Research Paper

Standardization of visual representation of noise and air quality for social consequences in urban planning

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Abstract

Noise and air quality remain major environmental problems affecting the health and well-being of millions of people in Europe. According to the World Health Organization, noise is the second largest environmental cause of health problems, just after the effects of air pollution. Therefore, data regarding these phenomena must be clearly represented and communicated to different stakeholders to mitigate their adverse social consequences. Standards are usually used to facilitate consistency and uniformity when representing different data. Therefore, a clear and standardized representation of invisible data such as noise and air quality is necessary for the infrastructure industry. This study aims to establish the state of the art of existing representation and visualization of noise and air quality, identify any existing standards in these data visualization processes, and understand if a standardized visualization can impact people's well-being. Following the PCC framework, a scoping literature review was adopted for the study in conjunction with semi-structured interviews carried out with experts in the fields of data representation of noise and air quality. The study will provide existing visualization patterns in the areas of noise and air quality across the infrastructural sector and conclude on the relevance of standards for 3D representation of noise, air quality, and other invisible data. A coherent representation will streamline and improve the comprehension of environmental data and contribute to improving people's well-being.

Keywords

Noise, Air-quality, 3D Visualization, Social consequences, Urban environment.

1. Introduction

As the urbanization process continues to advance, an increasing number of people are pouring into cities, exacerbating the impact of the urban environment on people's health (Wu et al., 2020). The increasing impact of the urban environment on people's mental health also requires better identification of the environmental factors that affect people (ibid) and the relationship between environmental and social data is undoubtedly relevant (Pye et al., 2008). According to (Pye et al., 2008), environmental quality also affects health and well-being through direct impacts (e.g., air quality effect on respiratory function) or indirect impacts (e.g., well-being affected by perceptions of environmental quality, reduced opportunities due to lack of investment in areas with degraded environment). Furthermore, they define three broad areas of impact: health impacts; socio-economic impacts on households and communities, and perception of environment and well-being effects.

A poor-quality environment can lead to different health problems (Pye et al., 2008). Invisible environmental data i.e., that which takes no geometric form such as water quality, waste management, vibrations, energy consumption, noise, and air quality are key to the perception of the well-being and surroundings and therefore must be considered in the design of new infrastructural developments (Wästberg et al., 2021). In urban planning, data representation constitutes a fundamental aspect of communication with different stakeholders (Ibid.). To facilitate decision-making amongst these stakeholders, many cities are adopting digital city models that allow the integration of vast information (Wästberg et al., 2020). These are referred to as coordination models by The Swedish Transport Administration. A coordination model is defined as a complex object-oriented information model (Wästberg et al., 2021). A coordination model allows project stakeholders, including government agencies, private companies, and the general public work together effectively to achieve common objectives with little to no conflict. Coordination models facilitate collaborative design between the different agents, allow graphic documentation to be updated in real-time, and prevent execution problems and additional costs (Fernández, 2023).

For the proper management of urban projects, large coordination models are needed. Those models today include vast and various types of information that make those models heavy and difficult to handle (Wästberg et al., 2021). Data usually included in large coordination models could be infrastructure data, land use data, demographic data, economic data, traffic data, social data, and invisible environmental data.

The representation of these invisible parameters in a visually comprehensible manner for different target groups remains a challenge (Billger et al., 2017). In recent years, efforts toward 3D visualization of invisible data have been made (Wu et al., 2020). General challenges in data visualization include the combination of different data formats from different sources as well as representing several different parameters in a single model. Particularly, the challenge for 3D models is how to incorporate photorealism and symbolism in the same 3D model (Billger et al., 2017). Visualization of data in spatial 3D models allows for the conveying of a better understanding of the respective environmental aspect and allows for the display of information that might not be visible in reality (Wästberg et al., 2021). Hence, providing a clearer understanding of abstract phenomena and allowing for a more informed decision-making process (Ibid.). Hence a standardized way of visualization of this data in these 3D models aids in clearer understanding.

Among other reasons, standards are commonly used to ensure consistency and uniformity, i.e., to establish uniform practices, guidelines, and procedures that could help eliminate variations and inconsistencies in processes, products, and services, ensuring a consistent and predictable outcome. This simplifies decision-making, improves efficiency, and reduces errors or misunderstandings. However, standards for representations of invisible data don't seem to exist. In fact, there are no clear requirements on how most invisible environmental data should be represented in a model. Each stakeholder interprets and represents the requirements in a different manner and hence the models vary in representation and scope (Wästberg et al., 2021). Consequently, considerable time must be spent by specialists on models each time a new supplier enters the field. This means that models differ in basic structure, and it becomes a challenge to conduct quality assurance and develop efficient and automated working methods (Ibid.). This creates a need to clearly streamline which objects, the level of detail, and what type of information should be included in the coordination model to advocate for a certain level of homogeneity. Hence information about invisible data must be represented in a clear comprehensible format using standardized choices regarding symbols and colors (Ibid.).

Therefore, the aim of this study is to investigate the state of the art of existing representation and 3D visualization techniques to establish any existing standards in this data visualization process and to identify a possible relationship between invisible data representation and social consequences. In order to restrict the field of research, the two invisible data chosen for the case study are noise and air quality as they both have a proven high impact on people's health (McAlexander et al., 2015; Miranda et al., 2016).

For this study, the formulated research questions are:

1. How can invisible parameters such as environmental data of noise and air quality be represented in large 3D urban models in a manner that can be readily understood by different stakeholders?

2. How is environmental data in urban planning visualized today?

3. What is the relationship between the representation of invisible environmental data i.e., noise and air quality, and social consequences with a focus on health and well-being?

This study started as a contribution to the research project MiljöVis (Effective representation of environmental information in infrastructural models) that aims at developing new knowledge on how complex object-oriented information models i.e., coordination models can become a more effective means of communication (Wästberg et al., 2021). The project is a collaboration between Chalmers University of Technology, Trafikverket (The Swedish Transport Administration), and Digital Twin Cities Centre (DTCC).

This paper consists of six sections. In Section 2, the research methodology is explained. Section 3 presents the research results. Section 4 presents the discussion. Section 5 provides the conclusion, including limitations and suggestions for further studies. Section 6 is dedicated to the reference list.

2. Methodology

For this study, two research methods have been employed: a scoping literature review and semi-structured interviews. Both approaches are described in the following 2.1 and 2.2 paragraphs.

2.1 The scoping literature review

A scoping literature review has been conducted to investigate the state of the art regarding the visual representation of noise and air quality in the 3D urban context. The Prisma population, concept, and context (PCC) framework for scoping review has been followed and populated as shown in Table 1. For the review, synonyms of concepts have been used.

Table 1. PCC framework for scoping review.

PCC framework	Concepts
Population	Noise, Air quality, Invisible data
Concept	3D visualization
Context	Urban environment

Scopus database has been used as the focus is on peer-reviewed articles. Proximity operators have been used to narrow the search toward the research scope. Subject areas have been limited to Energy, Computer Science, Environment, Decision Sciences, and Multidisciplinary. Only English articles have been included. Limitations based on years of publications have not been applied. All the results have been exported in RIS and imported into the online software Rayyan. Rayyan was used for individuating and removing duplicates (0 for noise, 95 for air quality) and for the following first screening of the papers, where inclusion/exclusion criteria were based on the relevance of titles and abstracts. From Rayann, the included papers, i.e., those relevant to the scope of the research (44 out of 99 for noise and 129 out of 1685 for air quality), were exported in (comma-separated values) CSV format. The CSV file was then restructured in Excel. Using the Digital Object Identifier (DOI) of all papers, when possible, PDFs were downloaded for further analysis. The retrieved pdfs were run through a Python script that retrieved all papers that included figures. This further narrowed down the papers that were relevant to the scope of the research.

2.2 The semi-structured interviews

Experts within the fields of noise and/or air quality data use, creation, and representation have been interviewed. The respondents were recommended by MiliöVis' researchers and represented Swedish agencies, the international research community, and one international consultancy company. Six respondents are employed at the Swedish transport agency (code A in Table 2), while one of them is currently holding also a position at one Swedish university (code AB). Two are employed at another Swedish university (code C). One works at the Swedish Environmental Research Institute (IVL) (code D) and two at the international consultancy company (code E). The respondents are documented in Table 2 below, which includes the respondents' background information and assigned codes. The codes consist of a number and a letter, with each letter referring to a different company (codes A, B, AB, C, D and E), and respondents from the same company were denoted by the same letter followed by a different number. Two respondents from the same organization opted to have a conjunct interview. Interviews were conducted in English or in Swedish based on the respondents' preferences. A semi-structured interview guide was prepared in English and translated into Swedish for the interviews to be conducted in Swedish. The interview guide comprised twelve questions that included similar questions to formulate a clear understanding of the respondents' background and the organizations that they represent and different questions based on the respondents' specialty: data users, data manufacturers, or researchers. All interviews have been conducted between March 24 and April 19. All interviews have been recorded, transcribed, analyzed, and summarized. The summaries have been sent to the respective interview for validation. Only one respondent has asked to exclude his interview results from the dataset, all others have been analyzed and are part of these research results.

Table 2. Interview respondents.

Code	Specialty	Experience (years)	Focus
A-1	Data user	19	Noise
A-2	Data user	16	Noise and Air Quality
A-3	Data user	4	Air Quality
A-4	Data user	2	Noise
A-5	Data user	3	Planning
AB-1	Researcher	30	Noise
C-1	Researcher	18	Noise
C-2	Researcher	36	Air Quality
D-1	Data user	33	Planning
E-1	Data producer	6	Air Quality
E-2	Data user	23	Noise

3. Results

The results are presented in two sections. The first is the literature review conducted and the second from the semi-structured interviews. The semi-structured interviews are further presented in three sub-sections. The first discusses the results regarding noise representation and standardization, the second presents air quality representation and standardization, and lastly a presentation of the relationship between this environmental data presentation and social consequences as pointed out by the respondents.

3.1 The literature review

Despite a substantial number of revised papers, only nine have a visual representation of noise and are mainly in 2D. Among them, only four represent noise in 3D (Haedrich and Breton, 2020; Liangliang, 2020; Y. Wu *et al.*, 2020; Bharadwaj *et al.*, 2022) while one paper represents it in 2D, and 3D (Bharadwaj *et al.*, 2022).

Among the one hundred twenty-nine reviewed papers, only twenty-three have a visual representation of air quality. They include (Buccolieri *et al.*, 2022; Zhu *et al.*, 2016; Tashayo and Alimohammadi, 2016; Putrenko and Pashynska, 2017; Schneider *et al.*, 2017; Hammond, Chen and Mallet, 2020; Lopez-Restrepo *et al.*, 2021; Song *et al.*, 2021; López-Noreña *et al.*, 2022; Myshko and Kurakina, 2022; Quaassdorff *et al.*, 2022; Wang *et al.*, 2022; Saidi, Valari and Ouarzazi, 2023), three of which are in 3D (Saidi, Valari and Ouarzazi, 2023; Buccolieri *et al.*, 2022; Zhu *et al.*, 2016).

None of the papers adopt or discuss a standardized representation of noise or air quality, but the different papers use different colors and/or representation methods. For noise, often the red-to-gray scale is used where red corresponds to the highest level of noise and grey to the lowest. For air quality, the color blue is often used, too.

None of the analyzed papers discusses social consequences in the context of noise and air quality representation or the relevance of representation to mitigate them. Mainly, the papers focus on analysis, simulations, and/or modeling of noise or air quality, suggesting an ad hoc representation.

3.2 The semi-structured interviews results

The semi-structured interviews have been analyzed by dividing the answers into themes: noise, air quality, and social consequences as the main driver. The themes have been defined based on the topics addressed by the research questions. Results are summarized in the following sections.

3.2.1 Noise

Regarding noise representation, the respondents gave different, sometimes contradictory responses. Findings indicate that noise is represented differently depending on the use and the target audience and the level of detail. The respondents in the consultation field have in-house templates for the representation of results depending on the customers. This typically dictates what data they collect and how they present the results to the customer. And this is also majorly the case because there are no clear guidelines on either the European level or national level that clearly describe the visualization protocol of noise data. On the other hand, the Swedish transport agency for example has its own color-coding scale that is followed for 2D noise mapping. Therefore, the consultants do follow such guidelines when they present noise mapping for the Swedish transport agency. No such color coding exists for 3D noise mapping yet.

According to most of the respondents, noise mapping in most of the projects is in 2D. C-1 points out that the merit of this over 3D is its ability to be easily comprehended even by non-experts. He adds that to a layman, 3D would require an explanation of the different facade color variations on the buildings, but if seen from above, i.e., in 2D, they can only visualize one color and accept that that's the noise level. Additionally, E-1 stated that 2D is not only easily understood, but also gives a better overview compared to 3D since it provides a representative aerial view, while 3D representations for example of a road wouldn't give a good overview and it requires several viewpoints and hence indicates the preference of 2D over 3D most of the time. However, E-2 stated that 3D noise mapping is most applicable in buildings where the data is height dependent and there is a need to ascertain the noise level variations depending on the height from the ground. This makes 3D noise mapping more applicable for planned residential houses. AB-1 believes that it is important to represent noise in both 3D and 2D. She points out a simplification of this by producing photomontages but also 3D with orthophoto to facilitate understanding of where the viewer is. She added that as much as 3D is important, it's not always needed. A-4, on the other hand, believes that 3D representation is most appropriate to decision makers as compared to 2D because that doesn't require going into intrinsic details. A-5 indicates that 3D representation is *"a lot of work"* and should be performed only if necessary. In some cases, some results produced by consultants are represented as written documentation with graphical illustrations in 2D and 3D contour maps where necessary.

No clear official standards emerged from the respondents regarding the visual representation of noise. However, guidelines and good practices at both European and national levels were cited by different respondents. Other respondents clearly indicated that they weren't aware of any standards to represent noise. A few responded that yes, standards exist, but could not clearly provide any reference for them. AB-1 indicates that there is some kind of standards for both 2D and 3D and refers to the 2010 document Instructions for mapping noise according to 2002/49/EC from the SP Sweden technical research institute by Hans Jonasson & Andreas Gustafson (Jonasson and Gustafson, 2002). Jonasson et al. (2002) follow the European Union's Good Practice Guide based on the 2002 Environmental Noise Directive (END) (THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2022) and elaborate guidelines to the Swedish conditions. The guidelines extensively describe calculation procedures, how to determine noise contours, and how to quantify the number of people exposed to the noise levels and then make a small mention of how this data should be reported. The guidelines describe four different noise level terms Lday, Lnight, Levening, and Lden. L stays for level and Lden is the weighted daily equivalent level. It follows that noise maps should be produced separately for each sound source for Lden of 4 meters and Lnight of 4 meters. And the noise maps should be represented with the following color coding for 5 decibels (dB) intervals and 10dB intervals (see Table 4 and Table 5).

Table 4. 5dB interval

Sound level interval	Interval color
55-59 dB	Yellow
60-64 dB	Orange
65-69 dB	Red
70-74 dB (Lnight over 70dB)	Violet
75dB and above	Blue

Table 5. 10 dB interval

Sound level interval	Interval color
55-64 dB	Yellow
65-74 dB	Red

75dB and above	Blue

The number of homes and people as well as the total area of the regions exposed to the different level intervals should also be presented separately for road traffic noise, train traffic noise, aircraft noise, and industrial noise. The representation should then describe the calculation accuracy classes used as well as information on the deviations from the specified classes and assumptions made.

AB-1 pointed out that the same colors are used to represent the noise both for 2D and 3D, but caution is needed when the noise levels go lower into the greener or blue area as they can easily be mistaken for water. C-1, who is a researcher and does not require standards, stated that he has noticed that the current noise maps have a different color scheme, and this could be a result of some sort of work being done toward creating standards.

A-2 and A-4 referred to a standard developed by the Swedish transport agency and used for 2D noise mapping. Since this is only applicable to that specific organization, it can be categorized as a norm or unofficial standard of the color scale for noise mapping at the Swedish transport administration rather than an official standard. C2 states that the current noise reports have maps with a pedagogic choice of colors, for example in the investigation of a new area for development, they use red to represent levels that would not pass the noise regulation. He explains that the Swedish regulations have the equivalent level as well as the maximum level, and both levels must be fulfilled when building new housing. Therefore, the consultants produce two different noise maps, one for the equivalent level and the other with the maximum level where different color scales are used for each of the maps. For the map showing the maximum level, red usually indicates an area above the allowable noise level.

C-1 claims that he always represents noise in 3D, but the delivery might be only numbers as his main target are experts and they do not necessarily need a representation. AB 1 states that it is popular culture to represent noise on building facades rather than on the terrain because it’s easier to do and it would require more time to calculate on the terrain. She further indicates that a dynamic way of representing noise data is by allowing the receiver to be able to listen to the sound and believes listening to noise would offer a better experience to the user. Auralisations, which are the demonstrations of the sound of non-existing situations, facilitate making this possible and have already picked up ground in Denmark. These are being used to allow users to perceive traffic noise and to experience the effect of noise barriers to suppress traffic noise. C-1 proposes that dynamic representation of noise would be effective if one intends to represent the distinction between noise propagation during the day and during the night. Then the noise propagation can be represented as a wavefront for example, and this would be intuitive and facilitate better understanding for both experts and non-experts.

3.2.2 Air Quality

A-3, an expert in the air quality field, pointed out that air quality is visualized both in 2D and 3D depending on the nature of the project. He notes that 2D visualization of air quality is advantageous over 3D because 2D spans a larger geographical area, therefore, 2D produces a better overview as compared to 3D. 3D on the other hand would allow to focus and zoom into a specific area and study closer details. He concludes by stating that both visualizations are crucial and any focus on just one of them would cause losses in another aspect, i.e., focus on 2D would create deficiencies in detail views and sole focus on 3D would breed deficiencies in the overview. C-2 notes that in 2D and 3D air quality representations, the concepts of color scales, temperature, and contrast are in some cases taken into consideration, with contrast being used to emphasize key messages. Greyscale was more common than color in the past time because it was expensive to print color. He advocates for 3D representation for several reasons among which the fact that 3D provides local variability and air pollution varies with elevation above the ground, especially in the countryside where there is different land use with forests, arable fields, and so on. It's important to note that the concentration of air pollution varies considerably over short distances and is affected by temporal and meteorological conditions. Hence, the air pollutants vary both vertically and horizontally and this would necessitate 3D representation in a local urban environment scale. He mentions that scientific papers about air quality represent it in three dimensions to some extent as diagrams on three axes.

E-1, an air quality expert in the private sector, notes that the representations are done differently across the different consultancy firms. For example, his firm uses colors and lines with numbers in their maps, while one of their competitors doesn't use any colors but black lines with numbers. The colors are represented against the different air quality standards. Green is usually used to represent when it is safe and under the air quality objective and red if it is above the allowable level. E-1 works with both 2D and 3D maps, but the majority of the time work is done in 2D because of its simplicity and commonality. However, 3D is created when building structures are involved. Color projections are used both above the ground and on building facades. In Denmark, advanced Computational Fluid Dynamics (CFD) models are also produced to facilitate visualization, and these can be used to create a dynamic means of air quality visualization. 3D maps are also used in air pollution data centers to assess cooling capabilities, wind effects, and air quality to have a better representation of the result. A-2 described that one of the ways to visualize air quality is by having maps with circular polygons to indicate the particle concentration in the atmosphere. The diameter of the particles is directly proportional to the particle concentration.

E-2 indicates that standards on air quality are available both at European and national levels. He points out that indices for air quality at the national level exist for 2D but nothing for 3D and uses the SLB standard for visualization. E-1 on the other hand says that he is not aware of any standards on air quality visualization and there are few guidelines on how to perform the modelling and present this data both for 2D and 3D. He makes mention of the reference laboratory for air quality modeling that offers some direction. Therefore, the consultant decides on how to present this data to the client. The Swedish APA offers some guidance and NFS 2019:9 gives an idea on how to present the results and at what height but nothing much in detail.

One of the private companies in which two of the interviews are employed has developed a cloud-based Digital Twin (DT) SHAIR that tracks and visualizes air quality in real time. Developed cities across the globe have installed sensor networks to keep track of the vast amount of air quality data and the DT is used to process and visualize this data. This cloud-based DT provides a coherent picture of air quality status and challenges allowing pollution hotspots and sources to be readily identified.

3.2.3 Social consequences as the main driver

"Without information, people don't know they can invest in their health" [C-1]

Several interviewees agree on the fact that social consequences are the main drivers for the work they do. A3 particularly states that one of their goals is for people to want to live in the areas in which they reside, and if these residents can effectively visualize this environmental data, it creates a sense of comfort and which per se improves their well-being. E-1 pointed out the Environmental and Social Impact Assessment (ESIA) reports that they generate, where the aim is to determine the relationship between the concentration of particles and the health effects. However, there are no maps to visualize this kind of correlation. AB-1 presented a paper at the Inter-noise Scottish event campus in Glasgow on the effect of noise on sustainability and believes noise can destroy lives. The paper's conclusion suggests that noise maps produced by the member states should be available to the public. This would allow people to make a choice of their housing based on these visual noise maps. C-1 believes that this is the sole purpose of the effort to have effective visualization and presentation techniques. If the exposure to these harms of noise and air quality can be easily visualized and understood, this would influence people's behavior and impact their decisions. This in turn puts pressure on the noise producer to reduce the noise they generate. The more visible it is, the easier it is to convince people. Therefore, there exists a financial incentive in the long run. In the case of building developers, it would be in their best interest to keep the noise levels at a minimum to attract customers. C-2 notes that environmental investigations suggest that well-represented environmental data has a direct relationship to decision-making. The UN pollution convention has presented that documents with potential effects of reducing emissions have played a major role in that effect. Therefore, there lies an obligation from the generator of information to consider the recipient. In the case of an expert in the field, the communication process can be complex; but for the good of the well-being of the general public, the information must be communicated effectively and efficiently to facilitate informed decision-making.

4. Discussion

4.1. Visualization of invisible parameters

Effective visualization of environmental data plays a major role among stakeholders in the planning process to allow for more sustainable solutions (Wästberg et al., 2021). Indeed, this has been evidenced both in the literature review and the interviews conducted. Noise and air quality are being objectively represented as either a written document with calculation levels and may or may not include graphs and or mesh plots, 2D maps, or 3D maps. Furthermore, noise is subjectively represented through auralization listening tests (Llorca-Bofí et al., 2022). The consensus from the interviews conducted showed a substantial preference for 2D representations over 3D based on clarity, simplicity, and time efficiency. The interviews stated that different audiences require different levels of detail, and this is a baseline factor in the choice of presentation. The nature of the project in turn dictates the representation format; visualization of noise regarding building structures is more representative in 3D due to varying characteristics based on heights than in 2D while noise terrain models along a road are better presented in 2D to produce a better overview. Therefore, effective comprehension of noise and air quality data can be achieved in more than one way without necessarily affecting the accuracy of the information.

Current studies have shown the possibility of integrating both visualization and auralization. Josep Llorca-Bofí et al (2022) argue that current noise mappings are limited to sound levels in frequency bands since they do not consider temporal and spectral information of the sound signals. Thus, it's impossible to analyze the true sensation of the sound perception to listeners in the urban environment. Hence, they propose that supporting the auralization technology with the 3D visual counterpart in the urban space provides a coherent virtual representation of the real environment. In their study, climatic conditions are considered since different weather conditions have different medium properties that not only change the visual effects but also the acoustic aspects. The results of this integration of visualization and auralization were presented as a 360-degree YouTube video (IHTApark. Physically-based auralization and visualization, 2022)

4.2 Visualization and social consequences

While the literature doesn't show any concrete results regarding social consequences, most of the interview respondents confirm (Wästberg et al., 2021)'s assumption regarding the relevance of environmental data and people's health. The respondents also agree on the relevance of the visualization of invisible data, and the role this could play during the decision-making process. One of the respondents stressed that "noise can destroy lives and it is unfair", underlining that managing issues related to noise, as well as other invisible data, might have discrimination consequences as well. This aspect has been supported by other interviewees as well as in literature (Ramos-Romero et al., 2022). Another respondent said that "There are environmental investigations that say that if you represent well, you can influence decisions". But also, communicating well "what you are doing" is as important an obligation. Indeed, the communication process must take into consideration, and likely be different, depending on the receiver, however, "communication is important in a democracy, and it is important to make the information available".

4.3 Need for Standards

Standards refer to established guidelines, criteria, or specifications that are widely recognized and accepted within a particular industry, field, or society. The purpose of standards is to provide a common framework that facilitates communication, interoperability, and mutual understanding among different entities. Among the interviewees, some confusion emerged regarding the use of standards or rather guidelines and common practices at a particular agency. However, as supported by (Wu et al., 2020), several agree on the need for standards for the visualization of invisible data, but also to mitigate social consequences, improve people's health, impact decision-making processes, and implement democracy. In this framework, the author claims the need to develop standards for the visual representation of invisible data where both 2D and 3D representations are factored in and where distinctions are made based on the targeted audience.

5. Conclusion

This study aimed to investigate the state of the art of existing representation and 3D visualization techniques to establish any existing standards in this data visualization process and to identify a possible relationship between invisible data representation and social consequences. Results suggest that most of the noise and air quality representation is still in 2D and that a common way of representing those invisible data does not exist. While an unofficial consensus for representation seems to exist, specific official standards do not. The need for standards seems to be confirmed by several interviews. The direct consequences of the representation of invisible data and people's well-being have been confirmed. Reasons span from the concept according to which knowledge is the first step toward well-pondered decisions, to knowledge as a fundamental aspect of democracy. Representation has the power to reach out to a wider audience who can take decisions, and push politicians and society toward a more livable environment.

While the literature review was conducted without any geographical limit, the interviews were conducted only with Swedish experts. This might have produced slightly biased results. However, the interviewees exhibited vast knowledge in the field that goes beyond geographical boundaries.

Future research on the topic should widen the horizon and interview not only local experts within the invisible data field but also international partners. Furthermore, the practical application of the suggested considerations to represent noise or air quality should be part of the following project.

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