World Experience in the Use of GIS Technologies in Solving Problems of Sustainable Development of the City

M H Abkharima¹, M V Perkova¹*, A A H Al-jaberí¹

¹Institute of Architecture, BSTU, Belgorodcki oblast, Belgorod 308012, Russia

E-mail: *perkova.margo@mail.ru

Abstract. Sustainable development has been discussed since the 1960s and has since been a focused subject in urban development. GIS was used in this purpose for e.g. water, air, and climate change planning and management and sustainable planning. This work is explaining the relationship between Geographic Information System (GIS) and Remote sensing (RS) with urban sustainability and sustainable development. Describing and discussing the tools that can be used to monitor urban growth. Specifying the countries and organizations that have developed new tools and methods to help in urban sustainability and urban development endeavour. Also, the methods and tools for rating that are used within a GIS environment for sustainable planning and development. Indicating the dependency of the rating tools on data acquisition accuracy and precision. Highlighting the case that there is no universal method of using GIS in sustainable development yet. And, the part that is played by GIS and RS in planning aspects and stages such as water accessibility, climate impacts, infrastructure planning, air pollution modelling, etc. Attempting to form analysis for economic and social sustainability in urban environments like; population distribution, proximity to recreation centres, school locations, the flow of people and goods, and demographics. In addition, answering if there is a known method for combining all three pillars of sustainability and measuring it and comparing the level of sustainability between cities.

1. Introduction

The global progression in urban growth compels the need to understand the dynamics of regions, as it is required to shape the developments that need to be employed [1]. The interrelationships between population, land use, transportation, economy, environment, and land telecommunication must be studied to achieve a comprehension of a region. To develop effective policies and identify where funding should be invested to create more sustainable urban habitat. In this endeavor, the use of the Geographic Information System provides solid, spatially referenced data [2]. Data serves as reasonably credible information that should be reviewed by decision makers to ensure a sustainable future for people and the planet. Hence, to avoid the Malthusian Trap, as much as possible, in the sense of managing resources in the most manageable direction. According to the United Nation Habitat reports, it predicts that the gradual shift in human residence from rural to urban areas, combined with global population growth, could add 2.5 billion people to urban areas by 2050. 55% of the total population these days live in urban zones, while this figure is relied upon to increment to 68% in the coming 30 years [3]. Pollution of air and water is one of the most essential issues that must be managed rigorously in urban areas. In addition, other urban issues like transportation, urban and suburban sprawl, sanitation and public health, and energy. The need to employ more sustainable
strategies is turning to necessities since the changing of the dynamic between people and habitat [4]. The myriad social, economic and environmental information and policy-making need to be collected, organized, analyzed and disseminated in order to evaluate these issues properly [2]. In some countries, this process has already started to operate [5]. However, it is not yet clear how to best assess urban areas for sustainability and what kind of tools and methodologies to be involved [6]. The issue remains how best to assess the sustainability of urban areas and what methodologies and tools are best used for such an assessment. Geographic information system (GIS) is, according to scholars, a fundamental tool that decision-makers need to use to ensure sustainability [7]. Despite of that, research has shown that these tools and methodologies are merely developed through academic and private sectors. Which make it a little harder to reach the decision makers who struggle with these issues on a daily basis. A way forward in securing a sustainable urban future is to resolve this problem. Sustainable cities, urban sustainability, or eco-city, can be defined as a city with social, economic, and environmental balance. A way of achieving a resilient habitat without making future generations experiencing the same problems. These cities are inhabited by people dedicated to manage and control resources [8]. The concept of sustainable urban development means the process by which sustainability can be achieved. Intergenerational equity, intragenerational equity including social equity, geographic equity, land equity in governance are some of the key characteristics of urban sustainability. And, the obligation to protect the natural environment and living within its carrying capacity urge decision-makers to pay attention to some aspects. Aspects like minimal use of nonrenewable resources, economic vitality, and diversity, community self-reliance, individual well-being, and satisfaction of basic human needs. In the academic, planning and other organizations, there is a considerable debate on the relative importance of each feature of urban sustainability. And there is even a discrepancy about whether it should be all taken into account when developing sustainability [9].

2. Urban sustainability and GIS
Various attempts had been made to measure sustainability as accurate as possible [10]. However, the lack of agreement on the definition of sustainability and development complicates the measurement of sustainable developments. And further complicates the measurement of many factors such as economic and social development. Sustainable urban development can be made possible through the spatial transformation of the urban environment and the quality of life of its people–via participatory, fair and responsible planning, management and management processes and systems that are effective. Cities are often seen as living organisms, and cities must evolve and adapt in a changing world like a living organism [11]. The city must be strong enough to take care of its people’s collective needs and fight any real or perceived problems which could weaken their ability to develop. GIS can play a major part in identifying and resolving urban conflicts and problems. GIS has a wide range of applications for urban areas which are only bound by their necessity [12]. However, GIS has a limitation, namely its dependence on processed data quality and accuracy. The quality and accuracy of the processed data cannot exceed GIS analysis accuracy [7]. This includes, for example, maps, satellite statistics, and images. A GIS software must be capable of combining data from different sources and of analyzing, visualizing and distinguishing spatial relations. GIS has three main applications; visualization and graphical analysis, selection and search [7]. GIS advanced applications are like, spatial correlations in which correlations can be analyzed, for example, between water quality and human health. And Location, which analyzes together a large number of geographic variables based on certain demands and results. Also, time and space changes, like changing detection studies. Studies such as these can analyze spatial correlations and the processes underlying these variations for example; the changes in the environment. The advantages of GIS is that several ground-truth points are collected and the same information can be interpreted over large areas. While complex correlation and large amounts of data can be visualized in a comprehensible manner [7]. However, combining all the factors leading to sustainability is a complicated matter, not only in terms of data but also because the definition of sustainability is inconclusive. However, researchers and professionals understand the potential to use GIS for sustainable development planning. It makes it easier to predict future changes.
and make reliable urban planning decisions [13]. Yeh et al. (1998) identify three main areas of urban sustainable development use of GIS and RS [14]:

- RS data classification can be used to update the GIS database for spatial information. This is very useful if there is no former GIS or RS data inventory in a region that is undergoing rapid change, such as urbanization.
- Enhance the detection of land-use changes and, eventually, improve decision making’s process.
- GIS and RS integration into environmental modeling and analysis, e.g. the vegetation pattern effects of the climate change scenario.

GIS and RS are far from complete as a single tool for sustainable urban planning. However, with its flexibility and user-friendliness, it has many possibilities to evolve and further develop into a more powerful tool. As it was mentioned earlier, GIS application in urban sustainability are plentiful, nonetheless, it was concentrated on the areas that affect human the most. For example, the concept of Energy Points, which recalculates the amount of energy available in one gallon of gasoline into one unit by cities’ energy consumption, water utilization, emissions of CO2, waste production, etc. This allows a comparison of the sustainability of various cities and areas according to their energy consumptions.

On the other hand, water consumption is, not only taken into consideration but also its transportation from source to point of consumption, whether fresh, salt or polluted, is also considered. Using GIS, it is possible to calculate the distance of water being transferred and to easily visualize and understand comparable results at national and global levels [15]. Various approaches for sustainable urban development in which fertile land for urban development is avoided. This is, also, done through GIS software analysis, which takes into account factors such as averages, soil type, pitch angles, etc. [16]. This approach can be used to determine which areas are more suitable for a constructed environment and still have local food and agricultural products produced as well as working opportunities. Furthermore, it is possible to analyze the complexity of urban settlements, which must take into consideration numerous factors, such as environmental, biophysical, green and socio-economic factors [17]. The most appropriate placement can be found by using a multi-criteria approach, i.e. placing different values on more or less desirable features of a future site. In pollution, dispersion modeling techniques were widely used to evaluate all the major contributing factors to pollution. This model can be adapted easily to new areas and pollutants, but there are some restrictions on dispersion modeling techniques [18]. There is a great demand for input data like; traffic networks, volume, and composition, speed of traffic, emission factors of all vehicle types. Moreover, other data like; road characteristics and meteorological conditions are required. However, by understanding these factors it is possible to implement a spatial model for road pollutants using GIS. Keywords such as GIS, DSS and water, air, climate change, and sustainable development, had many applications in the last 30 years, for e.g. [19-21]. Today, decision-makers can use the visualization of important decisions in urban landscape planning and expansion, as well as more complex analysis, such as climate adaptation strategies, sea-level increase planning and air-pollution surveillance [22]. However, measuring ground-level emissions through fixed monitor stations is a very rough method and is just an indicator of exposure to the population. On the other hand, it is costly to measure personal exposure that gives more detailed measurements and results. Traffic emissions and fossil fuel burning while transporting people and goods also have an impact on microclimate changes [23]. The use of fossil fuels creates small particles in the air, aerosols that affect precipitation and temperature; water molecules need a surface that can be attached and condensed to create raindrops and therefore clouds [24]. Through GIS, these issues can be analyzed and plans to be made to help resolve the impact of increased population and changing of the climate.

3. Sustainable development

There are many sustainable development rating tools and software that were built and executed globally [25]. However, most of these were employed on small scales, like campuses, city zones,
neighborhood or even buildings [26]. These tools can be classified to groups according to their functionality. The first group is planned neighborhood, which is consisted of tools like DGNB for Urban Districts in Germany, LEED for Neighborhood Development in the United States, South Africa, and Canada, BREAAM communities in Austria, The Netherlands, Norway, Spain, and Sweden, Green Mark for Districts in Singapore, GSAS for Districts in Qatar, and Pearl Community for Estidama in the United Arab Emirates. The second classifier is landscapes & parks, and it consists of Cooperative Sanctuary and SITES in the US, GSAS for Parks in Qatar, and Green Mark for Parks in Singapore. The third classifier is transportation & infrastructure, and it is consisted of CEEQUAL in the United Kingdom, Green Mark for Infrastructure in Singapore and IS Rating Tool in Australia. Besides that, there are some rating tools that are for special purposes, like CASBEE for Heat Islands in Japan, and H+T Affordability Index, Local Energy Scoring Tool and STARS - AASHED in the US. On the other hand, there are some rating tools that were included in the whole urban area of cities [2, 27]. Projects like MEP Eco-City, MOHURD Eco-Garden City and NDRC Low-Carbon City in China and CASBEE for Cities in Japan. One of the significant work is the one that was developed by Graymore et al. (2009) in Australia. In this project, a regional sustainability index was developed where a GIS-based multi-criteria DSS combines the three pillars of sustainability in order to prioritize areas that need help in achieving sustainable development. The focus area is the Victoria, Australia region of the Glenelg Hopkins Catchment Management Authority. The regional scale combines national top-down policies with local bottom-up local policies and links multiple spatial and temporal biodiversity scales with human uses and socio-economic imperatives [27]. This makes the regional scale suitable for both sustainability studies and natural resource management, as this is the scale where ecological functions can merge with social institutions and thus re-develop institutional resource management systems. The developed framework needs to be able to provide up-to-date information on sustainability at regional and finer scales in order to be an effective framework for achieving sustainable development, as large differences in sustainability can emerge at different scales. This needs to be based on local definitions of sustainability to ensure that it is measuring factors that are important to the region's sustainability, as well as information about the system's viability and performance [27]. Such a tool for sustainability assessment would provide guidance on which areas most needing sustainability initiatives. A system that can do this must be objective and fully integrate the indicators; with the ability to consider multiple criteria at once. Including a combination of qualitative and quantitative criteria, that can be achieved through multi-criteria analysis (MCA). Based on the current understanding of sustainability, it is, therefore, important to develop an accurate, objective method for the weight of criteria. This could be done by investigating and quantifying the interactions between indicators and their impact on sustainability through correlations and pair comparisons to help produce an integrated assessment of sustainability [27]. Implementing DSS in GIS would reduce potential errors and information loss experienced earlier when calculations were performed in spreadsheets and then transferred to GIS for visualization compared to today's GIS calculations.

Table 1. Indicators of sustainability Based on Graymore et al. (2010).

| Environmental | Social       | Economic               |
|---------------|--------------|------------------------|
| Land use (dry land pasture, pine plantations) | Age structure | Household income       |
| Remnant vegetation | Population growth rate | Employment diversity   |
| Dry land salinity | People completed year 12 | Unemployment rate     |
| Wind erosion   |              |                        |
| Water erosion  |              |                        |
| Soil structure decline |          |                        |
The project began in Australia, called Catchment to Regional Scale Sustainability Indicators, identifies indicators based on the three pillars of sustainability (environmental, social and economic) and institutional sustainability (monitoring and evaluation) and it develops a framework based on this [27]. The framework identified 44 indicators relevant to the region that could be followed over time and where the relationship between the indicators was considered. However, due to lack of consistency and quality of data and relevance in the sustainability assessment, only 13 were employed, as in Table 1. These 13 indicators are forming a Regional Sustainability Index and they indicate sustainability individually and collectively. And, in order to make a regional sustainability GIS-based decision support tool, this tool can effectively be integrated with GIS. The tool’s evaluation showed it was a robust and sensitive tool valid for sustainability assessment in Australia. It is a holistic method of assessing sustainability by using the MCA to take into account the interactions between the indicators and the differences in the impact on sustainability by aggregating indicators.

4. Conclusion

It is possible to use geographic information systems, remote sensing and decision support systems as tools to support sustainable urban development and management. They do not only work as tools for achieving sustainable urban development, yet also as a support for decision making in the planning process. Moreover, it is required for evaluating various alternatives and scenarios and setting realistic goals for plans. GIS and RS can be used for many planning aspects such as water accessibility, climate impacts, infrastructure planning, air pollution modeling, etc. for the environmental aspect of sustainable urban development. There are also many analyses to be made for economic and social sustainability in urban environments; population distribution, proximity to recreation centers, school locations, the flow of people and goods, demographics, etc. Even though there is still no known method for combining all three pillars of sustainability and measuring it to compare the level of sustainability between cities, it is highly possible to be achieved eventually. For now, it has to be implemented within singular cities due to the diversity and differences of factors between cities. As it was mentioned in Australia case, from 44 indicators that were considered only 13 were implemented due to lack of consistency and quality of data. Simply because the data (for the 31 neglected factors) that were acquired were not viable enough to be involved. However, it is possible to produce high accuracy tools if data acquisition and data accuracy and precision were within the required level. As a prediction, within the next decade, it is highly conceivable that such tools and methods to be available. And, in order to achieve maximum possible sustainability, several steps must be followed. Future research is needed in this aspect, and perhaps most importantly, to spread GIS knowledge to people working in the field of sustainable development. The more people who use it and realize the potential of GIS, the greater the creativity between users and the development and testing of new techniques and methods. While the full potential of GIS and RS has yet to be discovered, there is a bright future for the use of GIS internationally in urban sustainability. It is hoped that more people will be inspired by the potential of what maps and geographic information can mediate decision-makers, citizens and participants, highlighting specific problems and their solutions, and thus bringing development to a sustainable urban environment. As for the first time in the history of geomatics studies theoretical and technical capabilities are available to be executed.

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