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Towards a Land Use –Transportation Interactive Modeling: a Conceptual Model for Collaborative Planning

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Abstract

As the planning process moves from being rational to being more collaborative with multi stakeholder, the process becomes more complex and turbulent. New advanced tools, therefore, are required to cope with the evolving challenges arise from involving diverse stakeholders with conflicting interests during different phases of the planning. This paper aims mainly to propose a conceptual framework for a Planning Support System (PSS) that combines the analytical capabilities of the Integrated Landuse and Transportation Models (ILUTMs), from one side, and the visualization and data presentation capabilities of the Geographic Information Systems (GIS), from the other side. The paper starts with a discussion of the planning process and reviews some of the available ILUTMs in addition to the enhancements that can be gained when they are integrated with GIS. In the following section, a broad review of the available planning support systems (PSS), their components, and their characteristics are introduced. In the next section, a general framework for a proposed PSS consisting of GIS and ILUTMs in addition to other components is introduced. Finally, the paper concludes with suggestions for the further work on the proposed framework and some of the expected challenges and limitations.

Keywords: Planning Support Systems, Geographic Information Systems, Analytical Urban Models, Land Use Planning.

1. Introduction

As the world started moving from rational to collaborative planning, the planning process has involved diverse stakeholders including the general public, developers and interest groups—in addition to planners and decision-makers. This involvement makes the process more partnership-oriented, scenario-oriented, and more interactive and participatory process (Geertman et al., 1999). In the same time, the process became more complicated as a result of involving opposing point of views about the same issues (Geertman , 2002,), especially when the process involves "not in my back yard" people (NIMBYs) who became, in democratic environment, "now I must be involved" NIMBIs (Edelstein, 2004).

This diversity of stakeholders and their opinions requires innovative planning tools and techniques in order to have a smooth and successful planning process at different stages. Consequently, planners and researchers have made enormous efforts, over the past several years, to utilize new tools and apply new techniques to involve different stakeholders in the planning process (Dawwas, 2014; Nyerges, 1995; Meyer and Miller, 2001). Regarding the tools being used in the planning process, Geographic Information System (GIS) and Integrated Land Use and Transportation Models (ILUTMs) are commonly used tools, each of which has it strengths and weaknesses. While the GIS is a powerful data management and visualization tool, it is weak in tasks requiring sophisticated analysis. ILUTMs, on the other hand, are very powerful analytical tools with shortcomings in the visualization side (Bartholomew, 2005).

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As to the techniques used in the planning process, the technique of generating and evaluating different alternatives based on different stakeholders' inputs and specific criteria is a common technique in this field, especially in cases involving tradeoffs between stakeholders' requirements.

In this context, involving diverse stakeholders requires tools with three main characteristics: (1) having a user-friendly interface so that these tools can be used interactively by different stakeholders; (2) having the ability to generate alternatives based on stakeholders inputs and then preliminary evaluate them so that general public and/or decision-makers can understand how their suggested ideas affect the alternatives; and (3) having the ability to do further analysis for the selected alternatives in the first stages to select the final alternative.

This research proposes a conceptual framework for a planning support system (PSS) by integrating GIS and ILUTMs aiming ultimately to support urban planning practice with multi-user tools that can be easily used by different stakeholders. Particularly, the research focuses on one kind of planning in which different alternative scenarios are generated and tested. The work aims at combining the traditional methods of rapid and partial description of alternatives – usually happens in stakeholders' meetings—with GIS and ILUTMs to analyze the implications of each alternative. Therefore, the system intends to bring three main components together which are information, models, and visualization, and to introduce them as one system to stakeholders. The information contains not only GIS data but also statistics and information stored in text and graphic images. The model component includes tools for spatial interaction and analysis. The visualization component includes charts, images, and maps.

2. ILUTMs in the Planning Process

Besides their contributions in developing urban theories, understanding the interaction between transportation and land use (Wilson, 1998), educating modelers, and communicating with decision-makers, ILUTMs are mainly intended to help planners to do their job as advisors to public decision-makers since they first developed and used in the early 1960s (Lee, 1973). Since then, there has been a big gap between opinions of their opponents and proponents regarding their achievements in the planning process.

The opinions have run from saying that these models haven't achieved any of their goals, and the achievements are very limited, if any (Lee 1973, 1994), to saying that all critics the ILUTMs have received came either from unawareness of how these models being developed (Harris 1994), or the critics were valid in the past but they are no longer now due to the improvements in the theory behind these models (Klosterman, 1994), and the huge developments in the computational capabilities of computers besides the data availability (Harris 1994, Wegener 1994, Batty 1994).

Dramatic changes have occurred in the urban planning process and, consequently, on the use of ILUTMs since the emergence of the Clean Air Act Amendments (CAAA) in 1990 and the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, according to which MPOs became more responsible to reduce air pollution which in turn required them to define a comprehensive regional vision (Hnely and Marshall, 1997). As these environmental issues evolved, a general consensus emerged among urban planners about integrating transportation planning with land use and air quality planning (Hartgen et al, 1993).

This consensus is attributed to two main reasons; first, because traditional transportation modeling was unable to draw a complete picture for the future due to the intrinsic interaction between land use and transportation systems. This interaction is clear, for example, as the accessibility increases in a region, it leads to more households and/or firms locating in this region which are not accounted for in the transportation models or what is commonly known as land use/transportation cycle (Szeto et. al., 2015). Also the increase in the population and the activities increases the demand for the transportation facilities which is not assumed in the transportation models (Oryani and Harris, 1996).

Second, ILUTMs play an important role in predicting the air pollution, because transportation and air quality models can only forecast one source of emission which is on-road emissions, while ILUTMs allow planners to locate the non-mobile emission sources and their intensity (Lemp et al). Therefore, planners need to select projects that go along with different stakeholders' needs taking into account the vision of the area being studied and, in the same time, keep the area within the air quality limits (Carslaw and Robkins, 2012).

Achieving these requirements makes it inevitable to use ILUTMs to test different scenarios suggested by the stakeholders—either in general public's meetings, professional planners' meetings, or planners-policymakers' meetings—due to the ILUTMs' capabilities of anticipating the consequences of different alternate scenarios. The following section discusses in more details the incentives and the disincentives of using ILUTMs in scenario analysis.

2.1 ILUTMs and Alternative Scenario Analysis

The theoretical foundations and the sensitivity to changes in policies and regulations enable ILUTMs to play a major role in scenario analysis. These characteristics can help planners and policymakers to understand how plans will perform under different land use and transportation scenarios containing major decisions about new facilities locations, and major policies and regulations. Therefore, there are two main incentives to exploit the sensitivity of ILUTMs—to changes in policies and regulations—in order to generate and test different scenarios. First, the future land use development is uncertain due to the high number of factors that influence the possibility of development to occur in a region and to what extent, so ILUTMs play a major role in anticipating the consequences, of the interaction between these factors, on the land use development. Second, when planners and policymakers are to choose between different alternatives of major projects, ILUTMs are powerful tools to analyze, evaluate, and predict the pros and cons of these alternatives due to their highly analytical capabilities (Bartholomew, 2005).

Creating a scenario in ILUTMs, however, means building a complete model represents one possible image of the future with all complicated interactions between too many components, and with a high number of variables. This task requires enormous amounts of data which is in turn considered as one of the most challenging issues in applying these models, and described as hungriness (Lee 19973). The amount of data required to build an ILUTM is substantial and needs a consistent and deliberate effort to be collected, because this data usually comes with different design and format, and from different time periods (Lemp et. al., 2008). The high demand for data is, however, neither the only nor the last problem challenging planners and decision-makers.

Once the required data is made available, managing these data to create scenarios and presenting their results rises as a new challenge with two main consequences: (1) it makes ILUTMs tightly controlled by a few analysts who exclusively manage the input data, create scenarios, and interpret the results (Lemp et. al., 2008); and (2) a few scenarios are generated and tested, by analysts, due to the difficulty in combining enormous data including land use inventories, zoning policies, highway networks, spatial distribution of employment and households, socioeconomic data, travel trends and behavior…etc. This significantly limits the ability of ILUTMs to generate an adequate number of scenarios for the planners to adopt the best plans in the input side, as well as it limits their capabilities to display the huge sets of results understandably for decision-makers to take the right decision, in the output side.

2.2 Integrating ILUTMs and GIS

GIS are extensively used in land-use and transportation planning, and they allow efficient and flexible storage, display, and exchange of spatial data (Yigitcanlar et. al., 2010; Chylofia, 2003). These capabilities enable the non-user to understand the results by organizing the output for tabular, graphic, policy-oriented presentations (Macharis and Pekin 2009; Oryani and Harris, 1996). It can also be used to disaggregate spatial results of land use models with a courser spatial resolution to a finer resolution—from zonal level to census tract or block level as an example—which is better to visualize the development patterns and to produce detailed GIS coverages for environmental impact assessment (Johnston and de la Barra, 2000). In regard to scenario analysis, GIS is not being widely used to conduct the whole process of developing, testing, analyzing, and visualizing scenarios, due to its analytical limitations.

GIS tools are more common as developing and visualizing tools, while ILUTMs are more common to analyze and test scenarios due to their analytical capabilities (Bartholomew, 2005). As powerful data management and visualization tools, GIS would substantially improve the ILUTMs performance in creating and visualizing scenarios if the two tools—GIS and ILUTMs—were combined in one planning support system (PSS). Urban modeling systems including GIS capabilities were recommended by The US Department of Transportation Travel Model Improvement Program's Land Use Modeling Conference (Bartholomew, 2005).

Some ILUTMs have been completely integrated with GIS to take the advantage the GIS capabilities in manipulating the data and visualizing the results such as California Urban Futures Model (CUF) (Landis and Zhang, 1998), METROPILUS which is housed within a geographic information systems (GIS) environment to improve visualization of output (Putman and Chan, 2001).

Activity-based forecasting models incorporating GIS applications have also been developed by (McNally, 1997), ILUMASS has GIS components combining raster and vector-based representations to allow for the advantages of spatial disaggregation in land use representation and efficient network algorithms for transportation network model (Strauch et al. , 2003). More of these models will be discussed in further details in the following section.

3. Planning Support Systems (PSS)

PSS is a fairly new term for an old underlying idea started in the early 1950s (Geertman, 2002). PSS was developed based on the assumption that a greater degree of access to relevant information will lead to a well-informed public and then to a greater number of alternative scenarios (Shiffer, 1995). As defined by Geertman and Stillwell (2003b) a planning support system is a subset of computer-based geo-information instruments including abstract theoretical constructs, knowledge, and modeling capabilities, as well as it includes data sets, computer algorithms and display facilities. The main use of PSS is to support the planning process by communicating information and helps planners to generate solutions. There are two other well-known systems have much in common with PSS which are GIS and Spatial Decision Support Systems SDSS.

GIS can be defined in this context as general-purpose systems consisting tools for dealing with geo-reference data in variety of tasks (Malczewski, 1999). GIS usually fit in PSS to provide the data management and visualization parts. On the other hand, SDSS are usually designed to support a decision research process for complex spatial problems (Malczewski, 1999). They have much in common with PSS because they provide frameworks for integrating database management systems with analytical models and graphical display, and with the expert knowledge with decision-makers.

PSS, however, are usually designed to deal with particular long-range and strategic issues, while SDSS are designed for shorter-term policy-making by isolated individuals or business organizations (Birkin and Clarke, 1990). Therefore, it can be said that SDSS are dedicated to support executive decision-making rather than professional planning activities. In practice, trials to build PSS have taken different approaches. These approaches run from using PSS in public meetings as well as planners and decision-makers meetings as sketch planning tools, and systems for collaborative decision-making (Nyerges and Jankowski, 2001), to Web-based Public Participation Systems (Kingston et al., 2000, Peng, 2001). PSS components vary depending on where your PSS falls in this range.

Generally, a PSS is a combination of three main components (Batty and Harris, 1993): (1) The specifications of the planning tasks and problem being handled; (2) The models and methods used in the system to inform the planning process through analysis, prediction and prescription; (3) The process of transforming basic data into information which in turn provides the driving force for modeling and design. These components narrows down the definition of PSS to combinations of multiple integrated technologies designed for specific needs of the planning context which makes PSS driven by users more than technology.

Therefore, it can be concluded that PSS are dedicated specifically to activities associated with planning in practice, which is considered the main point distinguishing PSS from other systems such as Geographic Information Systems (GIS) and Spatial Decision Support Systems (SDSS). Based on this variety of definitions and applications, and based on Batty and Harries definition of PSS components, it is essential to precisely define the target groups, the spatial scale, and the planning context when designing a PSS because it is usually used to support public or private processes at a particular spatial scale within a specific planning context.

Besides many of individual articles and research have been published, there are several books consisting collections of papers on planning support systems such as Brail and Klosterman (2001), Greetman and Stillwell (2003), and Timmermans (1997). Generally, these collections give insights into the diversity of PSS that can be found in contemporary planning practice, and classify them into different categories according different characteristics. Following is a brief summary of six characteristics distinguishing PSS among each other with some examples from the practice field:

(1) Spatial Scale

PSS spatial scale range from neighborhood and city scale to several countries. EU-SPSS developed in Europe is an example of multi-country PSS spatial scale (Greetman and Stillwell, 2003b). In addition, some of PSS are area dependent (Relly,2003), while others are not like SPARTACUS (Lautso, 2002).

(2) Aims

PSS have a wide diversity of aims depending on their target group, planning and policy context, and spatial scale. For example, Planning System for Sustainable Development (PSSD) (Greetman and Stillwell, 2003a) which is a Web-based planning support system was designed specifically to enhance sustainability policies in three European countries which are Finland, Denmark, and Germany, and dedicated to support the tasks of professional planners.

(3) Capabilities

As with the aims, the capabilities of PSS show enormous variation. For example, the New Jersey Growth Allocation Model, known as GAMe and developed by New Jersey Office of State Planning (Reilly, 2002), is designed to identify the implications of plan based scenarios on land development. It enables users to explore various land-use policies by allowing them to select different policies in order to test how the selected policies affect the location of growth and the cost associated with the resulting land-use pattern. K2vI (Key to Virtual Insight), on the other hand, is a PSS that allows users to visualize, manipulate and analyze two-dimensional and three-dimensional spatial data within a virtual reality (VR) environment (Van Maren, 2003).

(4) Contents

While some PSS contain various components including data sets, storage and query tools, analysis methods, theories, indicators, etc., other PSS contain very specific components to perform specific tasks. The SPARTACUS system (System for Planning and Research in Towns and Cities for Urban Sustainability) is an example of multi-component PSS developed by a group of partners from Finland, the UK, Spain and Germany (Lautso, 2002). SPARTACUS consists of four main components which are a landuse transportation model MEPLAN, a GIS raster-based module, a database and presentation module, and a decision support tool, the system was used to test the sustainability policies at different locations in Europe. MIGMOD is an example of a specific-task PSS. It was developed in UK to specifically assist in the understanding how various indicators affect the volume and patterns of internal migration within UK (Champion et al. 2002).

(5) Structure

PSS structures differ in that some can be considered fully integrated systems in which all components are interconnected closely like WadBOS (Engelen, 2002), and other have loosely connected tools within a container like SketchGIS (Geertman, 2002), which is a stand-alone toolbox developed to support the first phase of a participatory plan-making process. It incorporates a diversity of loosely coupled tools with which associated planning tasks can be performed.

(6) Technology

In the case of applied technology, some PSS are stand-alone models like What if? Which is a stand-alone policy-oriented planning tool that can be used to determine what will happen if certain policy choices are made (e.g. spatial restriction on urbanization growth) and assumptions concerning the future (e.g. population growth rates) prove to be correct (Klosterman, 1999). Some other PSS, however, are developed solely for the Intranet or Internet like WBBRIS (the Wide Bay-Burnett Regional Information System) of which is an Internet-based PSS developed for the Wide Bay Burnett region Queensland, Australia (Petti et al., 2002) that incorporates a suite of SDSS tools to undertake multi-scaled planning analysis.

In addition to the PSS models mentioned above, there are some other PSS software being used in the planning process in different ways and at different stages. Generally, these PSS are used to support the process of creating diverse scenarios for the future, and then policy measures are developed and implemented based on this step. The collection selected in this review—which is mostly GIS based decision support tools with substantially common characteristics—is widely used to make traditional public meetings more effective. Following is a brief description of some of them:

PLACE 3S: is designed to support a workshop process, allowing for inputs from a workshop to be modeled in a fairly expeditious and objective manner (www.energy.ca.gov/places/index.html).

Community VizTM: is a decision support software consisting of three components: (1) Sitebuilder for 3-D visualization which enables the user to navigate through proposed scenarios in real time. (2) Scenario Constructor to analyze and evaluate different alternatives. (3) Policy Simulator to predict how applied polices affect the land use and socioeconomic characteristics in the study area (www.communityviz.com/).

Smart Growth INDEX: is GIS-based software that calculates the changes resulted from new projects in a given area. It offers number of indicators such as vehicle miles traveled, environmental quality, resource use, available housing types, and other variables (http://www.crit.com/index/).

ChoiceExplorerTM and **ChoicePerspectivesTM**: the former is designed to assist individuals to develop their perspectives and the latter helps to bring these perspectives together. A third software extension, GeoVisualTM, extends the decision making with mapping and geographic information analysis tools (James et al, 2000).

QuestTM: is a user-friendly tool used to explore and evaluate future regional alternative scenarios. It also supports Climate Change Calculator, which is designed to aware people about the greenhouse gases they produce through their daily activities (www.envisiontools.com).

Finally, there are some limited number of noncommercial software like the three used by Kmmeier (1999). The three software are LADSS: location – allocation decision support system, FlowMap: flow analysis and mapping, and LocNet: location analysis and planning in a network. These software packages were combined with other software in a user-friendly package to assist in an incremental planning support system used to guide the planning process.

4. Conceptual Model and Framework

As discussed in the previous literature review, the existing PSS vary in their structures, technologies, and functions based on their applications and their target groups—public, planners, and decision-makers—in the first place. One could question, at this point, what level of integration is required in PSS. The answer for this question is that while one might argue in favor of fully integrated system to avoid the nasty conversion issues, another might argue that such an integrated system will be too rigid and inflexible enough to respond to the needs of the participants in the diverse participatory planning processes.

Moreover, a fully integrated system could become a black-box instrument that invisibly steer the planning process. Especially at the early stages of the process, when brainstorming plays an essential role in defining the preliminary alternatives, the participants have to feel that they are completely in control of the content and structure of the discussion. In fact, this issue will not be solved in this paper, but it could be discussed in more details in further research in this topic. Therefore, at this stage the research will stop at "it depends" as an answer to this question. It depends on the six characteristics discussed in the previous section starting with the aim which is the most important factor and ending with the technology used in the system.

Based on this discussion and review of the available PSS and GIS models, some guidelines can be made about the proposed PSS and shown in the conceptual model illustrated in Figure (1) below:

(1) PSS should be an integral part of the planning process and context, and it should be adjusted to the specific characteristics of the policy context that influence the preferred technology. For example, a transparent technology is more preferable in democratic policy context. In addition, the way in which the PSS will be used should be taken into account during the design process;

(2) It is important to define in a PSS where different planning activities are linked to each of the planning phases. For participants, it is important to know at which phase of the planning process one can perform each particular kind of task or activity;

(3) It should meet the user's needs as well as the planners and the planning process needs. It should be adjusted to the professional tasks required at a certain phase in the planning process and, in the same time, to the capabilities of the audience with whom communication is required;

(4) It should take into account that planning is an interdisciplinary field in which issues are addressed from different perspectives. Therefore, a PSS should be able to link, for example, spatial issues to the social issues, environmental to economic and so forth;

(5) Builds on the previous points, the user-interface should satisfy users' requirements at different levels by providing them with suitable tools that respond to their commands promptly, and with understandable outputs; and

(6) When public involvement is required, it should fulfill participants' needs, and should allow them to enjoy using it too.

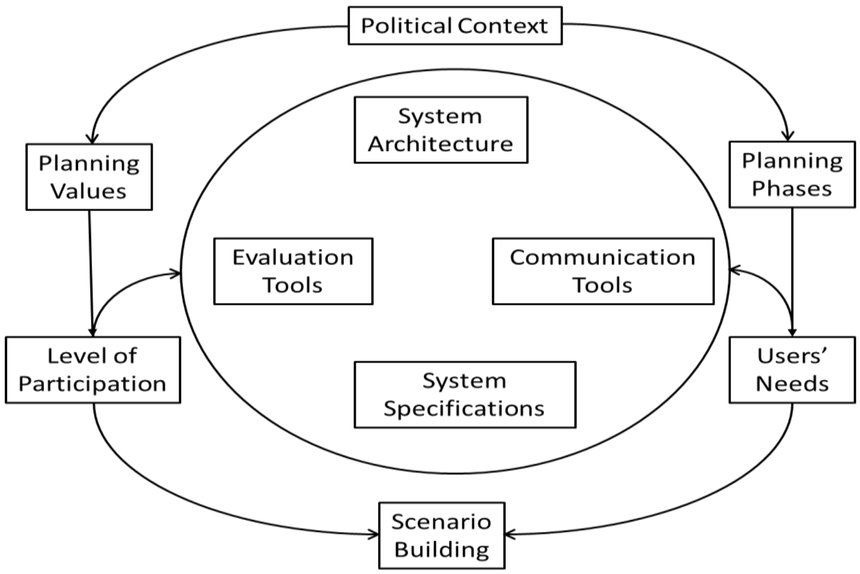

Figure 1. Conceptual Model for the Proposed PSS

Taking these guidelines into account, a PSS, shown in Figure 2, is suggested to consist of these following components:

1. Data Provider

To provide all types of data about the study area in all formats text documents, diagrams, metadata, photographs, maps at different scales. The main purpose of this tool is to make the data more available for all participants. Via the Data Provider, participants become well informed, and they have answers for common questions about current land uses, the distribution of land ownership, and the available future plans. This component could include in addition a Website that helps in spreading the data to the largest number of people.

2. Flowchart Tool

Stakeholders meetings are usually full of brainstorming tasks which makes it difficult to interpret, analyze, and manage all spontaneous thoughts and compile them in one image. A flowchart tool helps stakeholders in arranging their ideas and make connections between different sets of causes and effects at different hierarchy. For example, if you build a commercial center, traffic will increase, land use will change and so forth, and this can be represented in a flowchart.

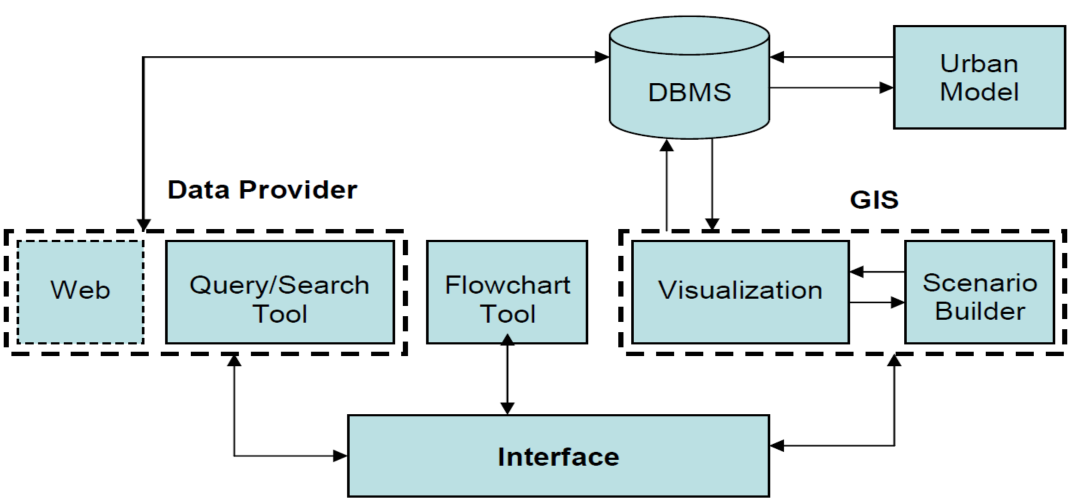

Figure 2. Working Flow of the Integrated GIS and Urban Model System

3. Scenario Builder

Enables stakeholders to create and, preliminarily, evaluate alternatives based on the information delivered by Data Provider and after understanding the interaction between different components of the project. This preliminary alternative creation and evaluation will stimulate the discussion about the future development. The evaluation is mostly qualitative at this level (for example, evaluating different alternatives based on on-screen comparisons between maps of generated alternatives) with some limited quantitative evaluation including lengths, area, sizes, and some other primary statistics.

4. Analysis Tool

Advanced analytical work and calculations will be done using this tool which will enable users to go beyond a qualitative evaluation. Connection with ILUTM and data exchange between the GIS and ILUTM will appear here. Attributes resulted for the generated alternatives will be exported to ILUTM which in turn will process these attributes and return them to GIS for the next step which is the visualization.

5. Visualization Tool

This is the final step which mainly aims at presenting final alternatives and their spatial impacts on the study area as maps (in 2D and/or 3D) supported by charts, graphs, and tables. This will make it easier for users to understand the reality.

5. Conclusion and Future Work

As the planning process is moving from being rational to being a collaborative process, developing new tools that can consider different stakeholders' inputs is becoming an insisting need for the planners. This paper proposed a conceptual framework for an integrated model that can do sophisticated analysis and visualize the output of the model so that planners can communicate easier with different stakeholders.

The next step, in this work, is to narrow down the scope of the proposed framework which is considered the most challenging task. This task consists of three main steps. The first step is to define the planning type, short or long-term planning, and the policy context. The second step is to define the target group—general public, urban planners, or decision-makers. Each one of these groups needs a specific collection of tools that satisfy their needs, and these tools should be easy to use in order to achieve the main goal of the proposed PSS which is to be a user-friendly system. The challenging point here is to keep the tools as simple as possible, especially in the general public and decision-makers case, and in the same time to be fully integrated so there will not be many of conversion steps when exchanging data between the GIS environment and the urban model. Finally, defining the spatial scale is also an essential step. Different spatial scales need different data sets and then different planning tools.

The system might be designed to serve at more than one spatial scale which mainly depends on the target group (i.e. general public are more involved in neighborhood scale than state scale). However, designing multispatial-scale tools makes the system more sophisticated due to the complicated relationships between different levels of jurisdictional policies and decision-making procedures.

Once this step is completed, further details –relating to the PSS aims, contents, structure, and technology— are necessary to be specified. These details are completely dependent on the three steps discussed above. Therefore, if the planning and policy context, target group, and the spatial scale are well defined, it will be easier to define the aims of the PSS, and then to go forward in the process of defining of the other components.

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