3-D visualization of Urban Environmental Quality indicators

Using the CityGML standard

Cláudio CARNEIRO[1]; François GOLAY[1]; Stéphane JOOST[1]; Gilles DESTHIEUX[2]; Adrien Vieira de MELLO[3]; Eugenio MORELLO[4]; Carla BALOCCO[5]; Virginia GORI[5]

[1] Laboratoire de Systèmes d'Information Géographique (LaSIG)
EPFL, Station 18, CH-1015, Lausanne, Switzerland
+41216935786, Claudio.Carneiro@epfl.ch, Francois.Golay@epfl.ch, Stephane.Joost@epfl.ch
[2] Laboratoire Energie, Environnement et Architecture (LEEA)
Rue de la Prairie, 4, CH-1202, Geneva, Switzerland
+41225462680, Gilles.Desthieux@leea.ch
[3] Service de l'Organisation et des Systèmes d'Information
Rue des Gazomètres, 7, CH-1211, Geneva, Switzerland
+41225467271, Adrien.Vieira-DeMello@etat.ge.ch
[4] Laboratorio di Simulazione Urbana (LSU)
Dipartimento di Architettura e Pianificazione (DiAP)
Politecnico di Milano, Via Bonardi, 3, 20133 Milano, Italy
+39223995561, Eugenio.Morello@polimi.it
[5] Department of Energy Engineering "Sergio Stecco"
Università di Firenze, Via S. Marta, 3, 50139, Firenze, Italy
+39554796236, Carla.Balocco@unifi.it, Virginia-Gori@libero.it

Keywords: 3-D models, LiDAR, 3-D visualization, Urban Environmental Quality (UEQ), indicators

Introduction

In October 2005, a survey to several potential end-users (surveyors, architects, urban planners, environmental and energy specialists, among others) of the City of Geneva (Switzerland) showed a strong interest for the integration of the third dimension in the available GIS data of the City of Geneva, mainly by the integration of new layers of information, here referred to as 3-D urban indicators [1]. In order to extract this type of indicators, different geo-referenced data of excellent quality, such as 2-D cadastral data, aerial images, LiDAR (Light Detection And Ranging) data and a 3-D vector model were used. A main focus was given to the construction of innovative 3-D Urban Environmental Quality (UEQ) indicators, which are highlighted through the 3-D visualization displays proposed here. A simple example is the exploration of the solar potential of building facades and roofs. In this case, the purpose is to evaluate the potential of buildings for the installation of solar panels (photovoltaic and thermal).

Aim of the research

The visualization of specific 3-D urban scenes can be done calling upon different techniques, from those more traditional, such as photogrammetry, to the most advanced ones, such as LiDAR, which uses different techniques and algorithms of selection and modelling of 3-D point clouds. The use and utility of this kind of data for the study of urban development remain however debatable. Indeed, indicators for urban development and durability are highly necessary and the best methodology to build and visualize them is largely open.
The real utility of tridimensional models for the visualization of UEQ indicators can be fully exploited only by involving end-users in the process, mainly by evaluating which are their requirements. Indeed, it is important to show and represent this type of indicators using distinct Levels of Detail (LoD), according to end-user requirements and applications, allowing the apprehension of the nature, scale and impacts of the observed phenomena. In this context, some questions may arise: do the extracted UEQ indicators have to be regularly 3-D visualized? If so, according to the CityGML standard [2], which LoD must be retained for each of these indicators?

Levels of detail (LoD) for 3-D visualization of urban indicators

Conventionally, the main reason for representing different LoD is efficient visualization, mainly due to cognitive and perceptive reasons [3], [4]. Well-organized analysis is another important cause for using LoD in optimal 3-D visualization displays. For example, counting the number of buildings in a city can be accomplished most proficiently by considering the buildings on a lower LoD. Hence, for the present study, the CityGML standard was chosen. This standard is a common information model for the representation of both complex and geo-referenced 3-D vector data along with the associated semantics, and includes a well-defined method for the visualization of different LoD (Figure 1) [2].

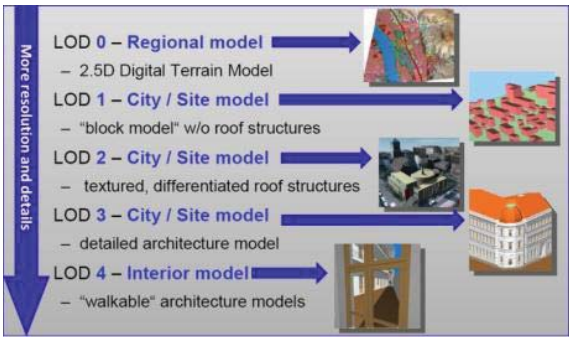

Figure 1: Levels of Detail (LoD) according to the CityGML standard. Adapted from [2].

The LoD classification method proposed inside the CityGML standard is perfectly appropriate for this study because it deals mainly with representation and detailed aspects of buildings. Indeed, most of the proposed UEQ indicators here highlighted and extracted are intrinsic to this type of urban objects.

Analysis of end-users' requirements

According to the analysis of end-users' requirements in the city of Geneva, a list of six main domains was defined: (1) architecture, urbanism and land planning, (2) urban traffic (motor vehicles, trains and airplanes), (3) environment and energy, (4) pedestrian and cyclist mobility, (5) security and emergency situations management, and (6) underground information. These six domains were grouped into different stakes. According to [5], a stake is defined as a general objective representing an expected evolution or a tendency for a given problem. Thus, for each stake, one or more geographical indicators considered as sufficiently representative and pertinent were mandatorily defined.

The utility of the proposed visualizations of UEQ indicators for potential end-users is important. Thus, it is essential to propose visualization displays that are in conformity with end-user's needs. For this reason, the questionnaires submitted to end-users in the city of Geneva also included a preliminary evaluation of different 3-D visualization possibilities of the proposed UEQ indicators:

- Which scales (building, neighborhood and city) of 3-D visualization should be used?
- Which LoD should be used for each scale of representation?

Answers to the two questions above are shown in Table 1. Indicators shown in bold and italic are those that due to its innovative characteristics related to UEQ were researched and extracted under this study [6], [7], [8] and [9].

Domain	Stake	Indicator	Scale of 3-D visualization	Level of Detail (LOD)
Architecture, urbanism and land planning	Maximize the quality of the built environment	Visibility analysis	City	LOD0
			Neighborhood	LOD0
		Sunshine analysis	Neighborhood	LOD1
			Building	LOD2 (without other urban objects)
Environment and energy	Minimization of the concentration of pollutants in the urban texture	Flow and air dispersion	City	LOD0
			Neighborhood	LOD2 (it may include other urban objects)
	Minimization of inhabitants exposed to radiation sources	Zones of the frontages of buildings exposed to radiation sources	Neighborhood	LOD1
			Building	LOD2 (without other urban objects)
	Exploration of the solar irradiation on building roofs	*Radiation collected by roofs*	*City*	*LOD0*
			Neighborhood	*LOD1 / LOD2 (without other urban objects)*
	Exploration of the solar irradiation on building facades	*Radiation collected by facades*	*City*	*LOD0*
			Neighborhood	*LOD1 / LOD2 (without other urban objects)*
	Estimation of the heating demand on the urban fabric	*Seasonal thermal energy requirements*	*City*	*LOD0*
			Neighborhood	*LOD1 / LOD2 (without other urban objects)*
		Seasonal heat losses	*City*	*LOD0*
			Neighborhood	*LOD1 / LOD2 (without other urban objects)*
		Seasonal gains	*City*	*LOD0*
			Neighborhood	*LOD1 / LOD2 (without other urban objects)*
		Seasonal thermal energy needs	*City*	*LOD0*
			Neighborhood	*LOD1 / LOD2 (without other urban objects)*
	Estimation of the lighting demand on the urban fabric	*Lighting demand analysis*	*City*	*LOD0*
			Neighborhood	*LOD1 / LOD2 (without other urban objects)*
Architecture, urbanism and territory planners + environment and energy	*Assessment of the morphological properties of the urban texture*	*Average height (building)*	*City*	*LOD1*
			Neighborhood	*LOD1*
		Type of roof	*City*	*LOD2 (it may include other urban objects)*
			Neighborhood	*LOD3 (it may include other urban objects)*
			Building	*LOD3 (it may include other urban objects)*
Urban traffic	Minimization of inhabitants exposed to noise	Level of noise	City	LOD0
			Neighborhood	LOD1
			Building	LOD2 (it may include other urban objects)
	Minimization of inhabitants exposed to pollution	Level of pollution	City	LOD0
			Neighborhood	LOD1
			Building	LOD2 (it may include other urban objects)
	Guarantee maximum safety for airplanes	Riks for airplanes	City	LOD2 (it may include other urban objects)
			Neighborhood	LOD2 (it may include other urban objects)
Pedestrian and cyclist mobility	Motivate the "sweet mobility"	Road and pavement slope analysis	City	LOD0
			Neighborhood	LOD0
Security and emergency situations management	Minimization of flood risk	High risk zones	City	LOD0
			Neighborhood	LOD2 (it may include other urban objects)
	Selection of suitable building roofs for helicopter landing	Flat and large roofs	City	LOD2 (it may include other urban objects)
			Neighborhood	LOD2 (it may include other urban objects)
			Building	LOD2 (it may include other urban objects)
Underground information	Integration of 3-D urban surface and underground data	Detection of zones of conflict	Neighborhood	LOD2 (it has to include other urban objects)
			Building	LOD2 (it has to include other urban objects)

Table 1: Scales of 3-D visualization and Levels of Detail (LoD) to be used for the representation of UEQ indicators.

Some examples of 3-D visualizations for UEQ indicators related to the stake "exploration of the solar potential on the urban fabric"

Indicators related to the exploration of the solar potential on the urban fabric, on buildings in particular, can be subdivided into two main topics: facade analysis and roof analysis.
Two examples of 3-D visualization for indicators related to solar irradiation analysis on facades are shown in Figures 2 and 3:

- 3-D visualization (LoD2): Figure 2 shows the average values per building facades;
- Novel techniques for 3-D visualization mixing 3-D representation (LoD2) with graphical and statistical data: the 3-D visualization proposed in Figure 2 can be enriched with a graphical profile showing the percentage of vertical surfaces subjected to direct irradiation with increasing height [%] (Figure 3). Such display highlights both the global vertical irradiation in the analysed

neighbourhood and the degree to which the top parts of buildings benefit from higher solar admittance.

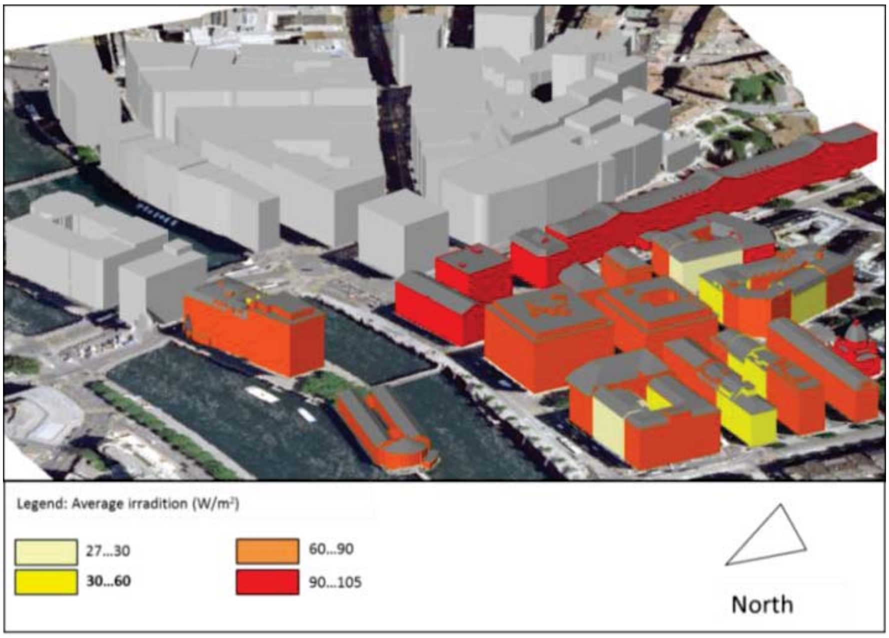

Figure 2: 3-D visualization (LoD1 and LoD2) of buildings considering a neighbourhood scale: quantitative indicator inherent to the average irradiance values (considering both direct and diffuse contributions, expressed in W/m^2) collected per building facades on the 10th of December at 12PM for a neighbourhood (business area) of the city of Geneva.

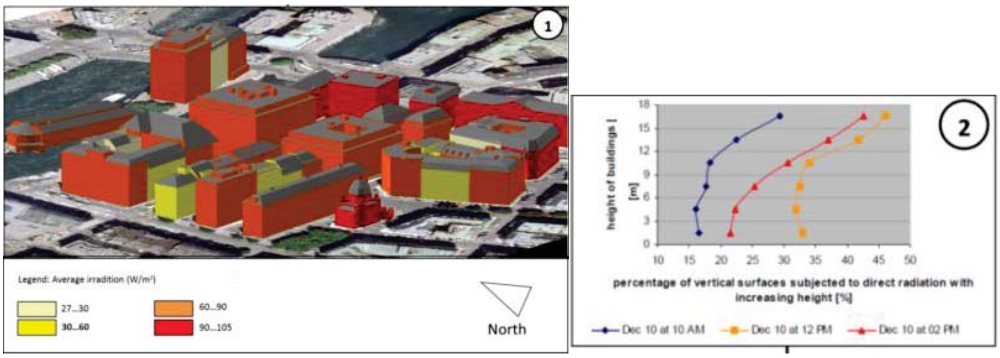

Figure 3: Hybrid approach of 3-D visualization of buildings for urban indicators: (1) - 3-D visualization (LoD2) of a quantitative indicator inherent to the average irradiance values (considering both direct and diffuse contributions, expressed in W/m^2) collected per building facades on the 10th of December at 12PM for a neighbourhood (pilot zone) of the city of Geneva; (2) - graphical profile with statistical data showing the percentage of vertical surfaces subjected to direct irradiation with increasing height [%] (in this case, for a selected building) for the same day, at 10AM, 12PM and 2PM.

As regards the indicators of roof solar irradiation analysis, potential users would be interested in assessing which section of the roofs would be suitable, or not, for solar panels collectors (for PV or thermal purpose), depending on the available solar admittance and roof area. When roof sections[1] are available (for example, in the City

[1] Usually, represents the 2-D projection of roof sections (vector format) existing in 3-D city models.

of Geneva), yearly irradiation values (KWh/m^2) can be aggregated on each roof section as to highlight a synthetic representation of which surfaces are suitable for the installation of solar collectors. Thus, three examples of visualization displays of the quantitative indicator inherent to the assessment of the yearly solar irradiation higher than 1.000 KWh/m^2 for all building roofs of the neighbourhood of Moillesulaz, City of Geneva, are shown in Figure 4 (LoD0 projected in a 2-D view), Figure 5 (LoD1) and Figure 6 (LoD2).

Figure 4: 2-D visualization of buildings using a LoD0 (projected in a 2-D view) considering a neighbourhood scale: quantitative indicator inherent to the yearly solar irradiation (KWh/m2) by roof pixels for a neighbourhood (Moillesulaz pilot zone) of the city of Geneva.

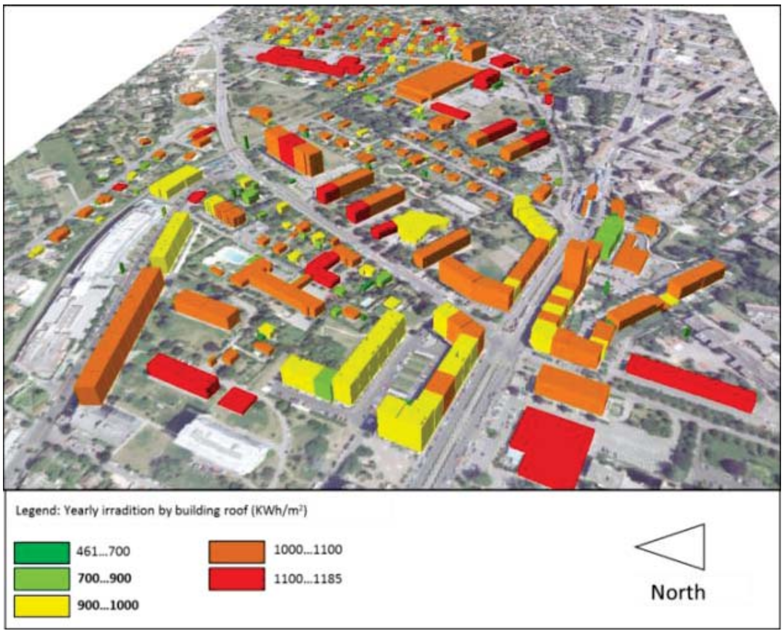

Figure 5: 3-D visualization (LoD1) of buildings considering a neighbourhood scale: quantitative indicator inherent to the yearly solar irradiation (KWh/m^2) by building for a neighbourhood (Moillesulaz pilot zone) of the city of Geneva.

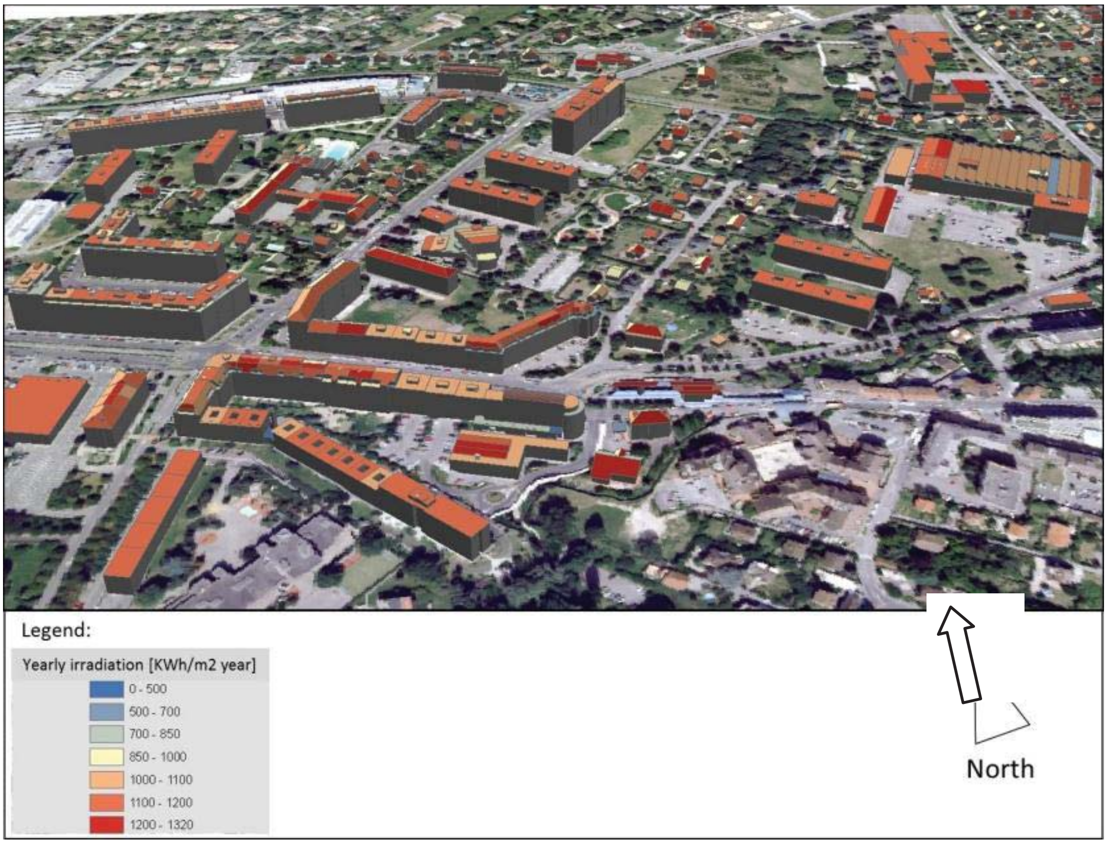

Figure 6: 3-D visualization (LoD2) of buildings considering a neighbourhood scale: quantitative indicator inherent to the yearly solar irradiation (KWh/m^2) by roof sections for a neighbourhood (Moillesulaz pilot zone) of the city of Geneva.

Some examples of 3-D visualizations for UEQ indicators related to the stake “estimation of the energy demand on the urban fabric”

Potential users may be interested in indicators related to the estimation of the energy demand on the urban fabric. In the example presented in this section, values are aggregated on each building in order to highlight a synthetic representation of the seasonal thermal energy requirements. Thus, three examples of visualizations: (1) 3-D using the same LoD, (2) 3-D using different LoD, and (3) 3-D using different LoD and the integration of labels, are shown in Figures 7, 8 and 9 respectively, for the case-study area of the European Organization for Nuclear Research (CERN), also located in the City of Geneva.

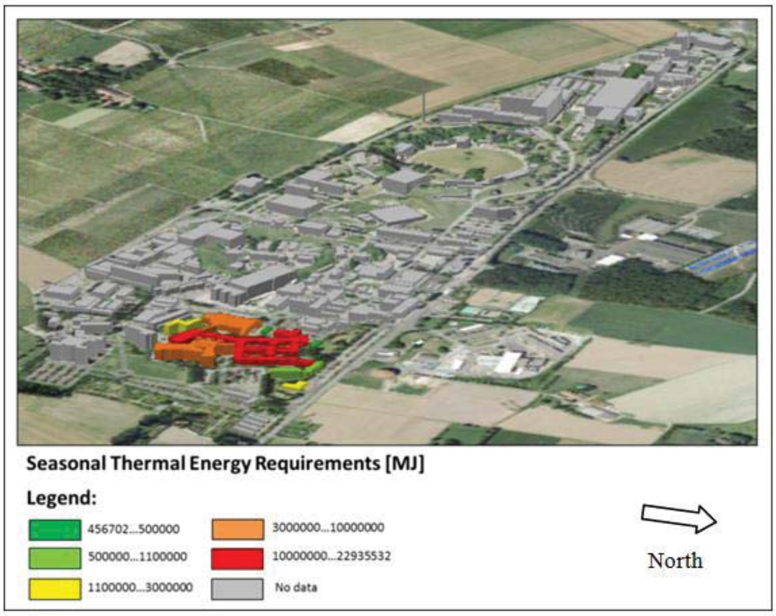

Figure 7: 3-D visualization (LoD1) of buildings considering a city scale: quantitative indicator inherent to the seasonal thermal energy requirements (MJ) by building, for the case-study area of CERN.

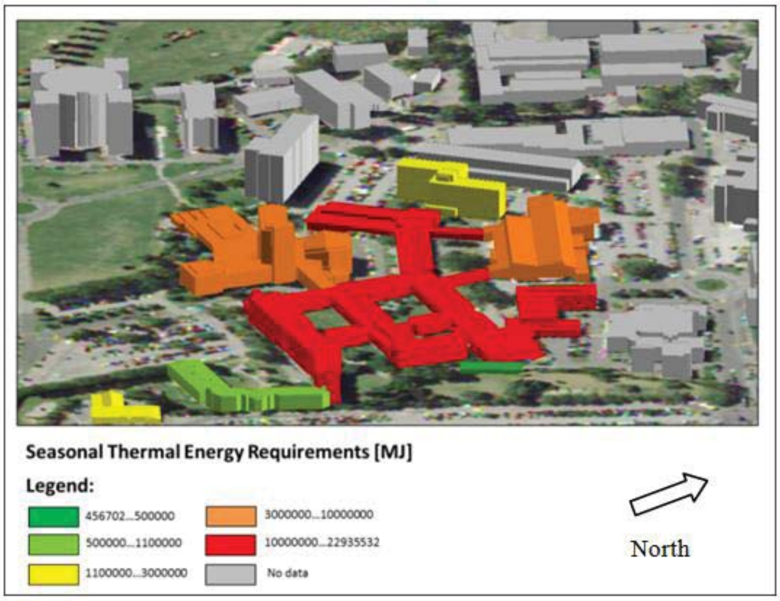

Figure 8: 3-D visualization of buildings considering a neighbourhood scale, using different LoD (LoD1 and LoD2): quantitative indicator inherent to the seasonal thermal energy requirements (MJ) by building, for the case-study area of CERN.

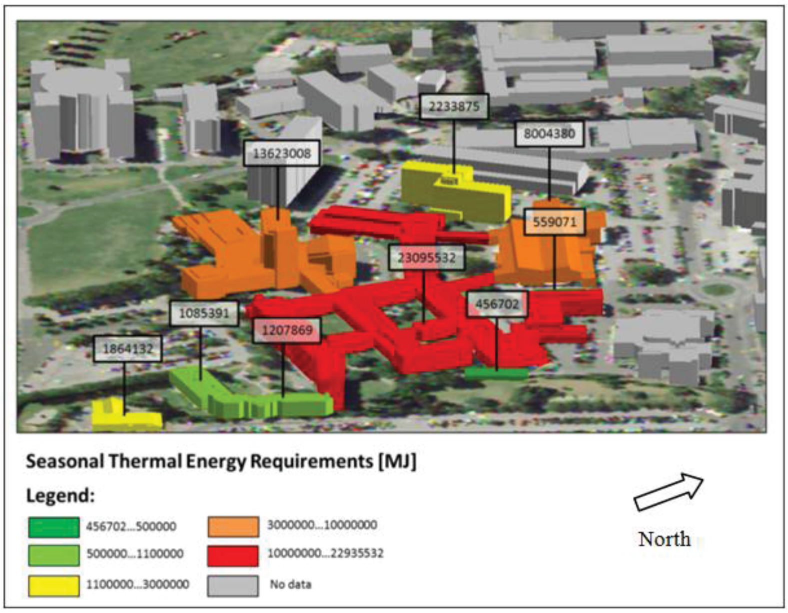

Figure 9: 3-D visualization of buildings considering a neighbourhood scale, using different LoD (LoD1 and LoD2) and building's labelling: quantitative indicator inherent to the seasonal thermal energy requirements (MJ) by building, for the case-study area of CERN.

It is worth mentioning that for some 3-D visualizations of UEQ indicators, the creation of displays using different LoD1 and LoD2 is an added value when the attention of the user must be guided to a neighbourhood or a set of buildings under analysis (Figures 8 and 9, and also Figure 2 concerning the solar irradiation analysis on building facades). Hence, the buildings considered for analysis are shown using a LoD2, whereas all other buildings, which were not considered for analysis, are represented using a lower level of detail (LoD1).

Conclusions and perspectives

The objectives of 3-D urban models users when visualizing spatial indicators must be carefully identified. In fact, very detailed urban models do not necessarily offer an appropriate solution for visualization of the majority of 3-D UEQ indicators shown here.

The goal of this survey was to make a preliminary utility analysis of the visualizations (using the CityGML standard) proposed to end-users, related to the UEQ indicators presented here. Many other aspects, such as analysing the impact related to the use of different degrees of transparency for selected displayed data or the integration of other urban objects (for instance, trees) on the 3-D interfaces created should also be taken into consideration for further utility and usability studies.

Finally, for different participatory situations, other methods using simpler representations of this type of indicators into 3-D visualisations should be considered for wider collaborative end-users and stakeholder groups, such as interested citizens of different ages. In this case, the use of qualitative indicators, instead of quantitative indicators, seems to be suitable because the communication process is simpler. Moreover, using heterogeneous groups of users with different experiences and ages allows the application of a more reliable usability analysis of interactive 3-D visualization displays.

References

[1] **Carneiro, C.** (2008), Communication and visualization of 3-D urban spatial data according to user requirements: case study of Geneva. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 37, Part B2, pp. 631-636.

[2] **Kolbe, T. et al.** (2005), CityGML - Interoperable Access to 3-D City Models. In Van Oosterom, P., Zlatanova, S., Fendel, E. (Eds.): *Proceedings of the Int. Symposium on Geoinformation for Disaster Management*, 21st–23rd March, Delft, Netherlands, Springer. (not paginated)

[3] **Guthe, M. and Klein, R.** (2003), Efficient NURBS Rendering using View-Dependent LoD and Normal Map. *Journal of WSCGs* (Int. Conf. in Central Europe on Computer Graphics, Visualization and Computer Vision), 3rd-7th February, Plzen, Czech Republic. (not paginated)

[4] **Reichenbacher, T. and Swienty, O.** (2007), Attention-guiding geovisualization. *Proceedings of the 10th AGILE International Conference on Geographic Information Science*, 8th-11th May, Aalborg University, Denmark. (not paginated)

[5] **Desthieux, G.** (2005), Approche systémique et participative du diagnostic urbain. Processus de représentation cognitive du système urbain en vue d'élaboration d'indicateurs géographiques. Thesis n° 3216, Ecole Polytechnique Fédérale de Lausanne, Switzerland.

[6] **Carneiro, C. et al.** (2008), Solar radiation over the urban texture: LiDAR data and image processing techniques for environmental analysis at city scale. *Lecture notes in geo-information and cartography*. *3-D Geo-Information Sciences*, In: Zlatanova, S., Lee, J. (Eds.), Part II, pp. 319-340.

[7] **Carneiro, C. et al.** (2009), Assessment of solar irradiance on the urban fabric for the production of renewable energy using LiDAR data and image processing techniques. *Advances in GIScience*, In: Sester, M., Bernard, L., Paelke, V. (Eds.), Springer, Berlin, pp. 83-120.

[8] **Carneiro, C. et al.** (2010), Digital urban morphometrics: automatic extraction and assessment of morphological properties of buildings. *Transactions in GIS*, Vol. 14, Issue 4, pp. 497-531.

[9] **Gori, V. et al.** (2011), The evaluation of solar energy potential and energy needs for heating and lighting using LiDAR data. *Proceedings of the 27th International Conference on Passive and Low Energy Architecture (PLEA)*, 13th-15th July, Louvain-la-Neuve, Belgium. (accepted, to publish)