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3D Geovisualization City-scenarios with combined data for Noise and Air Quality Mapping

Abstract. This study focuses on demonstrating the importance of a three-dimensional visualization of geographic information, in fields of urban planning. The 3D Geovisualization simulates with a high level of realism the urban landscape, therefore the viewer is able to observe and understand local changes at fine spatial scales, faster and easier than in 2D. Characteristic examples of 3D geovisualization constitute digital elevation models draped with orthorectified or satellite imagery and 3D city models. This study explores a visualization of a baseline scenario of the prone areas to air and noise pollution within the virtual city of Lisbon, Portugal. Air quality and noise data, relief, building densities, traffic, road infrastructures, green areas and population are the variables that have been used. The 3D city model has been created with low level of details, using CityEngine system. The suggested model serves the purpose of the study although few issues concerning the data and the 3D model had to be succeeded.

Keywords. 3D geovisualization, air pollution, noise pollution, urban model

INTRODUCTION

The three-dimensional Geovisualization is effectively used for communication purposes in landscape planning, in city architecture, in meteorology, geology and groundwater analysis (Berg et al., 2012; Kreveld, 2008; Lovett et al., 2015). Trying to theoretically explain 3D-Geovisualization, the definition for Geovisualization defined in the research agenda (2001) of the International Cartographic Association (ICA) Commission on Visualization and Virtual Environments is used. Thus, 3D Geovisualization "integrates approaches from visualization in scientific computing (ViSC), cartography, image analysis, information visualization, exploratory data analysis (EDA), and geographic information systems (GISystems) to provide theory, methods, and tools for visual exploration, analysis, synthesis, and presentation of geospatial data" (MacEachren & Kraak, 2001, p. 3) in three dimensional space with a set of (x, y, z) coordinates.

Nowadays, the 3D modeling for visualization of spatial data is being used more and more in urban design applications since facilitates the communication of planned changes to different stakeholders, by presenting information that it would not be feasible with a two-dimensional model (Rautenbach et al., 2015). Overall, a 3D city model represents the urban environment with a realistic way and supports sustainable urban planning (Luo et al., 2016.
A common 3D city model can be developed using different acquisition techniques such as "extrusion from two-dimensional footprints, photogrammetry and laser scanning, architectural models and drawings, synthetic aperture radar, handheld devices and Volunteered Geoinformation (VGI)" (Biljecki et al., 2015, p. 2843). The construction of it can be time-consuming, costly and with use limitations. On the contrary, a *rule-based* 3Dcity

model is a promising method to brace urban planning for large areas and fulfill the current increasing demand of three-dimensional modeling (Luo et al., 2016).

This study explores a rule-based 3D model of the city Lisbon, Portugal written in CGA (Computer Generated Architecture) *shape* computer language using CityEngine (CE) system, with combined air and noise pollution data for urban sustainability assessment. Parish and Muller (2001) presented CityEngine for mass modeling (volumetric model) of large cities by applying a set of explicit rules that can be extended according to user needs. Merely a small amount of input data; driven from two-dimensional Geographical and Sociostatistical maps is required (Parish & Muller, 2001). The CGA language is using *shape grammars*; which first introduced by Stiny [1975] (Wonka et al., 2010), with production rules, in order to generate three-dimensional architectural content. A set of production rules is applied to selected objects which consist of geometry and attributes, in order to create a city model with more and more details (Muller et al., 2006). This different level of detail (LoD) relates to the exterior and interior of the objects of each layer of the model (buildings, trees, terrain, networks) depending on the purpose of the study and the investment. More detailed city models use higher resolution ortho imagery and additional details such as facade texturing, materials of buildings, interior spaces, detailed streets, street furniture, signage, and infrastructure lines among others and CGA rules such us "extrude", "split" or "texture" are applying to the objects to give the different LoD to the model. In 3D city modeling, the LoD is not explicit, there are no common guidelines; meaning a unique widely-accepted LoD prototype besides specific standards such as Open Geospatial Consortium (OGC/CityGML) standards. Furthermore, there is no certain level of detail that a 3D city model should have for a specific application (Biljecki, 2017) so we could say that common sense will make the difference.

The 3D city model created here is focusing on the analysis of noise and air pollution in street level, mainly to support urban sustainability and urban health (Borrego et al., 2015 and 2016; Buccolieri et al., 2015) and not so much on the visualization of the city. Thus the LoD is low with not texturing in the buildings and in other components of the model. Exposure to air pollution and environmental noise pollution has shown serious impacts on both physical and mental health causing heart disease, hearing loss, respiratory disease, asthma, anxiety, and depression among others. Air and sound pollution can affect behaviors as well, by causing sleep disturbance, annoyance, aggression and the cognitive impacting on productivity levels and causing learning disturbance (Science for Environment Policy, 2016).

MATERIALS AND METHODS

STUDY AREA

The city of Lisbon is located in western Portugal on the estuary of the Tejo river. Lisbon is the biggest city and capital of Portugal with population 504.718 inhabitants in 2016 (INE, Pordata, 2018) and area of 100km^2. Within the borders of the city of Lisbon and the valley of Tejo, the levels of the air pollutants PM_{10} and NO_2 have been exceed the standardized limit values of European Union and World Health Organization (WHO) since 2001. Since 2006, Lisbon and Tejo Valley have applied Air quality Action Plan in order to enforce compliance with the legitimate limit values (Ferreira, 2015) and mitigate the impacts on public health caused by noise and air pollution.

Fig.1 Study area – Air quality Monitoring Stations (authors).

DATA INFORMATION

Air pollution data for the year 2016 and the city of Lisbon were taken from the Portuguese Environment Agency (APA). The air pollutant that has been studied here is the particulate matter (PM_{10}). PM_{10} are a mixture of solids and liquid droplets floating in the air. PM_{10} form coarse particles with diameter size from 2.5 to 10 micrometers. These particles are coming from anthropogenic stationary and mobile sources and natural sources for instance wildfires and volcanos. Stationary sources can be point and area sources. A point source consists of an identifiable source of pollutants´ emissions typically associated with large manufacturing or production plants such as boilers, spray booths or degreasers. Within a point source can be multiple emission points. Area sources encompass small emissions of a certain pollutant widely spread, but with considerable cumulative emissions. Residential water heaters, small engine, barbecue lighter fluid and hairspray are examples of area stationary sources Automobiles, trains, construction, farm equipment are examples of mobile sources of air pollution (SCAQMD, 2005; EPA 2017). Particles may be emitted directly or may be formed in the atmosphere by transformations of gaseous emissions such as oxides of sulfur (SO_x), oxides of nitrogen (NO_x), and volatile organic compounds (VOCs). The chemical and physical properties of PM vary greatly with time, region, meteorology, and the source of emissions. The values of the PM_{10} concern the average annual values in a daily basis in $\mu g/m^3$ for particles with size no more than 10 μm and the European standards for this pollutant is 40 $\mu g/m^3$. The WHO standards regarding PM_{10} for 24-hour average is 50 $\mu g/m^3$ and for annual average 20 $\mu g/m^3$ (WHO, 2005). The air quality data were collected from the stations of Santa Cruz de Benfica, Entrecampos, Avenida da Liberdade, Restelo, and Olivais (Fig. 1).

Noise pollution data, represented into a Db(A) scale, were acquired from the City Council for the year 2016. Main sources of noise and air pollution within the study area are the road traffic and the airport which is located in 7 kilometers distance from the city center.

Data regarding the green spaces and the road network and relief of the city for the year 2017 were acquired from the site of Lisbon Municipal Chamber. Green areas support biodiversity in the urban ecosystem, they provide physical and psychological health benefits since they reduce atmospheric pollution, they regulate the microclimate, and they provide cultural and recreational services among others (Madueira et al., 2015). Using relief data, areas more prone to concentrate air and noise pollution are identified. Valleys are considered more vulnerable areas in comparison with open spaces well aerated (Alcoforado et al., 2009).

Traffic data have been included in this study since the road traffic emissions constitute a key variable in the global accuracy of air quality modeling particularly at urban scale (Borrego et al., 2016). The average number of vehicles per day; using the morning and afternoon peak, multiplied by km of road hierarchy for the year 2005 has been used in this study (Câmara Municipal de Lisboa, 2005). Data regarding the buildings of the city were acquired from the Land Registry of Portugal. Population data were acquired from the National Statistical Institute of Portugal (INE) for the year 2011.

DATA MODELING

Data was acquired from different sources with different scales, thus a downscaling based on interpolation methods using the road network in order to obtain ground level values. Modelling is the best way to have improved, better and more reliable information to support research and policy makers (Borrego et al., 2015). Three spatial interpolation methods; Kriging, IDW, and Spline, have been tested in order to model the air pollution, so an aerial data (surface analysis) could be created and city/human exposure assessment could be done. Kriging belongs to geostatistical methods which are based on statistical models with autocorrelation. The spatial relationship between the measured point is known and it is estimated from the observed data with some level of certainty. Inverse Distance Weighting (IDW) method and Spline are deterministic interpolation methods, which attribute values to specific locations taking into consideration the surrounding measured values and using mathematical formulas in order to define the smoothness of the resulting surface (ESRI, 2016). The results using Spline interpolation were better fitted to the reality.

Noise pollution has been modeled by the Lisbon´s City Council using the CadnaA (Computer Aided Noise Abatement)[1] software. The noise pollution data were crossed with the traffic data. The green areas were checked using an imagery basemap and modified accordingly. The green spaces were crossed with the road network calculating the distance between them, using near proximity tool. A Triangular Irregular Network (TIN) model was created to represent the surface morphology and hydrology tools were used to define the valley areas of the study area.

In order to define the height of the buildings of Lisbon, a two-dimensional footprint with information regarding the number of the floors for each building was used. In this data set, the 22% of the buildings (12408) had with zero value in the field of floor´s number. To overpass that obstacle, 182 buildings of them which represent metro stations,

[1] CadnaA is a dominant tool for environmental noise modeling thanks to its powerful algorithms for noise calculation, assessment and prediction and its compatibility with GIS.

squares, underpasses, historical places were eliminated and for the rest, the number of their floors was calculated taking into account the average of the building´s floor of each street using field calculator and python scripts. The machine could not calculate the average of the floor for the buildings located on streets with buildings with only zero number of floors. Thus, the number of floors for these buildings was calculated from the average of the floors of the buildings per parish.

SCENARIO BUILDING

In order to identify the critical areas (dangerous, medium, poor) and good environment urban life quality and to assess the urban environment, two scenarios-methods are suggested; a *Baseline scenario* and an *Expert scenario*. The *Baseline scenario* is an overlay of the noise and air pollution data crossed with the traffic data and then crossed with the valleys of the study area. All the features were converted to raster and reclassify giving the values 1 -2- 3 to the classes with the lower, medium and higher values respectively. Afterwards, map algebra was used to overlay the variables and five successive outputs of critical areas were created. The *Expert scenario* is the weighted overlay of the features mentioned above. At this point, the study is focusing on the *Baseline scenario*.

3D CITY MODELLING

CityEngine system was used to demonstrate the spread of noise and air pollution within the study area in a three-dimensional environment. Using the *Get Map Data* tool, the imagery of the area of interest as texture-base map and the terrain taken from ESRI World Elevation were imported with high-resolution 4k (4096). The geodatabase concerning the buildings was imported, and after selecting the objects of the file, they were aligned to the terrain and the following CGA rule was assigned in order to extrude the height of the buildings and to give gable shape to the roofs (Fig.2). The shapefiles of the road network, green spaces, the overlaid air and noise pollution data were imported and aligned to the terrain, then CGA rules from ESRI library were applied for realistic visualization.

```
attr HEIGHT = 0
attr floor_height = 2.7
attr wallColor= "#fefefe"
Lot -->
  extrude(HEIGHT)
  Mass
Mass -->
  comp(f) {side: Facade | top: Roof}
Facade -->
  split(y){{~floor_height : floor}*}
floor-->
   color(wallColor)
Roof -->
  roofGable(30)
```

Fig.2 CGA rule for buildings

RESULTS

The designed methodology was computed mainly in ArcMap and it consists of a step-by-step map algebra analysis, so it would be possible to identify at an human scale, different critical areas. In fact we have come to 5 critical areas: the first (critical 1) was the result of an overlay between noise data and PM10 air quality data, the second (critical 2) results from the overlay between the critical 1 with the traffic data, the critical 3 was the output of the overlay between critical 2 and relief data; valleys, the fourth critical area (critical 4) comes from the overlay between a map of euclidean distance to green urban areas from the critical 3 and the critical 3 itself; and finnaly, the critical 5 area (Fig.3) was the result of a spatial analysis that identify the sub-seccções[2] where the more vulnerable people lives within a 200m distance 200m from the critical 4, class value 4 (poor and dangerous life enviroment roads). Therefore, by adding more detail through fundamental data in the step-by-step life quality assessment model we have been able to identify three types of knowledge-information: 1) the relative importance of each one of the features added to the model, since critical 1 to critical 5; the areas where the critical areas are taking place and how they change through the model by adding features; and 3) the amount of most vulnerable people to poor and dangerous life quality environment. This knowledge-information is presented on a 3D City model (Fig.3) and it is compared to a 2d map (Fig.4). In the 3D city model, it is more clear the to understand the role of the rest of the feuture to the high risk areas by just looking the image. In Fig.3 we can see that a critical area 5 is located within a valley, close to high traffic roads and with high building density.

Fig.3 Three-Dimensional Representation of Critical Areas 5 (authors).

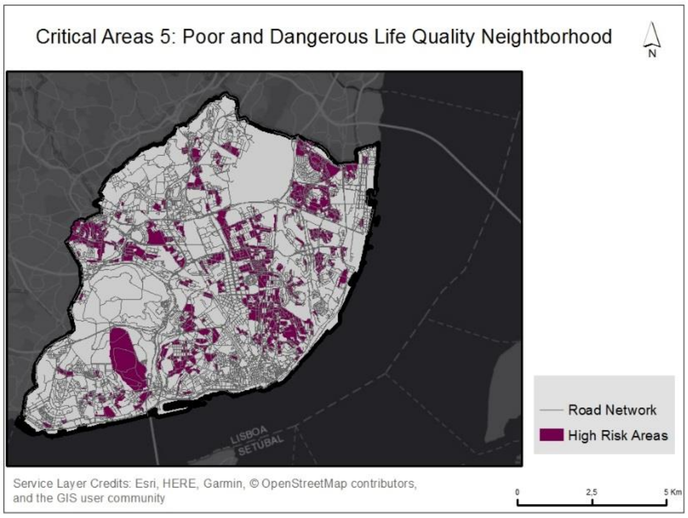

Fig.4 Two-Dimensional Representation of Critical Areas 5 (authors).

[2] It corresponds to the neighborthood in urban áreas. The smallest statistical territorial unit. Retrieved from http://censos.ine.pt/xportal/xmain?xpid=CENSOS&xpgid=censos_base_cartogr

CONCLUSION-DISCUSSION

As the world urban population grows, urban sustainability has to be assured in order to preserve the urban quality of life for now and for the near future. This study based on metrics and measures, technologies and people-oriented visualization and display constitutes a powerful tool for sustainable urban management and planning. It facilitates the communication and fills the gap between urban planners and stakeholders, and at the same time creates a tool that amplifies the vision planned and engage citizens to be part of it, by presenting information that it would not be feasible within a two-dimension. Although some obstacles had to be surpassed and some others they are still in the process. Initially, the used data were needed to be acquired at a human scale and in a homogeneous distribution through the city. Instead of it, point data were spatially interpolated to be able to obtain better values for the areas where there were not sensors or they were too sparse. To overlay and crossed the data, map algebra was used but conditional statements could be a better solution. Regarding the construction of the 3D city model, we can say that the CityEngien system is indeed a powerful tool to communicate complex geographic phenomena, integrating additional information into representation, performing a continuous mapping, and questioning in an interactive environment. Although, trying to model large areas as the study area, great computing power is required and the data have to be well-prepared since it is not feasible to use VGI. In conclusion we could say that the great outcome of this work is the contribution to the wake conscious for a urban air and noise policy as key features for a better urban suatainability planning. We consider that technology can give a huge contribution to a better quality of life if people-oriented policies are driven.

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