Building a Cellular Automata Model for Land-Use Change Simulation using Cadastral Data – A Case Study in Northern Greece

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Keywords: Cadastre, Land Use Planning, Cellular Automata, Geosimulation, Rough Set Theory

SUMMARY

The quality and plethora of recent geospatial and geo-referenced descriptive data has revealed new potentials for building fine scale land-use (LU) change simulation models. Cellular Automata (CA) Theory has largely assisted in creating such models where the transition potential for land-use change can be expressed through simply stated mathematical rules. Cadastral Data provide a high scale framework for the calibration of the model, in which the network of cadastral parcels gives a realistic representation of the boundaries in which land-use change is expected to take place and the descriptive cadastral database provides additional information on the owners, the property rights, the existing land-uses as well as information on the constructions that are currently located in each parcel. The present paper introduces a new vector CA model which primarily uses spatial and descriptive cadastral data in an effort to produce a reliable land-use geosimulation model for urban and peri-urban areas. The model makes use of the existing experience in building such models, in terms of defining the Cellular Automata system, but also inserts new elements in the decision making process regarding the property beneficiaries and their legal rights, data on the existing buildings etc. An experimental application of the model in Northern Greece has revealed the advantages and strong points of adapting such a model in an urban and peri-urban spatial planning context in order to design viable and sustainable cities.

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1. INTRODUCTION

Monitoring and modeling land-use change has been a key theme in recent urban planning research and literature. The current plethora of high quality geospatial data combined with the minimization of the required computing time has led to the production of a large number of integrated land administration models with specific focus on land-use management.
As a result, it has been noticed that the once classic land-use models of Christaller (Christaller,1933), Von Thünen (Von Thünen, 1826), Weber (Weber, 1909) and Lösch (Lösch, 1940) have been gradually replaced by more targeted ones such as spatial-econometric models, land-use transportation interaction models (LUTI) (Torrens,2000), Agent-Based Models (Manson et al, 2012) and Cellular Automata Models, which try to simulate the effect of specific parameters in land-use change. These models have profited largely from the availability of cartographic data covering various scales (from a country to an urban level) as well as from the ongoing interest and research towards building more functional and sustainable cities.
More specifically, Cellular Automata (CA) models have been increasingly used in modeling land-use change. Several scientific groups worldwide have focused on systematically producing and evolving such models, most popular of which are the Metronamica (RIKS,2005), SLEUTH (Clarke,2008), CLUE (Verburg et al.,2002), UrbanSim (Waddell et al.,2008), OBEUS (Benenson and Torrens,2004) and iCity (Stephens at al.,2007). The advantage of using Cellular Automata Theory rests on their ability to dynamically simulate very complex processes through a set of simple but clearly stated rules (Wolfram,1994, White et al, 2012). Indeed, a cellular automata model, in its classic and theoretical form, is comprised by the following components (White et al, 2012):

1.) A grid or lattice of homogeneous cells
2.) A given set of possible states which can characterize each cell per time step
3.) A well defined neighborhood for each cell of the system
4.) A set of simple rules that determine the possibility of cell state transition from one time step to another
5.) A set of time steps during which the algorithm will evolve.

However, this tight mathematical and algorithmic definition of cellular automata would not be appropriate in simulating such a multivariate problem such as land-use change so the term of «constrained-cellular automata» was introduced as early as 1993 (White & Engelen, 1993) in order to lead to a more realistic model that can adapt and incorporate various assumptions and restrictions set by the user concerning the spatial unit of the model (use of irregular polygons or real-world entities such as statistical boundaries or cadastral parcels), the shape of the defined neighborhood (through the creation of buffer zones) etc.
Perhaps the most important aspect in implementing a successful cellular automata model is the choice of the appropriate unit around which the model will be set and calibrated. The

decision is directly linked to the scale of the area under study, the required precision of the produced results and, of course, the availability of data (Ménard and Marceau, 2005). As CA models, have evolved from simulating land-use change at a country level to a regional or even urban level, it has become more common to use cadastral parcels as the unit of interest (Stephens et al., 2007, Moreno, 2008, Ballesteros et al., 2012) in order to represent realistically the boundaries in which land-use change is expected to take place.
The current paper, which presents the research carried out as part of a Doctoral Thesis currently underway at the Aristotle University of Thessaloniki, explores not only the use of the cadastral parcels network as the cartographic basemap for the CA model but also the ability to use and incorporate the information from the Land Registry Records regarding the parcel attributes, the property rights that have been recorded and the type of owners that have declared those rights, along of course with data from other sources such as demographic indices, land-prices, town planning regulations etc.

2. DESIGNING A C.A MODEL USING CADASTRAL DATA

2.1 Defining the spatial unit of the model

The basic unit of the CA model will be the cadastral parcel, defined by the National Cadastre and Mapping Agency S.A of Greece as the continuous area of land that forms an independent and cohesive property that can belong to one or more individuals and constitutes the unit around which all the collected cadastral data is organized (www.ktimatologio.gr,2014). Each parcel recorded by the Hellenic Cadastre is appointed a unique 12-digit code, which represents the prefecture (digits 1-2), the municipality (digits 3-5), the cadastral sector (digits 6-7), the cadastral section (digits 8-9) in which the parcel is located as well as its serial number in the cadastral section (digits 10-12).Cadastral Parcels are stored in shape files which include additional information on their geometry (Area, Perimeter), appointed address and origin (e.g land consolidation act etc).

Figure 1. Cadastral Map Extract produced by the National Mapping Agency S.A of Greece.

2.2 Defining the Land-Use Categories

The problem of defining the list of land-uses to be included in the CA model is of a rather complex nature as it has been proved that different agencies and organizations tend to use very different land-use categories according to their needs. In the case of Greece, there are 4 such lists that are broadly used. The first one is the CORINE land-use/land-cover classification system, in which there are 44 distinct categories to be used. However, the CORINE classification is usually preferred for studies concerning Greece as a whole or at a regional level as the space unit used by the model represents an area of no less than 25 hectares. The second list is that of the National Statistics Agency which up until 1991 consisted of solely 6 categories (agricultural land, grazing land, forests, water surfaces, urban areas, other areas). The list was altered in 2001, in order to be able to assimilate the data that has been provided by CORINE, including 4 categories (farm land, forests, water surfaces and areas of artificial human activity) and 18 sub-categories. The common element between these two lists is a strong emphasis on land cover instead of land-use, so they can prove to be problematic while studying urban or peri-urban regions where a highly diversified land-use pattern is present. The spatial unit used by the NSA coincides with a city block, in the case of urban areas, or, in the case of rural areas, it can be defined as a group of parcels which are surrounded by discrete physical or technical boundaries such as streets, rivers etc.

The third list was presented recently through the ratification of the Law 4269/2014 on "Spatial and Urban Planning Reform for Sustainable development" which dictates that in the context of urban planning there is a total number of 18 major land-use categories to be used, divided into several very detailed sub-categories. It is important to note that the above Law, as its predecessor (the Presidential Decree which was published in the Government Gazette on 21/1/1987), is very specific about two particular issues: the first one concerns the fact that its regulations can be applied only in those areas of the country for which there is an official urban/town plan approved by the local or regional government, leaving thus a very significant part of the country out of the equation. The second point has to do with its strong focus on avoiding contradictory land uses, for example avoiding settling industrial facilities near a densely populated area. The spatial unit in which each land-use refers to is usually determined by an entire city block. In rare cases (e.g co-existence of a small industrial unit with residences in a city block) the spatial unit can be downsized to a single parcel or a group of parcels.

The fourth list is the one provided by the National Cadastre and Mapping Agency S.A which organizes land-uses into 32 main categories (e.g agricultural land, residential land, services, transportation facilities et al.) and 69 sub-categories (e.g education facilities, offices, industries et al.), having the parcel as its prime spatial unit. The use of this final list has been considered to be the most reasonable choice for three main reasons: first of all, it is gradually adapted by other agencies, such as the National Directorate of Land Survey and Expropriations (Ministry of Transportation and Public Works), which tend to republish their relevant Technical Specifications Instructions in order to emphasize the need for compliance of their data with the ones of the National Cadastre. Secondly, this list is more urban (vis-à-vis rural) and land-use (vis-à-vis land cover) oriented so it can represent the land-use change processes taking place at an urban and peri-urban environment in greater detail, allowing thus the researcher to better explore those interactions that eventually lead to it. Finally, the National Cadastre Land-Use List seems to be more detailed and complete than the other three. In that sense, it is easier, to categorise and transpose the land-uses introduced by the other lists into this one without losing any valuable information for the model. The proposed CA model studies urban and peri-urban areas, so it was considered more appropriate to use only two of the lists, and more specifically the one proposed by Law 4269/2014 and, of course, the NCMA list to which the spatial and descriptive data refer.

For the needs of this particular model a database was created, which essentially included 3 main tables. The first one was the Land-Use look-up table (LUT) as it is used by the NCMA; which provides a unique 4-digit code for each land-use (digits 1-2:category, digits 3-4:subcategory) and a relative description. The second table, included the General Land-Use categories proposed by Law 4269/2014 and the third one, included their accompanying subcategories. These two tables were constructed following the format of the Land-Use LUT and more specifically, if a land-use described by Law 4269/2014 was considered to have the same content with another from the Land-Use LUT then it was appointed the same 4-digit code. If there was a significant differentiation between the two then the 2-digit code representing the category was maintained and the sub-category received a new 2-digit code. For example, “Residence” is represented uniquely in the cadastral data using the code “4000”. However, Law 4269/2014 introduces 3 distinct categories of this land-use referred to as “Residence”, “Residence at a neighborhood level” and “Residence at an Intermediate Level”. In this case, “Residence” will receive the code “4000”, “Residence at a neighborhood level” will receive the code “4010” and “Residence at an Intermediate level” will receive the code “4020”. The same method was used in registering the subcategories described by Law 4269/2014. Finally, a set of rules were created in SQL in order to check the compatibility of the land-uses that the CA model will assign to the ones defined by the approved Urban Plans of the Area, which of course have to be referenced and digitized at a city block level.

2.3 Defining the Appropriate neighborhood for the parcel

In the case of the most common CA models, where raster data is used, the choice of an appropriate neighborhood for each unit participating in the model usually evolves between that of a Moore or Von Neumann neighborhood as presented in Figure 2.
However, as the use of vector based models (e.g parcel based models) started to increase the problem of defining an appropriate neighborhood changed in nature. It is now common practice that when building such a model, the appropriate neighborhood is defined through several buffer zones of different radius that are only finally defined after a trial-and-error process during the calibration of the model.

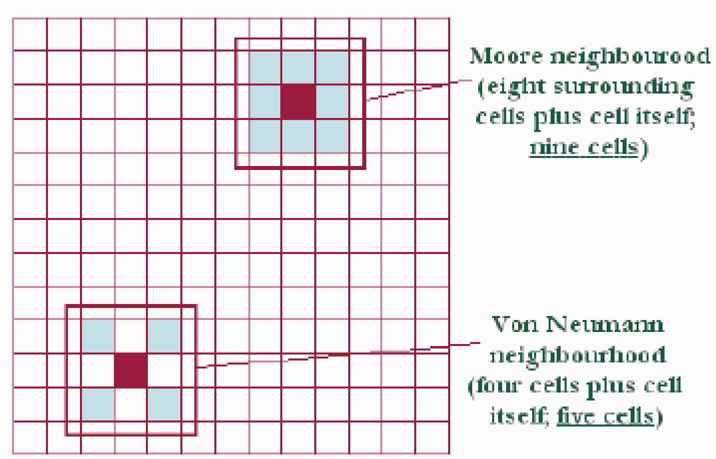

Figure 2. Moore and Von Neumann neighborhoods used in 2D C.A models (Torrens, 2000, p.22).

2.4 Defining the Time Steps of the Model

The time steps of the model are crucial for its correct calibration. The proposed time scale is in a direct relation to the scale in which the model is applied. For example if a CA model concerns a regional scale then it is reasonable to admit that a time scale of 15-20 years will provide the necessary framework for studying and modeling the way in which land-use change takes place. On the other hand, in the case of densely built urban and peri-urban areas it is a reasonable hypothesis to admit that a time frame of 5-10 years will suffice in providing an image of the under-going land use change processes. In any case, the time step that will eventually be used from the model will derive too from a trial-and-error process during the calibration of the model.

2.5 Defining the Methodology for Deriving the Transition Rules

The transition rules in a CA model can be split into conditional and mathematical, with the main difference between the two being that conditional rules can be extracted through a trial-and-error or data mining process, while mathematical rules aim at assigning weights to those parameters that have been identified to affect the land-use change process (Wu, 2002, Hasbani,2008, Hasbani et al., 2011). The most commonly used methodologies in order to extract mathematical transition rules involve the use of regression techniques, multi-criteria analysis or analytical hierarchy process (AHP), fuzzy logic, artificial neural networks and rough-set theory.

Rough-Set Theory (RST) was introduced in mathematics by Pawlak (1982) and was only recently applied in CA models by Hasbani (2008), Wang (2012) and Wijesekara (2013). In RST the available data is organized in the form of a table (decision table) in which every row describes a particular event (e.g the transformation on an empty plot to a residential area) and each column describes the values/attributes of every recorded land-use change factor linked to the event, forming thus a complete data system (Komoroski et al.,2011).

More specifically, in order to extract the transition rules of the CA model using RST, 4 basic steps can be identified (Hasbani et al.,2011, Wijesekara 2013).

- The first one involves the drafting of the list of factors that are expected to play a role in land-use change. This process involves extensive bibliographical research in order to record and test at a later stage their true effect on land-use change, but as a general principal this initial list has to be as thorough as possible.
- The second step concerns the preparation of the so-called decision table which is essentially based on the historic data of land-use change that are available for the area under study and the values of the factors described above that are connected to each record of change. It is crucial that for every type of land-use change recorded according to the historical data there is sufficient number of such incidents recorded in the decision table so that this type of change can be sufficiently simulated by the model.
- The third step, involves the extraction of those factors that actually have direct impact on land-use change for the simulation. For example, although ground slope has been widely recognized as a dominant land-use change factor in many CA models, in many cases it has been proven that in a rather small scale model (for example at a constrained urban environment) it is not expected to have a direct effect as its value will not vary significantly from one area to another in contrast to, for example, accessibility to transportation infrastructure, cultural facilities etc. In order to proceed with this step, we need to construct frequency histograms for every factor included in the decision table and for every recorded pair of land-use change (e.g from un-built urban area to residential area) in order to transform the discrete values of the decision table to continuous values. The interpretation of the frequency histograms is done by the user, based on 4 assumptions presented by Hasbani (2008) and Wang (2012) where each land-use change factor is considered as a variable for the system. In the case that the histogram reveals that the variable values follow some sort of known mathematical distribution then it can be expected that this particular variable influences the land-use change process. In the remaining three cases, if the histogram presents uniformity, or successively low frequencies or completely dissimilar values, then it can be assumed that the plotted variable is not responsible for the recorded land-use change and should be excluded from the decision table.
- The final step of the model involves the critical evaluation of all the steps mentioned before and the proceeding to the calibration and validation of the model.

In order for the calibration of the model to begin, the records of the decision table have to be transformed to simple stated mathematical rules through the use of RST software. The produced transition rules will be of the following form “IF 'land-use_inital'='unbuilt urban parcel' AND 'number of built residential parcels in NH1'=(5-10] AND 'number of built commercial parcels in NH1'= (1-3] AND 'number of built residential parcels in NH2'=(25-32] AND 'number of built commercial parcels in NH2'=(7-11] AND 'DISTANCE TO ROAD_1'=(50-100] AND 'DISTANCE TO PUBLIC TRANSPORT' = (200-350] AND 'DISTANCE TO CITY CENTER' = (100-320] THEN 'land use final' = 'residential'”.

2.6 Measuring the Accuracy of the Simulation

The discussion of the accuracy of the simulation usually takes place on the basis of computing the kappa index, $K_{histogram}$ and $K_{location}$ for the land-use map produced by the CA model and the land-use map that is available to the researcher. $K_{histogram}$ is used to measure the quantitative resemblance, while $K_{location}$ is used to measure the spatial land-use distribution’s resemblance of the two maps under comparison. However, these indices have proved to be very optimistic as they do not exclude the number of cells/parcels that maintained their initial land-use status during the simulation process (Hasbani et al.,2011). As a result Van Vliet et al. (2010) produced two more accurate indices in measuring the accuracy of the simulation process Ktrans and Ktransloc which focus only on those units that actually changed their land-use during the time framework of the simulation.

2.7 Sensitivity Analysis

Sensitivity Analysis is described by Saltelli et al. (2000), as a technique with which the relationship between the input and output data can be analyzed through the identification of those parameters that cause a significant differentiation of the produced results. In CA models, sensitivity analysis usually focuses on the choice of the unit to be used, the size and the shape of the defined unit's neighborhood, and, finally, on the chosen parameters that determine the land-use change events.

Although sensitivity analysis was not widely used in the early CA models, today it is considered a prominent tool with the credibility and accuracy of the produced simulation results can be checked and analyzed. It's popularity rose in parallel with the development of new methodologies and software for measuring accuracy (such as the Ktrans and Ktransloc indices), resulting in a large number of different scenarios to be evaluated using reasonably small computing time (e.g Kocabas and Dragicecic, 2006 were able to test 432 different scenarios concerning the raster model cell size and neighborhood definition).

3. CASE STUDY

3.1 Area of Study

The area of study for the implementation of the Cellular Automata Model based on Cadastral Data is based on the Northern Part of Greece and is comprised by 6 Municipalities (Ampelokipoi, Menemeni, Kordelio, Evosmos, Oraiokastro and Echedoros) located around the western part of the city of Thessaloniki, covering a total area of approximately 68,000 sq.km with a total population of 173,036 residents according to the census of 2011. The cadastral survey works for this particular area finished in 2013 resulting in the registry of roughly 200,000 rights of property organized around 33,500 parcels.

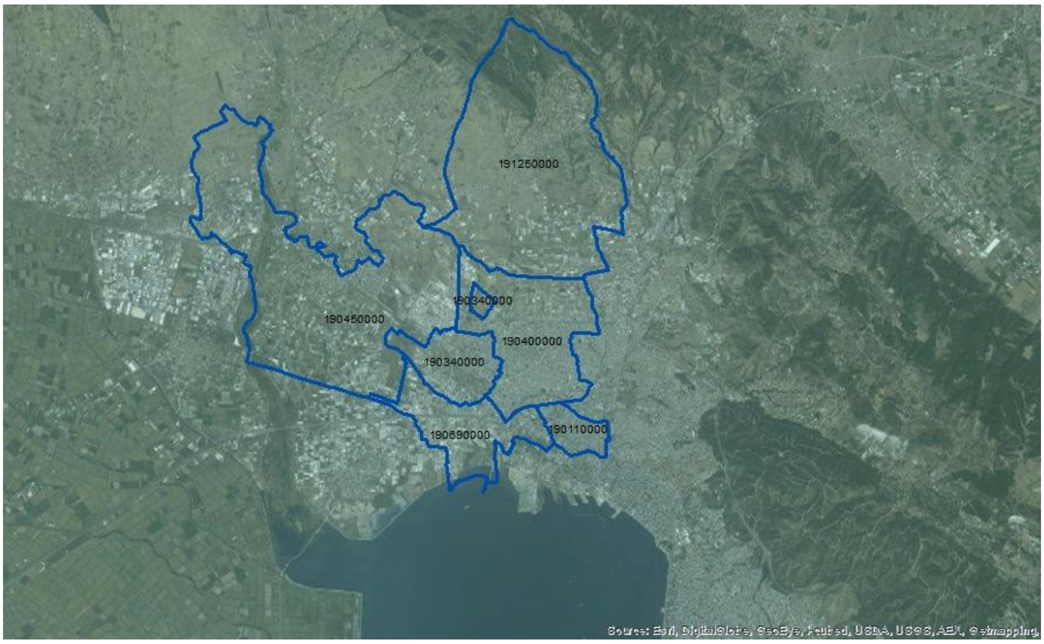

Figure 3. The 6 Municipalities constituting the Study Area.

3.2 Identifying Land-Use Change Factors

The initial set of land-use change factors that will be used for the calibration of the model derived from extensive bibliographical research regarding CA models of various scales and specifications. Generally speaking, these factors can be split into 4 basic categories as described in Table 1.

Main Category	Sub-Category
Socio-economic	1. Population Growth/ Distribution of Population in the Area
	2. Demographic Attributes of the Population
	3. G.D.P growth
	4. Property Prices
	5. Type of Ownership
Spatially Related	6. Slope/Height
	7. Accessibility to various infrastructure facilities
Town planning Related	8. Land-Use planning Map
	9. Building-permit regulations
	10. Areas under protective regime
C.A Related	11. Existing Land-Uses in the defined neighborhood

Table 1. Factors of land-use change that will be examined in the CA model.

3.3 Preparing the Data – Calibrating the Model

3.3.1 Software and Data

In order to prepare the calibration of the model three types of software packages are necessary; a GIS Platform, a SQL database and a statistical analysis software. In this case the organization and processing of the data was done through ArcGIS 10.1, Access 2007, Excel 2007 and R (v.3.1.0). The same software was used for the calibration process as well.
The basic data around which the model will be built is the spatial cadastral basemap containing all the recorded parcels of the area under study and its accompanying descriptive database containing information about the owners and their property rights as well as additional information on the parcels (e.g building characteristics, land-uses etc).

3.3.2 Processing the Descriptive Database of the Cadastral Data

The descriptive database, being very detailed and containing sensitive private data, has to be processed in order to extract the concise information that is absolutely necessary for the model. More specifically, 4 tables will be created from an initial sum of 46:

- The first one contains the categories of beneficiaries that have declared rights on each parcel without further personal data (e.g private owner, bank, public etc). The categories are enlisted at a relevant look-up table contained in the database.
- The second table contains the type of rights that have been declared on each parcel and the origin of ownership.
- The third table contains the deed type from which every right derived (e.g contract, court order etc).
- The final table contains succinct information on each parcel which will also be used to create the necessary historic data for the model (e.g property type, land-use, building-permit year, number of floors on the building etc).

The data that these 4 specific tables contain regard the year 2010. The next step in the methodology involves the creation of the historic data to be used in the calibration of the model as such data is not available from any other source in Greece in such detail and with a direct spatial reference as the cadastre provides. Historic data is needed for the years 1990 and 2000. The basic assumption behind the creation of the data involves the checking of the following three main parameters and their validation through research in the cadastral office:

- The first parameter is the building permit year which provides a first indication on when possible land-use change took place.
- The second one is the date of the deed that established the rights on the parcels, especially in the cases of land-plots that do not contain any constructions.
- Finally, the third one regards the origin of ownership which can provide additional hints of possible land-use change.

After, the parcels in which a possible land-use change event took place between 1990 and 2010 are extracted from the database a random sample is selected of about 20% in order to check the hypotheses made through research in former land registry offices that hold the records of relative deeds. The evaluation and the processing of the research findings, lead to two additional databases; one concerning 1990 and the other concerning 2000.

3.3.3 Enriching the Spatial Cadastral Basemap

The next step, involves the extraction from the descriptive database of points of interest according to their land-use. For example, if a parcel has a recorded use of cultural activities, park, hospital etc, then this information is connected to the GIS and a point is created inside the parcel using an appropriate symbology. These points of interest are afterwards enriched with information from secondary sources (e.g municipal thematic maps, town planning maps, transportation maps showing the public bus stops etc.). The goal of adding these points to the cadastral basemap is to be able to measure each parcel's accessibility to special land-uses that have been proved to be important to individuals.
Another important process in preparing the data involves the digitization of the effective town planning maps which contain polygons of permitted land-uses and building regulations per area according to the legislation mentioned in a previous paragraph as well as a hierarchy of the existing urban road network. This information will be used in the calibration of the model in the following three distinct ways:

- The provided hierarchy of the street network will be used to extract accessibility indices as before.
- The building regulations (concerning the minimum geometric characteristics that each parcel should have in order to be able to add a permanent construction in it as well as the permitted building index which reveals the level of development that can take place in each parcel) will be used in order to extract the parcels which by law cannot be built (and therefore are not expected to change their land-use drastically) and the parcels which will be more profitable to develop and therefore should be assigned a higher possibility of land-use change.
- Finally, the permitted land-use polygons will act as an exclusion (or re-loop) filter if an unfitted land-use is assigned to one of the model's parcels.

3.3.4 Defining the neighborhood of the model

The neighborhood of each parcel for the CA model will be defined through the use of different buffer zones whose radius will be checked and revisited if necessary during calibration. The initial definition involves:

- the parcels that share a common border with the examined parcel,
- the parcels that are within a distance of 50 meters, and,
- the parcels that are within a distance of 100 meters from the central unit. A general rule applied in CA models declares that each parcel can belong only in one neighborhood, preferable the one closest to the examined unit.

3.3.5 Calibrating the model using RST

The calibration of the model, using Rough Set Theory (RST), involves the construction of the decision table which contains all the land-use change events that emerge from the historical data tables along side with the values of each change driving factor. An important aspect that needs to be mentioned is that parcels which are connected to special land-uses (e.g road network, rivers, airports etc) as well as public owned property are excluded from the model as they are not expected to alter their land-use in the proximate future.

FID	KAEK	LU_1990	LU_2010	DIST_Transp	DIST_PUBLIC	DIST_ROAD	N4000-NH1	N7100-NH1
1	190110203004	7100	4000	245,24	155,40	76,54	8	1
2	190110205003	7100	4000	183,81	129,13	40,38	4	0
3	190110206007	7100	4000	157,12	91,35	76,85	2	0
4	190110207005	7100	4000	179,91	87,08	108,52	5	0
5	190110207009	7100	4000	139,31	65,56	99,86	4	0

Table 2. Extract containing the first 5 rows of the prepared decision table for the area under study.

After the construction of the decision table, the frequency histograms are created for each particular land-use change pair (i.e from Land Use A to Land Use B) and each driving factor in order to examine whether or not the particular factor plays indeed a role in land-use change or it should be removed from the list; and also to transform our discrete values to continuous. For example, Figure 4 presents a frequency histogram regarding the effect of the factor “Distance from Public Recreation Areas” (in meters) in the land-use change process from “Urban Unbuilt” to “Residence”. It is evident from the chart that almost 50% of the parcels that followed this particular pattern of LU change were at a distance of less than 110m. from a public recreation area. Furthermore, the histogram follows the form of a gamma distribution which according to the assumptions applied in RST, reveals that the factor under examination has a particular influence in the LU change process. After interpreting this specific histogram two particular intervals can be extracted one from (0,195] and a second from [195,460) in order to transform the discrete values included to the initial decision table to continuous.

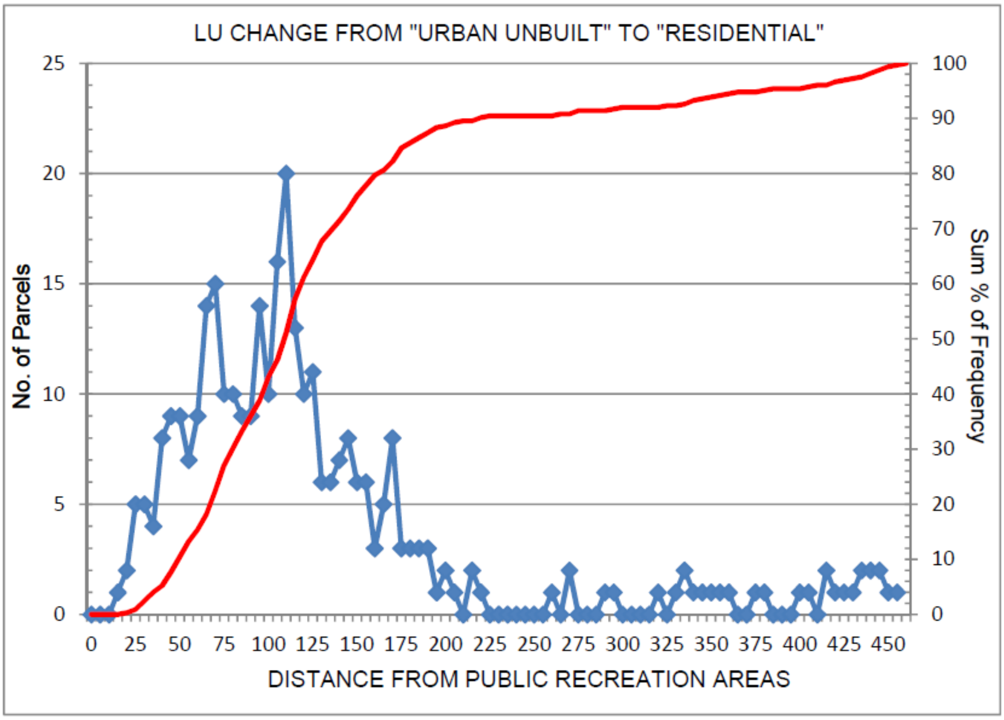

Figure 4. Frequency Histogram monitoring the effect of the recorded factor “Distance from public recreation areas” in the LU Change process from “Urban Unbuilt” to “Residence” for the area under study.

The calibration process proceeds as described in paragraph 2.5 for the extraction of specific mathematical relationships that will bind land-use change events. The produced land-use map for 2010 is then compared with the original cadastral map using the K_{trans} and $K_{transloc}$ indices in order to assess the success or failure of the simulation and repeat the calibration process if necessary. This step is done in parallel with a sensitivity analysis that tests the affect of the chosen neighborhood size and the selected land-use change factors.
Once the calibration process has finished the model is ready to produce the expected land-use change map for the year 2020.

4. CONCLUSIONS – FUTURE CHALLENGES

The use of spatial and descriptive cadastral data in land-use change geo-simulation models provides new opportunities for more realistic representation of the interactions that lead to the transformation of the urban environment. In addition, CA models can capture these interactions and express then in simple stated mathematical transition rules.
There are, however, still many challenges in creating and adopting such models in the future. Perhaps the most important one lays on the ability of the model to incorporate possible geometric transformations of the parcels as well as future development plans that affect large areas and are expected to cause a dramatic shift in the existing urban form and fabric.
In any case, land-use change models are expected to assist largely in providing and additional planning culture and mentality especially in countries like Greece where such topics are usually managed through solely legislative acts that emerge only too late.

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