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Geospatial technologies for physical planning: Bridging the gap between earth science and planning

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Abstract

The application of geospatial information technologies has increased recently due to increase in data sources from the earth sciences. The systematic data collection, storage and processing together with data transformation require geospatial information technologies. Rapidly developing computer technology has become an effective tool in design and physical planning in international platforms. Especially, the availability of geospatial information technologies (remote sensing, GIS, spatial models and GPS) for diverse disciplines and the capability of these technologies in data conversion from two dimensions to the three dimensions provide great efficiency. Thus, this study explores how digital technologies are reshaping physical planning and design. While the potential of digital technologies is well documented within physical planning and visualization, its application within practice is far less understood. This paper highlights the role of the geospatial information technologies in encouraging a new planning and design logic that moves from the privileging of the visual to a focus on processes of formation, bridging the interface of the earth science and physical planning.

Keywords: remote sensing, GIS, spatial model, GPS.

1. Introduction

The universal understanding of physical planning and design is based on knowledge-based approaches. The principles of this concept are still same since Design with Nature by Ian L. McHarg (1969), however today the volume of accessible information and instruments have largely increased as a result of advancing technology and the increase in multi-disciplinary studies. Thus, the concept of "big data" has emerged. As Eric Schmidt, the former CEO of Google, stated that data produced by humanity until 2003 is recorded every two days today. Processing and converting data into information became a major concern.

After the first geographic data processing software (SYMAP) with vector-based punch card-operated two-dimensional analysis capability at Harvard in 1965, ESRI (Environmental Systems Research Institute) released the first commercial Geographic Information Systems (GIS) software in 1982, and GIS completed its dissemination process until 1990. With the acceleration in computer

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technology after 1990 and the rise of climate change studies after 2000, the increase in multidisciplinary collaborative studies in geosciences have improved the amount of data and processing techniques.

From physical planning point of view, there has been a chance to use approaches that go from data-constrained studies to data-intensive studies, from static snapshot detection to dynamic continuous monitoring processes, from coarse-scale generalizations to high-resolution details, from simple and general models to more detailed integrated complex models.

Planning, which is defined as the process of systematically designing future actions, has a multidisciplinary structure by nature and the spatial decision problems of interest are in the form of ill-structured problems (ISP) (Davidoff and Reiner 1962). It started as a sub-field under the discipline of architecture, limited to field research and physical planning, primarily in the form of determining the locations and sizes of different land uses in urban areas. Over time, working disciplines that are closer to art have been influenced by the quantitative evolution in social sciences that started in fields such as geography and sociology, and have gained a technical discipline identity (White, 1974; Ceuclelis, 1982, Taylor, 1998; Brail and Klostermann, 2001; Çubukçu, 2008).

Spatial planning activities are tried to find a solution to “How can we create livable environments” question in bases. In this context, time and space-related data sets are constantly encountered. It can be mentioned about the processes that change depending on the structure and dimensions of the space, which is defined as Planning Support Systems (PSS) (Batty, 1995) and a part of the Spatial Decision Support Systems (SDSS).

As a result, the most important research question is, can we produce the right information with up-to-date spatial information technologies? Can we transfer the generated information to the planning and design process?

This study aims to evaluate the potential of remote sensing, GIS and spatial models for physical planning within the scope of spatial information technologies.

2. Spatial Planning and Geospatial Technologies

Geospatial sciences such as remote sensing (RS) and Geographical Information Systems (GIS) are provided essential tools in data preparation (digitalizing, extraction, definition, integration, registration etc.), and data analyzing (decision making, change detection, impact assessment, scenario development etc.) stages in the SDSS process associated with spatial planning.

Nowadays SDSS is used in many fields that is interested in geosciences because of multiple data assessment ability, multi criteria assessment techniques (MCA), and machine learning approaches are one of the most important parts of the geospatial science. Şatır (2013) was evaluated the studies related with MCA and GIS in planning, and decision assessment process. Land suitability (28.5%), plan and scenario assessment (15.4%), area selection (14.5%), resource analyses (11%), transportation (7.8%) and impact assessment (3.4%) were defined as the most studied areas of MCA and GIS.

RS provides easy, fast, accurate, low-cost and up-to-date opportunities in the process of obtaining the base data for planning. The benefits of RS tools in spatial planning are presented in Table 1.

Table 1 Benefits of RS tools in spatial planning (adopted from Şatır *et al*., 2022).

Information type	Material type	Method	Benefit
Land Use Cover Change and quantity.	Aerial photos and satellite dataset	Classification techniques, index-based approaches, change detection analyses	Mapping past and current Land use and covers.
Road networks, river streams and watershed boundaries	Ortho photos, radars and satellite images	Digitalization and automatic extraction techniques,	Accessibility analyses, stream network extraction, topographic situation.

		classification and 3D production methods	
Building stock and urban morphology	Aerial photos and satellite images	Extraction and digitalization techniques, classification techniques	Built up area detection, urban resilience definition, risk assessment.
Topography	Orthophoto production techniques (UAV etc.), radar datasets, sterio satellite images.	Point cloud production, ready to use data providing	Obtaining the Slope, aspect, elevation, land form, sun effect data.
Climate data	Thermal imaging, meteorological or atmospherically research satellites.	Thermal data processing techniques, radiative transfer models, ready to use data providing.	Surface temperature data, precipitation data, evapotranspiration data, humidity data.
Soil data	Hyperspectral satellites and aerial photos, broad band satellite and radar dataset (C and X bands).	Target based detection techniques, target-based indices, radar interpolation and processing techniques.	Soil humidity, soil salinity, soil organic carbon detection, some of the nutrient's detection in the soil, rough soil texture, structure and soil stoniness.
Vegetation data	Infrared satellite and aerial dataset.	Vegetation indices, classification techniques, object-oriented techniques.	Detection of green structure, vegetation type and plant species, change and Ecosystem service gain or loss.
Social data	Anthropogenic impacts on ecosystem such as (road, built up, industrial sites etc.)	Anthropogenic impact indices, environmental impact indices, landscape metrics.	Pressure on natural ecosystems and temporal changes.

The spatial planning tools have the capacity to integrate remotely sensed images, spatial plans, graphical information's or planning decisions inside the spatial modelling tools and can be incorporated into GIS environment effectively. The basic components of the spatial modelling were given in the Figure 1.

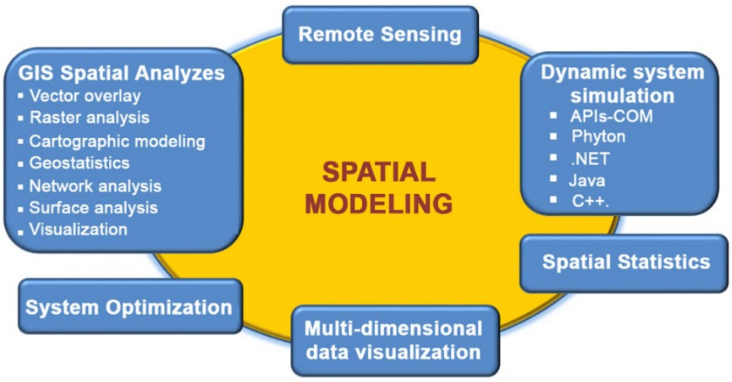

Figure 1 Spatial modelling context

The determination of suitability maps that meet certain criteria in geographic data to analyze information about location and condition is seen in the regional studies of Ian MacHarg, especially in the early period (1969-1980). As a result of the formation of regular data sets, the diversification of different data sources such as remotely sensed data (e.g., Landsat, SPOT) and their accessibility, the direction and trend of monitoring and change have begun to be examined since the 1980s. As a result of the intensive use of spatial statistics together with geographical data in the 1990s, it was ensured that the cause-effect relationship was understood together with the problem determination of the spatial distribution and pattern. Since the late 1990s, modeling studies have taken their place in geographic information technologies intensively. Increasing the software development skills of geoscientists and the transformation of climate change studies into an important research area have led to modeling studies. However, modeling studies, which allow simulating the results of plan decisions, have not yet entered the agenda of physical planners sufficiently.

Modelling is a simplified presentation of an occurrence for the purpose of planning, estimating, explaining, or describing. Terrestrial model types are grouped into four groups according to their purposes: Descriptive; Explanatory; Predictive; Normative models.

3. Environmental Modelling as a Spatial Planning Tool

Spatial models include regional economic development models, land and housing market models, facility location models, spatial diffusion models, migration models, travel and goods transport models, and urban land use models regarding all areas of human influence.

The use of these models makes important contributions to the production of quantitative data that will facilitate the plan decision making process. Today, at the point of data evaluation, only the basic functions of GIS are used to support planning decisions, while spatial models have capability of processing further (Figure 2).

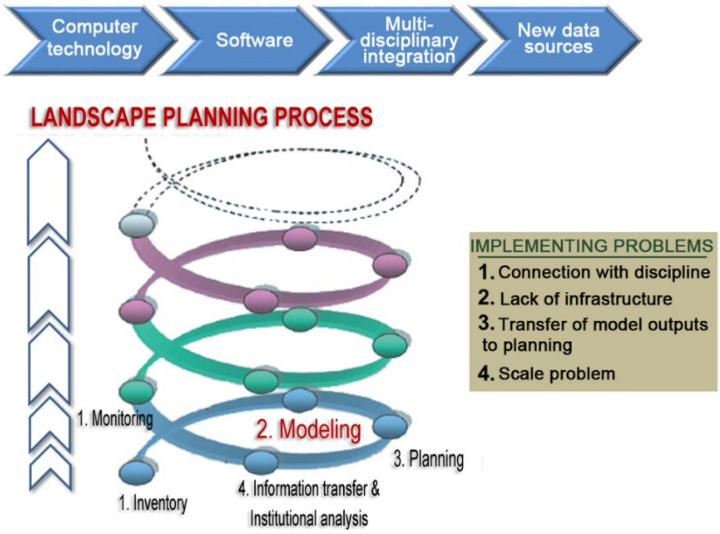

Figure 2 Spatial Modelling Development Process

Although the use of information technologies and modeling studies in recent years has brought great innovations in every field of physical planning, urban growth and 3D modelling techniques were presented.

Scenario-based urban modelling

Spatial modelling tools incorporated with scenario layer such as spatial plans are the key factor for the sensitive analysis and realistic planning for the future. The concept of scenario planning was developed for military purposes in the 1950s at RAND Corporation (Pillkahn, 2008; Heijden, 1996; Bradfielda et al., 2005). During the 1960s, scenario methodology was extensively used for social forecasting, public policy analysis and decision making. In the early 1970s scenarios were improved and use of scenario planning has significantly increased during the last decade. Scenarios reveals visions or possible alternatives and are used to evaluate the implications of decisions and policies (Chakraborty and McMillan 2015). Besides, increasing population, nonrenewable natural sources and environment, and the global climate change necessitates the integration of quantitative techniques into the planning process. Recently, remote sensing data with different spectral, spatial and temporal resolutions, and GIS have been successful in modelling the dynamic LULC change and scenario layers can be effectively evaluated into the modelling process. The advantages of modelling and scenario planning are reflected in the reduction of uncertainty by creating and identifying possible alternatives paths of the future developments.

Comprehensive studies are performed in order to understand complex relationships among the urban drivers with the spatial modelling. Urban system models are theoretically grounded, sophisticated, and data-intensive spatial models. They are based on theories and mathematical relationships to simulate a set of interactions between transportation, prices, land use, policies, demographic and economic systems across different scales (Klosterman 1997). Thus, in order to acquire ecologically sensible and environmentally sustainable urban plans, planning process should be based on quantitative modelling approaches.

Until today many quantitative techniques consider planning decisions or scenario layers have been developed (Dietzel and Clarke, 2007; Jantz et al., 2010; Berberoglu et al., 2016; Thapa and Murayama, 2012; Lord et al., 2015).

Today, many urban growth modelling approaches have been developed including, LUCAS, Markov chain, SLEUTH, Smart Growth Index, UPLAN and UrbanSim. Cellular self-processing (Cellular Automata (CA)) attracts the attention of researchers in simulating and predicting urban development. Although CA models seem simple in scope, they have the potential to simulate complex areas such as cities and successfully predict the process of the spatial structure of the city over time. The advantages of CA models include: (i) being interactive (results can be interpreted and quantified visually), (ii) easily correlated in a GIS environment, (iii) available from spatially-based cellular data, eg remotely sensed images (iv) easily correlated with environmental models (Akın, 2011).

To model urban process dynamics, Clarke and Gaydos (1998) developed a revised cellular automation method: SLEUTH (Slope, Land use, Exclusion, Urban, Transportation and Hillshade). Five basic input maps are needed in SLEUTH: urbanization, transportation, 'inference' areas where urbanization should not exist, slope and slope views. Urbanization is the most important layer in the model and spatial scatter images of the city from at least four different years are needed for statistical calibration (Silva and Clarke, 2005) (Figure 3).

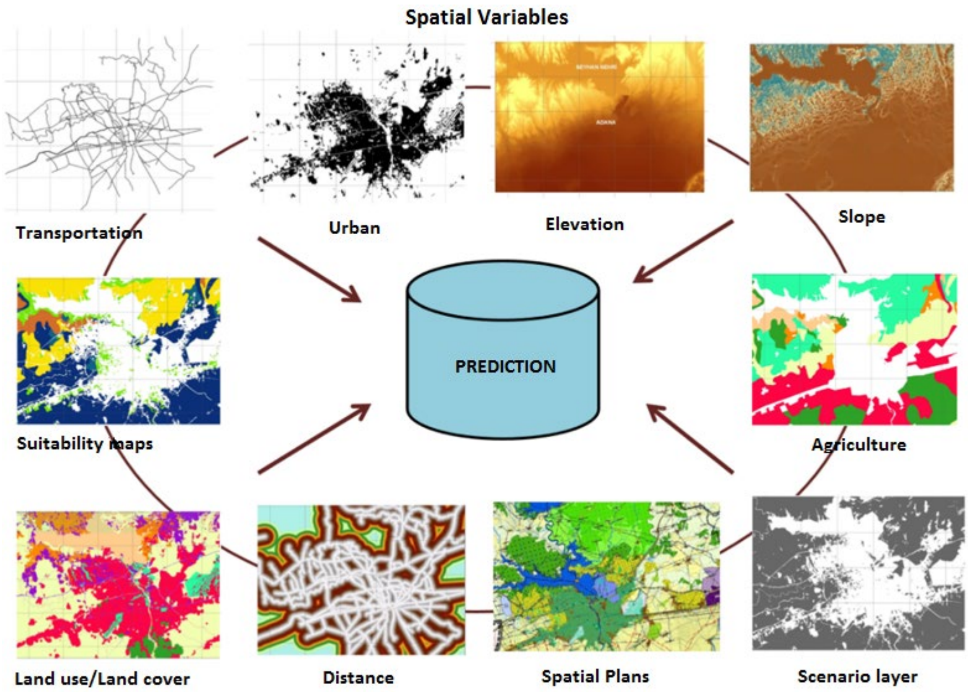

Figure 3 Urban growth modelling inputs for Adana.

Akın et al., (2014) investigated the effects of scenario layers on the future urban development including unmanaged growth with no restriction on growth (S-1); the growth by considering environmental protection and assumes managed growth with strict protection (S2), and managed growth with moderate protection (S3) derived from the 2023 spatial plans. Between 1967 and 2007, urban change was determined for Adana province in ten-year periods and urban growth probability images were created for 2023 using SLEUTH (Figure 4).

Eventually, the simulation of the current urban spatial pattern should help planners and decision makers to evaluate the past implementation of urban planning, and scenarios simulation can provide effective support for future urban planning by evaluating the consequences.

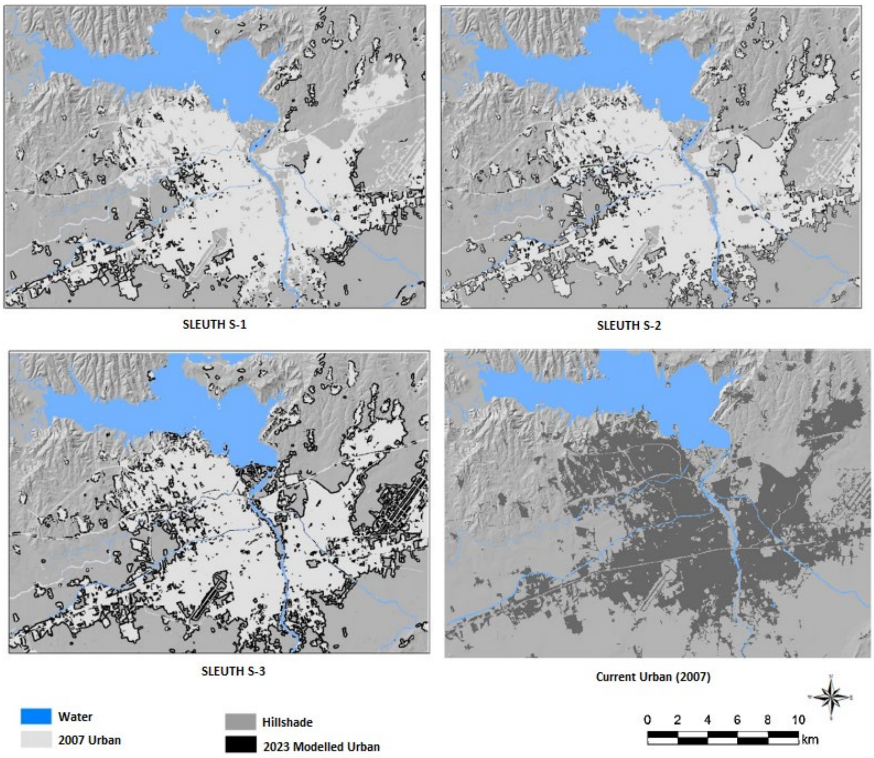

Figure 4 Comparison of potential urban growth for 2023 modelled with different scenario layers (Berberoglu 2011; Akın et al., 2014).

3.1. Three-dimensional data generation

Stereo Images

Digital tools are gradually developed from the two-dimensional level to the three-dimensional level and even the fourth dimension to support the decision-making process and to share ideas quickly and effectively so that they are easily accessible to users. Today, data produced by remote sensing and photogrammetry techniques are used in many areas. Unmanned Aerial Vehicle (UAV) photogrammetry may partially replace data collection from traditional platforms, but it also opens up new possibilities for many fields, both in research and in practice (Remondino et al. 2012, Colomina and Molina 2014, González-Jorge et al. 2017). UAVs provide users with great flexibility in terms of available sensor equipment, time and flight planning. UAV Systems can include video, thermal, multispectral, hyperspectral cameras or lidar sensors according to different carrying capacities. In addition, the GNSS/INS (Global Navigation Satellite System/Inertial Navigation System) system in UAVs provides high precision positioning of the data received from the sensors.

The use of affordable UAVs as versatile flying platforms for various sensors and photogrammetric software enables physical planners to create geo-referenced 3D models at a much lower cost and faster than traditional topographical survey methods. Data collected by UAVs is not limited to topography, but can also be used to assess flood risk, vegetation, or to base landscape design studies.

Conversion from overlapping images to point clouds, surface models or orthophoto images can be done at low cost and high speed (Figure 5).

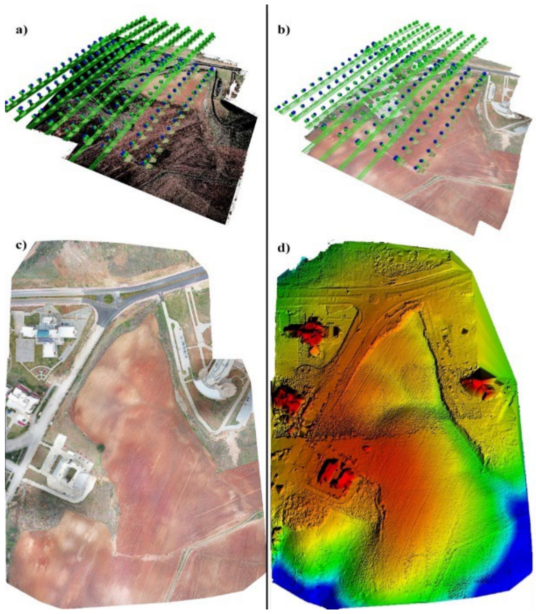

Figure 5 Generation of point cloud (a), surface modeling (b), orthophoto (c) and digital elevation model (d) images for merging photogrammetric images (Cukurova University Campus).

Images taken from UAVs with a 70% overlap are combined as a result of photogrammetric processes, and orthophotos are produced and used as a base in planning studies. As an example, the HEPP plant was used quite effectively in the rehabilitation project as a result of the deterioration in the topography during the construction. Topographic data is produced for the areas where restoration is required. The images were acquired over the areas using UAV and orthophoto maps were derived using photogrammetric processes with a sensitivity of 5 cm. (Figure 6).

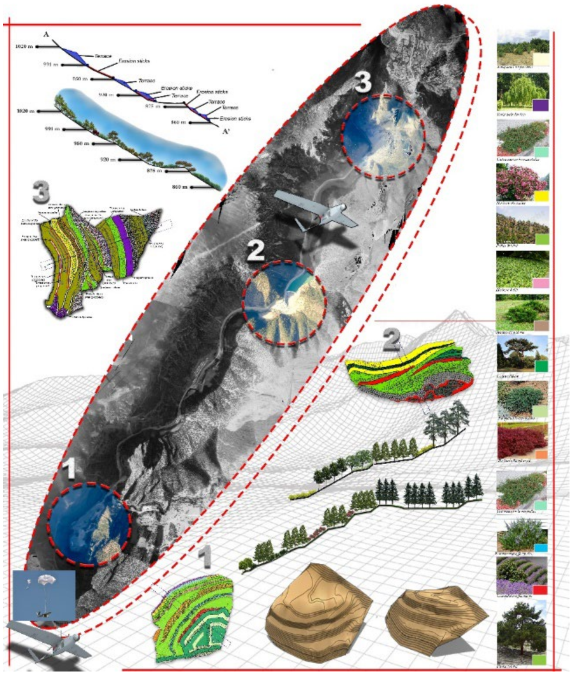

Figure 6 3D models created using UAV images and their use in landscape restoration projects (Adana, Saimbeyli - Yamanli HEP site)

Generating 3D with Lidar Images

Lidar (Light Detection and Ranging) technology plays an important role in digital imaging of objects, 3D scanning and modeling, and remote sensing and terrestrial photogrammetric methods in creating landscape topography. Lidar locates the distance of an object or a surface using laser pulses by determining how long it takes for the signal it sends to return. These positionings are created by sending millions of laser pulses per second, transforming them into a cloud of laser dots with millions of coordinates representing the scanned object with GPS / GNSS receivers. From the point cloud obtained from the LIDAR data; Basic measurement data, 2 or 3D drawings, 3D animation, solid surface models or 3D models with realistic surface textures can be obtained.

In recent years, laser scanning systems have been widely used in urban planning and design studies to produce 3D models with high accuracy (about 5 cm precision) (Figure 7).

Figure 7 Lidar sensors on unmanned aerial vehicles

Generating 3D with Radar Data

Remote sensing systems/sensors are basically divided into two as active and passive sensors. Active sensors use their own energy source to observe objects, while passive sensors need an energy source such as the sun. Active sensors detect the object by providing radiation in a certain waveband range without the need for a different energy source. Most active sensors operate in the microwave portion of the electromagnetic spectrum. Detection takes place when the energy sent by the active sensor reaches the object and some of the energy is reflected back to the sensor. While the energy reaches the object and returns to the sensor, the sensor creates a two-dimensional image of the surface by recording the range and magnitude of the energy reflected to the targets.

Synthetic Interferometric SAR (InSAR) data can be used to directly estimate Digital Elevation Model (DEM) generation using SAR data can be performed by various techniques. The main ones are radargrammetry and Interferometric SAR (InSAR). InSAR uses the intersection differences of at least two complex value SAR images acquired at different orbital positions and/or different times. The InSAR method is known to represent a unique method for detecting and mapping surface displacements with precision in the centimeter and even millimeter range. InSAR method is widely used in studies such as surface changes in urban areas.

4. Discussion

Spatial information technologies including remote sensing, spatial modelling, and GIS have been successful in dynamic environmental change such as urban growth. A realistic spatial planning should include realistic driving factors of environmental patterns and quantitative modelling techniques. These driving forces should include socio-economic, ecologic and multi-temporal data sets to achieve sustainable environmental management related with the effective spatial planning. Thus, given the recent developments in geospatial technologies and the increase in modelling methods and tools, have the many forms in which that spatial data is required. Besides, environmental models are among the objective geospatial methods for determining the priorities for planning process and designed to assess the ecological impact of variate spatial data associated with demographic, economic, policy, and environmental scenarios.

These well-established modelling tools have enabled a better understanding of the complex interactions of environmental processes. For example, GIS-based models of property and demographics traditionally associated with urban planning policy are being coupled with models of energy consumption traditionally associated with urban management (Saunders et al., 2020). Similarly, models associated with transportation and planning are being coupled with 3D models associated with urban design and development (Dawwas, 2018; Easa et al., 2002).

Spatial modelling with geospatial technologies can develop as a more effective discipline that promotes greater understanding and better decision making in the planning, design and management of cities and urban regions. Cities and urban regions can then be better prepared to mitigate environmental impacts through more sustainable practices (OECD, 2011).

Considering the education programs, academic studies are limited to classical data sets and techniques, so spatial information technologies (remote sensing, GIS, spatial models and GPS) within the field of physical planning, have significant advantages for planners. In this context, the main problem is transferring the information into planning and design through spatial information technologies. Our education programs, especially postgraduate studies, should support these areas, by bringing the model results into a format that can be transferrable to planning process, and there is a need to form the results into appropriate scales using downscaling techniques. Thus, it is important to train well-equipped physical planners who can understand and use spatial information technologies. The main goal is sustainable planning and design in harmony with nature, and the way to achieve this goal by using the right information in planning and design.

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Resume

Suha Berberoglu. He is head of Remote Sensing and GIS department in Institute of Basic and Applied Sciences. He has 23 years of broad-based field and laboratory environmental experience required in the application of environmental monitoring and management. Dr Berberoğlu is also involved in various national and international projects such as climate change, biodiversity mapping, soil salinity and SOC, change detection, hydrological modelling and biomass estimates. He has been modelling erosion, NPP, basin hydrology and land use/cover change. His major concern is transferring these modelling outcomes into the ecosystem-based planning. Dr. Berberoğlu is also the founder of the CU Landscape Architecture Remote Sensing and GIS Lab which is dedicated to providing innovative, state-of-the-art monitoring of environment using geospatial technologies (GIS, GPS and Remote Sensing).

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Ahmet CILEK is an Associate Professor at the University of Cukurova, Department of Landscape Architecture and Remote Sensing and GIS Division. He has involved in many national and international research projects including erosion modelling, forest productivity, risk analysis, spatial analysis and the carbon cycles research in the frame of integrated water and land resources management at the Eastern Mediterranean part of Turkey in last 10 years. His research expertise covers evaluating the land use cover dynamics and its interactions with biodiversity, ecosystems and climate in order to define land use suitability using remote sensing, GIS and spatial analysis and modelling. His main research involves GIS and remote sensing applications intensively together with spatial statistics for environmental management.

Merve Şahingöz is a PhD student in landscape architecture at Çukurova University, Adana, Turkey. Her PhD title is "Modelling Bioclimatic Comfort in Turkey under Climate Change Scenarios". Miss Şahingöz has involved in various research projects on modelling climate change, hydrology and developing Decision Support System at the Remote Sensing and GIS Laboratory in Çukurova University.