Models and interactive tools in support of environmental decisions

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Summary

Taking appropriate decisions for the mitigation of environmental problems and their impacts on our life is a challenging task due to their multi criteria nature, the involvement of stakeholders from different domains, and the uncertainty and complexity of environmental problems. Reliable and updated information on the current situation is the initial step, upon which proper alteration scenarios can be configured. Due to the close relationship between environmental phenomena and their locations, geospatial information plays a crucial role in the analysis of environmental problems, as well as in the configuration of mitigation solutions.

Geospatial information can be acquired from geospatial data through different techniques. This process requires the definition of a proper framework for the efficient access, maintenance, processing and presenting of geospatial datasets. During the last decades, different environmental studies have focused on the definition and/or implementation of geospatial frameworks. In line with these studies, a framework for supporting environmental decision making has been investigated in this study. Geodesign was chosen as the framework for multi-disciplinary decision making processes, due to its design-feedback loop which should be iteratively revisited by the involved stakeholders from different domains.

Geodesign contains different inter-related components whose agile performance have significant impact on the enhanced performance of the entire decision support system. These components comprise, among others, visualization, data integration, process models, design platform and impact models. The optimized performance of these components is reliant upon several factors, among which are the data availability, accessibility and interoperability, the system's performance capacity, and the accessibility and integration of process/impact models. Considering the current limitations on the performance of these elements, this study aims to enhance the [geodesign-based] decision support system components through efficient data, model and technology integration. The research conducted as part of this thesis presents the enhancement of these components for supporting environmental decision making.

Local impact of tree volume on nocturnal urban heat island: A case study in Amsterdam

Urbanization growth and the resulting development of the built environment in urban areas has led to an increase of the Urban Heat Island (UHI). One of the factors affecting UHI is vegetation cover. While different studies have investigated the impact of vegetation surface (2D) on the urban heat island, studies on the impact of tree volume on UHI on a city scale are scarce. This is due to information scarcity on the tree volume of a whole city. Chapter 2 of this thesis focuses on a quantification of tree volume impact on the nocturnal urban heat island of Amsterdam, using 3D tree models of the whole city. Sky View Factor (SVF) and urbanization degree as the local and regional urban compactness parameters, respectively, have been used in a multi-linear regression analysis, together with urban tree volume, to estimate tree volume contribution to UHI. Scale effect was investigated by examining aggregated tree volume on different radii to explore the highest impact of tree volume on UHI. The results of this study indicated that, in this case study, the highest impact of tree volume on UHI is within 40 m, where in this buffer

a 60,000 m^3 tree canopy volume increase leads to one degree UHI reduction. Furthermore, this study demonstrated how geospatial technology can be applied for automated information extraction, in high detail and for large extents, for efficient analysis of the relation between UHI and urban elements.

Developing a wind turbine planning platform: Integration of "sound propagation model–GIS-game engine" triplet

Environmental problems resulting from fossil fuel use have prompted us to consider energy production using renewable energy resources. Wind energy is a common renewable energy source which is widely used in many countries, including the Netherlands. However, despite the benefits of wind energy, wind turbine development projects face opposition from citizens due to wind turbine externalities, such as noise. A properly designed information system through which citizens, in collaboration with other stakeholders, can express their ideas and receive information on the current and designed situation can help to involve citizens, which can increase understanding in the siting of wind turbine allocation projects and make the wind turbine planning process more efficient. In Chapter 3, an interactive information system for wind turbine siting, considering its visual and sound externalities, has been developed. This system is an integration of sound propagation models, GIS and game engine embedded in a unified platform. This integration supported the optimized performance of the system and the real-time wind turbine sound calculation in any location of the whole country. Game engine-GIS integration provides a 3D virtual environment of the whole country, with existing geospatial elements, through which users can navigate, (re)place wind turbines and explore their visual impacts on the environment. The integration of sound propagation models in the game engine-GIS integrated environment, enabled the real-time calculation of wind turbine sound on its surrounding buildings in any location of the country. The game engine component supports the optimized performance for scene rendering as well as sound model calculations. The GIS component enables serving massive (on-the-fly) georeferenced data through tiling techniques as well as data accessibility and interoperability via cloud-based architecture and open geospatial standard protocols, to be applied both for visualization as well as inputs of the sound propagation models.

Interactive 3D geodesign tool for multidisciplinary wind turbine planning

Wind turbine site planning is a multidisciplinary task where stakeholders from different domains and with different interests and priorities are involved. An information system capable of integrating knowledge on the different aspects of a wind turbine can be of great importance in providing a common picture to all of the stakeholders involved. In Chapter 4 of this thesis, a multidisciplinary interactive 3D information system for planning wind turbine locations in the whole of the Netherlands was developed. The architecture developed for wind turbine planning through the game engine-GIS-sound model integration of the previous chapter, was applied as the basis architecture of this system and is further developed in this chapter to include other aspects in wind turbine planning. The integration of GIS, game engine and the analytical models has led to the development of an interactive platform with real-time feedback on the multiple wind turbine aspects for different environmental settings. This system supports iterative design loops and has been designed based on a geodesign framework. Each of the geodesign models is implemented in this system, which together form an interactive multidisciplinary wind turbine site planning platform for seamless wind turbine configuration and real-time feedback in any location of the country. This provides scope for an interwoven discussion process. The criteria applied in this system are: wind turbine sound, shadow, visibility from buildings, energy yield, wake effects and regulations. Different analytical and geometrical models have been embedded in this game engine-GIS integrated system to calculate these process/impact models in real-time upon (re)placing wind turbines in the scene. The multi-aspectual feature of this system broadens its applications and can lead to the involvement of stakeholders from different backgrounds.

Analysing the impact of spatial context on the heat consumption of individual households

The heating of residential buildings in temperate and colder climates accounts for a significant share of the total energy consumption of a country. This, in combination with the usage of fossil fuel for home heating, leads to an increase in global warming and environmental problems. Therefore, reducing home heating consumption leads to a considerable reduction in total energy consumption. The initial step here is to explore the factors influencing household heat demand. Most of these factors depend on individual choices (e.g. occupants' behaviour, interior building design, heating system efficiency) and are difficult to influence through urban planning. However, parameters affecting household heat demand regarding the spatial context can be influenced by urban planners. Yet the impact of spatial context on household heat demand on a city scale has not been adequately studied. This is mainly due to the scarcity of geospatial data and the massive computer processing required for capturing the spatial configuration elements of each individual household for the whole city. Chapter 5 focuses on exploring the combined impact of building shape and its surroundings on the household heat consumption of Amsterdam, both at individual household level as well as postal code level, through regression analysis. The spatial context of individual housing units was described through spatial data processing routines and algorithms and using detailed 2D and 3D geospatial data. GIS techniques were employed for the efficient processing of massive 3D geospatial data for all buildings in the city. The local housing unit level results demonstrate that compact neighbourhoods with less open space and buildings with higher numbers of housing units and less exposed perimeters have lower heating demand. Trees were found to lead to heat demand reduction when they are located on the northwest side of buildings. The results at postal code level highlighted the importance of demographic composition. (Larger) households with children have the highest heat consumption. At both individual and postal code scales, size and age of housing units have important impacts on heat consumption. Older houses consume more energy, but a *rebound effect* was found for the newest housing units.

From BIM to geo-analysis: view coverage and shadow analysis by BIM/GIS integration

Environmental analysis in urban areas, regarding current processes as well as alteration scenarios, has a significant impact on the different decision making processes. For this purpose, the integration of data from different domains and disciplines plays an important role. This integration provides the scope for more comprehensive and detailed analyses regarding the on-going processes. The difference between the disciplines, detail level and information model cause challenges for this integration. The integration of the Building Information Model (BIM) and geospatial data is such an instance. BIM comprises detailed geometrical and semantic information of a construction. GIS, on the other hand, consists of the physical and functional representation of the environment. These two information sources are often not integrated, which is mainly due to the difference in their level of detail, caused by different scales. The integration of BIM and GIS provides the scope for understanding the mutual impacts of a construction and its environment and supports performing different automated detailed analyses on a large extent. Chapter 6 introduces a pipeline for the automated integration of IFC BIM in a 3D GIS environment. The BIM-GIS integration was applied in two studies: view coverage and shadow analysis. In these studies, the detailed information of windows and roofs were extracted from BIM model and were subsequently used together with 3D geospatial elements (building and tree models) and process models for the estimation of view coverage quality as well as shadow coverage on rooftop segments. These analyses revealed the added-value of integrating BIM and spatial data for, for instance, spatial planning. In addition, it demonstrated the possibility of automating the whole process, from BIM-GIS integration to different analyses, supporting fast and accurate analyses on a large scale.

Conclusions

This study investigated solutions for performance enhancement of different components of Spatial Decision Support Systems (SDSS) for environmental problems. This included different aspects of a SDSS, such as [geospatial] data integration from different domains, interactivity, model development and model integration. The fundamental method for this performance enhancement was efficient Data-Model-Technology integration, which was applied based on a geodesign framework. The chapters of this thesis addressed one or more of the geodesign models, which together form the modules of environmental SDSSs.

Improvements in the scope of *representation models* were performed through efficient integration of massive 2D and 3D open geospatial data from different domains, which were accessible and interoperable through the implementation of web services and open standard protocols. In addition, this study contributed to the development of a boosted interactive 3D visualization platform, through game engine-GIS integration, where massive geospatial data on a large extent and from different domains can be served on-the-fly to the game engine with optimized scene rendering properties.

Enhancements in the context of *process models* were carried out through the development and implementation of these models on a large extent and, at the same time, with a high level of detail. This was fulfilled through the efficient employment of geospatial open data and technology as well as algorithms and routines for the automated extraction of detailed information on spatial elements on a large extent.

For *change models*, this study contributed in the development of a 3D interactive multidisciplinary design platform wherein different stakeholders from different domains can work collaboratively on configuring alteration scenarios. The responsiveness of this platform is boosted through the employment of game engine functionalities and the information content and extent is enhanced through embedding GIS techniques. These enhancements enabled seamless scenario configuration and analysis in any location of the country.

Improvements in the scope of *impact models* were performed through enhancement of their performance speed, efficient accessibility to input data and independence from third party software. These improvements were achieved through the efficient incorporation of impact models in the game engine-GIS integrated design platform wherein different game engine and GIS functionalities for the boosted performance of these models were applied. This has resulted in a fortified system where stakeholders can seamlessly configure different alteration scenarios in any location of the country and receive real-time feedbacks on different aspects of their design with no dependencies on third-party software.

In conclusion, it can be mentioned that efficient integration of Data-Model-Technology can significantly support the enhancement of environmental decision support systems. In this study, energy and liveability have been chosen as the case studies. However, the developed routines are scalable to other domains. This is, on the one hand, due to the cloud-based architecture of the developed modules and the technology applied for the accessibility to and interoperability of different datasets from different disciplines, and on the other hand, due to the development and application of loosely-coupled geospatial and/or game engine functionalities for the boosted performance of the different components of SDSS.