A Geospatial Tangible User Interface to Support Stakeholder Participation in Urban Planning

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Abstract: The complexity of urban projects today requires new approaches to integrate stakeholders with different professional backgrounds. Traditional tools used in urban planning are designed for experts and offer little opportunity for participation and collaborative design. This paper introduces the concept of Geospatial Tangible User Interfaces (GTUI), and reports on the design and implementation of such a GTUI to support stakeholder participation in collaborative urban planning. The proposed system uses physical objects to interact with large digital maps and geospatial data projected onto a tabletop. It is implemented using a PostGIS database, a web map server, the computer vision framework reacTIVision, a Java based TUIO client, and GeoTools. Based on a series of comments collected during an evaluation workshop with stakeholders in the fields of urban and energy planning, we discuss how maps projected on a table and physical objects can be an new approach to participatory bottom-up urban planning.

1 INTRODUCTION

Urban planning today provides a complex set of requirements to satisfy technical, political, economic, and social constraints. The designed artefacts need to respond to innovative strategies provided by cities, address social and demographic evolutions, and deal with the numerous constraints of sustainable development (Terrin, 2009). To increase citizen satisfaction, create realistic expectations, and produce better designs by accessing local knowledge and skills, new approaches have been developed to involve stakeholders in project planning phases (Al-kodmany, 2001; Loorbach, 2012).

Traditional urban planning processes are still dominating in practice. They are designed by and for experts, relying mostly on top-down approaches (Loorbach, 2012). A master plan is created by urban planners and other domain experts where specific topics are individually optimised, such as transportation, recreational and green spaces, or air quality. The tools employed offer little possibility for stakeholder participation and collaboration. However, the design of urban space calls for bottom-up approaches where stakeholders and citizens collaborate to build a vision. This vision is then realised through backcasting (Loorbach, 2012).

In this paper, we introduce the concept of Geospatial Tangible User Interfaces (GTUI) and study the feasibility of such a system to support stakeholder participation in collaborative urban planning. The proposed system embeds 1) interactive maps, 2) a table, and 3) physical objects to support the different needs in collaborative urban planning (see Figures 1 and 2).

As part of this work, we have developed a proof of concept that GTUIs can be useful for participatory urban planning and facilitate bottom up approaches. We seek to develop a first understanding on the characteristics of a GTUI that is useful for such scenarios. We describe a series of geospatial interactions that have been designed and implemented in an iterative, user-centred approach. Finally we present the results of a questionnaire that has been distributed to urban and energy planning experts of 5 European cities.

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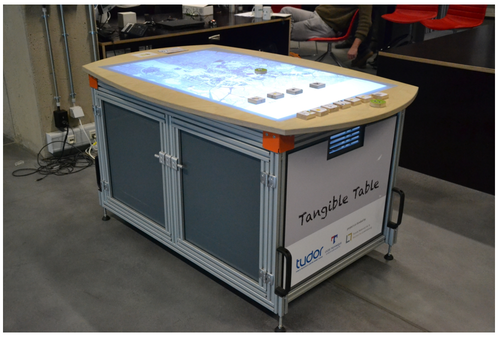

Figure 1: The geospatial tangible table.

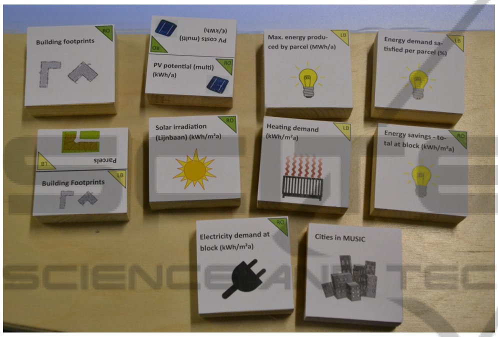

Figure 2: The different layers represented by wooden objects.

2 RELATED WORK

2.1 Collaborative GIS Tools

To date, few GIS tools have been conceived or extended to give stakeholders the ability to provide direct input to urban planning projects. More often, the focus is on stakeholder feedback and access to data, and less on collaboration and interaction (Kingston et al., 2000; Rinner et al., 2008).

Virtual Slaithewaite (Kingston et al., 2000) was one of the first online applications for participatory urban planning, allowing users to add comments to spatial features. Other applications have followed, e.g., the *Argumentation Map* prototype (Rinner et al., 2008) that provides a discussion forum wherein comments can be geo-referenced. (Bugs et al., 2010) investigated ways of engaging the general public in decision making using Web 2.0 technologies and a sample of volunteer users. The *Collaborative Spatial Delphi* project (Balram et al., 2003) investigated these matters from a methodological perspective. The goal was to facilitate consensus solutions on environmental planning and management issues by deriving decisions from a process of open debate. This method considers the participation process well beyond planning and decision making by also covering monitoring and management.

The approaches reviewed here focus on remotely connecting stakeholders to a central participatory system. While they provide varying levels of discussion, stakeholder-to-stakeholder interaction is a minor concern.

2.2 Tangible User Interfaces

Tangible User Interfaces (TUIs) extend the traditional desktop computing interfaces with a physical dimension, allowing users to physically interact with digital information (Ishii, 1997). To capitalise on natural interaction paradigms, TUIs make use of metaphors: drawing upon familiar concepts to entice users to interact with the digital world in a way that they would interact with the physical world.

Applications available via tangible devices have an inherent spatiality, allowing users to abstract problems of the urban planning domain and to gain insight by benefiting from natural mapping (Djajadiningrat et al., 2004). Furthermore, TUIs support both pragmatic and epistemic action (Klemmer et al., 2006) as they allow stakeholders in an urban planning setting to both understand problems and propose solutions.

So far a variety of geospatial TUI research scenarios have been implemented (e.g. landscape modelling (Mitasova et al., 2006)), but only few combine maps and tangible interaction to support participation in urban planning. (Arias et al., 2000) describe the *Envisionment and Discovery Collaboratory*, a tabletop application where participants work with computer simulations and physical tokens to anticipate and discuss consequences of modifying stops of a bus route. The MIT Media Lab developed the *Illuminating Clay* (Piper and Ratti, 2002), where users may alter the topography of a clay model in order to design and analyse landscapes. The results of a modification are constantly projected back into the workspace. A more recent example of a participatory tangible tool for urban planning is the ColorTable (Maquil et al., 2008). Stakeholders can discuss their vision of a site, subject to urban development, by co-creating mixed reality views with visual material, thus composing a scene. These scenes are created by assigning images to wooden blocks and placing them onto a tabletop map. The mixed reality view is then shown on a separate screen.

In contrast to desktop approaches, a TUI provides not only a participatory platform, but also a vector for stakeholder inter-discussion, bringing them together around a physical discussion place, and thus potentiating the development of plural understandings.

3 THE MUSIC APPROACH

The *MUSIC* project, which stands for "*Mitigation in Urban areas: Solutions for Innovative Cities*" aims at developing new innovative strategies to achieve a 50% reduction in CO_2 emission by 2030 in the partner cities: Aberdeen, Montreuil, Gent, Ludwigsburg, and Rotterdam. The partner cities address essential methodological questions on the process of emissions reduction: How can policy be translated into concrete and innovative projects? How can all stakeholders formulate one vision for a sustainable city? What role should companies, research institutes, and the government play? How can urban citizens be involved?

To tackle these questions, the partner cities are taking a novel approach to citizen participation using Transition Management (Roorda and Wittmayer, 2014). This method starts with gathering so called front runners in Transition Arenas. Front runners are actors (e.g., citizens, entrepreneurs, urban planners, energy experts) in their city who have ideas for engagement to improve the quality of life within the city. Transition Arenas start with gathering (geospatial) information about the city regarding the state of, for example, infrastructure, green areas, renewable energy potentials, logistics infrastructure, and distance to schools in order to establish the system's as-is state. Once this process has finished and the information is available, the next phase caters to the creation of visions. These visions are possible futures created by engaged front runners. Once these futures have been created a backcasting method is used to determine milestones that need to be realised to achieve a specific future (Loorbach, 2012). Recent work (Roorda and Wittmayer, 2014) realised in the *MUSIC* project has made it clear that in order to realise backcasting, for example by using transition management processes, there is a need for more complex and integrated information about the target city. This problem is addressed by using GIS based tools.

In order to facilitate the usage of geospatial data and processing services in this context, the integrated Geospatial Urban DEcision Support System (iGUESS) (De Sousa et al., 2012) was developed. The system is able to receive data from a multitude of sources and process them to make the processed data available in a geospatial dimension. iGUESS presents data in a structured and aggregated way. Expert users can further process geospatial data with integrated modelling and analysis tools to, e.g., assess renewable potentials within the city.

4 THE GTUI CONCEPT

To enhance the collaborative understanding of available data related to urban planning projects, we combine the opportunities of GIS and TUIs. To achieve this goal, we leverage three notions:

The use of *maps* as learning, exploration, and analysis tools is a common approach in urban planning. Encoding location within a multitude of everyday interactions, objects, and events allows to create a new perspective and, hence, to unlock solutions to various complex problems (Longley et al., 2010, p. 4).

A *table* is typically a place where people meet to discuss and exchange ideas. It supports a circular configuration of participants, each of them playing an equal part in the discussion. The tabletop becomes a shared space enabling social interaction, such as shifting the focus of a conversation or organising group members into subgroups (Fernaeus and Tholander, 2006).

Finally, the *physical objects* provide a simple and familiar access to the maps. They provide users with a feeling of intuitive directness, invite participation, and support collaboration (Schneider et al., 2011; Horn et al., 2009). In addition they support offline interactions, such as pointing, tapping, holding, or sorting, which are typical activities to aid cognition (Esteves et al., 2013).

The combination of these three notions allows us to define the concept of GTUI: a user interface projecting digital maps onto a tabletop and allowing multiple users to explore and analyse them using physical manipulations with objects.

5 A GTUI FOR THE MUSIC PROJECT

The specific GTUI instantiation used for *MUSIC* features a rounded tabletop sized 150x105cm, with an interactive surface of 120x75cm, see Figure 1. The wooden objects are shaped as circles, squares, rectangles, and triangles with a size varying between 4 and 7cm, see Figure 2. They are tagged with optical markers that are detected by a camera mounted on the bottom of the table. The digital maps, combined with other types of feedback, are projected onto the tabletop from underneath.

The GTUI instance of the *MUSIC* project was developed in an iterative approach using user input. Within these iterations, the presentation, objects, maps, and cartographic interactions have been iteratively designed and implemented using the rapid

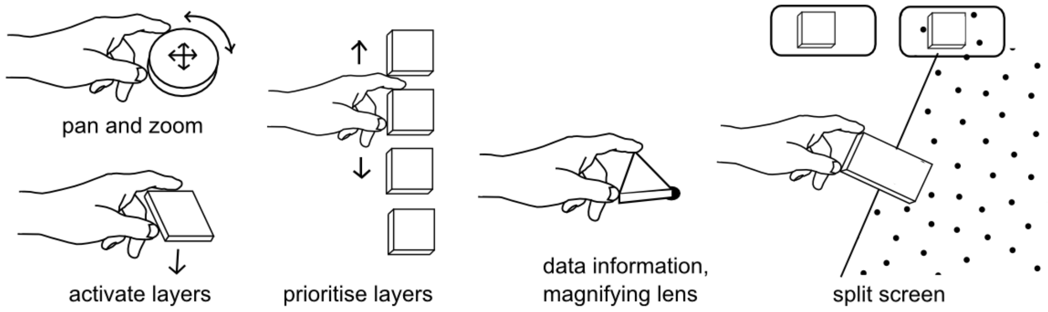

Figure 3: Cartographic interactions implemented on the TUI.

prototyping and feedback phases from multiple stakeholders.

While our first GTUI only contained the very basic cartographic interactions (panning, zooming, and adding layers), it was progressively refined with a series of developments. On the one hand, these concern the fluidity of manipulations that we improved by refining and tweaking the interactions to run more smoothly, and by reducing map loading times using multi-threading. On the other hand, object cluttering was addressed by mapping mutually exclusive layers onto a same objects which can then be rotated to activate different layers. Other improvements were related to the map size, which was increased by removing a vertical stripe reserved for object placement as well as to the introduction of new interactions to enable more advanced interactions, such as querying layers for information, splitting two layers, and magnifying parts of the map.

In the current version, the system supports a first series of basic cartographic interactions, as well as several more advanced interactions (see Figure 3):

Pan. A circular object can be placed on the map. By dragging it across the table, the view on the map is moved in the same direction.

Zoom. The same circular object can be rotated to the right to zoom in, and rotated to the left to zoom out.

Activate Layers. A set of square objects is provided with each object representing a different geographical data layer. 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 and the legend fades out.

Prioritise Layers. The vertical position of each layer object determines the order in which information layers are drawn. The bottom most layer is drawn first, hence forms the background of the map. The topmost layer is drawn last, hence occludes any layers underneath. As layers are transparent where they do not provide information, this setup is well suited to stack many different data layers.

Data Information. A triangular object shows a black dot at its peak. This dot can be placed on any graphical element. A window with the textual description on the graphical element is then opened next to the object. When removing or displacing the object, the window closes.

Magnifying Lens. In a similar fashion as the data information, a triangular object allows to move a black dot on a specific position. This object opens a round windows which shows the area where the object was placed in a higher zoom level.

Split Screen. A rectangular object allows to create two zones on the map separated by a line defined through the position and orientation of the rectangular object. Each zone is assigned to a different layer by placing the layer's corresponding object in a dedicated rectangular areas. This allows for the comparison of layers that would otherwise be conflicting due to their coverage or overlap.

Select Areas. Paper cards hold specific city areas with varying granularity. Users can load the map of these areas by placing the corresponding cards onto the tabletop.

With these interactions, users can explore a series of layers pertinent to sustainable urban planning. Layers created by the *MUSIC* project for this GTUI instance included: Renewable energy potentials, such as solar, geothermal as well as energy savings potentials; Socio-economic and health impact layers, such as energy poverty and urban heat island effects. The energy poverty layer shows access to affordable energy. The urban heat island layer visualizes heating and cooling of urban buildings. All layers provide detailed information at the building and neighbourhood levels within the city which enables stakeholders to interact with accurate information using the GTUI tabletop.

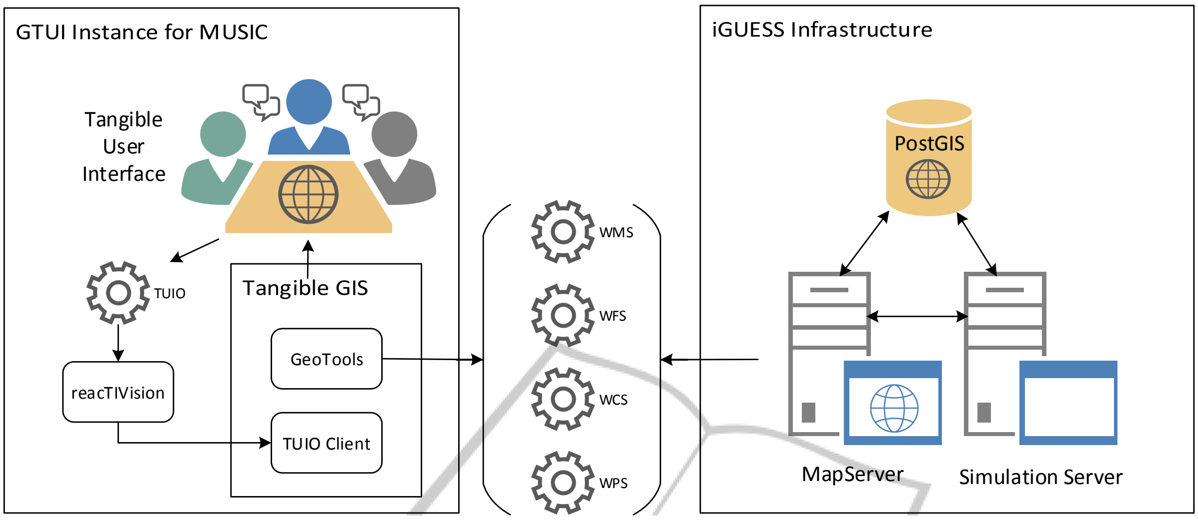

Figure 4: The software architecture supporting participatory urban planning. The *MUSIC* GTUI infrastructure backed by the Tangible GIS software (left) accesses services provided by the iGUESS infrastructure (right) such as mapping, simulation, and geospatial data.

6 SOFTWARE ARCHITECTURE

The GTUI instance described in this paper is based on a server-client architecture as shown in Figure 4. The table interface acts as a client that, in response to user input, fetches data from a remote server through an HTTP connection. Interaction between client and server relies on the web services specified by the Open Geospatial Consortium (OGC).

Spatial datasets from the *MUSIC* project are stored in a database managed by PostgreSQL[1], with the geospatial extension PostGIS[2]. Using the MapServer[3] software package, these geospatial data are exposed through several OGC services, namely: Web Mapping Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS). To generate new data sets via simulations, e.g. solar potential maps, PyWPS[4] is used to expose these simulations as web processing services (WPS). Apache, a HTTP server, manages incoming requests to all the above services.

On the client side, the tangible table is deployed with the LIST's Tangible GIS Java application. It relies on the reacTIVision[5] computer vision framework to capture and identify objects on the table. The objects are identified and their states, such as motion or rotation, are encoded using the TUIO protocol (Kaltenbrunner et al., 2005). Tangible GIS includes a TUIO Java client to receive these state descriptions. After interpreting these states, the application reacts by issuing requests to the OGC services. Tangible GIS makes use of the GeoTools[6] library. GeoTools exposes facilities to easily compose requests to and interpret responses from the various OGC services. After receiving the data or meta-data from the respective OGC services, the Tangible GIS displays the results on the table.

With this architecture the GTUI can be independent of the data services used in the participatory process. It is extensible and interchangeable with any other spatial data services that comply with the OGC standards. Therefore, the TUI scenario implemented here can be seamlessly applied to different contexts and domains.

7 EVALUATION

Within the scope of the *MUSIC* project we performed 2 workshops in Esch-sur-Alzette, Luxembourg in November 2013 and Ludwigsburg October 2014. The workshops were targeting stakeholders interested in new participatory urban planning approaches in their city and aimed at informing participants about the new solutions developed in the *MUSIC* project. In the Luxembourg workshop 20 stakeholders attended from

[1] http://www.postgresql.org
[2] http://www.postgis.net
[3] http://www.mapserver.org
[4] http://pywps.wald.intevation.org
[5] https://www.reactivision.sourceforge.net
[6] http://www.geotools.org

6 different cities where new participation approaches using Transition Management and iGUESS were discussed. Stakeholders had various backgrounds including urban planners, GIS technicians, social scientists, engineers, energy experts, and companies providing energy related services. All of them have already participated in or even organised bottom up participatory urban planning workshops. The GTUI was presented to them as a new type of interface and tool to explore opportunities for renewable energy sources in their cities.

To obtain insights on the potential advantages and disadvantages of such a tool, an anonymous questionnaire was distributed to each participant. It asked participants to imagine a participatory workshop with stakeholders aiming for sustainable urban planning in their city, and the use of the tangible table within the scope of that workshop. The questionnaire holds six statements about potential differences in the group dynamics and work practices:

1. Stakeholders will communicate differently.
2. Stakeholders will participate more actively.
3. It will be easier to understand the maps and layers.
4. Stakeholders will discuss longer before reaching a consensus.
5. Stakeholders will collaborate more.

Each of these statements could be judged using a five point rating scale (i.e., 1 corresponds to strongly disagree,..., 5 corresponds to strongly agree; range $[1,5]$), with the possibility to leave a comment in an additional space. Further, three open questions were asked about the major advantage, the major disadvantage, as well as envisioned next features.

1. What, in your opinion is the major advantage of the tool?
2. What is the major disadvantage?
3. Which features would you like the next version to support?

14 participants filled in the questionnaire and provided a total of 113 comments. Using the approach of thematic analysis, the comments were studied and grouped to identify relevant themes describing characteristics of the tool.

All participants agreed about their feeling that stakeholders will communicate differently (M = 4.50, SD = 0.52), will participate more actively (M = 4.36, SD = 0.75) and will collaborate more (M = 4.07, SD = 0.62). Further, participants agreed that stakeholders will better understand the maps (M = 4.29, SD = 0.73) and be more satisfied with the outcome (M = 4.18, SD = 0.54).

Regarding the time it requires to reach a consensus, participants had differing views or did not know (M = 3.07, SD = 0.92). P3 and P14, for instance, expect stakeholders to discuss longer, but P3 sees this positively as the stakeholders will get more information. P4 and P5, on the other hand, rather think that the discussion process will get shorter and that a solution will be found faster. P1, P2, P9, P10, P11, P12, and P13 specifically mention that they do not know and that several options are possible.

Our analysis of the qualitative data has revealed five themes that participants consider as particularly interesting. The GTUI uses maps to display data and information. Participants consider this as an important **visual aid**, providing a new type of overview (P2), which is more understandable. They expect that this will create increased satisfaction as "[...] the outcome will be based on the facts of the map." However, they also mention that maps can be difficult to understand in case they represent very technical data (P12,13).

A second aspect mentioned by participants is the high **interactivity** of the GTUI, "[making it] easier to understand the underlying links between data [...]" and allowing stakeholders to express themselves in a clear way (P11). This is assumed to generate more discussions (P5). P11, however, also mentions the need of having a sufficient number of layers in order to be able to see the discussed issue "[...] from different perspectives [...]".

Multiple participants mention that they expect stakeholders to be more **active** while using the table. On one hand they explain this by the circumstance that users will be standing (P5,9,13) instead of sitting. P13 even goes further, explaining that the standing configuration will create a more informal situation (P13). On the other hand, participants are referring to the fact that GTUIs are based on physical manipulations and, hence, require a more active disposition to be operated. P5: "You have to be more active anyway, working with the map/table to see the different layers, zooming in [...]"

Another theme deals with the support for **playful interactions**. Participants describe it as a "motivative tool" (P10), being easy to use (P6,8,12,14), and removing "fear of technology" (P6). They explain this by the playful nature of the tangible table: "The table looks like a game with all the layer pieces [...]" (P11).

A final series of comments deals with the increased collaboration around the table, supported by **a common, shared space**. This space allows everybody to participate, try out options, and influence the data (P1,3,4,5,6,12,14). More specifically they assume the particular form of the table to be beneficial as it allows to form a circle and to collaborate face-to-face (P11,14). Participants expect this to "encourage communication" (P6), and "create a dialogue instead of presentation" (P14).

Concerns expressed by the participants deal with the size of the table that can only hold a few people (P1,P8), the risk of being seen as a toy (P2) as well as the lack of features compared to GUI tools (P4,11). They also mention cartographic issues of the presented maps: "The maps are very complex and some citizen will have problems to understand everything" (P13). P12 points out that the maps need to be "[...] relevant, well-scaled, with instinctive colour map [...]". Practical issues are mentioned, like the room to store it, as well as the costs (P5). Finally, the participants mention the importance of properly introducing the tool in order to avoid that it is seen as a toy (P2), and that the discussion is well framed (P7).

These results allow us to derive an initial set of design guidelines for GTUIs to support participation:

- Ensure high interactivity and real-time feedback to attract participants, increase engagement, and discussion.
- Use a table in standing height to encourage users in being more active in the discussions.
- Use playful, simple interactions with physical objects to remove fear of technology and enhance participation.
- Use different layers to show phenomena from different perspectives.
- Make sure to define a protocol how the table is introduced and used in the workshop.

8 CONCLUSIONS

In this paper, we have shown that the combination of tangible tabletops and GIS to support collaborative understanding of complex data for sustainable urban planning is feasible. Preliminary results from two workshops within the *MUSIC* project support the assumption that such systems change the way stakeholders, involved in urban planning processes, communicate and improve participation as well as collaboration and the understanding of geospatial mapped information.

Our qualitative analysis has allowed to identify a series of design characteristics appearing to be beneficial in the use of participatory urban planning, in particular the interactivity, the visual representation of the data, the standing height of the table, the playful nature, and the shared space. Based on these results, we have provided a series of initial guidelines to be considered when designing GTUIs.

A limitation of the study is that results are based on a series of small workshops using the GTUI and the experience and judgement of these participants. It would be interesting to conduct a larger field trial with more participants and more use cases to confirm these results. Nonetheless, this work provides directions on how to set up and use such an interface in similar scenarios.

The GTUI concept provides many new opportunities and is currently used in urban logistics projects to explore logistics information and determine optimal placement of Urban Distribution Centres for freight delivery.

Further improvements of the system will be necessary to enable users to generate and input new information on the fly using web standards such as the web processing service (WPS) currently supported by iGUESS. This will enable the user to, for example, run different scenarios on the usage of renewable energy potentials or on city configurations and their impact on the urban heat island effect.

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