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A Proposed Workflow for Conceptual Visualization Studies in Urban 3D-Models

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Abstract Different types of invisible parameters, such as air quality and noise, are all affected by new constructions of infrastructure and buildings and should be considered as important aspects in the design of new urban environments. At the same time these parameters are difficult to communicate in a comprehensible way and their consequences can be difficult to grasp for non-experts. Effective visualization offers possibilities to include and create consensus among stakeholders in urban planning processes and thus contributes to a holistic view and more sustainable solutions. This paper presents and discusses a proposed method for conceptual explorations for visualizing environmental data, using a so-called sandbox model with fictitious data. One question is in focus: How can a sandbox model be used for the development of visualization concepts in urban 3D-models? In this paper we demonstrate our methodology using noise pollution data applied in one of our research projects carried out together with the Swedish Transport Administration (Trafikverket). This project explores new solutions for visualization of environmental data in Trafikverket's geographically large-scale 3D-models. In order to conduct design elaborations in an adapted environment a sandbox model was developed as part of the workflow. Here various concepts for visualization solutions were developed and tested in a series of user tests. Based on this developed methodology through application, we propose guidelines for conceptional elaborations in a sandbox model for visualization of data in urban 3D-models. This research approach contributes to developing new methodology for information visualization of environmental data in urban 3D-models.

Keywords: Sandbox-model, design research, data visualization, information visualization, urban 3D-models, urban planning

1 Introduction

Government agencies like The Swedish Transport Administration (Trafikverket) manage various environmental parameters in large-scale 3D-models, so-called coordination models, which show a large landscape area, where all data linked to a project is collected [1]. Such large, complex models can be difficult to manage, and the diversity and complexity of data can furthermore be a problem when it comes to creating an optimal user experience [2].

Different types of invisible parameters, such as air quality and noise, as well as social aspects, are all affected by construction of new infrastructure and buildings and should be considered as important aspects in the design of new urban environments. These parameters are difficult to communicate in a comprehensible way and their consequences can be difficult to grasp for non-experts. Information about invisible parameters needs to be represented in a clear and comprehensible way using standardized choices regarding colours and symbols. There benefit of standardization and convention is mentioned in Ware [3, p. 27].

Effective visualization offers possibilities to include and create consensus among stakeholders in the planning process and thus contribute to a holistic view and more sustainable solutions [4]. By visualizing data in spatial 3D-models a better understanding can be conveyed of various environmental aspects in a certain location [5]. Information that in reality is not visible can be displayed, such as different future scenarios and consequences of a building proposal. In this way, an increased understanding of abstract phenomena can be reached, forming base material for more informed decision-making. [6; 7, p. 91].

Our research group has over the years worked in various research projects aiming at visualizing environmental data in urban 3D-models, to facilitate understanding for different stakeholder groups in urban planning processes, for example [8; 9]. In these projects, the design and evaluation of the actual visualization had to be down-prioritized due to the handling of real data and the technical development of a photorealistic large-scale model. Managing large amounts of data in different formats and integrating it in an urban 3D-model is time consuming and a central challenge when working in projects based on real cases (often applied research) include how to obtain realism - both visual realism in the model, but also real data. Visual realism requires specific competences, is time consuming due to the need of numerous iterations, and real data can be hard to access and acquire. Herein also lies other problems such as data can be sensitive and therefore restricted in usage. Above all, data in a real context is usually incomplete regarding the research focus, i.e., a real setting does not contain all aspects of research interest. As this turned out to be a methodological problem, there was a need to develop a methodology to explore visualization concepts on the platform and systematically test different alternatives and evaluate those.

This paper presents and discusses a proposed method for conceptual explorations for visualizing environmental data, using a so-called sandbox model (see chapter 2) with fictitious data. The following research question has been in focus: How can a sandbox model be used for the design and evaluation of visualization concepts in urban 3D-models? Our research includes several projects all focusing on information visualization of environmental parameters in urban 3D-models, however, this paper focuses on one the projects, *MiljöVis - Effective representation of environmental information in infrastructure models* to exemplify specific aspects. This project explores new solutions for environmental data visualization in Trafikverket's geographically large-scale 3D-models, illustrated for noise pollution data. In the project two platform prototypes for concept exploration were developed: a prototype on a smaller scale, a so-called sandbox model, and a prototype of a large-scale model. In this paper we focus on the sandbox model, a fictitious 3D-model with a selection of the most important functions and elements of the built environment.

We base the term urban 3D-model on the definition by Döllner's et al [10] of a virtual 3D-city model as a model containing spatial and geo-referenced data over an urban area that includes terrain models, landscape elements such as vegetation, buildings, roads, and transportation systems. We expand this concept to include any area with existing or proposed man-made infrastructure. In general, visualizations and auralizations with immersive tools such as Augmented Reality or Virtual Reality work well in 3D models. However, as the focus in paper is on the information visualization and the related workflow to develop design concepts for visualizations, we apply desktop visualizations in a sandbox model.

2 Theoretical framework

Sketching is a way to represent and summarize information in visual format and is particularly effective because of its immediacy. Representation is essential in design work [11]; while representing a concept visually, new properties might arise that were not thought of initially; as expressed by Ware [3, p. 3]: "visualization allows the perception of emergent properties that were not anticipated. The perception of a pattern can often be the basis of a new insight." Concepts need to be understood to a certain extent in order to be reproduced into a visual output. In architecture and design information is communicated with drawings and visualizations throughout the design process [12; 13]. There are various types of sketching methods, with different levels of finishedness, ranging from hand drawn sketches to sketching on a screen aided by different software, all of which are suitable for different phases in the design process [14; 15]. Visual photorealism of information in virtual environments has advantages such as clearer communication [16] but might not always mediate correct understanding [17]. The problem of correctly interpreting and evaluating information in too visually realistic models during the design phases is known within architecture and design research [16; 17; 18]. It is therefore important to choose relevant levels of abstraction and detail for different stages in the process [19]. A fictitious model with a selection of the most important functions and elements of the built environment can help the viewer to focus on the simulated environmental phenomena that is aimed to be visualized; here referred to as a 'sandbox model'.

In research contexts we have found two origins for the term sandbox model; one of which can be found within the financial sector (FinTech), and one within computer science. According to Battaglia et al [20] and Leckenby et al [21] the so-called "regulatory sandbox model" seems to be originating primarily from the FinTech area where it was first used to further business innovation and to provide consumer safety. Within computer science the original sandbox model was a so-called security model provided by Java. The purpose of it was to ensure a secure environment for running untrusted code from open networks. [22] The concept has since then evolved and applications of the sandbox model can now be found within a wide variety of research areas where new technologies are implemented and tested and in different ways, such as satellite remote sensing [23], business law [24], AI research [25], computer science and software engineering [26], citizen science [20] and health care [21]. A common trait for the sandbox model in all these different applications seems to be that it is a safe space in a simplified environment to develop and test new methods and technological solutions (see Fig. 1).

Our own application of the sandbox model is to adapt and use it as a design tool within the area of urban planning and visualization research. We define the concept as an architectural 3D-model of a fictitious urban environment, built on fictitious data, where scenarios and situations are visualized and evaluated. It functions as a context and while being a testbed, it is designed to fit the needs of the study, I.e., it must contain relevant aspects to study concerning landscape and built environment. The design takes into consideration aspects such as level of detail, scale, and urban complexity.

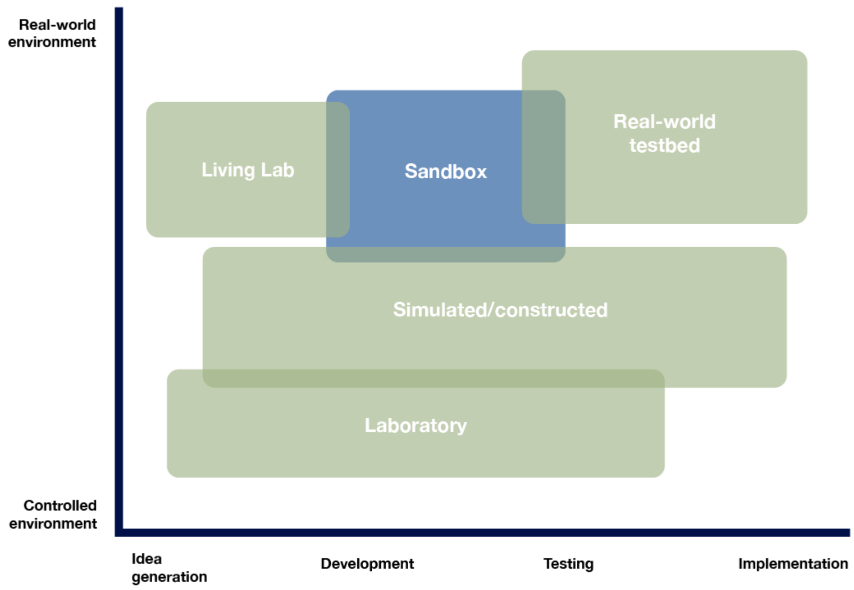

Fig 1. Different environments for elaboration within innovation and development, showing the placement for our sandbox model approach. Image adapted from Arntzen et al [27].

3 Development of methodology through application

This chapter presents the development of our research approach through design-based elaborations and gives a context to our research which we use to illustrate with examples. It describes the workflow for the development of design concepts, the development and design of the sandbox model platform and gives examples of how it can be used in the design of concepts for information visualization in 3D. The chapter concludes with examples from our user tests in workshop settings.

Our research is of a transdisciplinary nature and includes a combination of different methodologies, with emphasis on a qualitative and experimental approach. Most of the applied methods are connected to simulation and modeling research [28, pp. 275-300]. Primarily, a design-based research method was used and applied in an iterative process all the way from analog sketching to digital implementation [29]. Visualization concepts with scenarios were developed, applied in the sandbox model and at a later stage on the Digital Twin Cities (DTCC) platform [30], and user tested in iterative, cyclic processes.

3.1 Context to the research projects

The research projects which we base this paper on have aimed to develop new knowledge about how complex object-oriented information models, so-called coordination models, can become a more effective means of communication and quality tools. The projects also aimed to develop and evaluate new visualization solutions for the integration of environmental data. A more specific purpose has been to, in these models, be able to predict the effects of various implemented measures more easily and to be able to integrate different types of invisible effects, for example noise simulations and health effects, in one and the same model.

The studies on environmental data were based on Trafikverket's defined environmental areas and environmental protection areas, and focused on the environmental areas of noise, air quality and social sustainability. All three areas were initially treated in the project, but in-depth studies with prototype development focused on noise.

Various concepts for visualization solutions were developed which were evaluated in a series of user tests. To be able to demonstrate different visualization solutions in Trafikverket's coordination models, development of a workflow to generate digital twin models and visualize large-scale data was included but is not in focus in this paper.

3.2 Workflow for development of design concepts

In the work to develop the design concepts, three researchers, a designer and three programmers worked in the project in an iterative process, where scheduled meetings were supplemented with ongoing communication, primarily via email and Slack. The researchers' area of expertise was visualization in urban development, dialogue and planning, the designer had expertise in architecture and graphic design, and the programmers' specialties were platform development and Unreal Engine. The designer had the role of bridge between the researchers and the programmers, working closely with both groups. The researchers developed the design concepts and formulated how these would be tested in the sandbox model in a "storyboard" in PowerPoint in collaboration with the designer. The designer worked from the researchers' wish list and visualized the concepts, which were then programmed and implemented in Unreal Engine.

3.3 Sandbox model platform

The central motivation for using a sandbox model is that in such a model a fictitious world can be created, containing exactly the aspects in focus to study based on user needs. In a real project, the model usually does not contain all relevant aspects. We designed and developed the sandbox model to be able to work with different design concepts for the data. The requirements for the model were that it should include certain relevant and typical parts of a Swedish landscape, both regarding the built environment and surrounding nature. The built environment would first and foremost include a railway through the landscape, including a tunnel. In addition to the railway itself, the settlement would consist of both scattered farms and a smaller settlement, as well as roads that connected the different parts. The urban area would consist of mixed buildings: different types of housing, sensitive areas such as nursing homes, schools and kindergartens, office buildings, some industry and a centrally located railway station. The surrounding landscape would include arable land, forest areas and a lake. Elements composing the sandbox model were designed to resemble a typical context without describing any specific real place. From vegetation to housing typology, to the proportion of infrastructure, street canyons and landscape, the elements were inspired by randomized local examples (see Fig. 2-4a, b).

Fig. 2. Sketch of the plan for the fictitious study area, as a base for the sandbox model.

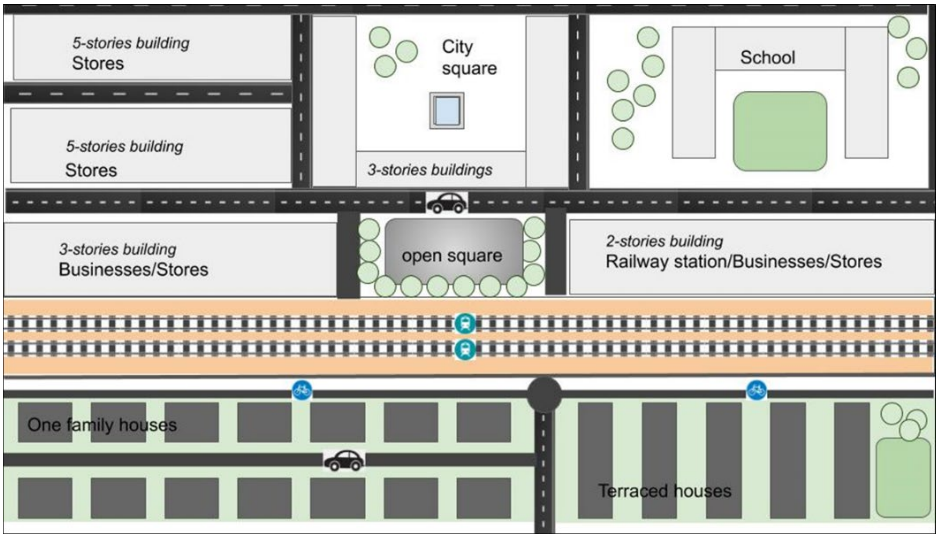

Fig. 3. Detailed sketch of the plan for the fictitious urban area included in the sandbox model.

Fig. 4a, b. Parts of the sandbox model, created in Rhino (Rhinoceros 3D).

3.4 Design concepts for information visualization in 3D

In the sandbox model, design concepts can be developed and explored for visualizing environmental data, in our projects the focus was primarily on noise in motion. The elaborations were based on discussions with specialists at Trafikverket regarding end user needs. The visualization aspects that were explored focused on shapes, primarily draped heatmaps and volumetric visualization (see Fig. 5a,b); colour and transparency (see Fig. 6); level of detail for data information in the user interface (see Fig. 7a,b), and for the surrounding environment (see Fig. 8a-c); for the selection of data in the model (see Fig. 9), perspective (see Fig. 10a,b); symbols (see Fig. 11a,b); and scenarios (see Fig 12a-c). The different design concepts were first modeled in Rhino and then developed as visualization prototypes in Unreal Engine.

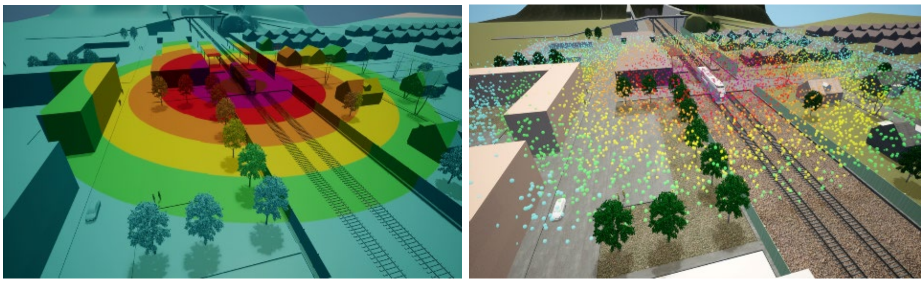

Fig. 5a, b. Examples of conceptual shape design for visualizing noise in motion: a) draped heatmaps for surfaces and b) point cloud visualization for in between spaces.

Fig. 6. Diverging, sequential and spectral colour scales based on different principles, such as colour choice, contrast, lightness, chromaticness, colour deficiency [3; 4; 31; 32] and different ranges. Some colour scales also included different transparency levels.

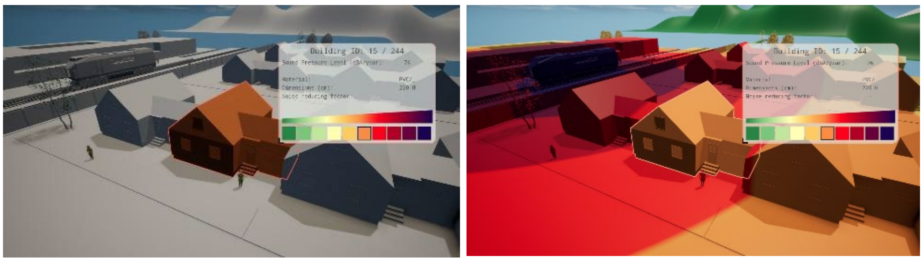

Fig. 7a, b. Exploration of how to reach different levels of detail for data information in the user interface.

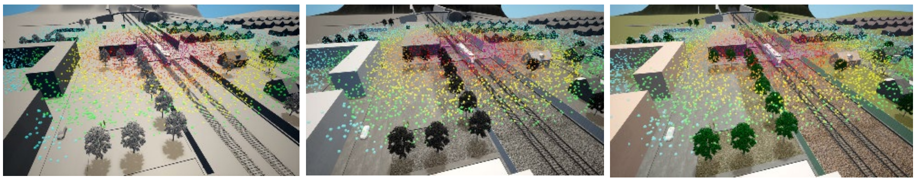

Fig. 8a, b, c. Exploration of how different levels of detail in the sandbox model affect the noise data visualization.

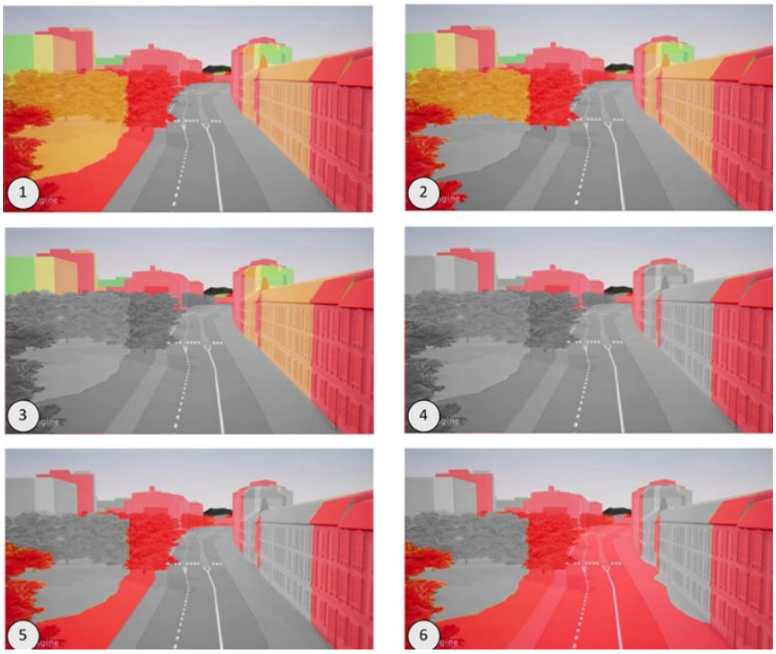

Fig. 9. Exploration of different ways of filtering data to show.

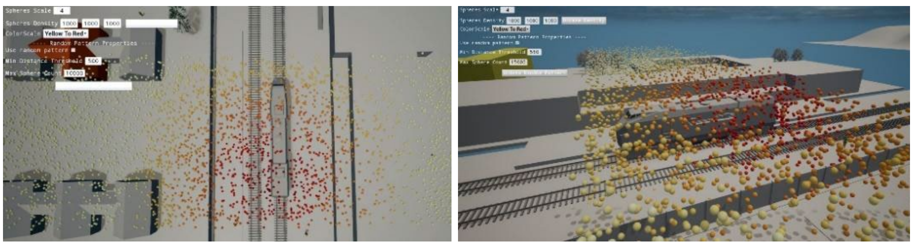

Fig. 10a, b. Exploration of different perspectives to view noise data in.

Fig. 11a, b. Exploration of integration of different types of 3D-symbols in the model.

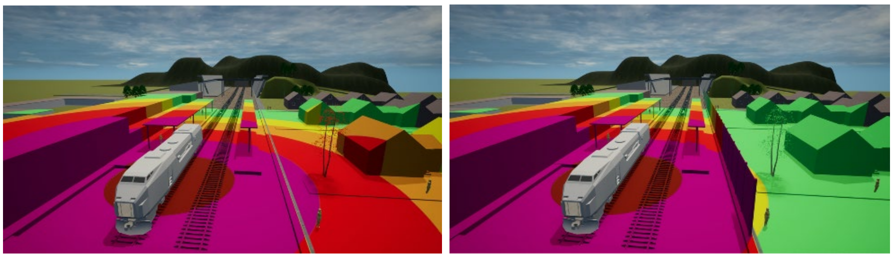

Fig. 12a, b. Exploration of scenario visualization, here a noise barrier by the railway.

3.5 User tests in workshop settings

In the MiljöVis user tests the design concepts in the sandbox prototype were evaluated and investigations were conducted on how different stakeholders interpret, understand, and experience the different prototypes (decision makers, specialists, the public). The user tests consisted primarily of workshops with end users at Trafikverket (specialists in the environmental areas Noise and Air, representing experts), and students (representing non-experts) from the areas of interaction design and architecture at Chalmers and Gothenburg University. Internal evaluations with the research group were also conducted, as well as interviews with specialists at Trafikverket, and results were analyzed in a cyclical process where researchers, designers and developers collaborated. However, the most extensive user tests were carried out in the workshops, where more elaborate concepts were shown and systematically evaluated. A total of ca. 250 people participated in five workshops. The workshops had a similar structure, but at the same time they were adapted partly to the needs of the target groups and partly to the project stage in which they were carried out (see Fig. 13).

Due to the pandemic, all user tests were conducted remotely on Zoom, and the tools used were chosen to be specifically suited for digital evaluation including Miro, Mentimeter and Zoom poll.

Fig. 13. Example from the workshops with specialists from Trafikverket, and students from Chalmers and Gothenburg University. In these workshops participants evaluated visualization solutions, and discussed user needs for different target groups.

4 Proposed guidelines for conceptional elaborations in a sandbox model for visualization of data

What is needed to create a sandbox model, how can it be done? In this paper we investigate different aspects of what is required to effectively visualize environmental data in coordination models. Based on experiences from our research, we suggest a workflow for how to test results in a sandbox model by the following points for development of information visualization in 3D-city models (see Fig.14).

Summary of concept development for information visualization in an urban 3D-model

1. Motivation for visualizing data in 3D, for example:

- To show the data in different spatial locations (x,y,z)
- To show the data in different scale and perspective
- To show different scenarios and consequences
- To show invisible parameters (e.g., air, noise, vibrations, meteorological phenomenon, safety, health, accessibility)
- Other reasons

2. Identifying and selecting target groups, and ways of visualizing data, with e.g., following methods:

- Research publications
- Focus group discussions
- Workshops
- Interviews

3. Defining what kind of data to focus on, for example:

- Domain (e.g., environmental, health, social, etc)
- Format (.dwg, .ifc, .fbx, etc)
- Dimension (e.g. 2d, 3D)
- Relevant attributes and metadata
- Geographical bounds
- Resolution (level of detail)
- If several datasets, make parallel lists and define which of the data sets to show in 3D and in 2D

4. Developing the sandbox model before developing the realistic location bound 3D-model, for example:

- Software (Sketchup, Rhino, Unreal Engine, Unity, etc)
- Design of the assets for the geographical 3D environment (buildings, landscape, road, vegetation, ...)
- Level of realism of the 3D environment (low abstraction level, photorealism, colouring, etc)

5. Developing prototypes for visualization of data, with methods for:

- What? (e.g., colour scale, level of information and detail, symbols, etc)
- How? (e.g., draped heatmaps, grid with spheres, particles, etc)

6. Testing the data visualization prototypes in the sandbox model:

- Adjust solutions both in the sandbox model and in the data visualizations
- Internal evaluations in the research group
- Iteratively develop solutions for further testing

7. Adapting the visualization to the needs of the target groups:

- Test different solutions according to the target group (different stakeholder groups, experts, non-experts, senders and receivers of information, citizens, etc.)
- Test different solutions according to purpose (e.g., stakeholder dialogue, domain expert analysis, public information)

8. Developing interactivity for effective and educational communication:

- Demonstrate scenarios (current situation and impact of different solutions) for a better understanding of the impact of different proposals at early stages
- Filter/delimit information according to needs
- Enable selection of visual level of detail and information as needed
- Use animations/films to show complex and moving data to provide an holistic picture and more effective communication

9. Developing methods for displaying multiple parameters (different data layers) simultaneously to:

- See links between different impacts, e.g., effects on environment and health
- Allow a more extensive picture of the situation
- Identify conflicts between different areas and parameters by comparison

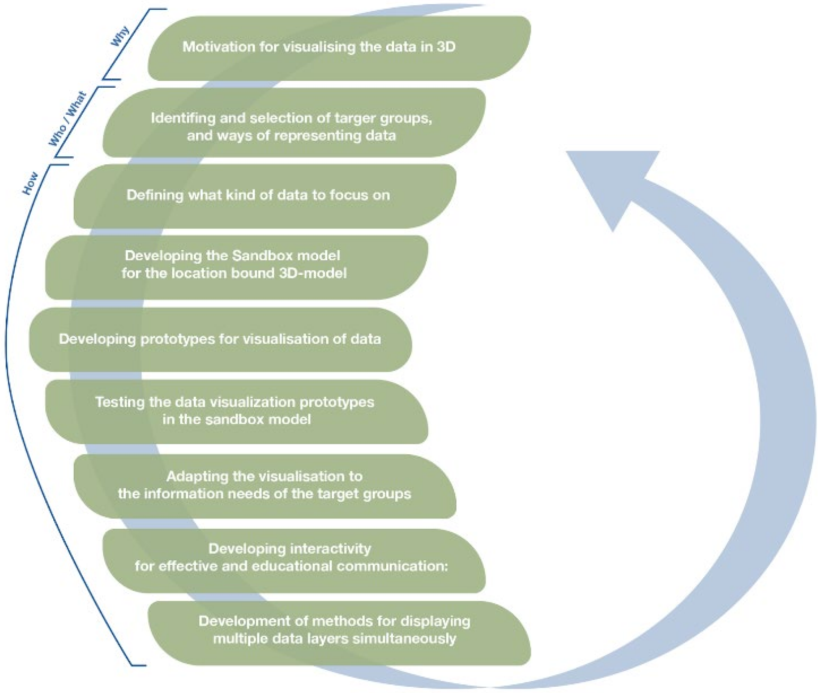

Fig. 14. Summary of concept development for information visualization in an urban 3D-model.

5 Concluding remarks

By developing a visualization language for representation of complex data in 3D models we can contribute to a clearer means of communication, more efficient decision-making and to a simpler quality assurance during the planning and construction process, as well as to see synergies and conflicts between different target images.

Our research aims to develop and evaluate interactive prototypes in 3D-models with scenarios showing different ways of visualizing environmental data, with the goal of facilitating understanding between different stakeholders in urban development. A central challenge in this kind of design-based research is that the development work and the creation of the model platform combined with data collection usually takes much more time than allocated for, leaving little time for the actual concept development. To put focus on the visualization of concepts for showing environmental data we therefore propose to do initial elaborations in a fictitious model, a so-called “sandbox model” with fictitious data. In this paper we have shown examples from such projects in collaboration with Trafikverket. This research approach contributes to developing new methodology for information visualization of environmental data in urban 3D-models.

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