Eurographics Workshop on Urban Data Modelling and Visualisation (2016)
F. Biljecki and V. Tourre (Editors)

From Regional LULC Model to Urban Population Density Simulation in Wallonia

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Abstract

Cities must develop "Smart" management and planning strategies to mitigate the challenges caused by urban population growth. The SmartPop project proposes a LULC model and dasymetric population density maps to Walloon policy makers for analyzing and simulating future city development and localization of citizens. In this study, the constrained Cellular Automata LULC change model developed for Flanders and the Brussels-Capital Region is applied to the Walloon Region. This paper presents the first outputs from both parts of the project. On the one hand, maps of current and simulated LULC in 2050, resulting from the the first prototype of the LULC model are presented. Secondly, the dasymetric mapping protocol developed for Flanders is calibrated with Walloon data. The resulting population density map is validated with anonymous data of the National Register of Natural Persons. This project makes use of existing tools and data to propose a common spatial planning model for Wallonia, Flanders and Brussels.

I.6.3 [Simulation and Modeling]: Application.

1. Introduction

Urbanization increases with unprecedented levels around the world. Cities must develop 'Smart' management and planning strategies to mitigate the challenges caused by urban population growth reaching a value of 2%/yr worldwide [CNW*12]. 73% of European citizens live in cities and this ratio reaches a value of 98% in Belgium [WB15]. The Walloon Region, South of Belgium, has an urbanization rate of 17 km² per year [Cuv15]. Driven by demographic projections of an increase of 200,000 households from 2011 to 2026 as quoted by [CRM13], a further increase of the impervious surfaces is expected. This paper refers to spatial requirements in sustainable city planning: reliable and precise land-use/land-cover (LULC) models and recurrent population distribution maps for analyzing and predicting the city development and the localization of citizens. These two decision support tools are respectively developed for the Walloon Region and the city of Liège. Moreover, in the particular case, the density map is an input as well as an output of the LULC model.

Simulating current and historical LULC changes offer opportunities for regional and city management. A dynamic LULC model helps studying impacts of a fast changing urban environment and increasing imperviousness. Floods, urban heat islands, mobility issues and other environmental and health risks increase with urban growth [SRE*13]. Only a dynamic LULC model can simulate scenarios and impacts of urban growth on these issues and the population. A sustainable territory planning requires then a decision support tool providing a holistic and dynamic vision of the fast changing environment either at regional or city level and the number of people living in these urban centers.

Over the last decades a broad range of LULC models have been developed to assist land management. LULC models are distinguished by their characteristics: static/dynamic, spatial (geographical patterns)/non-spatial (trends), inductive (process description)/deductive (parameters from correlation), agent-based/pattern-based [MKP*14]. Choosing one of these depends on the goals, inputs and validation data available and technical skills (developers/end-users). A spatially explicit approach could be preferred in order to project and explore alternative scenarios [SL01]. Cellular automaton (CA) based models have perhaps been the most popular way to model LULC change and spatially-explicit population density [CAR07] [KB11] because (1) they are intrinsically dynamic, (2) they have high resolution and thus produce results with useful detail and (3) they outperform other models in realistically modelling LULC changes [PVR10]. In CA-based LULC models, change is explained by the current state of a cell as well as by the changes within its neighborhood. As a consequence, these models are gradually becoming part of decision support systems for the assessment of policies aimed to improve spatial planning and sustainable development [DCC04]. At European Union level, the MOLAND LULC dynamics modelling framework initiated in the early 2000's the use of CA to forecast the sustainable development of urban and regional environments [LBM*04]. The constrained CA LULC change model chosen in this study has been developed by [WEU15] [WEU97] and proposes a tool for assessing scenarios of LULC policies in support of spatial planning in Belgium.

This tool has been under development in Flanders since 2007 and is known there as the 'RuimteModel Vlaanderen'. The RuimteModel Vlaanderen is applied is a policy support tool by a number of end-users within the Flemish governemnt, including the spatial planning department (Ruimte Vlaanderen), the agency for Nature and Forest (ANB) and Flanders Innovation & Enterpreneurship (VLAIO). Since the approach has been validated within the Flemish region and in order to have comparable results at both sides of the border, the project proposes a similar approach

DOI: 10.2312/udmv.20161422

in the Walloon region. One of the objectives of the project is therefor to study whether a relatively generic modelling approaches can be used in different contexts such as the highly urbanised region that Flanders is versus the more rural Walloon region. Cartographic representation of population distribution has been improved by innovative dasymetric technique [Pet12]. These techniques use ancillary information to distribute population data in homogenous spatial zones and increase spatial accuracy [EB01]. Traditionally, population density is based on data provided at administrative units scale by national statistical institutes, showing the density in terms of inhabitants per unit. While these administrative units have various size and shapes, these heterogeneities cause distortions in the spatial analysis. This problem is known by the scientific community as the Modifiable Areal Unit Problem (MAUP) [Gru14]. Dasymetric mapping techniques are applied worldwide to derive gridded, MAUP-free maps of population distribution. To do so, ancillary cartographic information representative of the features' locations is used. Some examples can be cited like gridded urban population density mapping using night time imagery [SRE*97], the Landscan global population database [DBC*00] or the European population map developed by [GP01]. The last one disaggregated official European population counts into 100m cells using Corine Land Cover (CLC) products. When more detailed ancillary data are available for some specific LULC classes such as the impervious areas, a nested approach of the disaggregation protocol can be defined [BGL13]. Very detailed spatial data are becoming increasingly available and can be used in dasymetric mapping to produce reliable estimates of cell-level information for both population and economics activities [WEU15].

2. Data

Spatial planning relies heavily on existing and accessible geospatial data. Access to geospatial data in Wallonia is heterogeneous. A willingness of data dissemination is currently on-going at the regional level to answer to Inspire (2007/2/EC) and PSI (2003/98/EC, consolidated by 2013/37/EU) directives. Walloon authorities have developed a geoportal called WalOnMap [SPW16] which give access to a large range of datasets.

The prime dataset is the LULC map of Wallonia (COSW) which has unfortunately not been updated since 2007. This dataset integrates several sources from 2005 and sooner [BLF07]. All available thematic data sources have been integrated into a unique 'use' and 'cover' legend inspired from the EU CLC map. The hierarchy legend of classes presents five thematic layers divided in 71 classes with a mix of land-use and land-cover definitions.

The application of a constrained CA (CCA) LULC model requires a large set of data, mostly GIS-data, but also census data including figures and trends with regards to socio-economic growth in the region in the next 25-30 years. Population numbers for the period 2008-2015 are taken from the National Statistical Institute [INS11]. Population projections for the period 2014-2050 are based on the projections from the Federal Planning Bureau [FPB16]. A large number of geospatial and statistical information are integrated in the first prototype of the Walloon model: zoning plans, protected areas, infrastructure networks, soil, risks and socio-economic datasets.

For dasymetric mapping, demographic data are also provided by [INS11] at the level of the statistical sectors. The National Register of Natural Persons (RNPP) localizes the exact number of people per houses [IBZ14]. For privacy reasons, the Walloon Institute for Statistical Evaluation and Prospective (IWEPS) has built an aggregated version of the 2013 data using a raster format with a 100x100m resolution.

3. Methods

3.1 LULC change model

In this study, the CCA LULC change model developed in Flanders by [WEU15] [WEU97] is applied to the Walloon Region, with a perspective of focusing on the city of Liège for local model development. The first prototype for the Walloon Region has been developed and is described in this paper. Setting up a model application involves decisions on which LULC categories to include, the spatial and temporal resolution, and the time horizon of the intended simulation runs. Furthermore, for each categories modelled, the physical, institutional and accessibility qualities of the cellular space must be calculated, by means of an overlay analysis on the basis of representative constituting map-layers in the GIS-database.

The CCA LULC model is made up of three sub-models. These represent spatial dynamics that take place at three geographical levels (Figure 1): (1) 'global' level, i.e., the entire Walloon Region, (2) 'intermediate' level, i.e., NUTS3 regions (Eurostat administrative units level 3, called arrondissements in Belgium), and (3) cellular level, i.e., a 100x100m grid. At the global level, future trends for population growth and employment scenarios are needed.

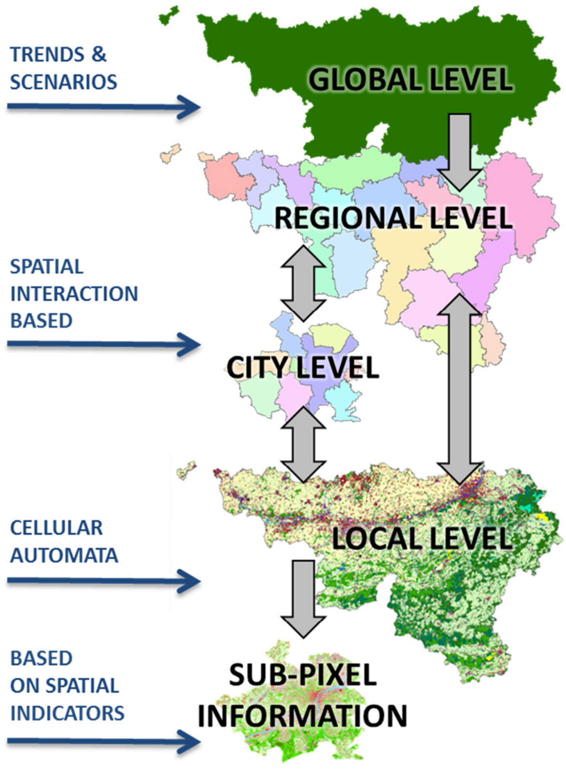

Figure 1: *LULC model: From Global to City level.*

These are adopted from the Federal Planning Bureau and give expected growth of the population and jobs in a number of economic sectors in Flanders, Wallonia and Brussels up to 2060. At the intermediat (regional) level, a spatial-interaction model is used to downscale these growth trends to the level of the arrondissements, and a density model is used to translate the population and employment numbers in an area demand for urban land use types. In the first prototype, these regional models are adopted from the RuimteModel Vlaanderen. The level to which the Flemish parameters are applicable to the Walloon region is part of the study traject and will be investigated within the project. Finally, at the local level, a CA-based model allocates the area needed for population and employment growth to the level of individual grid cells. This CA model simulates the evolving LULC until 2050 for each individual cell. The changing LULC patterns result from spatial interactions that take place between the different land-use classes within the immediate neighborhood around each cell, which are represented by a set of transition rules. These transition rules are a proxy for land rent and reflect the pressure exerted on the land. The account for the fact that the presence of complementary or competing activities and desirable or repellent land uses is significant for the cell's locational quality and thus for its appeal to particular land use types. In addition, they reflect the physical suitability, institutional status and accessibility of each location. The method is illustrated in Figure 2.

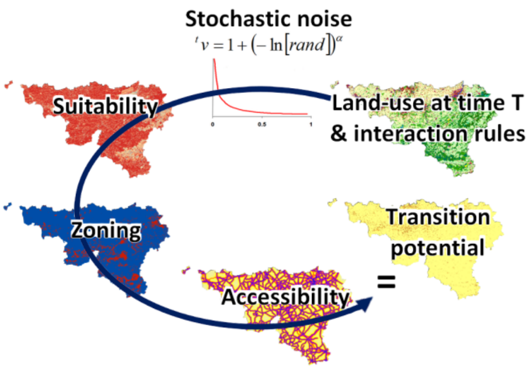

Figure 2: *LULC allocation at the local level based on the transition potential computed using 4 location components: neighborhood effect, suitability, zoning status and accessibility.*

Within the project, a city level model is under development, the methodology will be expanded with two extra scale levels (Figure 1). First of all, in order to take into account population growth at the level of the administrative municipalities, the CCA model results for the NUTS3-level can be further downscaled to the level of the municipalities based on a spatial-interaction model. Secondly, as stated by [PVR10] model results at the 100x100m resolution (LULC/population) should be further detailed by accounting for sub-pixel information.

3.2 Population density mapping

The dasymetric mapping protocol developed by [VVJ*09] is combined to the grid binary method, originally developed by [LMU91], in which population figures per administrative unit are assigned to populated land-use pixels. The WEISS software dasymetric mapping module has been developed by the Flanders Environment Agency (VMM) and the VITO. The dasymetric distribution of the population per administrative unit is done over the different LULC classes given a specific weight for each class calculated in terms of relative population density [PWE*15]. The total numbers are then corrected for deviations of the distribution of the LULC class in that region from the distribution of the classes across the entire study area.

4. Results

4.1 LULC change model

The transposition of Flanders CCA LULC model to Wallonia means some methodological adaptations. These adaptations refer to input data, calibration parameters and scenarios. The development of the model at the Walloon level is driven by several interactions with the end-users such as a quantitative survey, the direct involvement of experts in the steering committee and the definition of an implementation group [BSW16].

The base year of the prototype model is 2008. It corresponds to the year for which the COSW map is available as well as statistical data. The global level deals with economic and demographic activities including population and employment figures as well as projections.

The spatial interaction-based sub-model at the intermediate level differentiates 5 'sectors' (population, employment in agriculture, industry, commerce and service) and is calibrated using figures from the Federal Planning Bureau at the level of the 20 arrondissements, both for population and employment, in accordance with the RuimteModel Vlaanderen for Flanders. The density sub-model translates the regional growth numbers of population and employment into spatial claims.

At the local level, the Walloon Region is represented as a raster of 1,689,798 cells. The cells measure 100 by 100 meter (1 ha).

The most important model input is the LULC map. The COSW (71 classes) has been rasterised to a 10m spatial resolution and reclassified into 26 LULC categories referring to vacants (passively changing LULC types), functions (dynamicly changeing LULC types) and features (static) and then resampled to a 100m spatial resolution constrained by a conservation of area for each categories using the SpatAggr tool developed by RIKS NV [vmMH05].

Figure 3 shows the LULC maps for 2008 and 2050 according to the results of the BAU-scenario run by the first prototype of the SmartPop model for the Walloon Region and for the arrondissement of Liège. The maps show a clear expansion of the build-up land (mainly residential land). This residential growth is mainly taking place as a filling-up of the existing urbanised parts within the arrondissement.

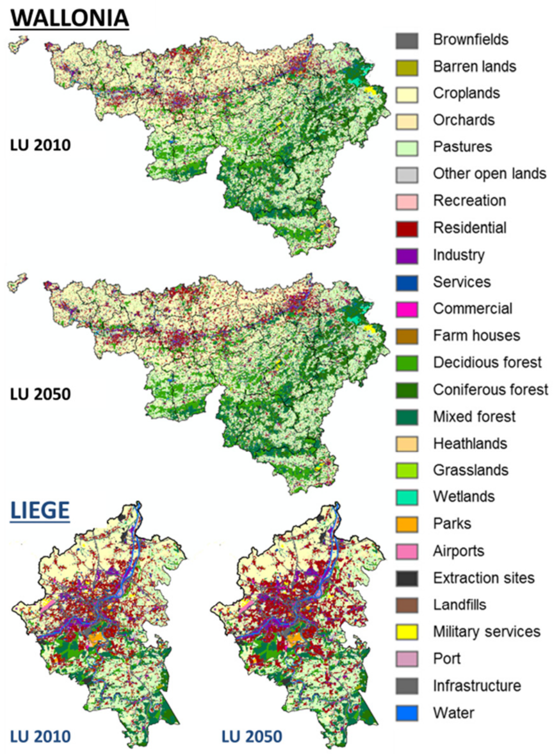

Figure 3: *26 classes LULC maps for 2010 and 2050 for the Walloon Region and arrondissement of Liège.*

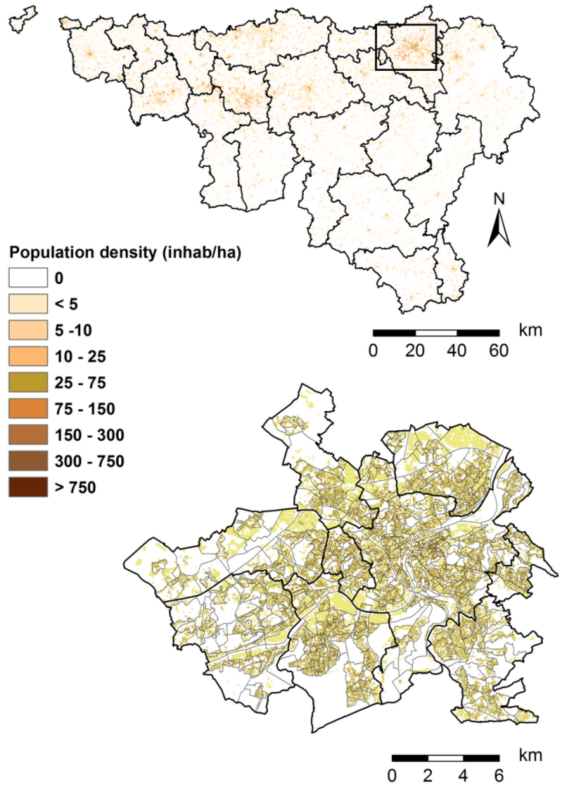

Figure 4 and 5: *Dasymetric population maps (1 ha resolution) based on 5 classes of density). Top: Walloon Region with 20 districts. Bottom: Liège urban agglomeration with 560 statistical sectors.*

4.2 Population density mapping

The WEISS dasymetric population protocol disaggregates statistical information that is available at the level of the statistical sectors on the LULC map. Since this protocol is executed per district, the demographical data provided at the level of statistical sectors is aggregated at this level. For the LULC map, two inputs are introduced in the software: a map describing classes of density of urban and non-urban LULC categories, and the relative importance of each of these classes (weights). To identify the inhabited LULC classes in the COSW, we executed a zonal statistic overlay with the RNPP dataset. Null and nodata cells have been qualified as 'uninhabited zones'. Finally, five density LULC classes are distinguished: three levels of density for the inhabited zones with respectively high, medium and low population density, possible inhabited (non-urban) and uninhabited zones (almost null or null zones). We derive from each of these classes the mean population density from the RNPP dataset, and use these values to weight the model.

The dasymetric mapping is illustrated on these figures for the Walloon Region and Liège urban agglomeration (including 9 municipalities) scales (Figures 4 and 5). We observe that density of the 'high urbanized' classes strongly vary between the more rural districts (Marche, Virton…) and the more urbanized ones from the North East of the Walloon Region (Liège, Verviers…) [HUP16].

While focusing at the level of the pixel size (100m) on the downtown of Liège, we can see the difference between the original population data provided at the level of statistical sectors within large units and the RNPP map with a high variability per pixels (Figures 6 A and B). However, we can see on the two next figures that the 100m resolution (Figure 6C) isn't precise enough for the city center where a 50m, of even finer resolution, is preferred (Figure 6D).

For this test, the rasterised version of COSW at 10m resolution has been resampled to 50m with SpatAggr . Figures 6E and F demonstrate the quality effect of ancillary data on the results.

Validation of these data has been done with an extract of the RNPP dataset provided at the original vector format on the city of Liège. After proper aggregation of vectorial population values into a grid with same extend and resolution. The two grids differences (RNPP minus dasymetry) give us an average error of 0.16 inhabitant/pixel, a RMSE of 20 inhabitants/pixel with a standard deviation of 20 inhabitants/pixel and a range of 90% percent of the values is from -30 to 30 inhabitants/pixel .

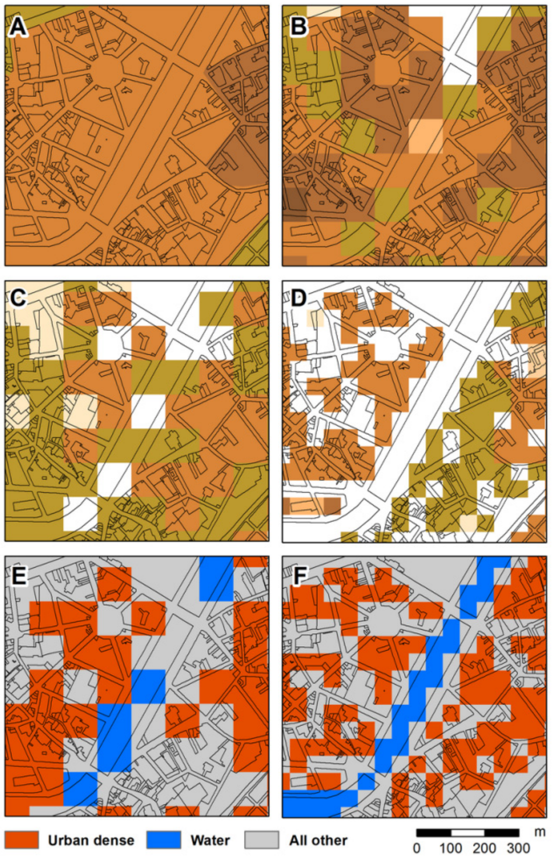

Figure 6: *Liège downtown, density of population (same legend as figure 4), by statistical sectors (A), by RNPP (B), by 100m dasymetry (C) and by 50m dasymetry (D). Rasterized COSW respectively at 100m (E) and 50m (F).*

5. Discussion and future perspectives

In this paper, some results from the first prototype of the SmartPop model are presented. Further developments are proposed in the CCA model in terms of data inputs, calibration of model parameters, activation of the sub-models at the intermediate and local levels, all in close consultation with the end-users. Although these modelling results are preliminary and a large number of input parameters and figures have to be updated, a general visual and dynamic impression quite similar to the conclusions from the RuimteModel Vlaanderen, can be drawn. In both regions, a continuous trend of urbanization is taking place with a rate of more or less 6 ha/day in Flanders and 2 ha/day in Wallonia. Having a common model helps to define scenarios of changes. This project makes use of existing tools and data to implement and apply a common spatial planning model for all three regions in Belgium.

By making use of the best available geospatial data, LULC modelling can go a step further and provide a holistic and dynamic vision of the fastly changing environment and can thus contribute to a smart spatial management of regions and cities. Current and simulated population density maps will be integrated in risks models in Wallonia in order to better estimate current and future risks and define policies. The resulting population and risk maps can be compared to previous risk simulations to assess their added value. A detailed interaction and discussion with the end-users with be carried out the implementation group. Finally, scenarios and input and output data can be adapted and will increase the value of the work.

One of the key objectives of the SmartPop project is geodata valorization. This requires more than scientific and public dissimination. In order to valorize the project outcomes, city managers and urban planners, as well as citizens, should become acquainted with the results. Visualization through dedicated or already existing web application (WalOnMap) is then foreseen for LULC and population maps in the next year of the project.

6. Acknowledgements

Authors would like to thank the Walloon Region, the City of Liège and IWEPS for providing all relevant data of interests. This project is funded by ISSeP call of project making use of the Moerman act budget.

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