Tailoring a geodesign model for analyzing an urban skyline

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1. Introduction

The Oxford English Dictionary gives two definitions for skyline: first, as “the line where the earth and sky appear to meet, the horizon; the representation of this in painting or another art;” second, as “the outline or the silhouette of a building or a number of buildings or other objects seen against the sky.” The term ‘city skyline’ refers to a profile of buildings that forms the cityscape in daytime and the silhouette at night (Lim & Heath, 1993). The urban skyline is a panoramic snapshot of the city’s esthetic values, diversity, integrity, the history of its buildings and geographical elements. The urban skyline reflects the results of the accumulation of historical, social, cultural and economic structures of a city over time. A city has an infinite number of different skylines, depending on the viewpoint and the viewing direction. Some skylines might be conceived as representing a city’s spatial, social and cultural characteristics, all of them abstract the city (Gassner, 2009). High-rise buildings, particularly skyscrapers, have a significant impact on the city skyline. For this reason, the city skyline is an important node on which to focus for the development of proper control mechanisms, particularly concerning the vertical development of structures that can significantly impact the skyline. An impressive skyline is an important factor in the development of tourism and it also shapes the esthetic responses of its permanent residents. Cities today are more concerned about their “image” as a potential tourist destination and the urban skyline is an extremely important component of this image (Heath, Smith, & Lim, 2000).

Due to improving technology and global competition there are few restrictions on the height of skyscrapers in many metropolitan areas. Although high-rise buildings are the most striking component of many urban skylines, such as Chicago, New York City, Shanghai, the increase in the number of high-rise buildings has been changing the silhouette of many other cities all over the world. Istanbul is an example of a city whose historical identity and image have also been dramatically altered by skyscrapers dominating the seven hills on which it was built. The urbanization process in Istanbul while has becoming relatively homogenous has neglected considering topography. While there have been several debates on the impact of high-rise buildings on the skyline, the analytical approaches that have developed so far about this topic have been limited (Akdag, Cagdas, & Guney, 2010a). This study therefore, analyses how the Istanbul Bosphorus skyline has changed over the last decade due to emergence of high-rise blocks along the Zincirlikuyu-Maslak artery ever since it was defined as a Central Business District (CBD) and a high-rise development area in 1991 by the Bosphorus Conservation Law (URL 1).
2. Istanbul skyline: a shift in values from historical to global

Spanning two continents, Europe and Asia, and once serving as home to three great world empires – the Romans, Byzantines and Ottomans – Istanbul has developed a reputation for notable architecture styles, rich histories, and the natural topography of the Bosphorus Straits. Istanbul is primarily known for its Byzantine and Ottoman architecture, and the buildings here reflect the various peoples, religions and empires that have ruled it over the years. In each era a new architectural layer formed; many of these monuments remain intact. As shown in Fig. 1, the iconic skyline of Istanbul is defined by mosques, palaces, churches, fortresses, walls and towers.

On the other hand, Istanbul as a mega city continues to evolve each day. Urban conservation is based on the integration of the historical patterns with the actual requirements of the contemporary city with an aim of providing continuity of the authentic characteristics of a site. Since the Republican era Istanbul has been negatively affected by a rapid and unplanned urbanization. In 1983, the Bosphorus Law came into force as the first preservation law for the Bosphorus. This law separated the Bosporus area into three zones: ‘Waterside and Front View Zones’, ‘Back View Zone’ and ‘Effect Zone’ (Kap, 2008; Salman & Kuban, 2006). Although this law with a vague zoning plan is expected to prevent the illegal urbanization process, the physical corruption of the Bosphorus historic site has continued. Massive urban development and regeneration projects became fashionable after 2000 and transformed the geographies of a city which had accumulated over thousands of years (Akdag, Cagdas, & Guney, 2010b).

The new identity of Istanbul's skyline was increasingly shaped by a globalization process which manifested itself through new urban spaces and high-rise buildings, the latter which started to become the dominant component in the silhouette of this mega city (Fig. 2).

3. An analytical approach based on spatial informatics

A skyline offers a variety of factors for evaluating the esthetics of a city (Bostanci, 2008). Hence, different methods can be used to make an aesthetic evaluation of the city. Initially these are classified as subjective and objective methodologies. While subjective methodologies include surveys and experimental research on psychological and behavioral sciences, objective methodologies deal with the numerical attributes of the urban form using several computation techniques based on fractal geometry, space syntax, entropy and fuzzy logic, etc. (Bostanci, Ocaıç, & Şeker, 2006; Chalup, Henderson, Michael, & Wiklendt, 2009; Cooper & Oskrochi, 2008; Crompton & Brown, 2008; Heath et al., 2000; Mak, Yip, & Lai, 2005; Ostwald, Vaughan, & Tucker, 2008). These computer based mathematical models allow measurability and hence carry important potentials for the evaluation of urban esthetics.

The need for advanced geocomputational models for three-dimensional (3D) spatial modeling and for decision making and forecasting purposes in urban planning and urban design, in particular concerning skyline assessment and development, is evident. ‘Geospatial Information System (GIS)’, as a geographical process model and analytical tool, is the fundamental technology of spatial informatics used to manage and handle the vast amounts of spatial data, and also tools for the implementation of spatial modeling.

The modern city system has increasingly become more complex in terms of its spatial context, with impressive 3D features shown on its skyline, such as high-rise buildings and road fly-overs. Modern city now is gradually extending into the third dimension both upwards and downwards, using elements such as tunnels and an underground infrastructure. Focusing on such complex systems, Urban GIS, traditionally only concerned with 2D spatial relationships, has now been pushed to analyze, model and manage the 3D features of the modern urban system. Although numerous works have been reported on the development and applications of 3D city models, which form the foundation of 3D Urban GIS, they mostly serve for visualization and presentation purposes. With increasing needs for Urban GIS applications, including urban planning, urban transportation, utilities management, environment modeling, land use, tourism and management, the 3D city spatial data model has gained more attention, and height-related characteristics as well as 3D topological relationships are becoming more significant (Barley & Ireson, 2001; Chen, Sun, & Zhou, 2000; Raper, 2000; Zhou & Zhang, 2004; Zlatanova & Gruber, 1998).

GIS technology has been used for mapping, analyzing and evaluating urban development for the past three decades. However, the skyline extraction has not usually been possible within current GIS functionality. The spatial modeling and analysis oriented use of GIS with 3D geovisualization to assess the vertical development of the mega city Istanbul has been implemented in the context of this study. The geomodel has been tailored as an optimized GIS-based model for skyline evaluation and proposed by offering better geospatial information and better spatial analysis technology for multi-criteria decision support processes in urban development applications. The following requirements are intended to be met by the geomodel which has been tailored for this study:

- determining the skyline of the area of interest with GIS technology,
- detecting the changes in the Bosphorus skyline over the last 10 years,
- specifying spatial factors that affect the formation of the Bosphorus skyline in order to prevent further corruption of it,
- helping to decide which different types of skylines contribute to the view quality,
- supporting the planning of skyline development applications,
- simulating the skyline change after constructing a new high-rise building.
4. The development and implementation of a geomodel for analyzing an urban skyline

The development process produced a ‘Unified Modeling Language (UML)’-based model showing many different facets of the city skyline scenario. Fig. 3 illustrates the conceptual model developed in this study with UML 2.x use case and activity diagrams. Fig. 3a captures the scenarios of how the various actors will use the model built. Fig. 3b contains information about data, how to process the data, and the sequence of geoprocessing. The geomodel is displayed as a process flow in Fig. 3b. Fig. 3b delineates the methodology, it is the techniques used, and combines these with the spatial informatics technologies that were utilized. First, the process was turned into components as stated below, such as data collection, data preparation, modeling. Second, a computational architecture was created to link those components so that they integrate rapidly in the best combination or sequence required to tailor products or services. In this study, ‘ArgoUML,’ which is an open source and free-of-charge UML modeling tool under the Eclipse public License, was used as a modeling tool.

UML is an ISO Standard (ISO/IEC 19501). The conceptual model created in this study is expressed using UML in the light of Istanbul’s experience with real-case study in order to simplify the requirements and objectives. Well-structured and transparent conceptual description of the geomodel for analyzing urban skylines in the context of spatial planning encourages other cities executing the model for their own scenarios characterized by their own variables and parameters.

The problem in this study is inherently a 3D problem; the skylines and line-of-sight, that are calculated for viewpoints are often based on 3D topography, 3D buildings and 3D direct distances. Moreover, some geospatial questions can only be answered in 3D. Hence, 3D GIS is needed to have analytic tools in order to execute 3D spatial analysis; this is far beyond the task of 3D geovisualization, such as the creation of a 3D city model. The main reason why ArcGIS Desktop 10, a commercial GIS software package developed by ESRI, was chosen in the study as a GIS platform to build, visualize and analyze spatial data in three dimensions, is that the ArcGIS 3D Analyst extension at version 10 is specifically used for working with such data in true volumetric space. ArcGIS 3D Analyst 10 brings significant improvements in 3D vector analysis when compared to its earlier versions, such as ArcGIS 9.3, and other GIS software packages. ArcGIS 3D Analyst 10 and its viewing applications, ArcGlobe and ArcScene, provide an extensive set of features to create, visualize, edit, analyze, and share geospatial data in three dimensions. ArcGlobe was used frequently in the process of the study since it provides a virtual globe-based 3D realistic visualization and accurately represents real-world geospatial entities. Thus, the 3D impacts of the buildings within Istanbul were visualized effectively.

In this study, ArcGIS Desktop 10 was run on a laptop with an Intel Core2Duo CPU P9300 2.26 GHz, 4 GB of RAM, Intel GMA 4500MHD without dedicated graphics memory, and a Microsoft Windows 7 64-bit Operating System. The hardware configuration significantly surpassed the minimum requirements for ArcGIS 10, and spatial analyses were properly executed.

4.1. Data collection

The first and most crucial step in this study was acquiring the appropriate 3D spatial data with sufficient position and elevation accuracy. Due to the fact that, when compared with 2D data, 3D data can describe the detailed features of city, this enables urban planners and decision makers to conduct more accurate and detailed simulation or analysis of urban areas. In this study, a series of 1/1000 scale digital photogrammetric maps produced by the Istanbul Metropolitan Municipality using Microstation software package developed by Bentley Systems was collected for the Levent region of the city in ‘Computer Aided Design (CAD)’ format. The eight-sheet set covering the area of interest was obtained for two different points in time. One set belongs to 1999, and for the second set, aerial photos were taken in 2005; vector maps were produced in 2008. The base map of the geomodel developed was comprised of 16 map sheets in vector format.

4.2. Data conversion (CAD to GIS transfer)

Although the ArcGIS Desktop software package has a specific extension for the import of CAD data, the semantics of GIS and CAD are totally differentiated. This made it compulsory to transform the acquired information as CAD drawings into the 3D geospatial environment as a GIS data model. This is because storing semantic information is not the intention of CAD systems. On the other hand, GIS is developed to record and research semantically rich spatial relationships between real world objects.

4.3. Geodetic infrastructure

The map sheets of 1999 were produced based upon the 2D coordinate system of the National Geodetic Control Network of Turkey,
of which datum is European Datum (ED50). On the other hand, the map sheets of 2008 were produced on the basis of a 4D (3D + time) coordinate system of the Turkish National Fundamental GPS Network (Türkiye Ulusal Temel GPS Ağı, TUTGA), of which datum is the International Terrestrial Reference Frame-Epoch 2005.000 (ITRF96 2005.0). Hence, the datum transformation for the map sheets is needed between ED50 and ITRF96 datums.

Although TUTGA is a 3D geodetic network, in Turkey, currently two different geodetic networks in use for position and height determination. Today, TUTGA is the most recent network and is used as the base of all geodetic works. The Turkish National Vertical Control Network (Türkiye Ulusal Düşey Kontrol Ağı, TUDKA) is a first-degree leveling network and is used commonly as a reference network for height. Vertical datum for TUDKA is defined with the
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</tbody>
</table>

**Table 1**

Transformation parameters for 1/1000 scale map sheets (Anonymous, 2005b).

The transformation between ED50 and ITRF96 geodetic datums was determined utilizing two different methods. In the first method, a geographic transformation was tried in ArcGIS. However, the datum transformation cannot be automatically applied between ED50 and ITRF96 datums because the transformation parameters between those two datums do not exist. To solve this problem, the datum of ED50 first was transformed into the World Geodetic System (WGS84), then transformed from WGS84 to ITRF2000, and finally, the map sketches of 1999 were converted from ITRF2000 datum to ITRF96 datum. As a result of first approach, the building transformed from ED50 to ITRF96 did not overlap with the buildings already in ITRF96 datum. In the second method, the transformation parameters between two datums were obtained from the Istanbul GPS Control Network (Istanbul GPS Nirengi Ag, IGNA) project (Anonymous, 2005b). IGNA was established in 1999 for compensating the geodetic infrastructure needs of the mega city and then resurveyed in 2005 by taking into account the affects of the eastern Marmara earthquakes (Anonymous, 2005b). Using the relevant transformation parameters for 1/1000 scale map sheets given in Table 1, the sheets of 1999 in the datum of ED50 have been transformed into ITRF96 2005.00 through ArcGIS by entering geographic 2D offset parameters. When comparing transformation approaches, the second has provided such accurate results that the transformed buildings overlapped with the buildings in the datum of ITRF96 2005.000.

4.4. Managing elevation information

The Digital Elevation Model (DEM) offers the most common method for extracting topographic information. Further the DEM of land surface provides significant information for many research activities such as, urban planning and urban design, 3D city modeling, viewed analyses. The accuracy of the DEM is very important for the applications based on the three dimensional model of the land. Although the ArcGIS Globe Services provide ready-to-use elevation services, the vertical resolution of two services (about 30 meters for the United States of America and approximately 90 meters for all land areas between 60° north and 56° south latitude) (URL 4), are insufficient for properly analyzing an urban skyline. To improve this, three different terrain data sets from various sources were used to generate DEM of the area of interest:

1. Extruded Buildings: This 3D modeling approach is suitable and efficient for reconstructing 3D buildings in large quantities as solid 3D geometries and is faster than the other reconstruction techniques. The 2D building footprint data for the area of study has been draped onto the 3D surface (TIN DEM 2) and then, the flat 2D objects are extruded to 3D objects using the building height attribute data in order to generate the 3D data of the buildings. Determination of building heights for the number of floors was made from the digital photogrammetric maps with 1/1000 scale, and then the elevation of buildings was correctly calculated. Storey number data have been extruded by a standard storey height of 3.5 m. Since the total number of 3D building models is approximately 2000 and the low-rises barely affect skylines of the mega city, the number of 3D building models reconstructed using the extruded building approach has been reduced to nearly 150 for improved performance by applying a Structured Query Language (SQL) filter. The filter criterion for the elevation of buildings was
determined as 10 floors or 35 m. The buildings with less than 10 floors were removed from the 3D city model of the area of interest.

(2) Textured Buildings: To get a realistic appearance of buildings focused on in this study, a highly detailed modeling approach was preferred for several high-rise buildings existing in the Levent district such as Sapphire, the Isbank Tower, and the Sabanci Tower as well as skyscrapers already under construction, such as the Dubai Towers Istanbul (101 floors), Ozdilek Tower (65 floors). This approach also made it easier to identify the high-rise buildings rather than extruded buildings in the overall silhouette. Furthermore, this approach accounts for the high-rises built after 2005 which do not exist in the digital photogrammetric maps of 2008 since the aerial photos of these map sheets were taken in 2005. 3D models of high-rise buildings in the area of interest were imported from ‘Google 3D warehouse’ and replaced the old geometry generated as extruded buildings with these SketchUp and COLLADA models in the ArcGIS Desktop 10 software package. The textured building models were geographically referenced by using Google SketchUp and Google Earth together; the position and orientation of the models were accurately planted into the terrain in the Google Earth snapshot with the aid of the extruded buildings. Although Google Earth is an amazing source of data, Google Earth is not specially accurate. Hence, location and height of the textured buildings have been verified with the solid models which have been acquired from the digital photogrammetric maps and extruded the height information obtained from the Emporis database. Fig. 4 presents that the horizontal and vertical accuracy of textured buildings used in this study are accurate enough for such works.

4.6. 3D city model

3D city representation is not only a visual experience of ‘Digital Terrain Model (DTM)’ and buildings; the 3D city model with 3D mapping and visualization of the built environment is also the true simulation of reality. The development of a 3D spatial model of the mega city has assisted in executing spatial queries and analyses. The 3D city model of the district of Levent of Istanbul covers over 10 sqkm. Fig. 5 shows a 3D view of the spatial distribution of the buildings over a 3D topography. In this view, 3D extruded buildings have been visualized in a color-coded manner. The color-code was used to indicate the building’s intended use; for example residences are rose-colored, commercial structures are coral, schools are brown.

4.7. Viewpoints over Istanbul

Skylines are an experience and provide knowledge for all viewers who have access to them, such as citizens and tourists, because the viewing place is publicly accessible. Hence the best locations for publicly accessible viewpoints have been carefully determined for the study as follows, and the red pins in Fig. 6 indicate the position of well-defined viewpoints:

(1) European sides of Bosphorus and Fatih Sultan Mehmet bridges: One viewpoint has been located at the west end of the Bosphorus Bridge where approximately 180,000 vehicles pass daily in both directions. The second point was located at the west end of the Fatih Sultan Mehmet Bridge, also known as the Second Bosphorus Bridge where around 150,000 vehicles pass daily in both directions. No pedestrians are allowed to use either bridge.

Fig. 4. The reliability of data sources for high-rise buildings.
(2) European side viewpoints: One viewpoint was located on the Seraglio Point (Sarayburnu), at the north end of the historic peninsula of Istanbul between the Sea of Marmara, the Bosphorus and the Golden Horn. Other viewpoints have been located along the Bosphorus waterfront in the “front” view zone, the section of the city which can be seen from the Bosphorus.

(3) Anatolian viewpoints: Camlica Hill provides the best views of the sprawling mega city of Istanbul since it is the highest point in Istanbul at 267 m above sea level. From there the Princes’ Islands and the Marmara Sea can also be seen. The other viewpoints on the Anatolian or Asian side of the Bosphorus were located at Kadikoy and Uskudar. The district of Kadikoy and Uskudar have very popular settlement areas for centuries.

(4) Area of interest: Five viewpoints, North, East, South, West and Central, have been located surrounding the study area.

Having identified different key viewpoints, the city skylines of the area of interest have been created with the inclusion of artificial and natural objects. The geometrically precise description of the visibility of skyline and high-rise buildings can be identified as strategically important in the process of decision making.

4.8. Building a database for buildings

A Microsoft Access database of high-rise buildings in the area of study has been built based upon the global building database, which is called Emporis. Emporis is the world’s largest free-to-use...
website about tall buildings (URL 5). In order to promote the use of attribute data, the qualitative and quantitative characteristics of the buildings have been stored in the database. Among 3D building data were attributes of the construction year, construction place, usage type, construction type, facade system, architectural style, designer, contractor, number of floors and height. To create custom features of interest, thematic maps can be produced using variables from the attribute data as themes for layers (Fig. 7).

4.9. Spatial query

With the building heights visualized, the database of buildings developed was then used to identify the buildings in the geomodel. Having correlated the spatial data with attribute data, 3D spatial queries were run to retrieve information from the database as attributes and/or location. As a result of a sample query on usage type in Fig. 7, the use of high-rise buildings built after 2000s is not only for office use, hosting primarily financial, insurance and real estate (FIRE) sectors, but also for multi-purpose usage including residence and retail applications.

4.10. Analysis in 3D

Since the modern city is more than 2 dimensional, urban planning and modeling should be undertaken in the 3D space. Hence, 3D geoprocessing, 3D GIS operations, and 3D Urban GIS have now been considered as one major direction of the spatial informatics research. A real 3D GIS has to be able to manage all GIS functions for the objects in the 3D real world. Especially in analyzing the notion of skylines and their relationships to individual tall buildings and the city as a whole, focusing on the mega city Istanbul, effectively 3D spatial and logical analyses are necessary for both the esthetic and analytical understanding of the city. However, currently most GIS operations are in 2D/2.5D. Present commercial systems are hardly able to offer solutions for advanced analysis like 3D spatial analysis. Today, more advanced applications require more functionality from such spatial system, e.g. applications in advanced urban planning. (Abdul-Rahman, 2006) However, 3D data models are not capable of dealing with problems of spatial queries that rely on topological relationships; nor can they provide adequate spatial operators for 3D spatial analysis (Zhou & Zhang, 2004). This is because the systems offered by various vendors based on Formal Data Structure (FDS) proposed by Molenaar in 1988 and modified by Pilouk (1996) and such spatial systems have been called 2.5D GIS (Molenaar, 1992; Zlatanova, Pilouk, & Tempfli, 1996). The development of 3D GIS is growing and many works are being undertaken in several research centers and universities, for instance, Simplified Spatial Model (SSM), Urban Data Model (UDM), Object-Oriented 3D Data Model (O03D Model) based on 3D FDS.

Even though ArcGIS 3D Analyst extension in the latest release V10 expose 3D vector features and 3D vector analyses, for example, the Select By Location tool dialog box uses 3D distances, and multipatch objects and can now participate in the Line Of Sight tool (Steph, 2010), it is performing spatial analysis within a 3D context? In particular, it became apparent that the Select By Location tool in ArcGIS Desktop 10 needs to be improved in such a way that all three dimensional geometries can be queried within a 3D context since the Select By Location tool works only in 2D with the footprints of the buildings on the terrain. Queries like “select specific usage types of single high-rise building or show the part of the buildings above 100 m height” could not be performed.

3D quantitative and qualitative analyses of visual impact assessment executed in the scope of this study include the following 3D GIS functionalities:

Skylines have been extracted using qualitative and quantitative techniques for two different points in time. Skyline Extraction of the study area first was visualized using 3D mapping and visualization functions of GIS (Fig. 8). In addition to the visual analysis of the urban skyline of the area of interest, the skyline was produced with geometric precision. The second approach is advantageous and for utilization in decision support processes due to its high efficiency and effectiveness. Fig. 9 shows some results of skyline analysis. Characteristics of each skyline such as their smoothness and the number of times the skyline is broken may affect view quality. The extracted skylines from different viewpoints in the model revealed that the impact of silhouette of a building may vary for each viewpoint within the city. For instance, the highest building of Istanbul, the recently constructed Sapphire skyscraper has the most dominant effect upon the viewpoints from Camlica Peak, Seraglio and the Second Bosphorus Bridge. However, from the First Bosphorus Bridge, the impact of Sapphire on the skyline is far less than that of the Sabanci Center building which is 103 m shorter than the Sapphire structure. Further the Tat Towers and Metrocity buildings display similar silhouette effects to the Sapphire building which is 120 m higher than the two aforementioned structures when viewed from Zincirlikuyu to Levent. Hence, development of the silhouette and skyline has to be planned according to the findings of a skyline analysis which has taken into consideration a much wider range of viewpoints. Displaying the modern quarters of the city, the skyline effect in the Levent district of Istanbul and the way it shapes or rather re-shapes the historical silhouette has to be examined. Thus the threats to the city’s silhouette, such as the

Fig. 7. A sample query on usage type of high-rises in the area of interest.
Fig. 8. (a) Visual skyline analysis in the West-East direction (1999). (b) Visual skyline analysis in the West-East direction (2008–...). (c) Visual skyline analysis in the North-South direction (1999). (d) Visual skyline analysis in the North-South direction (2008–...).

Fig. 9. (a) Temporal skyline analysis from the viewpoint on Bosphorus bridge. (b) Temporal skyline analysis from the viewpoint on Fatih Sultan Mehmet Bridge. (c) Temporal skyline analysis from the viewpoint on Seraglio. (d) Temporal skyline analysis from the viewpoint on Camlica Hill.
visibility of high-rises in Levent from the minarets of the Hagia Sophia, can be obstructed. Thereafter the landmarks symbolizing the more modern side of the city, such as the Bosphorus Bridges, can be displayed more effectively and the visual impact of newly developed constructions can be considered to be intrusive of the Bosphorus skyline.

The skylines from the identical viewpoints in both time (1999 and 2008) were visualized and compared to determine the change in the overall silhouette over a 10 year period. The spatial transformation of the specific skyline due to high-rise building has been obtained and the spatial relations between skylines and tall buildings have been revealed. The temporal dimension has been incorporated into the 3D geovisualization of skylines and spatio-temporal analysis for determining the changes of the urban skyline over the last decade has been executed for the area of interest. Periodical transformations due to high-rise buildings have been analyzed over past, current and future skylines. The CBD has rapidly grown vertically under the influence of globalization as it can be seen from Fig. 9 that presents the skyline development in the area of interest during the period of 1999–2008. In Fig. 9, the orange line displays the current skyline, the grey line illustrates the former skyline and the red line indicates the evolving skyline of the Central Business District of Istanbul viewed from different viewpoints. First the lengths of skylines were obtained from a skyline analysis and the metrics of their spatiotemporal changes based on two epoch data set belongs to 1999 and 2008 are given in Table 2. Fig. 10 compares the lengths of these skylines in scalar context based on the values in Table 2.

Visibility planes have been calculated from the viewpoints. The TIN surface in Fig. 11 defines the top of the volume that is hidden from view from the viewpoint on Camlica Hill. Comparing this surface to the base elevation surface, the 3D space between the visibility planes and the ground in the area of interest has been calculated. The 3D spaces represent elevations that cannot be seen from the view positions. In this way, the following question can be answered: “How tall can the buildings located in a place/parcel in the study area be and not affect the skyline?” The answer makes it simple to identify where structures of a certain size can be built while remaining concealed from view at a particular the viewpoint(s). Fig. 11 displays the hidden building height for the Central Business District.

Thereafter GIS technology was used to calculate ideal building heights which have no effect on the skyline, and ideal building heights were shared in order to be evaluated and used in planning decisions, which have impacts on the city skyline. This data needs to be made available to the public, government officials and urban

### Table 2

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<td>51.894</td>
</tr>
</tbody>
</table>

**Fig. 10.** Comparison of lengths of skylines from 1999 to 2008.

**Fig. 11.** Ideal height limits in the Central Business district due to skyline review process.
planning decision makers. As a real urban development use case for immediate implementation of ideal height limits in the Central Business District, displaying the visibility change of the high-rise buildings using the maximum elevation from a viewpoint, e.g. Camlica Hill, without affecting the skyline completes the analysis of this problem. Fig. 12 illustrates the buildings with respect to ideal height limits obtained from the skyline analysis of Camlica Hill. Fig. 13 shows a chart that compares graphically the existing and ideal heights of high-rise buildings.

The volumetric shadows of high-rises within the study area change at various times of the year; these changes were calculated using a shadow analysis template based on the movement patterns of the sun and skyline tools. Fig. 14 displays the shadows of the buildings within the study area at June 21st, 2010 with regular 1 h intervals from 6.00 to 16.00 local time (UTC + 2 h). As shown in Fig. 14, the impact of the shading generated by the existing high-rises on the surrounding buildings is negative and the shadow impact of buildings planned for the near future on the adjacent spaces is multiplied this negative effect. The negative consequences of shading include the loss of natural light for passive or active solar energy applications or the loss of warming influences during cool weather. This analysis helps urban planners calculate the area affected by the shadow of existing buildings and/or the shadows of the proposed buildings based upon the time of day, the day of the year and the geographic location. The thematic mapping obtained from 3D spatial analysis methods, such as skyline analysis and shadow analysis, can be seen as invaluable part of a spatial decision support infrastructure which constitutes a multi criteria analysis of urban planning, design and management.

4.11. Automating tasks with model builder in ArcGIS

The model builder in ArcGIS is used to automate GIS processes by linking data input, ArcGIS tools/functions, and data output. The main advantage of using the ArcGIS model builder for GIS work is that the GIS procedure for a specific work can be automated without using any code. Another advantage is that the model builder provides a graphical flow diagram that can be understood by non-GIS and GIS team members. In this way, the model builder is a productive mechanism to share methods and procedures with others within, as well as outside, the organization. It is easy to redo the exact same procedure multiple times, or to alter data and parameters slightly because the model can be saved, modified and rerun. Since ESRI has supported Python with their own native ArcPy implementation model, having created a basic framework of the model, it can be exported to three different script formats: Python, JScript and VBScript. Fig. 15 displays the ArcGIS model of the geoprocessing part of the geomodel which was tailored in this study.

4.12. Publishing 3D spatial content to the Web for sharing

The gap between Desktop GIS and Web GIS is closing, so that Web-based GIS is becoming ubiquitous – it is available on the desktops, laptops, cell phones, GPS navigators, and other mobile devices anywhere, anytime. This reflects the growing use of the Web as a platform that supports authoring geoprocessing models and maps, then publishing them as services that can be easily consumed by a variety of client applications. Furthermore, Web GIS is experiencing the development from 2D system to 3D system due to the fact that, in some applications, the knowledge of 3D position is crucial for dealing with them. In their few years of existence, Virtual Globes such as Google Earth or Microsoft Bing Maps 3D have already received an enormous attention. However, 3D Web GIS is not yet widely being used in Web applications since the reason is to use current 3D web technologies in Web-based GIS still has...
some technical constraints to be implemented using current web technologies which includes the shortcomings in 3D storage and manipulations tools (e.g., 3D spatial indexes, 3D generalization data or LOD logic, storing 3D primitives, such as polyhedron geometries, TINs, in the database), and 3D robust viewers (e.g., displaying 3D objects). For this reason, 3D Web GIS technologies today is generally for visualization (respectively user interaction) purposes only and usually ignores the attribute data behind the spatial object to perform 3D spatial analysis on the Web (Aditya, Iswanto, Wirawan, & Laksono, 2011; Held, Abdul-Rahman, & Zlatanova, 2004; Ming, 2008; Uchoa, Paulo, Filho, & Ferreira, 2006; Zhu, Tan, & Chan, 2003). In order to share the GIS project and analysis in 3D with its stakeholder shortly, the following implementation approach has been chosen to achieve a 3D Web GIS.

ArcGIS for Desktop was utilized as a GIS desktop platform to manage geospatial analyses efficiently, to understand the relationship between skylines and high-rises, and to evaluate the potential for high-rises in promising locations. Thereafter, ArcGIS for Server was used to publish geospatial contents in the 3D GIS project that had already been created with ArcGIS for Desktop to the Web for sharing. ArcGIS Server 10 for .NET framework with Oracle 11g relational database management system, both run on Microsoft Windows Server 2003, was utilized as a GIS server platform for creating and managing GIS Web Services and Applications. Active Sever Pages (ASP) technology combined with the Internet Information Server (IIS) as web server environment was used to allow for interaction with the database. The generated skylines and other data were uploaded to the ArcGIS server and related services were created. The services hosted in the web application server can be published with 2D dynamic and cached maps as well as 3D globes. Custom Web GIS applications were created using the following approaches:

1. Building Web Mapping Applications: The 'ArcGIS Desktop Application' was converted to 'ArcGIS Server Web Application'. The feature classes of ArcGIS Desktop Application were configured to run as a web application and web services on ArcGIS Server. The user interface of the web application is available on URL 6. Moreover, the geospatial contents were uploaded and shared in both ArcGIS Online (built on JavaScript technology) (URL 7) and ArcGIS Explorer Online (built on Silverlight technology) (URL 8), then downloaded and opened with ArcGIS for Desktop 10, or ArcGIS Explorer. Web applications can display geospatial information to user on-line by 2D, and cannot present skylines.

2. Browser-side GIS APIs: The 2D services available on ArcGIS Server can be consumed with viewer application on users’ web browsers. GIS viewer applications can be built quickly using the ArcGIS APIs for JavaScript, Silverlight, Flex. A 2D dynamic mapping application of the GIS project was implemented using ArcGIS API for Flex which enables navigating and exploring the data in a web browser environment (URL 9).

3. Standalone GIS viewer: 3D mapping services (including globes) can be used by ESRF’s ArcGIS Explorer Desktop, which is a free standalone GIS viewer to maintain 3D visualization and analysis of GIS data. 3D Globe Service (URL 10) provides GIS experts, professional users, and public users with 3D views and enables

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Fig. 14. Shadow analysis of the tall buildings within the study area.

Fig. 15. The model builder window with a typical model.
them to use spatial information in 3D. But it has an essential limitation in data interoperability. ArcGIS Explorer Desktop only supports file formats that are generally supported by ArcGIS and another ESRI products.

4.13. Spatial governance

3D geovisualization eases recognition and encourages the user to explore the map. 3D visualization and interaction helps citizens and other stakeholders (e.g., urban planning professionals, local government agencies, decision makers, and NGOs) to intuitively understand terrain topography and development plans. Web GIS combines GIS technology with Internet technology, which changed GIS systems from a closed system to opening to the public, making GIS eminently more accessible for a wider range of distributed users with minimal investment in additional hardware, software, and infrastructure. Thanks to taking 3D Web GIS to the cloud, mashups and spatial analysis results are easily shared as services with a specialized audience (such as municipal staff – GIS professionals and knowledge workers without any GIS experience –) and general audiences (such as the public), which brings transparency to the government decision-making process. Presenting the 3D views of skylines and the maximum heights permitted on the parcel allow end users, the community's elected representatives and analysts to work with data in a 3D mapping environment. This brings transparency to the government decision-making process. Even the changing skyline scenarios of the mega city can be shared with the public for public consultation with an urban planning department. If the public approves it, the basis for the non-statutory guidance on the protection of the skyline can be formed. Web-based 3D GIS technology merges authoritative content, such as large scale 3D GIS models, with user-generated content to deliver location-based information and applications to a broader audience. Such a spatial governance approach makes decision-makers pay attention to this vertical development because the public will force it to do so.

5. Conclusion and outlook

The effect of the increasing vertical urban sprawl in the “back view” zone from the Bosphorus to the waterside, and the “front view” zones can be observed evidently. Such a great variation of the skyline over the last decade has revealed the fact that the need for an analytical approach to preserve the identity of the mega city is essential. This study has illustrated that building height limits, with respect to the proposed skyline, can be regulated in the Central Business District of Istanbul through the geomodel and GIS technology. This implementation was a case-study which can be a part of a comprehensive analysis of Istanbul’s entire skyline, identifying the essential features that make up Istanbul’s identity and key views of those features. In this way, the height limits for the entire mega city could be established as part of area-specific land use. For example, the height limits in the Central Business District and the Historical Peninsula are needed as different factors form those skylines. In the present system, neither the borders of the Bosphorus “front view zone” are defined by the law; further, the authorized administration which is responsible for the Bosphorus area are not sufficient for preserving the Bosphorus skyline. As an example of this legislative complexity, the Central Business District is currently under the jurisdiction of four different district municipalities, in addition to the Istanbul Metropolitan Municipality. As a result, high-rise blocks built with proper planning mechanisms and legal arrangements, have come up with divergences and negative effects on the Bosphorus skyline due to inclined topography and 2D planning.

On the other hand, there is now no vacant area which can be filled with settlement areas in Istanbul. The only way to maintain growth in Istanbul is by the city developing vertically in order not to destroy further natural resources surrounding the city such as lakes and forest land. Hence, a policy which does not exist presently needs to be established for high-rise buildings in Istanbul based upon urban design guidelines which will be developed on the 3D topography, not 2D plans, of the mega city. The policy for high rises provides the implementation of the ideal height limits by discussing with the public their impact on the skyline and utilizing computer resources such as a web-based 3D GIS. Furthermore, 3D GIS approach can also be used to operationalize the existing zoning law and shape future policies in the analysis urban skylines.

Planning for a distinctive and sustainable city is an increasingly complicated process and requires comprehensive analysis of visual impact factors such as skyline analysis and shadow analysis. The geomodel developed here is considered to be the initial step for a decision support system which will assist in assigning land for high-rise building development in Istanbul and in cities worldwide where the skyline is of primary concern. It is clear that henceforth the decision support system for the control of the skylines for cities will inevitably require new insights from many other perspectives and disciplines.

References


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