Introduction

The increasing complexity in environmental management has emerged from the consideration of multiple environmental, social and economic factors and thus the related industry is becoming more sophisticated in the use of technology. The involvement of different groups of decision-makers generates the need for the development of reliable, comprehensive and easily accessible tools. Such tools are meant to provide information in a structured way, in a form easily understood and interpreted by the different groups of stakeholders and decision-makers in planning processes, which are fundamentally heterogenic and usually follow different interests.

A Decision Support System (DSS) is a computer-based information system intended to help people to compile useful information, identify issues, assess them and help in making decisions (Böhner 2006). A DSS is capable of supporting complex decision-making and of solving semi-structured or unstructured problems through an interface, which presents information and evaluation results in a readily understandable form. DSS are developed and used for a variety of applications, covering a wide range of thematic areas, like, biomedical applications, business applications, management and forecast etc. (Jao 2012).

Decision-making situations that involve geospatial information are quite complex, making it difficult for individuals to process all of the necessary information. Human cognitive deficiencies in memory and analysis abilities prevent decision-makers from efficiently addressing complex spatial problems or issues and the use of DSS in those cases is essential. This kind of system – also referred as Spatial DSS, or SDSS – helps describe the evolution of a phenomenon in space and time, provides knowledge-based formulation of possible actions, simulates consequences or actions of decision possibilities and assists in the formulation of implementation strategies (Sugumaran & De Groote 2011).

The basis of geospatial decision support is the Geographic Information System (GIS) technology. The basic functionality of GIS includes data management to extend human memory, graphic display to enhance visualization and spatial analysis functions to extend human computing performance. Beyond these common GIS decision aids, special features include modeling, optimization and simulation functions required to generate, evaluate and test the sensitivity of computed solutions. Other functions, such as statistical, spatial interaction and location/allocation models, can be also supported by a DSS (Nyerged 2010).
As DSS technology is moving forward, developments involving Planning Support Systems (PSS) are getting underway (Batty 2006). A PSS is a generic term for describing the variety of computer-based tools that urban and regional planners have been using for decades. The focus recently is on how to make use of decision support capabilities incorporating GIS and analytic models in a planning context. The rising pressure for ensuring sustainability in the urban environment leads planners to take into account the environmental, economic and social considerations at once and analyze the potential impacts. Therefore, there is an arising need for developing specific evaluation methods and tools to address multiple inter-disciplinary aspects within decision-making in urban planning.

**DSS in sustainable urban planning: the BRIDGE system**

The BRIDGE project (Chrysoulakis et al. 2013) illustrated the advantages of considering environmental issues in urban planning, by focusing on specific components of urban metabolism: energy, water, carbon and pollutant fluxes. A DSS prototype was developed (Chrysoulakis et al. 2010) as part of the BRIDGE project, introducing urban metabolism components in the planning process combined with socio-economic aspects. The BRIDGE DSS provides the potential to evaluate planning actions, which better fit the goal of changing the metabolism of urban systems towards sustainability.

A structured assessment of methods is integrated in the BRIDGE DSS, for the comparative analysis of urban planning alternatives, their ranking and selection from among them. With the use of numerical modeling and simulations, it is possible to evaluate how planning alternatives modify the fluxes of energy, water, carbon and pollutants. This is further translated as impact to the urban sustainability with the use of suitable indicators, which make it possible to combine with socio-economic indicators using a Multi-Criteria Evaluation (MCE) approach (González et al. 2013).

To cope with the complexity of urban metabolism issues, objectives are defined in relation to the interactions between the environmental elements (fluxes of energy, water, carbon and pollutants) and socio-economic components (investment costs, housing, employment, etc.) of urban sustainability. As described in detail in Chapter 15, the evaluation of the performance of each alternative is done according to the relative importance ascribed by the user to each objective. Indicators, organized in groups, are used to characterize objectives. The planning alternatives are finally ranked by assessing the performance of all indicators selected as relevant in each particular case and the evaluation outcomes depending on the objectives that the user establishes. Different objectives can be set and prioritized, some of which may conflict, and the final evaluation is a trade-off between objectives and their relative importance.

The BRIDGE DSS demonstrates the advantages of having a tool for assessing the behavior of key urban metabolism components in relation to social and economic aspects for urban planning and it highlights the necessity for further research and development in the field. The prototype and its main components are described in this chapter. The system architecture is outlined and the main components of the DSS are presented in the following sections. The method implemented to evaluate the performance of the urban planning actions using the prototype is described, and examples of the evaluation process are also presented and discussed.

**System architecture**

Depending on use, the architecture for building a DSS varies. Despite the differences, the operational functionalities of a DSS can be roughly subdivided into: (a) data management; (b) models, including both decision and simulation models; and (c) Graphical User Interface (GUI). Data management refers to the organization of the data into databases, easily and quickly accessible to the models and the user.
In DSS terminology, by models we usually refer to the models used for alternatives / scenarios evaluation (decision models). In the case of the BRIDGE DSS, numerical models were implemented in the DSS for simulating energy, water, carbon and pollutant fluxes and they are referred as simulation models. The user interface is the most important component of a DSS, since it provides the link between the user (decision-maker), the data and the models. The user, not the system, is the one making the decisions, thus, it is important to ensure good understanding of the DSS processes and results. For spatial DSS, user interfaces are graphical (GUI) and they are often built based on existing platforms to exploit the respective GIS software capabilities.

A simplified diagram of the BRIDGE DSS architecture is shown in Figure 16.1 (left). The different components of the DSS are shown in this diagram, as well as the connections between them. Every arrow in the diagram represents a procedure implemented in the DSS as a module. In short, the BRIDGE database feeds the models with input data and also receives model outputs (simulations). Encoder and decoder modules are implemented for this reason. Both input and output data visualization is possible through the GUI. In addition, a dedicated module of the GUI is used for accessing the models parameters. The BRIDGE DSS prototype was built in Visual Basic (Schneider 2000). SQL (Din 1994) was used for database development and the GUI was developed as part of the ArcGIS software (Ormsby 2004) to allow the user to exploit its extended GIS capabilities for visualization and further processing at will. Figure 16.1 (right) shows the BRIDGE DSS toolbar in the ArcGIS environment. More details on each module are provided below.

**Database**

The BRIDGE database is the core of the system. All components of the DSS are linked to the database and the implemented procedures are accordingly developed to interact with it. Although Figure 16.1 presents the BRIDGE database as a whole, the diversity of the data for this application necessitated a more complicated geo-database structure and several processors for the data transformations and adjustments to the models’ needs. Data collected from the case studies during the implementation of the project (see Chapters 5, 6 and 13 for more details on the data collection) are included in the database.
This data is processed by the DSS modules and is made available to the simulation and decision models for calculations, which in turn return their outputs to the database. Special procedures (encoders and decoders) were developed to implement the interactions between the database, the models and the GUI. All datasets are easily accessible to the user through the GUI, to view, further analyze, process and update the database at will.

Simulation models

The simulation models are the most essential components of the BRIDGE DSS. All the information related to the environmental assessment of the planning alternatives is derived with the use of state-of-the-art numerical models that simulate physical flows. Extensive details on the simulations are given in Part II. Some of the simulation models are very demanding in terms of computation power. This made impossible to directly integrate them in the prototype. Those models were therefore run in a powerful computer cluster for all the BRIDGE case studies (for all the respective planning alternatives) for a period of one year with an hourly time step. The simulation results were post-processed and then integrated in the DSS database.

The nature of planning alternatives was different for each of the case studies examined in BRIDGE and thus different implementations were used in the simulation models. The planning alternatives for each case study were interpreted to fit the specifications of the models and the system. In cases, for example, where a planning alternative implied the development of new buildings, the land use types were changed accordingly to match this intervention. In the case of the application of cool materials, different albedo values were assigned to the respective areas. In cases of planting vegetation, or green roof implementation, fractional vegetation values were modified accordingly in respect to urban surface cover.

Decision models

A decision model was developed in the framework of BRIDGE for the evaluation of planning alternatives taking into account the performance of the indicators described in Chapter 15. The BRIDGE decision model combines environmental, social and economic indicator values with the user preferences to assign appraisal scores to the planning alternatives. The user can decide on the indicators to include in the evaluation, as well as on their relative importance. A MCE algorithm is used to measure the intensity of the interactions among the different indicators and the preferences.

To overcome problems such as model uncertainties and the lack of precise socio-economic information regarding the alternatives, the adapted decision model compares alternatives, rather than estimating absolute appraisal scores. One possible planning alternative is considered by the user as the reference alternative and the other alternatives are compared to it. The reference could be the actual situation, or one of the proposed alternatives. Thus the estimated appraisal scores do not refer to absolute estimations, but rather measure the performance of each alternative compared to the reference.

Values for the environmental and socio-economic indicators are estimated and used as input to the decision model. Appropriate algorithms for each case were developed to aggregate the simulation model results, at both geographic (intervention area and surroundings) and temporal (annual) levels, resulting in values for environmental indicators. Thresholds are used in some cases to establish the nature of the indicators’ performance. Information provided along with the detailed description of planning alternatives is used to estimate values for socio-economic indicators, for instance the cost of intervention or the total length of new roads.
Furthermore, as described in detail in Chapter 15, scores depicting the performance of the alternatives compared to the reference situation are estimated for each indicator. Scores for indicator groups are estimated in a similar manner. The overall score of each planning alternative is calculated in the same way as the groups’ scores, using a function of groups’ scores and weights.

In summary, the decision model adapted in BRIDGE DSS is based on a value function using scores and weights: the first one translates the relative performance of the planning alternative under evaluation when compared to a reference situation, while the second translates the relative importance of indicators (and indicator groups) ascribed by the user. Results are more than just one appraisal score for each alternative. The final appraisal score is simply a representation of all the collected information. The user may examine their performance by assessing individual indicator scores, as well as the scores of indicator groups. Indicator values can also be visualized, in respect to their geographical and temporal variability.

GUI

The user interface is always a very important aspect of any application developed. For the BRIDGE DSS, the GUI aimed at facilitating the set-up of the models and at illustrating the model outputs in a way easily and correctly interpreted. When dealing with spatial multi-criteria decision problems it is important to present all the components of the problem in a comprehensive and structured manner. The user is the one making the decision, thus, it is important to ensure the good understanding of the DSS processes to enable correct parameterization and to ensure good representation and explanation of the results. A balance has to be kept though, because revealing too much information about the processes in the analysis may confuse the user.

As aforementioned, the BRIDGE prototype was built in a GIS environment, which provides extended functionality on visualizing and further processing spatial data. Information associated with the case studies, describing the current situation and the planning alternatives, is included in the database and can be easily accessed using the GUI. The various datasets are presented in a self-explanatory and comprehensive way and they are categorized per planning alternative to facilitate further processing, using both the DSS capabilities and other GIS functions as well.

For the model set-up, a set of input dialog windows were developed as part of the GUI. The main concepts introduced in BRIDGE (the use of indicators to access the performance of alternatives, what specific indicators stand for, the hierarchical approach, the relative importance of indicators and indicator groups, etc.) are depicted in the GUI. Detailed descriptions and tutorials, as well as information on the modules are provided in the documentation accompanying the DSS.

The representation of the DSS results is a challenge, because of the complex nature of urban sustainability and the diversity of possible users. The DSS makes assessments of the behavior of indicators in relation to the user’s preferences to answer the question, ‘which alternative is better, when compared to the reference situation’, on the basis of a single number. However, this number shouldn’t be regarded as the only DSS output, since the DSS can do much more than that. It assesses the performance of indicators and indicator groups and the user has access to all this information through graphical representation to enable comparisons (see Plate 15). Moreover, spatio-temporal representations are available to the user through a tool that generates different kinds of maps of indicator values (see Plate 16). The maps produced are made available to the user for further processing and analysis.

Evaluate planning alternatives with the BRIDGE DSS

This section describes the procedure for evaluating planning alternatives using the BRIDGE DSS prototype. The aim is to reveal the system’s functionality and potential through a step-by-step
FIGURE 16.2 Selection of indicators input window of the DSS GUI

walkthrough. The procedure is represented graphically in Chapter 3 (Figure 3.1). The system provides all the necessary tools for the user to set up the evaluation according to his preferences, run several examples, choose between different types of results’ visualization and post-process the results, with the ultimate goal to decide upon the optimum alternative.

The first step in the evaluation procedure is the representation of the case study and the planning alternatives in question. Upon selection of the case study, the user has access to detailed description of the planning alternatives and, more importantly, can visualize several spatial and non-spatial data featuring the current situation and the proposed planning actions.

Then, the user has to set up the parameters for evaluation according to his preferences. At first, the indicators to be included in the evaluation need to be defined. The list of available indicators is presented in a structured way in a dedicated window, shown in Figure 16.2, and the user is asked to select from among them. The hierarchical organization of indicators in three main groups depicting the environmental, social and economic dimensions of sustainability, is mapped in this structure (Figure 16.2).

The relative importance of indicators (and indicator groups) is defined by slide-bar windows for each group, as for example in Figure 16.3a. The user has to decide if he wants to change the relative importance of any indicators, or indicator groups, from equal, to more or less important. Normalized weights are computed by the system using the method described in Chapter 15. All levels of the hierarchy are accessible through this main window and relative importance can be defined at all levels of hierarchy if the user wishes to change it from the default (equal importance).

The calculation of selected indicator values for each planning alternative follows. This is performed in different ways depending on the nature of the indicator. Environmental indicator values arise from
physical flow simulations by the simulation models, while socio-economic indicators reflecting objective values (number of houses constructed, number of jobs created, etc.) are given as data attached to planning alternatives. As mentioned above, some simulation models were very demanding in terms of computational power. Thus, they run off-line and their simulation results were stored in the DSS database. However, some other models were integrated into the on-line system. The latter can be parameterized and run by the user through the DSS GUI.

No simulation models were used for socio-economic indicator value estimation in BRIDGE, since that was out of the scope of the project. Therefore, the user is required to provide these values for each planning alternative, using the form shown in Figure 16.3b. There is a choice of providing absolute or relative indicator values. Relative values reflect the relative performance of indicators between the alternative in question and the reference situation. Allowing for relative values is very useful, when the absolute values of indicators cannot be defined. For example, regarding the employment indicator, one may not know how many job positions a planning alternative will create, but it might be estimated that they will double compared to the
reference situation. This is a good fit with the general methodology followed in BRIDGE, which assesses the performance of each planning alternative in relation to the reference situation.

Once all the parameters for the evaluation are set up, indicator scores are calculated from the decision models in all levels of hierarchy, as relative values between the alternatives and the reference situation. Spider diagrams are used to graphically represent the individual appraisal scores of all planning alternatives. In a spider diagram, the reference situation is always represented as a circle, having all appraisal scores equal to 1. Appraisal scores for the planning alternatives may be either higher or lower than 1, which indicate better or worse performance than the reference situation, respectively. A final appraisal score for each planning alternative is calculated as a combination of the above scores and weights, which depicts the overall performance of the alternative compared to the reference. Plate 15 shows an example of the evaluation results form. The final appraisal scores for the planning alternative are shown at the top of the window, and individual appraisal scores on the right. Each color in the spider diagram represents an alternative. The representation of all scores in one diagram facilitates comparisons. Careful interpretation of a spider diagram provides valuable information for deciding between alternatives.

This information is not enough for deciding on the best alternative. Indicator maps can reveal more information necessary for decision-making. Indicator maps are representations of the indicator values aggregated in space and time. The user is given the option to choose between different visualizations of indicator maps, aiming at providing a clear picture of the spatial and temporal distribution of the indicator values in the area. The user adjusts the desired time period and chooses between different statistics to apply for visualization. Many combinations are available, to produce seasonal maps, daily maps or yearly maps at will. The option to visualize maps of differences between the alternatives and the reference situation is also provided, to allow comparisons in accordance to the BRIDGE decision model, which is based on relative comparisons.

Additional tools are provided by the DSS, to help the user draw conclusions about the best planning alternative. These include the projection of the intervention in the land use of the broader area and in future time, given extreme future scenarios. The first is accomplished by a cellular automata model, which is integrated in the DSS and is used to simulate land use dynamics (Blecic et al. 2009). This model serves the purpose of determining future spatial distribution of city-wide land uses, taking into account the local interactions between different land uses, as well as the physical, environmental and institutional factors and other relevant characteristics of each cell. Thus, it enables accounting for the broader effects of planning decisions, in terms of a spatial distribution of land use types.

Finally, the BRIDGE DSS provides the ability to evaluate user’s priorities in response to different extreme future situation scenarios. Three Strategic Scenarios were considered in the framework of the BRIDGE project, as described in detail in Chapter 17. The values of the environmental indicators in these Strategic Scenarios cases are modeled, by projecting to the year 2030 the energy, water, carbon and pollutant fluxes for the reference situation and for all the planning alternatives considered. For these projections, assumptions on environmental conditions were made, based on the Intergovernmental Panel on Climate Change (IPCC) scenarios A2, A1F1 and B1 (IPCC 2000). The socio-economic indicator values for Strategic Scenarios were defined by the Communities of Practice (see Chapter 12). The evaluation of the planning alternatives against Strategic Scenarios is done by adjusting the indicators’ relative importance considering the extreme situation outlined by each scenario. The underlying decision process is similar to the basic one, adjusted for the extreme conditions of scenarios, and new appraisal scores are calculated for each Strategic Scenario for all planning alternatives. Both the cellular automata model and the evaluation of the Strategic Scenarios module provide valuable information to assess the performance and the robustness of the proposed alternatives in the future, supporting in this way the final decision.
Example of use

An example of the use of the DSS is briefly presented in this section, with selected results, aiming to demonstrate the system’s functionality. The example uses the case study of Athens, Greece, and more precisely the area of the Municipality of Egaleo, where planning interventions are foreseen. Egaleo is located close to the center of Athens, with little urban vegetation, a lot of traffic and thermal discomfort issues. As discussed in Chapter 3, the proposed planning alternatives were: (a) to apply cool materials on the buildings and the roads of the Egaleo municipality; (b) to transform a brownfield area (Eleonas) to residential area; and (c) to construct a park in this brownfield area. Examples of use of the DSS to assess the performance of the proposed alternatives in relation to the ‘business as usual’ situation, which is regarded as reference here, are presented below.

The spider diagram in Plate 15 shows the evaluation results for Egaleo, for all indicators included in the analysis considered of equal importance. In this case, the third alternative is found to have the highest final appraisal score (0.923), compared to the reference alternative, followed by the first (0.795) and the second one (0.665). The first impression of the results is that building a park in the Eleonas brownfield is a better solution than applying cool materials on buildings and roads, or converting it to residential area. Careful interpretation of the spider diagram reveals more information. For example, the third alternative might have gained a higher overall score, but in terms of thermal comfort, the idea of applying cool materials on buildings and roads (1.12) seems a slightly better solution than creating the park (1.04). More conclusions can be drawn by adjusting the relative importance of indicators and observing the differences in appraisal scores.

Furthermore, indicator maps reveal the spatial and temporal patterns of indicator values, which are very important to account for in planning decisions. Plate 16 shows the spatial distribution of the indicator mean PM10 concentration (μg/m³), for the summer of 2008. Higher concentrations than the surroundings are observed in all cases in the main roads. The situation does not change much between alternatives in Leoforos Athinon and Iera Odos, which are far from the area of proposed intervention (Eleonas). However, Leoforos Kifisou, which is the main street in the area Eleonas, is observed to have around a 10 μg/m³ difference for the third alternative (Plate 16d), compared to the base case (Plate 16a), as well as to the other two alternatives (Plates 16b and 16c). Similar conclusions are extremely important for urban planning, due to the limits established by the European Union (EU). For example, according to EU Directive 2008/50/EC, the 24-hour average PM10 should not exceed 35 μg/m³ more than 35 times in any calendar year, thus the third planning alternative is compatible with the EU Directive. More indicator maps can be drawn for different time periods and combinations with the BRIDGE DSS.

Conclusions

Several studies have addressed urban metabolism issues, but few have integrated the development of methods for the combined analysis of physical fluxes in a city environment. The methodology developed in BRIDGE is based on the application of numerical models for assessing the performance of urban planning alternatives, based on environmental and socio-economic indicators. The BRIDGE DSS integrates environmental observations with social and economic data, to evaluate planning alternatives and thus addresses and jointly examines these three pillars of urban sustainability. The DSS illustrates the advantages of using a software tool to assess the behavior of certain urban metabolism components (energy, water, carbon, air pollutants) in relation to social and economic aspects for urban planning and it highlights the necessity for further research and development in the field.

An important aspect of the evaluation process implemented in the BRIDGE DSS is the capability of accounting for user preferences. This is highly important for decision-making, since the final selection
is subject to the interests and priorities of the city planners and stakeholders. The philosophy behind the method implemented in BRIDGE is to study the behavior of planning alternatives in different decision conditions and to compare the impact on sustainability for each potential implementation. In this way, it supports the user in selecting the optimum alternative with respect to environmental, social and economic criteria, concerning both the current situation and future hypotheses.

References


