Towards visibility and audibility algorithms for assessing perceived safety and security in public areas based on digital 3D city models

Georg Vogelbacher, Jörg Finger, Ivo Häring

Safety Technology and Protective Structures, Fraunhofer Institute for High-Speed Dynamics, Germany. E-mail: *Georg.Vogelbacher@emi.fraunhofer.de*, *Joerg.Finger@emi.fraunhofer.de*, *Ivo.Haering@emi.fraunhofer.de*

The assessment of feeling comfortable, safe and secure versus feeling not at ease in cities is an important issue when planning to (re)design urban built environments such as public areas and residential districts. The general feeling of security in the public space is known to be related to perceived visibility and audibility. Based on digital 3D city models of existing or planned urban spaces, this paper focusses on determining visibility and audibility. Also, other potential quantities are introduced: brightness, overview, and person distribution. It presents a tentative analytical framework and algorithmic approaches expressing the relevant inputs and necessary calculation steps as well as pseudocode expressions. The paper relates the general concept of calculations involved to existing similar implementations in the literature. The proposed calculation scheme for the analysis of visibility and audibility is able to take additional factors into account, for instance exposure of persons, psychological factors, physical perception and transparency of urban furniture regarding view and sound propagation. It is able to consider psychophysical facts like decreasing of visibility and audibility with increasing distance or reflection and absorption of sound waves on urban components. The proposed approach determines visibility and audibility measures intended to be used for planning processes of safer spaces in cities.

Keywords: urban planning, visibility, audibility, brightness, digital 3D city models, safety and security.

1. Introduction

Cities are changing - their populations are growing and new technologies are providing more data and connectivity. The rise of people living in cities, which will lead to structural compaction and new challenges in urban areas. Challenges include: How can the city be shaped to make it safer? How can the subjective perception of security of citizens be taken into account?

Urban sociology has since such landmark concepts as "dance of the street" (Greenberg 1995; Tickamyer et al. 2007) and the "broken windows theory" (Wilson and Kelling 1982; Fuller and Löw 2017) a strong tradition of investigating the influence of the spatial environment and its perception on the actual and perceived level of individual and group-specific safety and security.

In recent time, an ever increasing effort is made to take advantage of the growing accessibility and quality of semantic digital data to investigate and empirically challenge such and similar theories. Examples for digital formats of digital urban data that is accessible include Building Information Modelling (BIM) (Volk et al. 2014), CityGML (Gröger and Plümer 2012), Open Street Map (Haklay and Weber 2008), 3D GIS (Liu et al. 2017) and Google Earth (Gorelick et al. 2017). Urban digital data opens a plethora of applications, see e.g. Biljecki et al. (2017).

After the introduction, which showed that digital semantic urban spatial data is used for an extensive range of applications the paper is organized as follows. Section 2 announces that this data is expected to be usable also for urban safety and security spatial assessment. Section 3 will investigate which approaches are already available with potential for determining visibility and audibility. Section 4 provides an overview how safety and security quantities based on digital urban spatial data are used iteratively for improving scenarios. Section 5 provides (textual) algorithms to compute visibility (seeing and being seen). Section 6 and section 7 cover overview / visible space and audibility respectively. Section 8 briefly addresses additional and auxiliary quantities such as brightness and person density. Section 9 summarizes and concludes.

2. Challenge of identifying unsafe and unsecure urban areas using digital city data

Key aim of the project Urban Security 3D (German: Stadtsicherheit-3D) is to support the collaborative and informed increase of safety and security and its perception of people living in

Proceedings of the 29th European Safety and Reliability Conference.
Edited by Michael Beer and Enrico Zio

Published by Research Publishing, Singapore.
ISBN: 978-981-11-2724-3; doi:10.3850/978-981-11-2724-3_0122-cd

cities by resorting to semantic digital urban 3D data, which is increasingly commonly available.

The design of public spaces makes a significant contribution to ensuring that people in their environment feel safe and that crime can be prevented. Such quantities as visibility of persons in public spaces, audibility, local brightness, and easy orientation play a decisive role.

"Places of fear" are to be understood as (urban) spaces in which the citizens do not feel well, for example because these areas are deserted, rather dark or dimly lit, such as remote platforms or underpasses. Also urban parks at night, sparsely populated areas or industrial areas can be areas of fear.

Digital semantic models contain additional information that is important in modeling besides purely geometric building information like geometrical shape and height. For instance additional information about use of a building can be used to estimate the number of persons present in buildings.

Generally we believe that spatial factors can be identified, operationalized and taken into account in modelling. The procedure can be demonstrated on the basis of the operationalization of poor visibility, poor audibility and (percentage of) areas hidden from view. This paper focusses on visibility and audibility of persons on public places.

3. Existing similar implementations in literature (related work)

3.1 *Visibility – related literature*

Chmielewski and Tompalski (2017) provide a good overview on different visibility modeling methods distinguishing between ray, surface and voxel based approaches, including combinations.

There are several voxel based visibility modeling methods (Baer et al. 2005; Morello and Ratti 2009; Hagstrom and Messinger 2011; Fisher-Gewirtzman 2012; Chmielewski and Tompalski 2017) . Some papers define a measure for the volume of visible space (Yang et al. 2007; Pyysalo et al. 2009; Morello and Ratti 2009; Fisher-Gewirtzman 2012). Other work determines the visible building façade surface (Baer et al. 2005; Bartie et al. 2010; Hagstrom and Messinger 2011; Fisher-Gewirtzman 2012; Koltsova et al. 2013; Suleiman et al. 2013; Feng et al. 2015; Bartie and Mackaness 2016). Only some of the listed papers regard visibility through vegetation (Llobera 2003; Baer et al. 2005; Pyysalo et al. 2009; Bartie et al. 2010; Hagstrom and Messinger 2011; Fisher-Gewirtzman 2012; Feng et al. 2015; Bartie and Mackaness 2016).

For the current project, the most interesting literature is identified as:

- Turner et al. (2001) describes a methodology how to get from Isovists to visibility graphs (visible areas from given views) and illustrates it by the example of the Tate Gallery in London.
- Batty (2001) extends the work of Turner et al. (2001) with mathematical formulas as well as different visualizations of the visibility.
- Fisher-Gewirtzman (2012) defines a Spatial Openness Index (SOI) for the volume of visible space seen from different viewpoints in the built environment.
- Suleiman et al. (2013) show a new algorithm for 3D Isovists, which might be interesting for the current project.
- Koltsova et al. (2013) propose different measures for calculating visibility. They define weighted visibility measures taking into account additional factors like distance, angle and walking direction.
- Bartie and Mackaness (2016) determine the visual magnitude for the example of Edinburgh. They present an algorithm which is able to calculate visible exposure of landmark buildings.

3.2 *Audibility – related literature*

So far 3D data is used to model how citizens are harassed by noise in cities (Kluijver and Stoter 2003; Pamanikabud and Tansatcha 2009; Lu et al. 2016) and how to mitigate this noise pollution using noise barriers (Law et al. 2011; Ranjbar et al. 2012). 2D GIS models are often used (Kluijver and Stoter 2003).

Additional 3D geo information has an advantage, because based on refraction there are different sound levels in different heights (Kubiak and Ławniczak 2015). The results can be visualized cartographically in 3D noise maps (Law et al. 2006; Stoter et al. 2008).

Semantic information is often not considered but it can lead to better results knowing object type and material type of walls (Czerwinski et al. 2006; Kurakula 2007).

Many of the mentioned models are considered in parts useful for the calculation of audibility in the current project. All of them analyze sound propagation. However, this project is interested if someone is being heard at different places, for instance when crying for help. Accurate models for the sound propagation are computation-intensive and time-intensive and therefore a compromise between accuracy and speed has to be found.

Essentials for analyzing sound propagation are given in the literature on the subject of reflection, refraction and diffraction of sound waves (Maekawa 1968; Boye and Herrmann 1989; Reiterer et al. 2009; Lutz 2013), for example at building facades or vegetation walls.

Furthermore damping effects caused by the absorption of air, by vegetation and by meteorological influences are relevant (Boye and Herrmann 1989; Willems et al. 2016).

In the light of the documented state of the art, the work of Maekawa (1968), Lutz (2013) and Willems (2016) are most promising for the intended work. Since they use approved methods and are structured clearly.

4. Process and methods overview

Within the approach, spatial factors will be identified and operationalized, which aim at determining a wide variety of (in)security perceptions among citizens in urban areas. Based on experience in best practice examples (from Berlin, Germany and worldwide) and on-site measurements in three case study areas, the identified factors are incorporated into algorithms that serve as the heart of a software-based planning aid.

The approach is intended to be applied to existing three-dimensional non-propriety city models, like models based on the CityGML standard. The focus is on the identification of places that are subjectively perceived as dark, or to exhibit a poor visibility and poor audibility.

Fig 1 gives an overview of the steps of the process of assessing security of urban spaces.

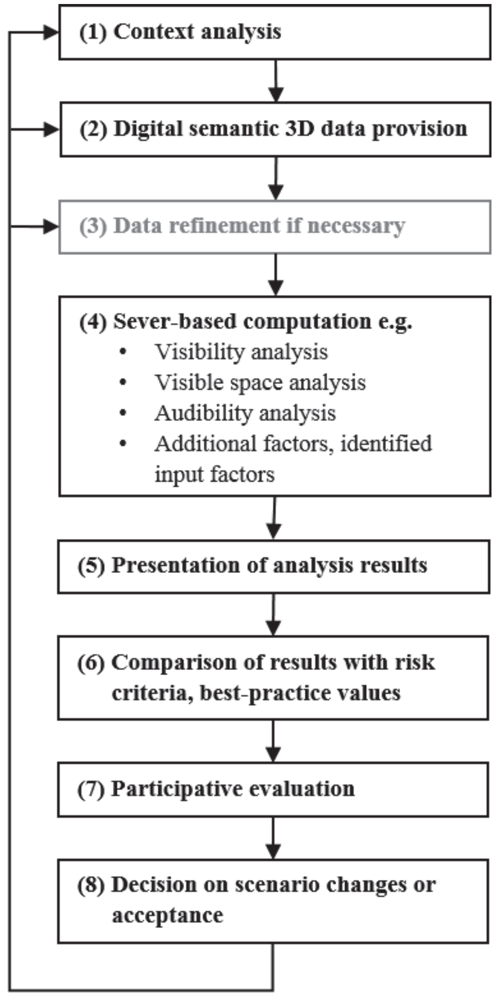

Fig. 1. Assessment process for security in urban areas with focus on visibility and audibility using semantic spatial data.

5. Visibility

This section describes an algorithm for determining the visibility of a person located on the street, i.e. how many persons can see the person (“being seen”) and how many persons can be seen from this person (“seeing”). The aim is to obtain measures for assessing the feeling of security of this person.

5.1 *Average number of persons seeing a person on the street*

For a person at a given position on the street the average number of persons seeing this person can be defined as:

$$N_{\text{tot}}^{\text{being seen}} = N_{\text{building}}^{\text{being seen}} + N_{\text{street}}^{\text{being seen}} \qquad (1)$$

In Eq. (1) $N_{\text{tot}}^{\text{being seen}}$ is the average number of persons seeing a person on the street at a given position, $N_{\text{street}}^{\text{being seen}}$ is the average number of persons on urban street and sidewalk surface elements seeing the person on the street and $N_{\text{building}}^{\text{being seen}}$ is the average number of persons in buildings seeing the person.

5.1.1 *Seen from indoors*

$N_{\text{building}}^{\text{being seen}}$ of Eq. (1) can be determined by the following eleven-step algorithm:

(1) Loop over all buildings.

(2) Loop over all building surface elements.

(2.1) Surface elements has window?

(2.2) Line of sight from person to surface element?

(2.3) Determine number of persons being close to the window.

(2.4) Add (in the sense of take into account) probability that a person close to the window looks towards the person on the street.

(2.5) Add transparency factor of the line of sight.

(2.6) Add probability of being able to physiologically resolve person at given distance when looking in the correct direction (depends on distance and light conditions).

(2.7) (Optional) Add probability of being able to recognize dissocial behavior or dangerous event.

(2.8) (Optional) Add probability that person reacts (calls out of window, leaves building to help or calls police).

(2.9) Add received value to the overall value of "seeing persons".

Measures for the number of persons seeing the person on the street or reacting in case of a dangerous event are obtained.

5.1.2 *Seen from outdoors*

$N_{\text{street}}^{\text{being seen}}$ of Eq. (1) can be determined in a similar way using a ten-step algorithm:

(1) Loop over all urban surface elements.

(2) Loop over all urban subsurface elements.

(2.1) Line of sight from person to urban subsurface element?

(2.2) Determine number of persons on urban subsurface element.

(2.3) Add probability that a person on the urban subsurface element looks towards the person on the street.

(2.4) Add transparency factor of the line of sight.

(2.5) Add probability of being able to physiologically resolve person at given distance when looking in the correct direction (depends on distance and light conditions).

(2.6) (Optional) Add probability of being able to recognize dissocial behavior or dangerous event.

(2.7) (Optional) Add probability that person reacts (calls on street, goes towards the person calling or calls police).

(2.8) Add received value to the overall value of "seeing persons".

Fig 2 illustrates the algorithm for two street elements with one person and a given position $\vec{r}$.

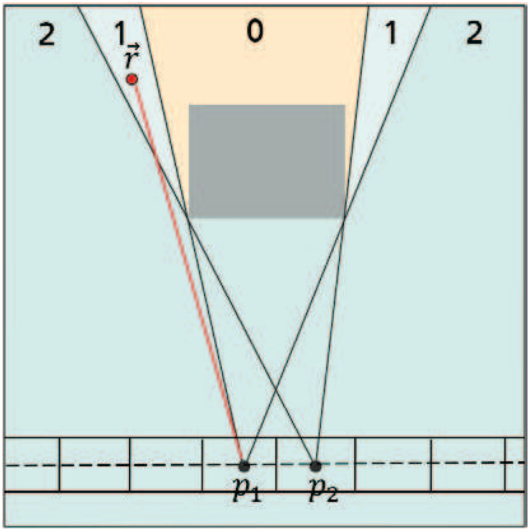

Fig. 2. Illustration of the seen area for two different persons on two urban sub-surface elements. The given position $\vec{r}$ is only seen by person p_1.

5.2 *Average number of persons that can be seen by a person on the street at given daytime*

In a similar way to 5.1, the average number of persons that can be seen by a person on the street at a given daytime can be defined as:

$$N_{\text{tot}}^{\text{seeing}} = N_{\text{building}}^{\text{seeing}} + N_{\text{street}}^{\text{seeing}}. \quad (2)$$

5.2.1 *Seeing persons that are indoors*

$N_{\text{building}}^{\text{seeing}}$ of Eq. (2) can be determined by the same algorithm as in section 5.1.1 without steps (2.4), (2.6) and (2.7). Step (2.4) is removed because Eq. (2) is the number of persons which can be seen by the person looking around. Note that even without these changes $N_{\text{building}}^{\text{seeing}}$ is expected to be different to $N_{\text{building}}^{\text{being seen}}$ because of the relative light conditions as incorporated in (2.6).

5.2.2 *Seeing persons that are outdoors*

$N_{\text{street}}^{\text{seeing}}$ of Eq. (2) can be determined by the same algorithm as in section 5.1.2 without steps (2.3), (2.6) and (2.7).

6. Visible space

As practical application, often the visible space is of interest. The visible space A_{visible} can be determined similar to section 5.1.2 without using the number of persons on the urban subsurface elements (see steps (2.2) and (2.3)) but including critical distances and/or weighting factors for the distance.

Furthermore the total existing space within a certain distance A_{tot} can be determined. The ratio of the visible area A_{visible} relative to the existing area A_{tot} provides a measure that affects the feeling of security. It is possible to calculate several of these ratios for example for a near, a middle and a far distance.

7. Audibility

This section describes an algorithm how to determine the audibility of a person. The algorithm proposed determines how many person hear a shouting person. The aim is to obtain a measure for assessing the feeling of security of this person due to perceived audibility, assuming that people realistically assess whether they can be heard.

7.1 *Fast algorithm for determining sound level at all positions based on an initial shout*

The following algorithm can be used to determine the sound level reaching a person on a volume element after an initial shout:

(1) Set sound source position (shouting person) with an initial sound level.
(2) Determine sound spherical launching grid with given directional resolution.
(3) Follow each path taking into account reflections, absorption and damping till sound level is below critical value (non-hearing threshold also taking superposition into account).
(4) Determine for given volume resolution whether for each reachable volume sound rays are present that determine the loudness.
(5) If not, refine launching grid in step (2) and repeat step (3) and (4).
(6) (Optional) Test convergence by further increasing launching grid refinement.
(7) (Optional) Test critical value of sound perception.
(8) (Optional) Test sensitivity with respect to parameters in used in step (3).
(9) Extract loudness at all volume elements as superposition of the reaching reflected audio

paths and the loudness due to sound diffraction within a given echo perception time threshold.

Fig 3 illustrates some sound rays starting at the source (red). Two of the rays reach the receiver (black). There is a direct ray and a ray with reflection. The loudness is influenced by

- the length of the paths
- the length of the paths through vegetation (illustrated as green rectangles)
- decrement because of the reflection of the second path

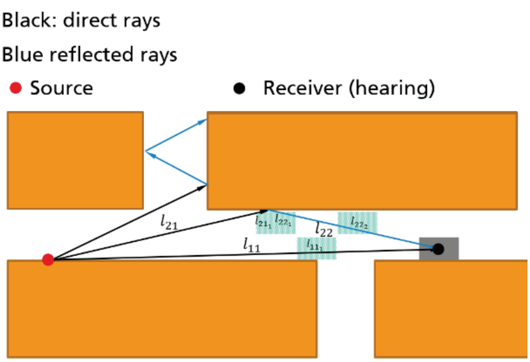

Fig. 3. Illustration of sound rays with a given resolution. Two of the rays reach the receiver.

Most calculation of the proposed algorithm is done in (3). Several inputs are used to determine the sound level at each point on the path. Decreasing of the sound level on the basis of the distance depends on pitch level, temperature of air and humidity of air.

Reflections of a path also lead on to a damping factor which is based on component material at the position of reflection. Decreasing of the sound level on the basis of traversing urban furniture depends on damping factors for different urban furniture and on the length of the paths within the urban furniture. This is similar to the transparency factor of the visibility algorithm.

For the receiver it is also of interest to understand the initial shout. So the echo perception threshold should be used to determine if reflected sound rays are perceived as one unit and not as echo.

7.2 *Average number of persons that can hear a person on the street*

For calculating how many persons can hear a person on the street a similar algorithm as in section 5.1.2 is employed using the results of section 7.1:

(1) Loop over all urban surface elements.

(2) Loop over all urban subsurface elements.

(2.1) Get sound level on urban subsurface element as calculated in section 7.1.

(2.2) Determine number of persons on urban subsurface element.

(2.3) Add probability of physiological perception of the audio signals at person position on urban subsurface element taking account sound level (2.1) and background noise.

(2.4) (Optional) Add probability of being able to recognize dissocial behavior or dangerous event (understanding shout, interpret shout as appeal for help).

(2.5) Add received value to the overall value of “hearing persons”.

Please note the conformity of the algorithms for visibility and audibility, given the local loudness is available.

8. Additional factors, identified input factors

8.1 *Brightness*

As input for the algorithms of the visibility brightness maps can be rendered.

The brightness plays an important part for determining the visibility measures of section 5. E.g. Dwimirnani et al. (2017) measure the impact of public lightning on visibility in urban parks. The relative brightness of a defined place affects what a person at another place can realize (e.g. mimic of persons or only silhouettes).

8.2 *Person distributions and liveliness of urban places*

Another important input for the visibility of section 5 are person distributions due to different daytimes. The more people are on a specific place, the more people can potentially see a dangerous or critical situation.

9. Conclusions, innovation and perspectives

For the first time, a software tool based on digital data will be developed, with the help of which safety assessments can be performed systematically and empirically based on urban digital semantic 3D data, which will be available on an ever higher resolution.

The tool thus helps urban planners and security experts in designing for more security in urban areas. Although the planning aid does not depict all the reality on the ground, it will provide a supporting framework and approach for the design of squares, residential areas and inner-city quarters for improving perceived safety and security.

The provided sample algorithm is expected to be feasible to be implemented resorting to and significantly extending state of the art.

Main challenges that are expected for the refinement of the process approach and the implementation of the algorithms are

- Process design that enables participation and avoids negative discriminations and attributions (or even self-fulfilling prophecies)
- Limited application time and computation resources
- Need of fast algorithms to get an applicable software
- Need of sufficient input for "soft" psychological model parts and factors

Acknowledgements

This research has been funded by the Federal Ministry of Education and Research (BMBF) in Germany under the "Research for civil security" program (www.sifo.de) in a call on prospective safety in urban spaces ("Zukünftige Sicherheit in Urbanen Räumen").

References

Baer, W., N. Baer, W. D. Powell and J. Zografos (2005). *Advances in terrain augmented geometric pairing algorithms for operational test.* NAVAL POSTGRADUATE SCHOOL MONTEREY CA.

Bartie, P. and W. Mackaness (2016). "Mapping the visual magnitude of popular tourist sites in Edinburgh city" *Journal of Maps* 12 (2), 203–210.

Bartie, P., F. Reitsma, S. Kingham and S. Mills (2010). "Advancing visibility modelling algorithms for urban environments" *Computers, Environment and Urban Systems* 34 (6), 518–531.

Batty, M. (2001). "Exploring Isovist Fields: Space and Shape in Architectural and Urban Morphology" *Environment and Planning B: Planning and Design* 28 (1), 123–150.

Biljecki, F., J. Stoter, H. Ledoux, S. Zlatanova and A. Çöltekin (2015). "Applications of 3D City Models: State of the Art Review" *ISPRS International Journal of Geo-Information* 4 (4), 2842–2889.

Boye, G. and U. F. Herrmann (1989). *Handbuch der Elektroakustik. Technik und praktische Anwendung.* 3., überarb. u. erw. Aufl. Heidelberg: Hüthig.

Chmielewski, S. and P. Tompalski (2017). "Estimating outdoor advertising media visibility with voxel-based approach" *Applied Geography* 87, 1–13.

Czerwinski, A., T. H. Kolbe, L. Plümer and E. Stöcker-Meier (2006). "Spatial data infrastructure techniques for flexible noise mapping strategies". In: *EnviroInfo 2006. Managing environmental knowledge: proceedings of the 20th International Conference "Informatics for Environmental Protection", Graz (Austria).* Ed. by K. Tochtermann, A. Scharl. Aachen: Shaker, pp. 99–106.

Dwimirnani, P., K. Karimi and G. Palaiologou (2017). "Space after dark. Measuring the impact of public lighting at night on visibility, movement, and spatial configuration in urban parks". In T. Heitor (ed.) *Proceedings, 11th International Space Syntax Symposium. XI SSS, Lisbon, 3-7 July 2017.* Lisbon: Instituto Superior Técnico Departamento de Engenharia Civil, Arquitetura e Georrecursos, Portugal.

Feng, W., W. Gang, P. Deji, L. Yuan, Y. Liuzhong and W. Hongbo (2015). "A parallel algorithm for viewshed analysis in three-dimensional Digital Earth" *Computers & Geosciences* 75, 57–65.

Fisher-Gewirtzman, D. (2012). "3D models as a platform for urban analysis and studies on human perception of space". In: *Usage, Usability, and Utility of 3D City Models – European COST Action TU0801.* Ed. by T. Leduc, G. Moreau, R. Billen. Les Ulis, France: EDP Sciences, p. 1001.

Fuller, M. G. and M. Löw (2017). "Introduction: An invitation to spatial sociology" *Current Sociology* 65 (4), 469–491.

Gorelick, N., M. Hancher, M. Dixon, S. Ilyushchenko, D. Thau and R. Moore (2017). "Google Earth Engine: Planetary-scale geospatial analysis for everyone" *Remote Sensing of Environment* 202, 18–27.

Greenberg, M. (1995). *The poetics of cities. Designing neighborhoods that work.* Columbus: Ohio State Univ. Press.

Gröger, G. and L. Plümer (2012). "CityGML – Interoperable semantic 3D city models" *ISPRS*

Journal of Photogrammetry and Remote Sensing 71, 12–33.

Hagstrom, S. and D. Messinger (2011). "Line-of-sight analysis using voxelized discrete lidar". In: Ed. by M. D. Turner, G. W. Kamerman: SPIE, 80370B.

Haklay, M. and P. Weber (2008). "OpenStreetMap: User-Generated Street Maps" *IEEE Pervasive Computing* 7 (4), 12–18.

Kluijver, H. de and J. Stoter (2003). "Noise mapping and GIS: optimising quality and efficiency of noise effect studies" *Computers, Environment and Urban Systems* 27 (1), 85–102.

Koltsova, A., B. Tunçer and G. Schmitt (2013). "Visibility analysis for 3d urban environments".

Kubiak, J. and R. Ławniczak (2015). "The propagation of noise in a built-up area (on the example of a housing estate in Poznań)" *Journal of Maps* 12 (2), 231–236.

Kurakula, V. (2007). "A GIS-based approach for 3D noise modelling using 3D city models". Master's Thesis. International Institute for Geo-information Science and Earth Observation.

Law, C.-W., C.-K. Lee, A. S.-W. Lui, M. K.-L. Yeung and K.-C. Lam (2011). "Advancement of three-dimensional noise mapping in Hong Kong" *Noise Mapping* 72 (8), 534–543.

Law, C.-W., C.-K. Lee and M.-K. Tai (2006). "Visualization of complex noise environment by virtual reality technologies" *Environment Protection Department (EPD), Hong Kong. http://www. science. gov. hk/paper/EPD_CWLaw. pdf, Access Date: March 2008*.

Liu, X., X. Wang, G. Wright, J. Cheng, X. Li and R. Liu (2017). "A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS)" *ISPRS International Journal of Geo-Information* 6 (2), 53.

Llobera, M. (2003). "Extending GIS-based visual analysis: the concept of visualscapes" *Transgenic Research* 12 (6), 761–763.

Lu, L., T. Becker and M. O. Löwner (2016). "3D complete traffic noise analysis based on CityGML.". In A. Abdul-Rahman (ed.) *Advances in 3D Geoinformation*. 1st Edition: Springer International Publishing.

Lutz, P. (2013). *Lehrbuch der Bauphysik: Schall Wärme Feuchte Licht Brand Klima:* Springer-Verlag.

Maekawa, Z. (1968). "Noise reduction by screens" *Noise Mapping* 1 (3), 157–173.

Morello, E. and C. Ratti (2009). "A digital image of the city: 3D isovists in Lynch's urban analysis" *Environment and Planning B: Planning and Design* 36 (5), 837–853.

Pamanikabud, P. and M. Tansatcha (2009). "Geoinformatic prediction of motorway noise on buildings in 3D GIS" *Transportation Research Part D: Transport and Environment* 14 (5), 367–372.

Pyysalo, U., J. Oksanen and T. Sarjakoski (2009). "Viewshed analysis and visualization of landscape voxel models".

Ranjbar, H. R., A. R. Gharagozlou and A. R. V. Nejad (2012). "3D analysis and investigation of traffic noise impact from Hemmat Highway located in Tehran on buildings and surrounding areas" *Journal of Geographic Information System* 4 (4), 322–334.

Reiterer, H., T. Frech, M. Wibmer, D. Ohrwalder, C. Schmidl and T. Bergmann (2009). *Schallausbreitung*.

Stoter, J., H. de Kluijver and V. Kurakula (2008). "3D noise mapping in urban areas" *International Journal of Geographical Information Science* 22 (8), 907–924.

Suleiman, W., T. Joliveau and E. Favier (2013). "A New Algorithm for 3D Isovists". In S. Timpf and P. Laube (eds.) *Advances in Spatial Data Handling: Geospatial Dynamics, Geosimulation and Exploratory Visualization*, pp. 157–173. Berlin, Heidelberg: Springer Berlin Heidelberg. URL: http://dx.doi.org/10.1007/978-3-642-32316-4_11.

Tickamyer, A. R., G. Hooks and L. M. Lobao (2007). *The sociology of spatial inequality*. Albany: State University of New York Press.

Turner, A., M. Doxa, D. O'Sullivan and A. Penn (2001). "From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space" *Environment and Planning B: Planning and Design* 28 (1), 103–121.

Volk, R., J. Stengel and F. Schultmann (2014). "Building Information Modeling (BIM) for existing buildings — Literature review and future needs" *Automation in Construction* 38, 109–127.

Willems, W. M., K. Schild and D. Stricker (2016). *Formeln und Tabellen Bauphysik. Wärmeschutz - Feuchteschutz - Klima - Akustik - Brandschutz*. 4. Auflage. Wiesbaden: Springer Vieweg.

Wilson, J. Q. and G. L. Kelling (1982). *Broken windows*.

Yang, P. P.-J., S. Y. Putra and W. Li (2007). "Viewsphere: A GIS-Based 3D Visibility Analysis for Urban Design Evaluation" *Environment and Planning B: Planning and Design* 34 (6), 971–992.