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Visualizing environmental data for pedestrian comfort analysis in urban planning processes

Beata Stahre Wästberg, Monica Billger, Jens Forssén, Maria Holmes, Per Jonsson, Daniel Sjölie and Dag Wästberg

Abstract

Digital tools are being developed for involving stakeholders in urban planning and transformation processes. One challenge is how to visualize and act upon all parameters that are relevant for dealing with complex planning problems, such as environmental factors. Dialogue tools involving visualization can bridge the distance between planners and citizens. This paper focuses on the problem of representing invisible environmental parameters affecting the urban climate such as wind, solar radiation, air pollution and noise, in a city model. The aim of the paper is to discuss challenges for representing and communicating environmental data in city models. This paper is based on results from a literature study, results from our own conceptual modelling and prototype studies in three projects, as well as from a survey recently carried out with 24 urban planners. We conclude with defining design criteria for dialogue tools creating a comprehensible base for communication in urban transformation processes.

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1. Introduction

1.1 Digital tools for stakeholder involvement

One of the great challenges for urban planning today concerns how to gather, handle and communicate the huge quantities of data found in today's society. For more than a decade, digital tools have been developed for involving stakeholders deeper in urban planning and transformation processes. Digital tools with a high degree of interactivity can promote dialogue with societal groups not usually engaged in participative urban transformation processes (Senbel & Church, 2011) and bridge the distance between planners and citizens (Bailey et al, 2011). However, this potential for inclusive dialogue and learning is seldom realized (Brown & Kyttä, 2014). Most digital communication in planning today appears to be of the one-way, monologue type, due to technical and financial challenges linked to implementing more interactive modes of communication (Williamson & Parolin, 2013). To be tailored to citizens' co-production of urban knowledge, digital tools need to be better adjusted to non-expert usage (Schively Slotterback, 2011). One challenge is how to visualize and act upon all parameters that are relevant for dealing with complex planning problems (Kyttä et al, 2013) (Figure 1A, B).

Digital tools may enable citizens to move from passive end-users to active creators of urban environments (De Longueville, 2010). However, few studies of the usability of visualization tools focus on the implementation of visualization tools in real planning processes (Kyttä et al, 2013). Initiatives to develop different types of digital tools for citizen dialogue in planning have typically been project-based, short-term and poorly linked to regular processes. Research on such tools usually focuses on tools developed by researchers with few applications in real cases (Senbel & Church, 2011; Billger et al, 2016). When planners or consultants have developed digital tools, scientific studies are rare. Research shows the potential of visualization tools in dialogue processes. However different kinds of tools are better suited for different parts of the process or different kinds of meetings (Forssén et al, 2009; Jagla et al, 2012). The greater part of the research report on user evaluation studies of a single tool or a comparison between tools (Bergman et al, 2015; Balakrishnan et al, 2007; Brown, 2003; Jerrett et al, 2005; Drettakis et al, 2007). User evaluations of IT-tools in real dialogue process cases are rare (Lange, 2005; Forssén et al, 2009; Richens & Schofield, 1995; Bergman et al, 2015; Balakrishnan et al, 2007).

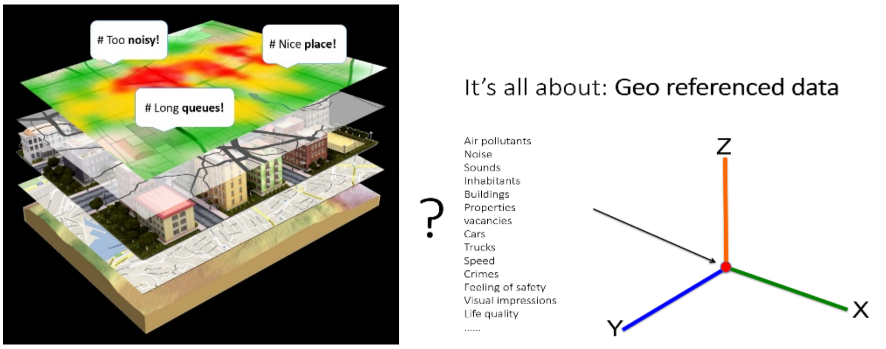

Figure 1A, B. A) Conceptual sketch showing layer upon layer of information regarding different aspects of the city environment. **B)** Large amounts of data are place specific and of great variety in format and quality. Geo referenced heterogenous data can be gathered in order to show various aspects in the same context.

By the term visualization we refer to the definition stated in (Billger et al, 2016), where visualization comprises digital tools and approaches based on e.g. 2D/3D-visualizations and different forms of geovisualization, i.e. georeferenced spatial data, and information visualization, that are implemented in Virtual Reality (VR) and Augmented Reality (AR) environments. By visualization tools for dialogue we likewise use the definition by Billger et al (2016) when referring to tools that support dialogue through visualization. They are here regarded as systems based on a 3D city model or a 2D city map used in participation processes within urban planning, involving different levels of interactivity and/or presentation technique.

1.2 Scope and objective

Environmental parameters in the city, such as air pollutants, solar radiation, wind and other types of comfort data, while important for our experience of the city, are still difficult to present in a visually comprehensible way. The accessibility to data connected to these parameters is low. As a result, these factors often get a low priority in urban planning processes. Given the current trend of urban densification, it is important to understand the effects this will have on the urban climate and pedestrian comfort, especially considering a future possible rise in temperature and extreme weather conditions. Our research deals with methods for communication in urban transformation processes. Technological developments, which among other things offer a number of visualization tools, are considered both an opportunity and a challenge for participatory urban planning (Billger et al, 2016). Our objective is to develop methods for visualizing environmental data in urban 3D-models with the aim to provide better understanding of how these parameters affect the experience of the city, as well as how they are affected by urban transformations. This paper focuses on the problem of representing invisible environmental parameters affecting the urban climate such as wind, solar radiation, air pollution and noise, in a 3D-city model. The aim of the paper is to discuss challenges for representing and communicating environmental data in 3D-models based on literature studies, our own experience in our research, and an inventorying survey with urban planners.

1.3 Research approach

This research has a design-based approach (Anderson & Shattucki, 2012), meaning the testing of concepts in iterative processes, were a wide variety of multiple, often mixed methodologies are used, combined with a variety of research tools and techniques. The main authors have backgrounds in architectural research comparing physical spaces to virtual environments (Billger et al, 2004; Stahre & Billger 2006). It is therefore important to point out that the research here presented has an architectural, holistic perspective, where the experience and understanding of the whole spatial context is central. Architectural research often requires a transdisciplinary approach that involves both researchers from different disciplines as well as practitioners. We present a user-centered design approach in the development of the methodology for visualizations, by utilizing an iterative, user-informed process throughout the entire design and development cycle. In each of the studies different competences have been used depending on the research focus of the project, and the research group has therefore changed overtime while keeping its core of architectural researchers.

In this paper, we have accounted for literature studies inventorying needs and challenges, examples from our conceptual modelling and prototype studies in three projects, as well as a survey with 24 participants, all working with various kinds of environmental data within urban planning.

Our research, ongoing or completed, joins competences from academic research groups at the University of Gothenburg /Chalmers University of Technology (Dept. of Applied IT), Chalmers University of Technology (Dept. of Architecture, and Dept. of Civil and Environmental Engineering), together with representatives from the Environmental Office and the Planning Office at the City of Gothenburg, consultants from the urban development company Tyréns and representatives from Johanneberg Science Park.

2. Challenges for representing environmental data in 3D-city models

Various challenges for implementation of dialogue tools in urban planning processes are defined in the literature (Kahila & Kyttä, 2010; Kanervo, 2010; Devisch et al, 2016; Billger et al, 2016). Billger et al (2016) identified five challenges for implementing visualization tools: *Managing new visualization tools in established organizational structure*s; *Development of engaging dialogue processes*; *Integrating data; Representing data*; and *Avoiding misinterpretation*. In this paper, we will focus on aspects of the last three of these challenges, and thus narrow it down to (in the order corresponding to our focus): *Representing environmental factors*, *Creating trustworthy visualizations*, and *Integrating different kinds of data*.

2.2 Representing environmental factors

2.2.1 Visualization

By visualizing abstract environmental data in spatial 3D-planning models, a better understanding for various environmental aspects can be reached which consequently have an impact on the planning of new areas and buildings. Such models already exist today – in most cases presented in a planar view. However, street perspective is important for evaluating more complex situations, such as densification projects (Yuan & Ng, 2012). To facilitate a better understanding through visually more detailed information of for example air pollution at street level, a visual concept for 3D-city models needs to be developed where a "walk through" perspective at street level is included. This could for example enable different design alternatives to be evaluated on a micro level. There is a need to design visal-analytical tools to explore multi-faceted geospatial data and generate knowledge out of this. Misinterpretation of data may be a problem, and various trends for visualization and ways of analysis is another challenging factor (Pack, 2010).

In order to facilitate the communication to end users, the data must be presented in an engaging and easily comprehensible form (San José et al, 2011; Jerrett et al, 2005). When it comes to visualizing abstract parameters, the special character of the 3D-media can be used to advantage, since its visual bounds of reality can be stretched. But the challenge still lies in how to convey the message in a way that maximizes comprehension and minimizes the risk of wrong interpretation (Figure 2A, B).

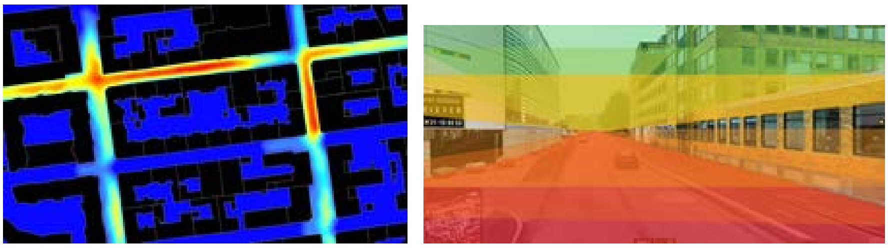

Figure 2A, B. A) Air pollution data in 2D-planar view, displayed in separate layers (i.e. this image showing one layer). **B)** Conceptual 3D-view of buildings and pollution data from a street perspective. The same presentation method with horizontal layers as used in Figure A is applicable here.

2.2.2 Auralization

Auralization, which can be seen as a technique of creating audible sound files from numerical data, has been widely used during recent decades for room acoustical purposes see for example Vorländer (2008). More recent interest has been toward using auralization for outdoor environments with a large focus on the dominating road traffic noise, for example Forssén et al (2009); Jagla et al (2012) and Bergman et al (2015). To actually listen to a planned environment can become a valuable tool within decision making on transport corridors and qualities of urban areas, as a complement to the use of noise maps with their time averaged, single-number noise levels. A major challenge lies in collection of input data for traffic and other sound sources. Time-averaged road-vehicle flow data do often exist whereas the availability is generally poor concerning completeness and updates. For auralization, however, detailed time patterns of different road vehicles are needed as input, including position, speed and engine load. Such input data could result from continuous roadside recordings or from microscopic traffic modelling with field data updating. Recordings together with intelligent identification systems can be used to not only provide the acoustic source data input, but potentially also to assess other aspects of the environment, such as social aspects linked to perceived safety.

2.3 Creating trustworthy visualizations

Depending on the aim with the visualization, the choice of technologies and techniques varies. The design of the visualization, including level of realism, scale and view, influence how we experience and interpret the visualizations. Kwee (2007) notes that the area of digital architectural presentations focuses on the technology’s provision for speed and ease of information retrieval. In the meantime, the quantity and presentation of information in these visualizations is assumed, without proof, to be currently adequate for mediating correct understanding. Balakrishnan et al (2007) observe that physical objects rather than the spatial experience are emphasized in common digital tools for design visualization. In current rendering technologies great achievements are made in representational similarity through increased photorealism. Accordingly the challenge lies in the experimental concordance with a corresponding real space. (Balakrishnan et al, 2007) For the creation of trustworthy virtual environments in the process of forming a design idea, there is a need for different expressions and levels of representation. According to Brown (2003), different types of representations appear to fit different phases of a design, and one challenge is how to integrate different computer generated representations into the process. The visualizations have to be able to interpret some issues exactly (e.g. Drettakis et al, 2007), while just sketching others (Lange, 2005). A high level of realism could then lead to a too definite and non-negotiable expression in a visualization, and suggest that the project plans cannot be changed (Richens & Schofield, 1995; Hannibal et al, 2005). On the other hand, rich texture information and accurate perception of eye-height is important when simulating virtual settings (Ooi et al, 2001).

2.4 Integrating different kinds of data

Today, data handling increasingly concerns interactions (Cheshire and Batty, 2012) and how to gather, handle and visualize big data is a common central issue. Even though spatial simulation methods that make use of big data are being developed (Benenson, 2011), there is still a long way to go. To combine the physical environment (e.g. built structures, traffic, water levels) with invisible aspects (e.g. air pollution, sound/noise and energy distribution), or social and societal aspects (e.g. safety, health and well-being), in a city model is challenging both when it comes to the handling of data and the simulations, and how to represent it. To handle and combine large data sets from different origins and in different formats into the same platform is central in this context (Figure 3). One challenge lies in the integration of enough relevant parameters for the case at hand in the tool.

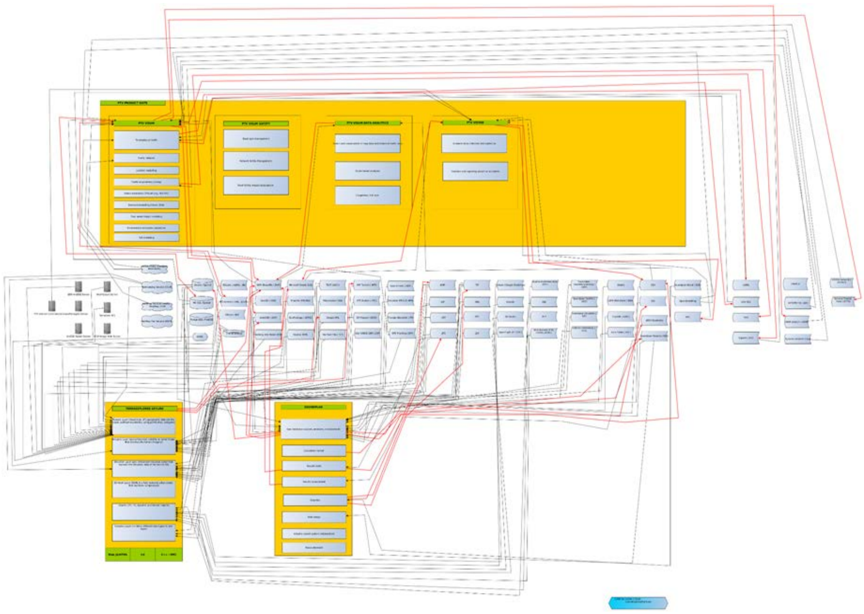

Figure 3. This image illustrates the complex use of software and workflows in the research project Data Fusion. Acknowledgement to Camelia Elena Ciolac at Big-Data@Chalmers for mapping out the scheme in the Data Fusion project.

3. Examples from research studies

3.1 Prototype exploration

Over the years our research group has developed a cluster of research projects were the aim has been to test different solutions for representation of environmental data in city models. One of the general main difficulties has been the integration of data. In previous connected projects, several tools for urban modeling and visualization have been used, such as VISSUM, Urban Strategy, ArcGIS, the Gothenburg city model and SoundPlan.

In a pilot study, accounted for in (Stahre Wästberg et al, 2013) architectural researchers joined competences with environmental researchers and a GIS-specialist. Elaborations were made with different ways of representing air pollution data in a 3D-model from a street perspective. An urban area in central Gothenburg was studied regarding air quality following changes in the built environment. Dispersion calculations for particles were carried out based on the plan for new buildings in the area. For comparison, a scenario of the current situation was produced, based on existing calculations for emissions from traffic and harbour activities. Throughout the project, the main challenge lay in data handling, in particular in the input and output of data from different programs. The outcome of the project can be looked upon as a first step towards a method for solving the stated issues (Figure 4A-C).

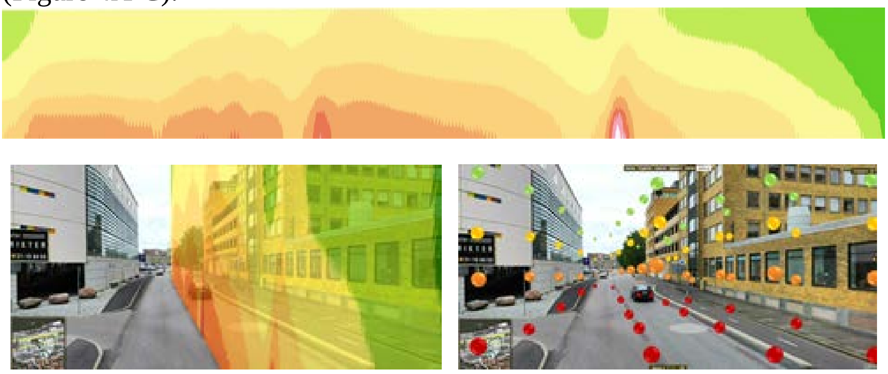

Figure 4A, B, C. A) Calculations were made in the software SoundPLAN based on geographic 3D-data input, generated in ESRI ArcGIS. The result regarding quantities of air pollution was extracted in high resolution grids for 16 vertical levels, using the Kriging method in ArcGIS. These grids then formed the base for a 3D-visualization through an interpolation between corresponding grid cells for adjacent vertical level. **B)** Conceptual sketch of data extracted as a vertical line, based on the 2D-pollution data grid. **C)** Conceptual sketch of data extracted as vertical points, based on the 2D-pollution data grid.

Following the pilot study, the architectural researchers developed a short project together with researchers in acoustics and interaction design, as well as research engineers within computer science and engineering. In this step of the research the aim was to identify and compile types of heterogeneous data representing traffic flows (Sánchez-Díaz et al, 2015), acoustic noise (Forssén et al, 2009; Forssén et al, 2014), air pollution (Habermann et al, 2015; Stahre Wästberg et al, 2013), and water rise, and illustrate how this could be used for analysing the development of River City Gothenburg in an interactive demo. The game engine Unreal Engine was used for visualizing sound in a 3D-model (Figure 5A,B). By using a modern game engine such as Unreal Engine we gain easy access, well developed integration with rapidly developing commercial technology such as Virtual Reality (Figure 5A,B), and editors for exploring novel visualization technologies such as advanced particle systems. As in the pilot study, differences in the data formats used in different software and the platform were challenging. There were problems with combining different material formats in the 3D-models with what was needed for the Unreal Engine.

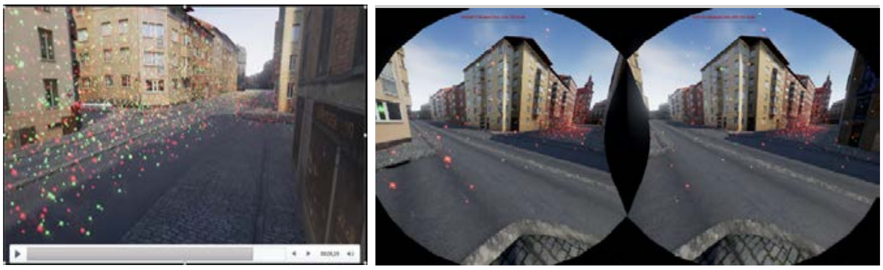

Figure 5A, B. In on-going elaborations with auralization a 3D-city model with a high level of photorealism was used in the game engine Unreal Engine to present visualizations of acoustic data sets. B) Image from within the VR application, where the viewer uses goggles and gets a strong impression of being in a 3D-world.

In a recently started project the aim is to meet the challenges and realize the proposals shown in previous research phases to assess urban performance in specific areas of the city of Gothenburg. Different design concepts for visualization of various types of invisible environmental factors are developed and evaluated, and will be displayed in an interactive 3D-city model, primarily from a street perspective. Particular challenges concern how to display multiple types of parameters simultaneously, and how to visually use symbolism and photorealism in the same model. The possibility to encode several parameters into the appearance and behavior of particles in advanced particle systems, as mentioned above, is of interest. Two case scenarios are planned in central areas of Gothenburg. During the project stakeholder workshops for co-creation and feedback on proposed solutions will be held. They will be documented and used as a base for analysis, focusing on workflow and inventory of needs, evaluation of conceptual solutions, and evaluations of proposals for the developed dialogue toolkit.

3.2 Survey inventorying needs of visualization of environmental data

For mapping out end user workflow for communicating environmental data; existing use of software and input and output data; and any need for improvement, a survey with 24 participants, all working with various kinds of environmental data within urban planning, has been carried out. Preliminary results show that the digital tools used to manage environmental data varied a great deal among the participants. Most of them used a selection of different tools, both digital and analogue, with a focus on GIS-programs such as ArcGIS. Respondents expressed an interest in how to use the tools to manage environmental data; the possibility to combine different data and data sets; to improve the import and export between programs; and a general improved usability was called for. A majority thought that the visual presentation of environmental data (in planning processes) could be improved. Among what was called for was the possibility to visualize more clear and easy to read information; a better use of colouring to improve the understanding for the material; more possibilities to use 3D and VR; and the opportunity to combine more than one parameter at the same time. When it came to how they would like to visualize environmental data for optimal understanding, suggestions such as to visually present environmental effects of different scenarios, to use interactivity (in VR), and to combine, and graphically present different data simultaneously were put forward. Other suggestions included the possibility to edit the presented material in real time, include points in the visualization with in-depth information, and to have features that clearly show boundaries regarding invisible factors such as air quality.

4. Concluding remarks: Design criteria for dialogue tools representing environmental data in 3D-city models

Based on our earlier above described research, including the survey with planners and architects, we have here defined important design criteria for dialogue tools creating a comprehensible base for communication in urban transformation processes:

- *Representing different parameters of geo-referenced data simultaneously.* To present different data sets in a comprehensible way is a challenge. This could for example mean to simultaneously compare at least two sets more thoroughly, or compare simplified versions of several sets.
- *Switching between street view and planar view.* Most city models existing today are used in a planar view. However, in street view a different scale and detail of the spatial context can be shown, giving the experience of how it feels to actually walk or drive in the city. To combine these two perspectives would give

the representation the added values of both the overview of the planar view and the detail of the street view.

- *Presenting different scenarios.* To visualize different scenarios, for example a before and an after scenario, or multiple different proposals, is an effective way of conveying understanding of, for example, how a planned building will have an impact on the city environment.
- *Using interactivity.* By using interactivity a better understanding of relevant aspects of the city can be reached, adding a further dimension to the experience. The use of VR and VR technology both provide the opportunity to explore data interactively and intuitively and to get an embodied understanding of it, for example by having to walk a certain distance to see changes in the data.
- *Finding the suitable level of abstraction and information.* This is connected to who the target audience is, their previous knowledge of the project, and how much information it is suitable to convey in order to maximize the understanding. When visually using symbolism and photorealism in the same model, it is important to use an imagery that visually divides realism and non-realism, for example by a knowledgeable use of colours.
- *Translating quantitative measurements to perceived experience.* Presenting environmental data as numeric values does not indicate how the environment is subjectively perceived. What levels of, for example, noise or wind, are acceptable is dependent on how a space is used and varies over time. It is therefore important to present these measurements in terms of comfort criteria relevant to the space rather than as absolute values.
- *Evaluating proposed solutions with target groups.* In order to create a tool that is actually going to be used it is important to know the needs and wishes of the target audience and to invite end users to evaluations of the design throughout the design process.

5. Outlook forward

In our ongoing project, the aim is to realize the proposal shown in our demonstrations, in order to assess urban performance in specific areas of the city. Our intention is that the results from this research will contribute to the development of digital dialogue tools that better can support dialogue between stakeholders in the planning process. The knowledge gained can also be applied to other areas dealing with invisible values such as health, social equality, justice, safety and architectonic and urban spatial qualities. A visual planning tool of this kind can further be used for local climate work, for example to predict different scenarios linked to climatic factors. Thus it can enhance interaction between research and design practice. Such cooperation can provide the tools for identification and solution of problems that are clearly noticed by users of 3D-modelling but so far not consistently scientifically addressed.

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