Methods for Integrating Spatial Analysis in Assessment of Community Sustainability

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ABSTRACT: Faced with a large amount of data, obtaining useful information and providing effective support for urban planning is a new and increasingly difficult challenge. The effectiveness of planning decisions can be greatly enhanced by providing planning professionals, policy makers, and other stakeholders with methods and tools to evaluate the different impacts of proposed planning decisions on urban sustainability at the neighborhood, city and regional scales. These methods and tools should rely on quantifiable metrics and indicators that can be easily measured and tracked over time. Incorporating interactive forms of decision making in planning processes using Geographic Information Systems (GIS) is an approach that provides an effective means to address this challenge, and GIS applications are increasingly being used to develop such metrics and systems. Existing capabilities of GIS systems can provide effective strategic decision support to planners and private and public organizations and assist them in enhancing their information infrastructure. This paper provides a review of two recently completed studies utilizing GIS applications and related tools in assessing different aspects of community sustainability in the City of San Antonio and the South Texas region. The two case studies, conducted by the authors, are used to illustrate the capabilities of spatial analysis using GIS applications at the neighborhood and regional scales respectively. The paper presents and analyzes the methodologies used in the two case studies as a means of illustrating different approaches in utilizing GIS capabilities in the assessment of urban and community sustainability. Policy implications for local governments and recommendations for future utilization of the models and metrics developed in both studies are also identified and discussed.

KEYWORDS: Sustainable Development, Spatial Planning, Neighborhood Analysis, Workforce Housing.

1.0. Spatial Planning and Decision Making

Faced with a large amount of data, obtaining useful information and providing effective support for urban planning is a new and increasingly difficult challenge. Currently there are three main technological platforms that are used to provide support to planners to complete their specific objectives (Anthony, et. al. 2006; Ning-rui, D. and Yuan, L. 2005):

- *The Planning Support System (PSS)*: This system was proposed by the American scholar B. Harris in 1989, and followed by other scholars and planning officials who made it widely used. This system intends to provide support to the whole process of planning. It covers not only the ultimate decision-making, but also discovery, analysis and evaluation of the planning problems.
- *The Expert System (ES):* This system is also known as a knowledge-based system, and is an intelligent computer program that uses artificial intelligence technologies to simulate the decision-making process of experts and solve problems in some specialized fields using existing knowledge and experience. Without differentiating various types of users, it aims at the optimal or ideal decision rigidly aided by knowledge and experience provided.
- *The Decision Support System (DSS)*: This is an interactive information processing system used to help decision-makers use data or models to solve unstructured or semi-structured decision-making problems using computers. It provides a good environment for policy makers to formulate policies through the man-machine dialogue. It can analyze problems, establish model, simulate the decision-making process and results, and help the policy makers improve the quality of decision-making by making full use of information resources. It requires users to identify clear rules of judgment and objectives. It usually provides several options, and lets users make the final decision for themselves. (Zhana, et. al. 2008).

In addition to urban areas, Planning Support Systems (PSSs) have been applied to urban-rural planning for the past 20 years. Developed countries with advanced economies, societies and technology, perfect systems and laws, mature method and skills of urban-rural planning are also in an advanced status regarding the data, technology and software of PSSs. The main idea proposed by Harris (1989) was to combine information technology with methodology of urban planning to provide decision-making in every step during the planning process (Mao, et. al. 2008).

Another area where spatial planning was integrated into decision making is growth management and sustainable development. The significance of this area is discussed further in two case studies presented in this paper. Additionally, in the Netherlands both the fourth National Environmental Policy Plan (Ministry of VROM 2001a) and fifth National Policy Document on Spatial Planning (Ministry of VROM 2001b) emphasized the responsibility of local authorities for creating a sustainable environment, stressing that spatial planning at the local level has direct impacts on the urban and rural environments. In practice, this means finding a sustainable balance between the influences of present and proposed human activities and the sensitivities of the urban and rural environment. This requires coherence between spatial and environmental policies and an integrative, area-specific planning approach at the local level. It is essential for this integrative approach that environmental aspects are incorporated into the planning process at an early stage, instead of being evaluated afterwards. To do so, local authorities and urban planning officials need tools that enable them to review the potential environmental impacts of spatial plans quickly and indicatively, as exemplified by the Neighborhood Sustainability Assessment case study, and to explore alternatives in an iterative and interactive way. Another example of this approach can be found in a research project started at Wageningen University in 1998, which aimed to develop a GIS-based Strategic Tool for integrating Environmental aspects in Planning Procedures (STEPP) (Carsjens et al. 2002). The objective of STEPP was to support interactive spatial planning processes at the local level, especially with regard to identifying options in the early phases of the process.

Subsequently, the benefits of incorporating interactive forms of decision making using GIS applications have developed from an operational support system into a strategic decision making support system (Grothe 1994; Cornelius and Medyckyj-Scott 1991). These systems take advantage of GIS' ability to bundles time and efforts to improve the position of private and public organizations by enhancing their information infrastructure. GIS applications are contingent upon the use of spatial data, progress in information technology and computer science and engineering, availability of digital geo-information, and importance of its implementation. GIS is therefore a vital technology that has important applications not only on the neighborhood level, as illustrated by the first case study, and on the regional level as shown in the second case study, but also on the national level. It deals with information on people (demography), facilities, businesses and land (use and planning), zoning, employees, customers, facilities and the market (Huxhold and Levinsohn 1995; Saleh and Sadoun 2006).

2.0. Spatial Analysis Applications AND sustainability

Compared with STEPP and similar tools, newer generations of GIS offer more sophisticated and extensive database management and display capabilities, and are much more user-friendly (Malczewski 2004). These new trends have stimulated the development of geo-technology tools to support different aspects of the planning process, particularly tools in which participation is a key element (Geertman 2002). These participatory GIS tools have materialized under the generic term Planning Support Systems (PSS) (Harris 1989; Brail and Klosterman 2001; Geertman and Stillwell 2002; Geertman 2002). PSS are spatial decision support systems (SDSS) (e.g., Jankowski and Richard 1994) that have primarily been developed to support planning processes (Geertman 2002), based on the assumption that an increase in access to relevant information will lead to a greater number of alternative scenarios, and thus a better informed public debate (Shiffer 1995). (Gerrit and Ligtenberg 2007).

Additionally, GIS as a spatial analytical tool has been noted to be very useful in monitoring, appraising, and updating urban sustainability assessments. GIS has the capability to link location data with attributes and also perform spatial analysis on these data. Urban sustainability, as well as site suitability assessments, involves measurement and evaluation of spatial data that can be handled to some extent by GIS. Apart from data manipulation, integration, and analysis, GIS could be used in visualizing different scenarios of the indicators of sustainability... Experiences from empirical studies (Blaschke 1997; & 2001; Lautso et al. 2002) have shown that GIS and related technology could be very useful in urban sustainability assessment and in the quest towards achieving sustainable cities. Indeed, the operationalization of sustainable development locally and globally requires spatial thinking and spatially explicit approaches (Blaschke 2001) that consider the spatial heterogeneity and interdependency of developmental processes and impacts. The trend of sustainability assessment studies is towards the development of holistic approaches that will integrate the different aspects of spatial planning into the appraisal (Bond et al. 2001). Therefore, there is clearly a need to integrate the evaluation of the planning process with the appraisal of the process outcomes in order to improve understanding of how planning could foster sustainable cities (Alshuwaikhat and Aina 2006).

3.0. Background of the two case studies

To illustrate the use of GIS applications in spatial analysis and planning decision support, this paper presents a review of two recent studies utilizing GIS software and related tools in assessing different aspects of community sustainability and identifying the common approaches and methods used in them. The paper presents and analyzes the methodologies used in the two case studies, conducted by the authors, as a means of illustrating the different approaches in utilizing GIS capabilities in the assessment of community sustainability, and the different scales such studies can address.

The first case study (Rashed-Ali, 2012a & b) addresses the issue at the neighborhood / city scales and involves the use of the INDEX PlanBuilder software (Criterion Planners, 2011) to develop a neighborhood sustainability model for the City of San Antonio, Texas. This model aimed to provide support for sustainability-oriented neighborhood planning activities across the city. The model was based on 29 sustainability indicators, and was used to calculate an overall Neighborhood Sustainability Index for each of 275 neighborhoods within the city. This overall Neighborhood Sustainability Index consisted of seven component indices, six of which were based on the six livability principles developed by the Partnership for Sustainable Communities[1], while a seventh was developed for Environmental Impact. In addition to the quantitative indices, maps representing the spatial distribution of each indicator were developed for each neighborhood. This Neighborhood Sustainability Index aimed to provide support for neighborhood planning activities across the city with the aim of reducing energy and water consumption, vehicle miles of travel, pollution emissions and the overall carbon footprint of the city. This index will help planners, policy makers and other stakeholders evaluate the long-term environmental impacts of their decisions, compare available planning alternatives, select optimum ones, as well as develop new alternatives to address issues identified in the analysis and generally make more informed planning decisions.

The second case study (Kamal, 2012) focuses on the regional scale and consists of a site suitability analysis, which utilized GIS spatial analysis functions and other statistical models for assessing areas for residential developments to accommodate the workforce required for the oil and gas production in six counties located in South Texas: Dimmit, Frio, La Salle, Maverick, Webb, and Zavala. Since the 2008 discovery of Eagle Ford Shale, the South Texas region, which extends over 24 counties, has experienced extensive economic growth estimated to have 20 to 30-years lifespan and is ranked among the largest 10 US oil fields. The counties identified for this study are responsible for more than50% of the drilling activities of the entire shale, and are surrounded by the cities of Eagle Pass, San Antonio and Laredo. The purpose of the site suitability analysis was to provide a systematic method that could aid policy makers in allocating local and state resources needed to meet the housing supply of workforce over the next 15 years (from 2010 to 2025). It also aimed to provide the developers and local housing authorities with proposed locations with appropriate commuting range to oil and gas drilling sites. The influx in demand for workforce housing arose amid the 2008 discovery of an oil shale field in the region.

4.0. Developing the GIS Methodology

4.1. Neighbourhood Sustainability Assessment Study

The methodology used in the first study relied predominantly on quantitative methods focusing mainly on the processing and analysis of preexisting GIS data in deferent agencies at the city, county and regional level. The methodology consisted of the following:

- *Indicator selection:* The selection of neighborhood sustainability indicators for the study was based on a thorough review of similar sustainability assessment studies in a variety of US cities. Notable studies reviewed include a sustainability framework for the Twin Cities Region (Kaydee-Kirk et al, 2010), and the STAR Community Index (2010). Several case studies of the use of the INDEX software in different US cities were also reviewed including studies in Portland, Kansas City, Redwood City, Austin, and Grand Rapids (available at www.crit.com). Based on the literature review, an initial set of more than 50 indicators was identified for further evaluation. This set was then compared to the sustainability indicators available in the INDEX software, which resulted in the selection of a smaller set of 35 indicators. 3.The availability of citywide GIS data and other required inputs for the indicators was then investigated, which resulted in a final set of 35 indicators.
- *Indicator score calculation (INDEX PlanBuilder):* Raw scores for selected indicators were calculated using the INDEX PlanBuilder Software. The Process involves loading the GIS data collected from various sources as well as other needed data and defaults into INDEX. When available, required data and defaults representative of local conditions used (Author reference). If this data was not available, national level data or INDEX software defaults (also representing national level averages) were used.

- *Neighborhood sustainability indices*: As previously stated, the selected indicators were combined into seven sustainability indices. Six of those indices were based on the HUD/EPA/USDOT livability principles discussed earlier, while the seventh related to the environmental impact of the neighborhood. Each of the seven indices was based on a subset of the indicators calculated within the study based on the relevance of the issues addressed by each indicator to the focus area of the index. To aggregate the indicator raw scores, scores were standardized so that they all fall on scale from 0-1. The standardization was achieved by comparing each indicator's raw score to a maximum and minimum threshold score for it. Indicators were assigned equal weights in calculating different index scores. However, several indicators were used in more than one index thus resulting in increasing their relative weight. All index scores were calculated on a scale of 1 -100. The approach of relating neighborhood sustainability indices to livability principles was based on the Twin City Region study discussed earlier. Finally, an overall *Neighborhood Sustainability Index* was calculated based on the seven component indices. Different relative weights were assigned to each component index based on the relevance of the issues it addresses to the environmental performance focus of the project. Accordingly, indices relating to environmental impact, housing equity, and transportation were assigned higher relative weights than other indices. This resulted in further modifications in the relative weight of each indicator in the overall *Neighborhood Sustainability Index.*
- *Pilot neighborhood*: To test the capabilities of the INDEX PlanBuilder software and the effectiveness of the developed neighborhood sustainability model, the model was first applied to two neighborhoods with contrasting urban sustainability characteristics, a neighborhood with high urban density, high use mix, high street connectivity, available amenities, and good transportation coverage and one with low-density mostly single use neighborhood with low street connectivity, low public transportation coverage, and low availability of amenities. The results of this initial assessment were consistent with expectations and clearly exhibited the contrasting sustainability characteristics of the two neighborhoods
- *Citywide implementation*: The model was then applied on a city-wide scale. To achieve this, the city was divided into 10 zones based on geographic location and the major highway network (see figure 1). Each of these 10 zones was then divided into its constituent neighborhoods based on the boundaries of registered neighborhood association. In total, 275 neighborhoods were assessed within this project. An assessment of existing sustainability conditions was conducted for each of the 275 neighborhoods identified within the city. Results generated for each neighborhood include scores for all indices (the overall Neighborhood Sustainability Index and the seven component indices), raw scores for the 29 indicators used, as well as maps describing the geographical distribution of some of those indicators within the neighborhoods (figure 2). All project results were made available to the public on the project website (author reference).

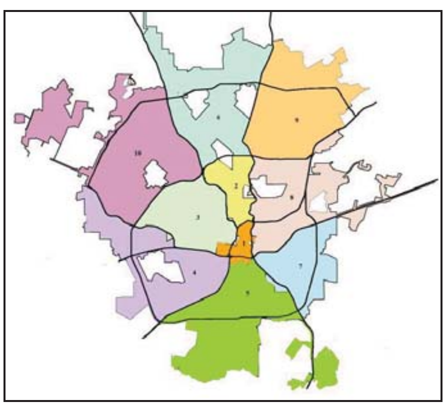

Figure 1: Geographical zones used in the study

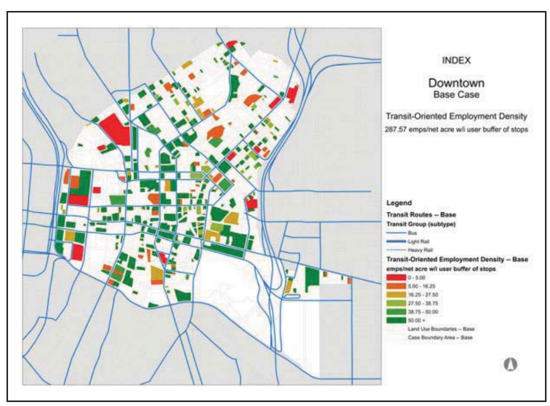

Figure 2: Indicator map for one of the neighborhoods within the study.

4.2. Site Suitability for Workforce Housing

In contrast, the methodologies used in the second study included both quantitative and qualitative methods including: 1) interviews with professional to establish a workforce metric, 2) six focus groups with local stakeholders to identify the study parameters, 3) Population projections (from 2010-2025), 4) projection of housing demand by tenure and by type in the six counties, 5) GIS mapping for site suitability analysis to identify development sites for oil and gas workforce housing, and to identify existing housing vacancy and foreclosure stocks. The following are the methodology stems:

- *Identifying workforce metrics:* Interviews with oil and gas industry professionals and geologist were used to develop the workforce metrics. The metric was based on drilling footprint and its impact on well counts and rig counts; the latter was used to calculate the number of jobs needed to run each rig and Total number of jobs per rig was estimated to be 105 jobs divided into 94 transient jobs, and 11 permanent jobs; both types are shown in figure 3.
- *Projecting population and households (2010 to 2025):* Projection of current population was conducted by applying Hamilton-Perry (Smith, et. al. 2001) projection model, which accounts for aging existing population, and considering birth, mortality and fertility rates in the county. Adding permanent rig-related jobs and households to the natural population growth model in the community from 2010 to 2025 according to the following considerations: 1) Adding newcomers (permanent jobs in each community) at a ratio of 25 percent in cohorts 45 years and older, and 75 percent to cohorts 0- 44 years, 2) An assumption was made that the major unincorporated communities will absorb the entire permanent jobs created in each county.
- *Projecting households and housing units (2010 to 2025):* Total population adjusted by adding the incoming workforce was used to create household model through three household categories: age 15 to 44 years, age 45 to 64 years; and retired householders: 65 years and older. Texas household size, 2.75 (US Census Bureau 2010) was used to estimate household counts. Two classes of tenure[2] (10% Owner-Occupied Household, and 90% Renter-Occupied household) were used to estimate future housing demand per each household category. Housing projections by type[3] excluded RVs, vans, and boats, and was normalized to the pre-launch year of 2010, before intensive drilling activities took place in Eagle Ford Shale area.
- *Mapping convenient commuting range:* Locating areas within each of the six counties where potential development was based on identifying optimum driving distance to and from existing oil and gas drilling-on-schedule wells. Various publication and studies show that the average commute range is between 15.5 miles in rural areas (Transportation Research Board 2000) and 45.6 minutes for the average two-way trip per day (The Gallup Poll Briefing, Carroll 2007). Based on results from both studies, we identified the optimum driving distance for the workers from all drilling sites as 15.5 miles, as shown in figure 4. This distance was incorporated into GIS buffer analysis, to identify the ranges from current active wells to define potential sites for residential workforce development.

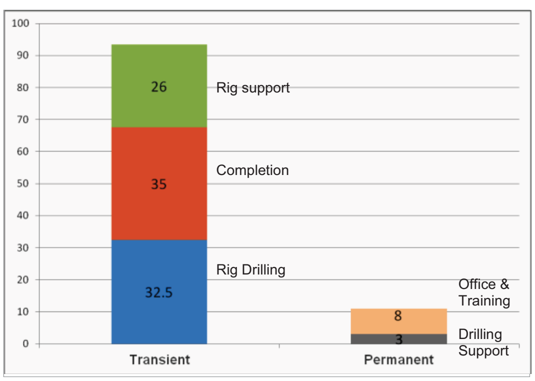

Figure 3:. Job counts and types per rig

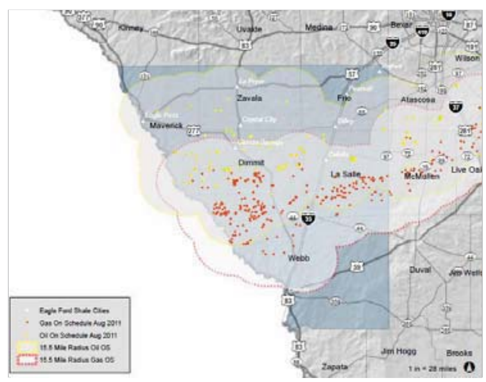

Figure 4: Commuting ranges identifying potential residential development

- *Mapping vacant and foreclosed housing stock:* Location of vacant housing units was mapped in each city where wells are active and the community has an increased workforce population within the study area. Vacant units data was extracted from the Census block groups data (US Census Bureau 2010). Foreclosure counts by county and by community were retrieved on November 17, 2011. List of housing units on foreclosure were categorized by city's available properties on foreclosure, as well as the mean and median price of the property. All RVs, vacant land, and other uses were excluded from the list. Data was integrated into GIS map, which manifests the foreclosure count in each of the communities and counties. The analysis concluded that an estimated 6,509 units are available within the jurisdiction of the unincorporated communities in the six counties.

5.0. Discussion: A Metric for Future Studies

5.1. Neighbourhood sustainability assessment study

The results of the neighborhood assessments conducted in this project are in themselves very valuable for different stakeholders in San Antonio including planners, policy makers, neighborhood associations and the general public. They provide these different stakeholders with a detailed and quantified assessment of different sustainability metrics and issues. However, the larger benefit offered by this study lies in the considerable potential it offers for future work that would further build on the advantages offered by having such an assessment system in place. First, the assessments conducted in this study represent the existing conditions of different neighborhoods and are based on GIS data available at the time of conducting the analysis. Repeating this assessment on regular bases would offer the city the ability to track progress towards achieving its sustainability objectives as well the potential for evaluating the success of different sustainability and other initiatives, at both the city and/or neighborhood levels, in improving sustainability. Second, the comprehensive nature of this model results in it overlapping with several existing models in different sectors (e.g. emissions models, transportation models, etc.). While most of these models work at a higher level of aggregation than the one addressed in this project, comparing the results of the neighborhood sustainability assessment project with those of other existing models can result in further improvements in the accuracy of the neighborhood model. Finally, the existing conditions results offer a valuable starting point for neighborhood associations to evaluate existing and future development plans they may have and to compare different alternatives and identify the ones achieving the best improvement in neighborhood sustainability.

5.2. Site suitability for workforce housing study

Since oil and gas drilling activities in Eagle Ford Shale area are dynamic, they need to be studied periodically in order to integrate the facts about population, workforce, and drilling activities that unfold within the projection scenario for the 15 years' time span included in this study. Accordingly, policy makers in the Eagle Ford Shale area need to integrate the developed workforce metric and to utilize it in updating the overall estimate of population, households, and housing units. The advantages of this metric is that it allows addressing changes in housing demands emerging from the dynamic nature of drilling activities in the statistical model and its adjusted ratios for both population and housing units. The metric as well as the qualitative data analysis of the interviews and focus groups provided concrete evidence that the following unincorporated communities could represent a workforce hub:

- Carrizo Springs, located in Dimmit County, TX
- Crystal City, located in Zavala County, TX
- Dilley and Pearsall, located in Frio County, TX
- Cotulla, located in La Salle County, TX
- Laredo, located in Webb County, TX.

The results of the spatial analysis is that within optimum community ranges of 15.5 mile from drilling sites, vacant parcels located in the jurisdiction of the identified workforce hubs are suitable for new residential developments, the design of which needs to be adaptable to accommodate local residents upon the end of oil and gas lifecycle. Finally, the potentials for incorporating existing vacant and foreclosed housing units exits due to the large stock of both.

CONCLUSIONS

In conclusion, while the two case studies presented in this paper address different community sustainability issues, as well as different scales, the analysis presented clearly illustrates the value that GIS spatial analysis tools can bring to sustainability assessment both at the neighborhood / city scale as well as on the regional scale. In both case studies, GIS tools were used both to process large amounts of data, which would not be possible if these tools were not available, and then to use this processed data to develop usable, quantifiable, and trackable metrics that provide valuable support to the planning decision making process at the two different scales addressed. Through having these quantitative metrics, planners, policy makers, and other stakeholders will be able to evaluate the long term environmental impacts of their decisions fat the neighborhood scale and to make strategic decisions in identifying developable sites in economic boom regions at the regional scale. The large potential offered by these two models also lies in the potential they offer to planners and policy makers to compare available planning alternatives, select optimum ones, develop new alternatives to address issues identified in the analysis, and generally make more informed planning decisions that lead to reductions in energy use, emissions, and other environmental impacts benefiting neighborhood(s) or regions in question. Local and state policy makers can also make decisions to allocate resources such as rehabilitation funds and home repair programs to areas with high vacant and vacant and foreclosed housing units. The outcomes of the process can also be used to inform the general public and solicit their involvement in the decision making process. The availability of the tools used within the two case studies, the existing conditions assessments conducted within both of them, and the expertise developed through them will facilitate this process and provide valuable assistance to neighborhoods, counties and regions in their planning activities. These decisions would be flourished by a continuous updates of already-established metrics that aid future decisions, assessments and allocation of resources.

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REFERENCES

Alshuwaikhat, H. and Aina, Y. 2006. GIS-Based Urban Sustainability Assessment: The Case of Dammam City, Saudi Arabia. *Local Environment*, 11 (2), pp. 141–161.

Anthony, Y., Xiaodong, S. and Xinyi, N. 2006. *Geographic Information and Planning Support System*. Beijing: Science press.

Blaschke, T. 1997. Sustainability with GIS? Towards a proactive nature conservation approach, in: J. Johnston & M. Gomarasca (Eds) *New Developments in GIS*. Ann Arbor: Ann Arbor Press.

Blaschke, T. 2001. GIS-based regionalization of indicators and ecobalances for a sustainable regional planning, in: F. Prettenthaler (Ed.) *Human Dimensions Research in Austria and Central European Countries*. Graz: University of Graz.

Bond, R., Curran, J., Kirkpatrick, C., Lee, N. & Francis, P. 2001. Integrated impact assessment for sustainable development: a case study approach. *World Development*, 29(6), pp. 1011–1024.

Brail, R.K., Klosterman, R.E. (Eds.), 2001. *Planning Support Systems: integrating Geographic Information Systems, Models, and Visualization Tools*. Redlands, CA: ESRI Press.

Carsjens, G.J., van Lammeren, R.J.A., Ligtenberg, A. 2002. STEPP: strategic tool to integrate environmental aspects into planning procedures. In: Geertman, S., Stillwell, J. (Eds.), *Planning Support Systems in Practice*. Springer-Verlag, Heidelberg, pp. 139–154 (chapter 8).

Cornelius, S., Medyckyj-Scott, D. 1991. If only someone had said! *Mapping Awareness* 5(7), 21–28.

Criterion Planners, 2011, *INDEX PlanBuilder Planning Support System, User Notebook. 2011*. Available at: http://www.crit.com/

Geertman, S., 2002. Participatory planning and GIS: a PSS to bridge the gap. *Environment and Planning B: Planning and Design*. 29, 21–35.

Geertman, S., Stillwell, J., 2002. Planning support systems: an introduction. In: Geertman, S., Stillwell, J. (Eds.), *Planning Support Systems in Practice*. Springer-Verlag, Heidelberg, pp. 3–22 (chapter 1).

Gerrit J. and Ligtenberg, A. 2007. A GIS-based support tool for sustainable spatial planning in metropolitan areas. *Landscape and Urban Planning*, 80, pp. 72–83.

Grothe, M., Scholten, H.J., Van der Beek, M. 1994. *GIS, Noodazaak of luxe? Een verkenning naar het gebruik van geografische informatiesystemen bijprivate ondenemingen in Nederland*, Netherlands Geographical Studies, Utrecht.

Harris, B. 1989. Beyond geographic information systems: computers and the planning professional. *Journal of the American Planning Association*, 55, 85–90.

Huxhold, W.E., Levinsohn, A.G. 1995. *Managing Geographic Information Systems Projects*. Oxford University Press, Oxford.

Jankowski, P., Richard, L., 1994. Integration of GIS-based suitability analysis and multicriteria evaluation in a spatial decision support system for route selection. *Environ. Plan. B: Plan. Des*. 26, 393–408.

Kamal, A. 2012. *Strategic Housing Analysis of the Middle Rio-Grande Region: Sustainable Choices for the Growing Demand of Eagle Ford Shale Housing*. A report submitted to the Institute for Economic Development. Center for Urban and Regional Planning Research, UTSA, San Antonio: TX.

Lautso, K., Spiekermann, K. & Wegener, M. 2002. Modelling policies for urban sustainability. Paper presented at *the 42nd Congress of the European Regional Science Association*, August 27–31, 2002, Dortmund, Germany.

Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. *Prog. Plan*. 62, 3–65.

Mao, F., Yu, W., Zhou, W., and He, G. 2008. An Urban-Rural Spatial Development Planning Platform Using GIS. *Geoinformatics and Joint Conference on GIS and Built Environment: The Built Environment and Its Dynamics*, Proc. of SPIE (7144), pp.K1-K9.
Ministry of VROM. 2001a. *Where there's a will there's a world—working on sustainability. 4th National environmental policy planning Den Haag*, Ministry of Housing, Spatial Planning and the Environment (VROM).
Ministry of VROM. 2001b. *Making space, sharing space. 5th National policy document on spatial planning 2000/2020. Den Haag*, Ministry of Housing, Spatial Planning and the Environment (VROM).
Ning-rui, D., Yuan, L. 2005. "Planning support system (PSS) and its application to decision-making for urban spatial development". *Journal of Wuhan University of Hydraulic and Electric Engineering*. 38[1]: 137-142.
Rashed-Ali, H., 2012a. *The City of San Antonio Neighborhood Sustainability Assessment, Final Report*. Submitted to: Office of Environmental Policy, City of San Antonio. Available electronically at: http://www.sanantonio.gov/oep/pdf/NeighborhoodSustainabilityAssessmentReport.pdf
Rashed-Ali, H., 2012b. *City of San Antonio Neighborhood Sustainability Study website.* Available electornically at: http://saneighborhoodsustainability.org
Saleh, B. and Sadoun, B. 2006. Design and implementation of a GIS system for planning. *International Journal on Digital Libraries*, 6(2), pp. 210–218
Shiffer, M.J., 1995. Interactive multimedia planning support: Moving from stand-alone systems to the World Wide Web. *Environ. Plan. B: Plan. Des*. 22, 649–664.
Smith, S., Tayman, J., and Swanson, D. 2001. *State and Local Population Projections: Methodology and Analysis*. Ney York, NY: Plenum Publishers.
U.S. Census Bureau. 2010. *U.S. Census 2010*. Available at: http://2010.census.gov/2010census/
Zhana, Q., Pangb, Q., Denga, M., and Zhoua, S. 2008. GIS-based Approaches for Planning Support. *Geoinformatics and Joint Conference on GIS and Built Environment: The Built Environment and Its Dynamics*, Proc. of SPIE (7144), pp.L1-L8

ENDNOTES

[1] The livability principles were developed by a partnership between the Department of Housing and Urban Development (HUD), Department of Transportation (DOT), and the U.S. Environmental Protection Agency (EPA). Available electronically at: http://www.sustainablecommunities.gov/aboutUs.html
[2] Tenure refers to owner occupied units and renter-occupied units.
[3] Type includes single family, multifamily, and mobile homes.