

COMMUNICATION AND VISUALIZATION OF 3D URBAN SPATIAL DATA ACCORDING TO USER REQUIREMENTS: CASE STUDY OF GENEVA

C. Carneiro¹

¹ Geographical Information Systems Laboratory (LASIG), Ecole Polytechnique Fédérale de Lausanne (EPFL)
CH-1015, Lausanne, Switzerland – Claudio.Carneiro@epfl.ch

Commission II, WG II/5

KEY WORDS: urban data, three-dimensional, user requirements, modelling, visualization, LIDAR

ABSTRACT:

In 2005, the main commission of the technical services of the city of Geneva launched a study to evaluate which users would potentially be interested to integrate the third dimension in the available geographical data. The result showed that the great majority of them would like, in the future, to manage its specific data in a 3D format. Hence, it was decided to give rise to the “3D Geneva” project, presented as follows in this paper. A preliminary inquiry concerning the user requirements for the implementation of a 3D project in Geneva was launched. Based on the obtained responses, six different domains were determined: architecture, urbanism and territory planners; urban traffic (motor vehicles, trains and airplanes); environment and energy; pedestrian and cyclist mobility; security and emergency situations management; underground information. According to the assessment of the specific needs among each of these domains, several interviews were carried out in which 30 users decided, at different scales of visualization, which level of details (LOD) and reconstructed objects were better perceived in a 3D urban model.

1. INTRODUCTION

The accurate amount of 3D urban data available nowadays can be applied to communication and visualization on a wide variety of applications depending on user requirements. Regarding communication specifications, the main goal is to allow users to rapidly locate and interpret pertinent 3D urban geographic information to make presumptions. The fundamental challenge for the development, implementation and designing of geo-visualizations is to avoid complexity, as well as too detailed and too dense visualizations.

Geo-visualization has been defined by MacEachren and Kraak (2001), as “the integration of visualization in scientific computing, cartography, image analysis, information visualization, exploratory data analysis and GIS, which all together provide theory, methods and tools for visual exploration, analysis, synthesis and presentation of spatial data”. Thus, 3D geo-visualization can be applied at different phases, with distinct levels of detail (LOD), according to user requirements and applications.

For all these reasons, a preliminary inquiry concerning the user requirements for the implementation of a 3D project in Geneva was launched. The usability of the 3D urban models proposed is associated to a cognitive visual interpretation of the end user: according to the “CityGML” norm proposed by Kolbe *et al* (2005), different LOD have been proposed and evaluated. This combination between utility and usability increases the level of acceptance among the different users (especially for urban planners and architects) of the 3D visual models proposed. Moreover, for the great majority of users and applications, this same approach is a better tool for visual communication than 2D information.

This study also shows the large potential to re-use 3D geo-information for communication and visualization purposes according to specific user requirements. Re-using data is not only of significance for end-users but also for data holders who can better justify the costs for purchase and maintenance of this type of data.

2. BACKGROUND

During the last two decades, 3D urban modelling and geo-visualization has been an interesting research topic among several domains of application, such as: 3D GIS (Königer and Bartel, 2004); computer graphics (Foley *et al.*, 1995); architecture, urbanism and engineering (Eastman, 1999). While 3D GIS are used to manage georeferenced data at different scales of visualization, 3D data integrated on the field of architecture and urbanism provide more detailed and precise models relative to the processes of construction of new infrastructures (Kolbe and Plümer, 2004). Many papers have tried to describe the methods to acquire 3D urban models (Rottensteiner and Briese, 2003), Vosselman (2003), Schwalbe *et al.* (2004). The representation of geometry and topology of 3D objects has been analysed by Hellul and Haklay (2006). The management of 3D models at different scales was more particularly put under discussion by Gröger *et al.* (2004). However, with regards to the analysis of user requirements for 3D urban modelling and geo-visualization very few studies have been undertaken. One of the few possible examples is a study about re-using laser scanner data in applications on 3D topography, as proposed by Elberink (2007).

3. UTILITY AND USABILITY OF 3D URBAN SPATIAL DATA FOR COMMUNICATION AND VISUALIZATION

According to Nielsen (1993), the acceptability of any visual exploratory system is strictly related to its utility (feasibility of the information to be visualized) and its usability (cognitive visual interpretation of the 3D urban models proposed).

This combination between utility and usability determines the level of acceptability among the different users (in particular for architects and urban planners) of the proposed 3D urban models (Reichenbacher and Swienty, 2007).

User requirements concerning the utility and usability of 3D urban models for communication and visualization purposes

have not yet caused much attention within the world of researchers and developers. Thus, for different users and applications, it is fundamental to clearly distinguish which LOD should be implemented and, based on this classification, which urban objects should be or should not be visualized. This filter of criteria is essential, in order to avoid too dense and confusing urban scenes.

For this reason, it is fundamental to execute detailed interviews with pre-classified groups of different users, to assay which are its specific requirements, explained as follows in section 4.2.

4. CASE STUDY: CITY OF GENEVA

4.1 Presentation

In October 2005, the GIS department of the city of Geneva acquired a new set of LIDAR data with a planimetric precision of 15 centimetres and an altimetric precision of 20 centimetres. A preliminary inquiry carried among some of the potential users showed a strong interest for the integration of the third dimension on the available geographical data. Hence, the GIS department launched two 3D urban case studies for the city of Geneva:

1. On a pre-defined area of 16 hectares, near the Rhone River and the old town (Figure 1), mainly chosen for the variety of existing urban objects and specific characteristics (structures and roofs) of buildings;
2. On a residential area of 12 hectares of the Collonges-Bellerive district, in order to evaluate the integration of new architectural projects on the existing built environment;



Figure 1. Pre-defined area of the case study in Geneva's city, near the Rhone River and the old town

For the 3D urban reconstruction of the city of Geneva many data sources are available, such as: 2D vectorial data, 2.5D raster data, alphanumerical data containing altimetric information about buildings heights, LIDAR and terrestrial laser data, orthophotos and terrestrial photos (Figure 2 shows 2 examples of available data).

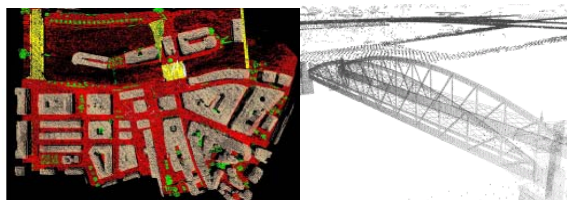


Figure 2. Two examples of available data for 3D urban reconstruction of the city of Geneva: raw LIDAR data (left) and raw terrestrial laser data of an existing bridge (right); (source: DCMO, Geneva)

4.2 User requirements

4.2.1 Preliminary inquiry

A preliminary inquiry concerning the user requirements and the relevance of 3D urban information (utility study) was launched to all potential users. This preliminary inquiry and all the user requirements' evaluation here explained follow the methodology proposed by Dumas and Redish (1999). In this first evaluation, some very generic questions concerning the reconstruction of a 3D urban model were put, such as:

- Interest and utility for users' activities?
- First idea about the desired LOD?
- Urban objects to be visualized (more specifically for buildings: generic, bicolour or real geo-visualization)?

This first inquiry, which was answered by more than 30 users, highlighted that more than 90% of the replies consider that there exists a real need to reconstruct and visualize 3D urban spatial data.

4.2.2 Identification and classification of the existing users in different fields

Based on the answers obtained and in order to better organise and comprehend the existing user requirements, the results of the first inquiry were classified into six distinct fields:

- Architecture, urbanism and territory planners;
- Urban traffic (motor vehicles, trains and airplanes);
- Environment and energy;
- Pedestrian and cyclist mobility;
- Security and emergency situations management;
- Underground information;

Hence, in order to clarify and look further into the specific user requirements, several interviews were led with pre-defined and selected users of each one of these six classified fields.

4.2.3 Interviews

Based on the users' classification presented here in section 4.2.2, interview sessions were organised between researchers, owners and users of 3D geo-information of the city of Geneva. For these interviews, an assessment of the user requirements concerning the various possibilities of 3D visualization was considered extremely relevant. Thus, in order to support some of the questions made to all groups of users, five different levels of detail (LOD) of visualization for buildings, as proposed by Kolbe et al. (2005), were presented and brought into discussion and analysis (Figure 3).

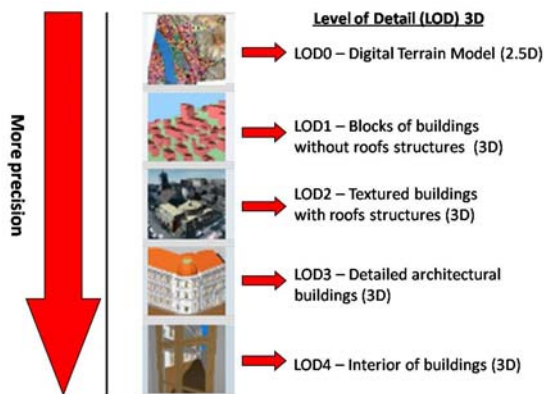


Figure 3. Different Levels of Detail (LOD), as proposed by Kolbe et al. (2005)

According to this methodology, the same object can be represented simultaneously at various LOD, allowing its analysis and visualization for different objectives and perspectives. For instance, the LOD1 only includes 3D information about buildings. The LOD2 and LOD3 allow the representation of other urban objects, such as trees. The LOD4 supplements the LOD3 by adding the interior structures of buildings, such as rooms and staircases.

In order to be more precise with regards to the analysis of user requirements for 3D urban visualization, three additional LOD for different visualization of buildings and other urban objects were presented to all groups of users (Figure 4):

- **LOD2A: visualization of general buildings façades** created from façades of existing buildings. Usually, this general façades are established from the analysis of the most common architectural façades of the buildings of the city taken into consideration for 3D urban modelling;
- **LOD2B: visualization of bicolour buildings with roofs structures.** The buildings façades are non-textured and are visualized with a single colour. The roofs are geometrically represented only with structures and are visualized with a different colour of buildings façades.
- **LOD2C: visualization of bicolour buildings with roofs super-structures.** The buildings façades are non-textured and are visualized with a single colour. The roofs are geometrically represented with all super-structures and are visualized with a different colour of buildings façades.

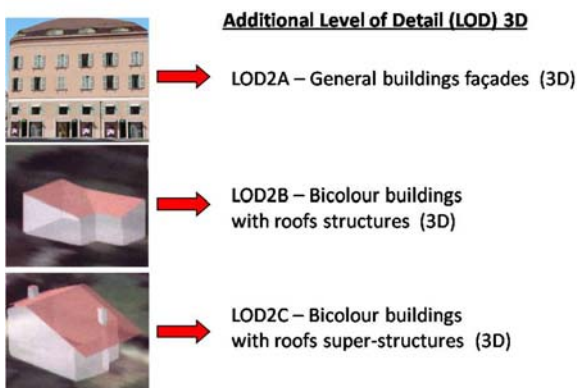


Figure 4. Additional Levels of Detail (LOD) proposed

For the generic 3D urban model of Geneva, a deep analysis was carried out (mainly with architects and urban planners) in order to decide if LOD2C (roofs with super-structures) should be implemented or in turn, if LOD2B (simple roof structures) should be sufficient. Results showed that simple roof structures seem to lack some important information (namely insufficient cognitive visual interpretation), especially in old neighbourhoods and landmarks of the city: for example, as showed in Figure 5, the building located on the low and central part of both images is a landmark (church) with many detailed roofs. If we visualize this landmark only at LOD2B and not at LOD2C, its representation is clearly insufficient for generic 3D visualization use.

On the other hand, for environment or energy users, buildings using these simple roof structures are considered sufficient in order to model, visualize and analyze specific phenomena (such as noise distribution on building façades) in the urban space. It can be therefore implied that using detailed objects will render a 3D urban model that is too dense and cognitively hard to interpret.

In Section 4.4, are shown three distinct examples of the urban models proposed for visualization showing all these constraints, and based on user requirements.

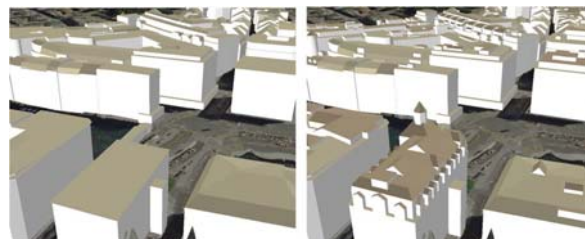


Figure 5. Visual comparison and analysis between LOD2B and LOD2C, for the case study near the old town (source: DCMO, Geneva)

Regarding the communication and visualization of 3D urban spatial data, some of the most important questions asked to users were:

- Which objects are considered mandatory for 3D visualization purposes?
- Which objects can be considered superfluous for 3D visualization purposes?
- Which are the LOD to retain for 3D visualization purposes?
- Must we adapt the choice of the urban objects to visualize (and also the LOD) according to the different scales of visualization considered (such as at the scale of a building, at the scale of a neighbourhood or at the scale of a city)?
- LOD0 is sufficient for the urban visualization of certain phenomena (such as the 3D spatial analysis of the noise caused by motor vehicles)?

4.3 3D urban applications

The evaluation of the user requirements for communication and visualization of 3D urban spatial data for the city of Geneva allows the definition of several 3D urban applications by fields of activity, as showed in Figure 6.

Some of these 3D urban applications refer to the visualization, at different LOD, of specific urban indicators, such as the roofs adapted to receive solar panels or the pollution caused on buildings façades by motor vehicles.

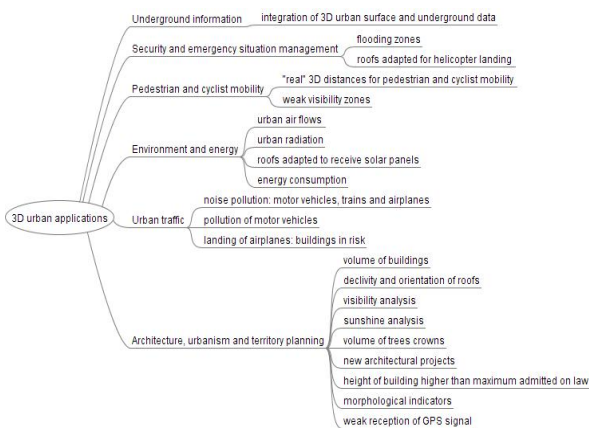


Figure 6. List of 3D applications

4.4 Analysis of interviews and some examples of visual representations using 3D urban data

4.4.1 Overview

Results from questionnaires that were put during the interviews with expert evaluators are presented in the following. The interviews results were compared for each of the existing six groups of users. This classification allows the definition of specific 3D visual representations (some examples are here shown) inherent to each group of users and based on the 3D applications evaluated, which are presented in section 4.3. The results of the questionnaire and interviews are not used for statistical analysis, instead, are only used to highlight trends among the existing users.

4.4.2 Architecture, urbanism and territory planners

Five architects, two urban planners and two territorial planners were invited as expert evaluators. The architects work at the university, at the municipality and in private companies. The urban planners and territorial planners work for municipality and private companies.

Throughout the interviews, the expert evaluators refer that a great advantage of 3D visualization when compared to 2D visualization in this field of activity is that 3D views are considered to be much more interesting in order to compare a building with the neighbouring ones: *“It is still difficult to imagine how five floors are compared to the surrounding buildings using only 2D maps”*. Generally, they also prefer more detailed LOD (between LOD3 and LOD4) for the representation of new architectural projects and buildings, mainly for communication purposes. Especially for architects, at a neighbourhood scale, the integration of LOD 1, LOD2B/LOD2C and LOD3 in a same view are considered to be much more interesting in order to compare a new building (LOD3) with the neighbouring ones (LOD2B/LOD2C) and more far-away buildings (LOD1): *“You can find more details about the building under analysis, that will be constructed, and the rest you know already”*. Thus, this type of view will cognitively guide the attention of the user to the new building to be constructed and surrounding buildings should be clearly identified (please consult example showed in Figure 7).

These users also consider important to represent roofs with super-structures, especially for landmarks: *“These objects are very useful to determine where we are on the city”* and to represent people to have an assessment about real size in a 3D

model: *“To evaluate how much space buildings take up. Trees, lamp-posts and bus stops are useful to render the model more real but they could be many meters high. In fact, some human beings would be very useful to assess proportions more realistic”*.

The urban and territorial planners agree that the use of more simple views, such as LOD2B and LOD2C, instead of more complex views, such as LOD2A, LOD3 and LOD4, for public presentations, can avoid exaggerated expectations and misunderstandings: *“The use of these LOD is especially indicated for new urban areas where changes often occur. Furthermore, vegetation softens the implications of new architectural projects and should also be avoided to render the 3D urban scenario as ‘worst as possible’”*. When using LOD2B and LOD2C, the 3D model orientation can be supported using other means, such as highlighting landmarks (Fuhrmann, 2002).

Finally, architects, urban planners and territorial planners all agree that this technical development undoubtedly implies some reflection on the legal validity of the different 3D models and scenario proposed for the city of Geneva: *“This will avoid the risks of abusive use of 3D models, in particular during the phase of promotion of new projects or the presentation of plans for territorial development, according to the target public. Thus, the architects, the urban planners, the territorial planners and the public bodies, all together, should define a certain number of pre-necessary rules and constraints, so that a final 3D ‘product’ should be declared in conformity and thus, ready to be used by the public policies and as information tool for the population in general”*.

The Figure 7 shows an example of integration and visualization of new architectural projects in the case study of Collonges-Bellerive district, following all the analysis here shown. In this case, new buildings, designed with a CAD tool, have been georeferenced to the existing 3D model and are represented using LOD3 and LOD4. The existing buildings in the neighbourhood of new architectural projects are represented with LOD2C and more far-away buildings are represented using a LOD1. Other 3D urban objects, such as trees and streets are also represented.



Figure 7. Different LOD of representation of buildings suggested within the case study of Collonges-Bellerive district, for the integration and visualization of new architectural projects (source: DCMO, Geneva)

4.4.3 Urban traffic

Two technicians working at the municipality, on the urban traffic management department, and two technicians working at the airport of Geneva, were invited for the interviews as expert evaluators.

Throughout the interviews, the technicians of urban traffic management mentioned that they don't remark any advantages of using 3D models for communication and visualization purposes instead of 2D models used for the representation of the pollution and noise caused by motor vehicles on urban environment, especially when considering the neighbourhood and city scales: "In fact, when representing spatial phenomena in a 3D urban scenario, such as pollution and noise caused by motor vehicles, each façade has an indicator value that can be visualized by a single colour. For a great set of buildings, this representation will render the 3D model too confuse and for that reason we prefer to continue using the 2D model".

On the other hand, these expert evaluators mentioned that: "When analysing a small set of buildings for larger scales it may be interesting to have 3D models with a LOD1 or LOD2B representing the noise or pollution caused to each façade, visualized by a single colour. In this case, other urban objects needed should be streets and pavements".

The technicians working at the airport of Geneva mentioned that: "The use of 3D models for communication and visualization representing (LOD2C) buildings that may eventually be located within the area of risk, where airplanes are landing or taking off, can be useful".

An example of 2D representation of the diurnal urban traffic noise at a neighbourhood scale, for the case study of the city of Geneva, near the Rhone River and the old town, is shown in Figure 8. In this case, each façade has an associated colour and value representing the number of decibels caused by the diurnal traffic noise, also called noise pollution. For each façade, this indicator is calculated at its central point, 2 meters above the ground.

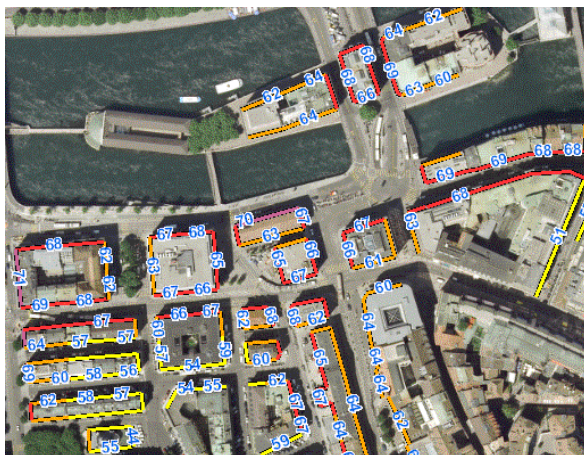


Figure 8. Example of 2D representation of the diurnal urban traffic noise at a neighbourhood scale, for the case study of the city of Geneva, near the Rhone River and the old town (source: SITG, Geneva)

4.4.4 Environment and energy

Two technicians working at the municipality, on the environment department, and two technicians, also working at

the municipality, but more precisely at the energy department, were invited for the interviews as expert evaluators.

During the interviews, these four technicians mentioned that: "The use of 3D models with LOD2A can be very useful to represent and visualize some urban indicators at neighbourhood scales, such as the sunshine analysis or the roofs adapted to receive solar panels. In these cases, other urban objects can eventually be represented, such as streets and pavements".

The environment expert evaluators mentioned that: "In specific applications, such as on the assessment of urban radiation caused by antennas of telecommunications on the façades of buildings, it can be very interesting to represent (LOD2A) the affected façades with a different colour. In this case it is also mandatory to visualize these antennas as urban objects that should be represented".

An example of 3D visualization of the daily sunshine exposition of each building for the summer solstice (21st of June) can be visualized in Figure 9. In this case, each building roof has an associated colour representing the number of hours of sunshine exposition for each building.

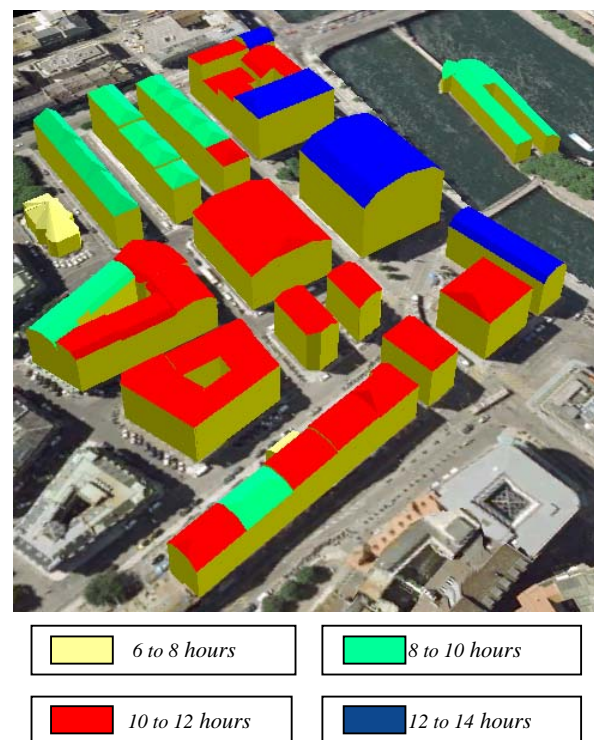


Figure 9. Example of 3D visualization (LOD2A above orthophotos) of the daily sunshine exposition of each building for the summer solstice (21st of June)

4.4.5 Pedestrian and cyclist mobility

Two technicians working at private enterprises were invited as expert evaluators.

Throughout the interviews, they mentioned that the use of 3D models for communication and visualization can be a very useful tool: "In specific applications, such as the analysis and visualization of the zones of weak visibility for pedestrians, the use of 3D models with LOD2C and LOD3 can be a powerful and useful tool. In this case many urban objects, such as streets,

lamp-posts, bus stops and other urban objects must be represented and taken into consideration for visual analysis”.

4.4.6 Security and emergency situations management

Two technicians working at private enterprises were invited as expert evaluators.

According to them the use of 3D models for communication and visualization can be a very useful tool for several applications. Two paradigmatic examples were mentioned: “The use of 3D models with LOD2B in order to visualize potential areas that can be flooded by the Rhone River presents a case of its possible application. Employing the LOD2C can be very interesting in order to visualize the buildings’ roofs adapted for helicopter landing, represented with a different colour. Nevertheless, in both cases, streets and trees can be also represented”.

4.4.7 Underground information

Two technicians working at private enterprises were invited as expert evaluators.

Throughout the interviews they mentioned that the integration of 3D models with the urban surface and underground data can be a very useful tool for analysis, communication and visualization purposes: “Visualizing simultaneously 3D surface data (LOD2B or LOD2C) and underground data allows users to have a better perception concerning the integration between these distinct types of objects. Furthermore, it can be a very useful tool for 3D underground analysis, namely for the evaluation of which underground works can be undertaken in security, guaranteeing that existing underground objects will not be damaged. In this case, underground objects must be fully represented and surface objects, such as buildings, must be represented with some level of transparency”.

5. CONCLUSIONS

This article shows the diversity of the existing needs based on user requirements for 3D urban models, which require different level of detail (LOD) and visualization of the city and its inherent objects.

Thus, the objectives (related to communication and visualization purposes) of all users of 3D urban models must be carefully identified. In fact, very detailed urban models, on its own, do not offer an effective solution for the majority of 3D applications shown in this paper.

The user requirements established for this case of study do not claim to the universality or the completeness. Other cities, different in its nature and structure, will undoubtedly imply different needs.

6. REFERENCES

Bretar F. (2006). Couplage de données laser aéroportés et photogrammétriques pour l’analyse de scènes tridimensionnelles. Phd Thesis, Ecole Nationale Supérieure de Télécommunications de Paris, France.

Dumas S., Redish C. (1999). *A Practical Guide to Usability Testing*. Intellect Books, Exeter, United Kingdom.

Eastman C. (1999). *Building Product Models: Computer Environments Supporting Design and Construction*. CRC Press.

Eelberink, S. (2007). Re-using laser scanner data in applications on 3D topography. *3D Geoinfo07 Conference*, 12th-14th

December, Delft University of Technology, Delft, Netherlands (2007)

Ellul C., Haklay M. (2006). Requirements for topology in 3D GIS, *Transactions in GIS*, 10(2), pp. 157-175, Blackwell Publishing Ltd.

Foley J, van Dam A., Feiner S., Hughes J. (1995). *Computer Graphics: Principles and Practice*. Addison Wesley, 2nd Ed.

Fuhrmann, S. (2002). Facilitating wayfinding in desktop geovirtual environments. PhD. Thesis, Institut für Geoinformatik, Universität Münster.

Gröger G., Kolbe T., Plümer L. (2004). Mehrskalige, multifunktionale 3D-Stadt- und Regionalmodelle. *Photogrammetrie, Fernerkundung, Geoinformation (PFG)*, February 2004 (in German).

Kolbe T., Gröger G., (2004). Unified Representation of 3D City Models. *Geoinformation Science Journal*, Vol.4, No. 1.

Kolbe T., Gröger G., Plümer, L. (2005). CityGML - Interoperable Access to 3D City Models. In: Oosterom, Zlatanova, Fendel (Eds.): *Proceedings of the Int. Symposium on Geoinformation for Disaster Management*, 21st-23rd March 2005 in Delft, Springer.

Königer A., Bartel S. (1998). 3D-GIS for Urban Purposes. *Geoinformatica*. 2(1), March 1998.

MacEachren, A.M., Kraak, M.-J. (2001). Research challenges in geo-visualization. *Cartography and Geographic Information Science*. 28 (1): pp. 3-12.

Nielsen J. (1993). *Usability Engineering*. Morgan kaufmann-Academic Press, London, United Kingdom.

Reichenbacher T., Swienty O. (2007). Attention-guiding geovisualization. *Proceedings of the 10th AGILE International Conference on Geographic Information Science*, 8th-11th May, Aalborg University, Denmark.

Rottensteiner F., Briese C. (2003). Automatic generation of building models from LIDAR data and the integration of aerial images. In *ISPRS working group III/3 workshop “3D reconstruction from airborne laser scanner and InSAR data”*, Vol. 34, Dresden, Germany.

Schwalbe E., Maas H.-G., Seidel, F. (2004). 3D building model generation from airborne laser scanner data using 2D GIS data and orthogonal point cloud projections. In *Workshop “Laser Scanning 2005”*, Vol. XXXVI, ISPRS, Enschede, The Netherlands.

Vosselman, G. (2003). 3D reconstruction of roads and trees for city modeling. In *ISPRS working group III/3 workshop “3D reconstruction from airborne laser scanner and InSAR data”*, Vol. 34, pp. 231-236, Dresden, Germany.

7. ACKNOWLEDGEMENTS

The author is definitely indebted to Laurent Niggeler and Adrien Vieira de Mello, from the Direction Cantonale de la Mensuration Officielle (DCMO) of the city of Geneva, for its vast contribution to this project.