the object, by twisting the country border object turned out to be straightforward for some participants whereas others needed additional time or explanations. This was unexpected, as all had previously used an object twist to change the map state when zooming. The task of prioritising layers for three users was quick and easily completed whilst five users had trouble. Three participants instinctively stacked the objects on top of each other. P4, for instance, first stacks them with the first layer of the list lying at the bottom (see Figure 5: a), then, being unhappy with the results, creates a second stack with the last layer of the list lying at the bottom.

Figure 5: Two approaches for prioritizing layers: a) stacking objects, or b) putting them side by side.

An alternative approach was provided by P5 who noticed small arrows on the labels, and interprets the need of putting the layers side by side (see Figure 5b), *"I realize that maybe the little symbol on the objects is like the order of the priority of the different objects in the map"* (P5). This demonstrates the misinterpretation of labelling and semiology of the objects. Participants were unsure whether they solved the task of prioritizing layers correctly as they were expecting additional feedback. *"We can't see that on the map. So I guess something is missing, but I don't know what."* (P7)

4.4 Interpreting Layers and Legends

Participants were asked to identify, between France and UK, the shipping route with the most, and the least amount of traffic. We observed differences in how participants organized their workspace for solving this task. P3 worked on the very left side of the table, preventing her to see the surroundings. However, she is not panning the map, nor mentioning a limitation in her field of view. In contrast, other participants make use of known features to identify correct answers. For instance, P2 moves the line of objects one by one to the right. *"So that I can see something…"* Then, she switches between full map and country borders to be able to identify the symbols.

A common procedure was also to remove unnecessary information to obtain a better view. For instance, P6 decides to remove some of objects. *"I will bring out everything which I don't use, to have something a bit more clear"*.

Nevertheless, all participants were unable to locate the shipping route with the least amount of traffic. Participants were mentioning difficulties in seeing the difference between the lower values. This illustrates the need to improve the cartographic representation of the data layers and the information and visualisation of the legends.

4.5 Requesting More Information

Finally, participants were asked to find the names of the ports using the info tool. This task turned out to be particularly challenging. Only three participants identified the correct information (38% completion rate, very low), however, even those who completed the task took a long time (average time was 03:53). P8, for instance, first places it pointing down onto the centre of the shipping route, waits a short moment, and then turns it into the other direction, pointing upwards onto the centre of the route. Then she points onto one end of the route, and the other end. Then she taps the object. She is prompted to explain her action. While answering the question she replaces the object and a window opens. This issue can be explained by the fact that the table sends the request for information when there is no action on the object, and provides no hint when exactly this is done. Users expected immediate feedback, and without this feedback, they concluded that they have made a manipulation mistake. They replaced the object before the system sent the answer.

5 DISCUSSION

We have classified the observed issues into three themes: a) understanding cartographic elements on tangible tables; b) object manipulations; and c) use of non-responsive "offline spaces".

5.1 Understanding Cartographic Elements

To aid the general spatial cognition of maps, there are a number of well-defined map elements (like scale and direction, title, inset maps and use of legends) that should be integrated into the digital mapping interface. The use of these simple well established conventions can improve interpretability and understanding of the information. At present, only the use of the legend has been implemented on the geo-tangible interface. This absence of map elements led to confusion and reduced understanding of the geographic information. The use of these types of cartographic elements are not new and have been clearly defined from research with paper maps but what is required is in depth understanding on how they can be integrated into the

TUI to ensure they enhance users geographic understanding.

Currently, the zoom object is unrestricted. Participants were able to zoom indiscriminately in or out of the map. Frequently, we observed users zooming so much that they ended up at the bottom of the ocean, with no clear understanding associated with what or why they were just seeing no data. This lack of feedback with the map's scale can be improved with the following simple guidelines:

- Restrict the zoom capacity according to the scenario's context and common sense.
- Display feedback reflecting a change in the zoom made by a user.
- Provide an inset map so users can see how and where they are navigating to on the map. To avoid taking valuable space away from the map, consider using a separate interface projected on wall or via a smartphone, for example.
- Provide a tangible to reset the map zoom.
- Provide tighter control between the two functionalities of zoom and pan. Explore alternative tangible actions and objects for zooming.

The legend is one of the most important map elements, without a meaningful legend spatial cognition is weak. As with many digital map legends, the legend details can be derived by default from the layer information, but default labels often reduce the ability to interpret data classifications. The legends used in this scenario were developed by default from the external projects database. Legends fell foul to system defaults that made sense only to technical developers. The legend display, to the right of the object placed on the table led to misinterpretation. When only one piece of information was displayed, some users did not realise that this information was part of the legend and interpreted it as a further location on the map, certainly due to the absence of information to identify the symbol and label as the legend. The following suggestions would improve spatial cognition of legends:

- Consider projecting the legend in the offline space or integrate it within a separate device
- Differentiate the legend from the map using neat lines and titles and visual cues.
- Design legends for the user: labels and text should reflect their mental models. Legend data classes should be rounded to whole numbers and arranged vertically with lowest numbers at the bottom. The textual descriptions for the data classes should add meaning for the user.
- Enable to switch the legend on or off.

When working with layers consider:

- The reorder of layers based on either horizontal (left – right) or vertical hierarchy (top – bottom)
- Automatically change the cartographic styles of the layers based on where they are positioned in the visually hierarchy.

5.2 Object Manipulations

Particular to interactions on TUIs are the physical manipulations with tangible objects. In previous work, the mapping of physical objects to digital information has been seen as central (e.g., Ullmer, 2000), and aspects related to, e.g., embodiment and metaphor have been discussed (Fishkin, 2004).

The way in which participants interacted with the object varied considerably. We observed participants shifting, dropping and lifting the objects. Some used stacking, twisting, tapping to try and instigate a change in the map, initiate, or cancel an action, suggesting future versions of the interface could make more of these natural interactions, and conform to users' natural expectations. Also observed were very different ways of manipulating the objects. Some work with two hands, other with one. Some prefer to lift and drop, others shift the object slowly around the table. Some make a lot of quick and short movements, other read and reflect a lot, then make only few considered movements.

The current implementation of the interface was impacted by the different working practices which led to unexpected changes in the map state for the user: data not loading when quick movements were made, the map moved unexpectedly when users tried to move the zoom and pan object out of the area of interest on the map. The following guidelines could reduce the impact of unexpected results occurring from different working styles with the objects.

- Provide hints and tips to get started –a brief help video could be shown if the users touch the table when no objects are on it.
- Provide user feedback if an object is moved too quickly, like: "I think you are trying to move the map, try again but slower".
- Enable users to go to their previous view by providing an object or turn/action with an object
- During panning, restrict the object to deactivate the zoom action.
- When the result of a geospatial interaction cannot be provided immediately during the

manipulation, provide a visual feedback ensuring the user that the manipulation was correct and that something is happening. For instance, a data refreshing symbol.

- Provide clear labelling of interactions on the objects - arrow to show the need and direction of rotation for zoom.
- Ensure objects with different functions are uniquely differentiated, enabling them to be easily recognized. Make use of shape, colour, sizes and heights and group objects of similar functional types accordingly.
- Where it makes sense consider the use of use of objects that represent everyday metaphors (e.g., toy cars for a road layer or trains for the railway network).

5.3 Non-responsive “Offline” Spaces

One of the inherent properties of TUIs is the intense combination of the physical and the digital, enabling a rich range of interactions. A large number of these can be done offline, on non-responsive spaces. As already previously observed, TUIs enable an “extra layer of interaction” on spaces that are not recorded into the system (Fernaeus et al., 2008). In collaborative settings, these spaces were used to make suggestions, demonstrate next steps, or set a common focus (Maquil and Ras, 2007).

We have made similar observations with participants of the geo-tangible interface. To fulfill tasks participants made use of offline interactions to reduce their mental load. In particular, they organised the workspace in order to have a better view on the map, as for instance, P2 who was shifting layer objects outside her field of view. Another type of offline interactions were used to aid cognition in the stepwise following of the tasks, i.e. P1, who was touching the object layers as soon he has found them. Finally, we saw that participants used non-responsive spaces to adopt another perspective. P2 was bending herself multiple times between two positions, as well as P6 who was leaning himself onto the border of the table while he felt stuck. Thus, the offline space is an important feature of the geo-tangible interface and it should be supported by the following features:

- Support a change of perspective: enable users to do a few steps, bend and stretch themselves, or lean against the table. The tabletop should provide a good view from different positions and support actions not only at the middle of the table, but also on the sides.
- Allow users to customize their views: provide a non-reactive area where objects can be placed when removed, consider providing dedicated repositories where users can place objects of different types – to aid relocating of the objects for future use. Also enable objects to be placed on different positions on the interactive surface to support users in customising their view.
- Non-reactive touching: allow for touch interactions that have no effect in the system, hence allowing the users to use them for externalising their cognition.

6 CONCLUSIONS

This paper has presented the first usability study of our geo-tangible user interfaces. It was conducted using established methodological practices designed around the completion of predefined tasks and Think Aloud protocol analysed using video analysis. The result is a first set of insights into how the novice user explores tangible interfaces to carry out specific tasks. On first use with the objects, experiment participants were cautious and object movements were hesitant as they were uncertain of the interface. However, we observed all participants quickly becoming confident with using the objects to manipulate the map, with various different working styles emerging. Indeed, in the authors’ experience, it would not be possible to learn so quickly to use a conventional desktop mapping application. A comparison with which would be a suitable topic for a further study.

Based on this observation, we can conclude that the geo-tangible user interface is particularly useful in situations involving lay users. Typically such situations appear in participatory approaches, such as participatory urban planning. A geo-tangible table could improve communication between heterogeneous stakeholders by, on one hand, allowing experts to explain geospatial phenomena to novices, and, on the other hand, supporting novices in sharing an own perspective with the expert. We also see its potential for the development as a teaching and learning platform for younger audiences. As interaction is simplified in TUI scenarios, complex GIS manipulations will be limited. So this approach is less useful for situations purely implicating geospatial expert users.

The results of our analysis highlight the necessity to consider three different dimensions in the design of geospatial tangible tables: cartographic elements, object manipulations, and non-responsive spaces. Observed issues dealt with the lack of cartographic elements adding geographic meaning, such as a cartographic scale or an inset overview map. We also observed a series of issues related to feedback in general. Although learned object movements could be easily repeated, they appeared hidden to the users at the beginning. Better and timely feedback, informing the user of what is happening, would allow him/her to appropriate the interactions more effectively.

Based on our analysis we have formulated an initial guidelines design for geospatial tangible tables to ensure their ease and straightforward to learn and use. In future work, we hope to investigate the most intuitive and effective use of tangibles for geographic interactions and understand how different types of objects and their interactions can be optimized for geospatial TUIs.

This study shows the real usefulness of user studies to establish guidelines for the development of novel interfaces such as the interactive tangible table. To successfully interact with such a system, special interactions are required, that, on one hand, build upon fundamental principles and, on the other hand, make use of new possibilities of emerging technologies.

REFERENCES

Djajadiningrat, T., Wensveen, S., Frens, J., and Overbeeke, K. (2004). Tangible products: re-dressing the balance between appearance and action. *Personal and Ubiquitous Computing*, 8(5): 294-309.

Faulkner, L. (2003). Beyond the five-user assumption: Benefits of increased sample sizes in usability testing. *Behavior Research Methods, Instruments and Computers*, 35(3), 379-383.

Fernaeus, Y., Tholander, J., Jonsson, M. (2008). Towards a new set of ideals: consequences of the practice turn in tangible interaction. In *Proc. of TEI '08*.

Fishkin, K. (2004). A taxonomy for and analysis of tangible interfaces. *Personal and Ubiquitous Computing*, 8(5), 347–358.

Fuhrmann, S. al., (2005). Making useful and useable geovisualization: design and evaluation issues. *Exploring geovisualization*, pp.553–566.

Goodchild, M.F., (2010). Twenty years of progress: GIScience in 2010. *J.of Spatial Info Science* (1).

Haklay, M. & Tobón, C., (2003). Usability evaluation and PPGIS: towards a user-centred design approach. *Int. J. of GIS*, 17(6), pp.577–592.

Hornecker, E., & Buur, J. (2006). Getting a grip on tangible interaction: a framework on physical space and social interaction. In *Proc. of the CHI 2006*.

Hwang, W. & Salvendy, G. (2010). Number of people required for usability evaluation: the 10±2 rule. Commun. *ACM* 53, 5 (May 2010), 130-133.

Ishii, H., Ullmer, B., (1997). Tangible Bits: Towards seamless interfaces between people, bits and atoms, *Proc. of CHI '97*.

ISO/TR 16982:2002: ISO/TR 16982:2002, "Ergonomics of human-system interaction -- Usability methods supporting human-centred design," *International Standards for Business, Government and Society*.

Jones, C.E., Haklay, M., Griffiths, S., Vaughan, L., (2009). A less-is-more approach to geovisualisation – enhancing knowledge construction across multidisciplinary teams. *Int. J. Geog. Information Systems*. 23(8), pp 1077-93.

Jones, C.E., (2010) Practical Cartography. In Haklay, M. (Ed), Interacting with Geospatial Technologies, *Wiley & Sons*.

Jones, C.E and Weber, P., (2012). Towards usability engineering for online editors of volunteered geographic information: A perspective on learnability, *Transactions in GIS*, 16(4) pp 523 – 544.

Landauer, T. K., & Nielsen, J. 1993. A mathematical model of the finding of usability problems. *Interchi '93, ACM Computer–Human Interface Special Interest Group*.

MacEachren, A. M., Cai, G., Sharma, R., Rauschert, I., Brewer, I., Bolelli, L., Wang, H., (2005). Enabling collaborative geoinformation access and decision-making through a natural, multimodal interface. *Int. J. of GIS*, 19(3), pp 293-317.

Maquil V., De Sousa L., Leopold U., Tobias E. (2015) A geospatial tangible user interface to support stakeholder participation in urban planning.. *Proc. of GISTAM 2015* (to be published).

Maquil V., Psik T., Wagner I., Wagner M. (2007) Expressive Interactions Supporting Collaboration in Urban Design. *Proc. of GROUP 2007*.

Maquil, V., and Ras, E., (2012). Collaborative Problem Solving with Objects: Physical Aspects of a Tangible Tabletop in Technology-Based Assessment. In *Proc. of COOP 2012*.

Marshall, P., (2007). Do tangible interfaces enhance learning In: *Proc. of TEI '07*, Baton Rouge, LA, USA,

Nagel, T., Maitan, M., Duval, E., Moere, A. V., Klerkx, J., Kloeckl, K., & Ratti, C., (2014). Touching Transport- A Case Study on Visualizing Metropolitan Public Transit on Interactive Tabletops.

Parsons, E., (2013). The Map of the Future May Not Be a Map! *The Cartographic Review*, 50(2), pp 182-186.

Scott, S., Allavena, Cerar, K, Mcclelland, Cheung, V., 2010. Designing and assessing a multi-user tabletop interface to support collaborative decision-making involving dynamic geospatial data. *Tech rept*, Uni of Waterloo, Canada.

Ullmer, B. (2000). Emerging frameworks for tangible user interfaces. *IBM Systems Journal*, 39, pp 915–931.