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Research Article

DESIGN FOR 3D CITY MODEL MANAGEMENT USING REMOTE SENSING AND GIS: A CASE STUDY FOR THE GOLDEN HORN IN ISTANBUL, TURKEY

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ABSTRACT

Recently, three-dimensional (3D) city modelling has gained great importance for applications in a wide range of areas including the documentation of city features. During this process, professionals in urban planning, utilities, fire and rescue as well as security turn to GIS data sources. In this study, the Golden Horn (Haliç) is one of the historical and major waterwards located in Istanbul, Turkey which was chosen as the study area due to its unique geographical and historical features. Four models were created with varying levels of detail and discussed in terms of their role in integrated coastal zone management. Coastal areas and estuaries are particularly important sites since they are very sensitive to anthropogenic impact. In this paper, it is also discussed how 3D visual analysis provides scenario-based recommendations to assist urban planners with the decision-making process and creation of new city plans. Besides, a 3D city model for the unique coastal area was modelled and analysed with the help of remote sensing and GIS.
Keywords: 3D city modelling, terrestrial laser scanning, GIS, integrated coastal zone management.

1. INTRODUCTION

Recently, the importance of three-dimensional (3D) models has increased finding application in several areas such as city modelling, mapping, urban planning [1, 2, 3], disaster management [4, 5], real-time simulations for training [6] and indoor navigation [7]. At the same time, there is a steady increase in the number of 3D city models being built by municipalities, local or national government surveying agencies, and commercial and other organizations. This is mainly due to the significant improvements in 3D reconstruction methods that have been made in the last decade [8, 9, 10, 11].

Many disciplines, including but not limited to architecture, telecommunications, tourism, planning/management and environmental protection, have an increasing demand for digital 3D city models to use this data in different applications in planning, analysis, visualisation and simulation. Also, open geographic viewers (for example, Google Earth and Virtual Earth) use 3D

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city models. Meet this growing demand for 3D models, and there is a need to create city models in a fast, precise, detailed, complete and economical way [3, 8, 10, 11].

3D modelling has several advantages. It extends beyond the modelling of topographic data integrating geo-referenced data and providing not only visual intelligence for decision-making but also combining conceptual and design models (e.g., 3D city models, 3D GIS, civil engineering plans, subterranean utility and power networks) as well as thematic models (building information, demography, statistics). This brings a holistic, integrated approach to urban planning. 3D city modelling facilitates communication between stakeholders within and outside a municipality, and attract and consolidate interest for projects and land development that require capital spread out over a larger group of financial investors (12, 13, 14, 15, 16]. In developing and implementing 3D technology could be used to support management of urban coastal zones because the broadcast of area features in the form of a 3D model could help build understanding and views of the areas with greater clarity [17]. The 3D for Integrated Coastal Zone Management (ICZM) is computerised system capable of supporting and assisting decision making in ICZM [18, 19].

The Golden Horn (Haliç) located in Istanbul, Turkey has unique geographical and historical features. It is a historic inlet of the Strait of Istanbul (Bosphorus) dividing the city of Istanbul and forming part of the natural harbour that sheltered the Greek, Roman, Byzantine, Ottoman and other ships for thousands of years. It is a scimitar-shaped flooded estuary that joins the Strait of Istanbul just at the point where that strait enters the Sea of Marmara, thus forming a peninsula at the tip of which is the "Old Istanbul". Lying in the centre of a historic city, the Golden Horn plays a substantial role in the city culture for thousands of years. It has witnessed many tumultuous historical incidents and its dramatic vistas have been the subject of countless works of art. In a recent regulation of Istanbul Municipality, the Golden Horn is referred to as the ‘Culture and Art Valley’.

Among the converging issues of concern in global development, the arrival of large coastal cities has received little research attention. In addition to all the stresses that coastal cities are facing population grown, re-urbanization, corruption of heritage, etc. for old cities, such as Istanbul which significantly oriented towards, and/or actually or potentially affected hydro dynamically by an extensive body of surface fresh or salt water. According to Timmerman and White [20]; this could include cities at some distance from the water’s edge and include in the definition cities on major enclosed seas, lakes, estuaries, and rivers that are immediately emptying into larger bodies of water. Besides these definitions, urban-coastal zone must be examined a bi-polar area, bounded on the landward side by the local hinterland of the cityscape and on the waterward side by the functional ecological integration of the coastal littoral zone. The coastal city is characterized by the reciprocal interplay of two rich and complex subsystems, one natural and one built. The immense challenge for the appropriate management of coastal cities is to sustain the integrity of both systems. Nevertheless, it is also important to recognize that the economic system is ultimately inside the ecological system.

With its historical and geological features mentioned above, the Golden Horn is one of the most suitable places to present the management of sustainable coastal zones. There is a relationship between the quality of city life and the quality of the local natural ecosystem, but this relationship is complex, and is only expressed directly in modern cities when there is extreme stress. Therefore, in this study, the coastal zone features of the Golden Horn were documented in a selected area using modern geoinformatic techniques. These techniques could be applied for Golden Horn which is one of the best examples of both historical coastal cities and urban coastal zone.

2. STUDY AREA

The Golden Horn is a 7.5 km long, 200–900 m wide horn-shaped body of water that connects the Alibeyköy and Kağıthane Rivers to the Strait of Istanbul (Bosphorus). The maximum depth, where it flows into the strait of I stanbul, is about 35 meters. The estuarine surface area covers 2.6 km^2 and has a maximum depth of 36 m at the mouth, sloping to <1 m near the tributary inflow (Coleman et al. 2009). The main freshwater inputs are provided by Alibeyköy and Kağıthane streams, but following the constructions of several dams in the watershed, freshwater inputs were significantly decreased [21]. A rescue excavation was conducted in the ancient harbour of Istanbul (Yenikapı, 2500 m from Golden Horn mount) by the Sea of Marmara, revealing a depositional sequence displaying clear evidence of transgression and coastal progradation during the geologically Holocene. The basal layer of this sequence lies at approximately 10 m below the current sea level [22, 23]. According to recent investigations, the sedimentation rate has always been high both at the bottom of the sea and along the coastline of the Golden Horn. To date, several types of data (ortho-image, terrestrial laser scanning data, vector data and bathymetric data) have been collected and used for the documentation of the anthropogenic and natural features of the Golden Horn (Fig. 1).

Figure 1. The Study Area

3. METHODOLOGY AND DATASETS

3D modelling has emerged as an important research area to monitor the changes in the topography of cities from past to present and reveal their current situation in order to use this data in future planning and conservation work. Such studies give information about the destruction caused by nature and helps restore the city. The process of performing 3D visual analyses based on scenarios provides city planners with recommendations for the creation of new plans [23]. In addition, documenting the characteristics of an old city, thus presenting and preserving cultural heritage is an important goal of this type of work.

Considering the density and size of monumental buildings, traditional methods cannot provide fast and accessible data for the accurate measurement of these objects. However, with the recent developments in engineering measurement techniques, laser scanning has emerged. The architecture of this system is suitable for use in the protection of cultural heritage particularly in areas that have been deformed. Millions of points scanned through lasers can now be processed using 3D processing and visualization software and are made widely available. This data is generated using the 3D drawings created in GIS software and is then used to create 3D city models. This study utilized the laser scan data as the most appropriate technological method for creating a 3D city model of the study area for the purposes of effective coastal zone management.

3.1. Design and Development of the 3D City Model

3D city models are generally used to collect, analyse and synthesise city data to make predictions about the effect of disasters for effective coastal zone management. One of the most important features of 3D city models is that they allow the data collected from the same environment to be used for different purposes by integrating different spatial data to create complex urban models. 3D city models are frequently used in the architectural design, presentation and evaluation of cities [25, 26, 27, 28].

3D modelling for specific products using different data sources is a time consuming task. For this reason, it is important to determine the requirements for the level of detail (LoD) and quality required for the specific purpose. In this study, the following four 3D city models with varying LoD were created using Open GIS Consortium (OGC) and analysed in terms of their usefulness in coastal zone management : LoD0 = a two and half dimensional digital terrain model, over which an aerial image or a map may be draped, LoD1 = a block model as an extruded footprint of the vector data, LoD2 = a roof model with detailed roof structures, LoD3 = an architectural model with detailed roofs and facades, and LoD4 = a detailed exterior and interior model (Fig. 2).

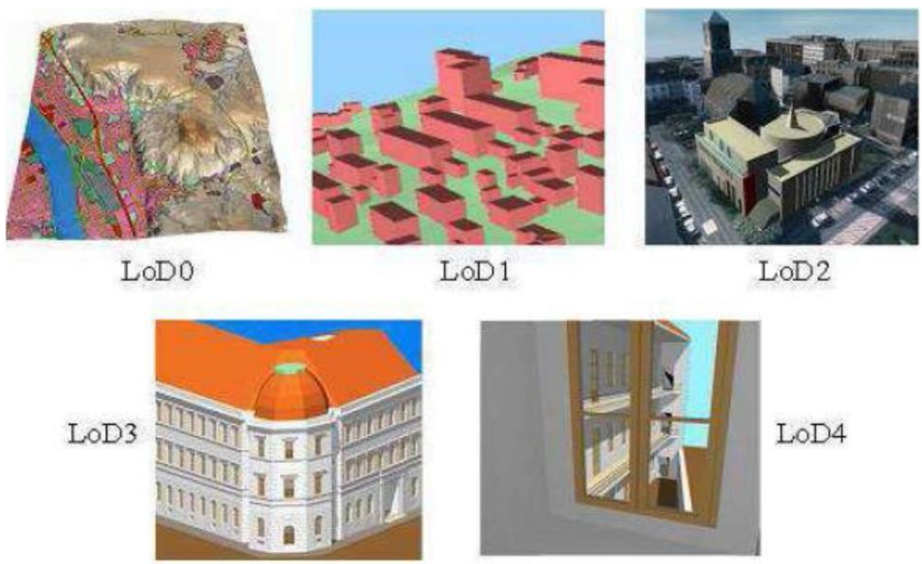

Figure 2. LoD defined by OGC for 3D city models [29]

3.2. Data Acquisition by Terrestrial Laser Scanning

A terrestrial laser (Leica HDS4500) was used to scan the study area and obtain 3D point data at the desired intervals at a high speed. HDS4500 can measure distances up to 53 m. Four devices were used to scan all the buildings with a resolution of 15 mm for each object. For the processing of the scanned point clouds, which includes the stages of registration, geo-referencing and segmentation, Cyclone 5.2 and Polyworks 4.1 were used. Fig. 3 presents the field scanned by the laser.

Figure 3. Part of coastal zone from the Golden Horn used in terrestrial laser scanning

The target object was scanned from horizontal and vertical orientations depending on the length of the optical-mechanical measuring with the scanner. The result was the creation of a detailed 3D image of the object that provides millions of points, of which sets of points form a point cloud from the intense laser signals [30]. The geo-referenced point clouds from laser scanning were used for the line mapping of the facades. The required standard deviation of the positions of 0.2 mm in the map corresponds to 4 cm in the object space in terms of relative accuracy. An example of the mapping of the building facades with Z-MAP Menci-software is shown in Fig. 4.

Laser data can be recorded using the computer-aided design (CAD) drawing process. CAD data can then be integrated into and displayed in a GIS environment. This process is performed in the 3D modules of ArcGIS, namely ArcScene and ArcGlobe. The scanned data can be identified as suitable for the purpose. This data is presented in colour and has a high value. Fig. 5 shows an example of a coloured drawing based on the data collected from the study area.

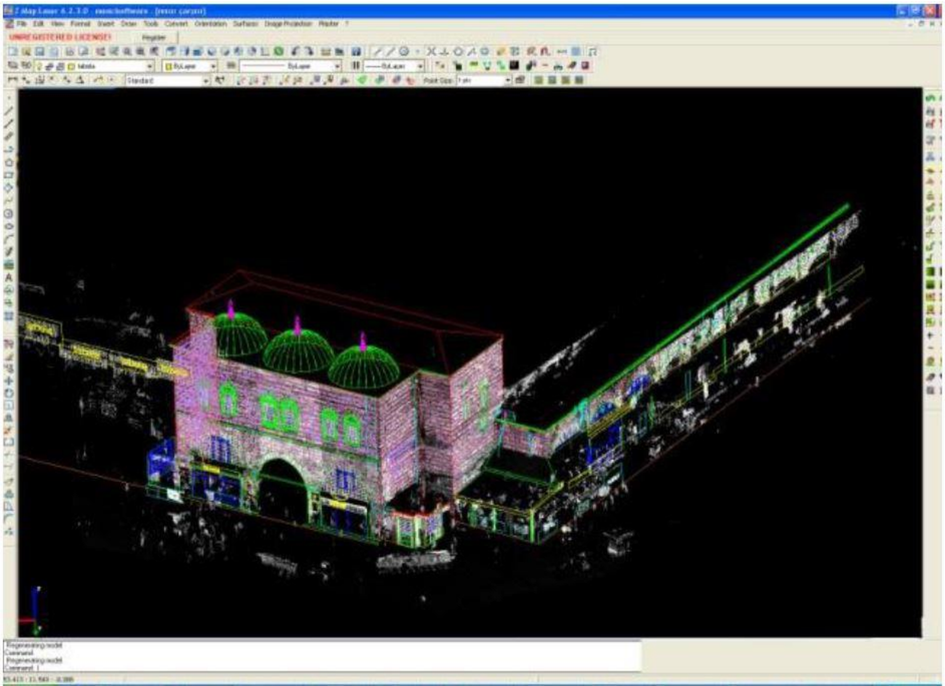

Figure 4. 3D polylines map of building facades based on Z-MAP laser

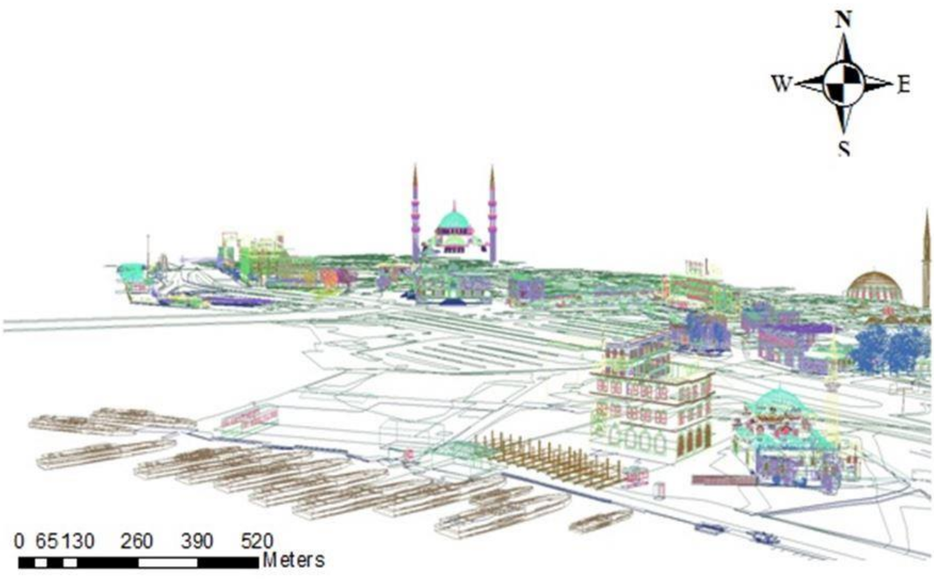

Figure 5. Coloured drawing based on the data collected from the Golden Horn

3.3. Bathymetric Data

A bathymetric map shows the depth of water in lakes, oceans, rivers and seas. In this map, 1-m resolution digital elevation model (DEM) is generated using height values. Fig. 6 presents coloured hill-shaded map created using a 3-m resolution DEM for a portion of the land and 1-m resolution DEM for the water area demonstrating the land-water relationship.

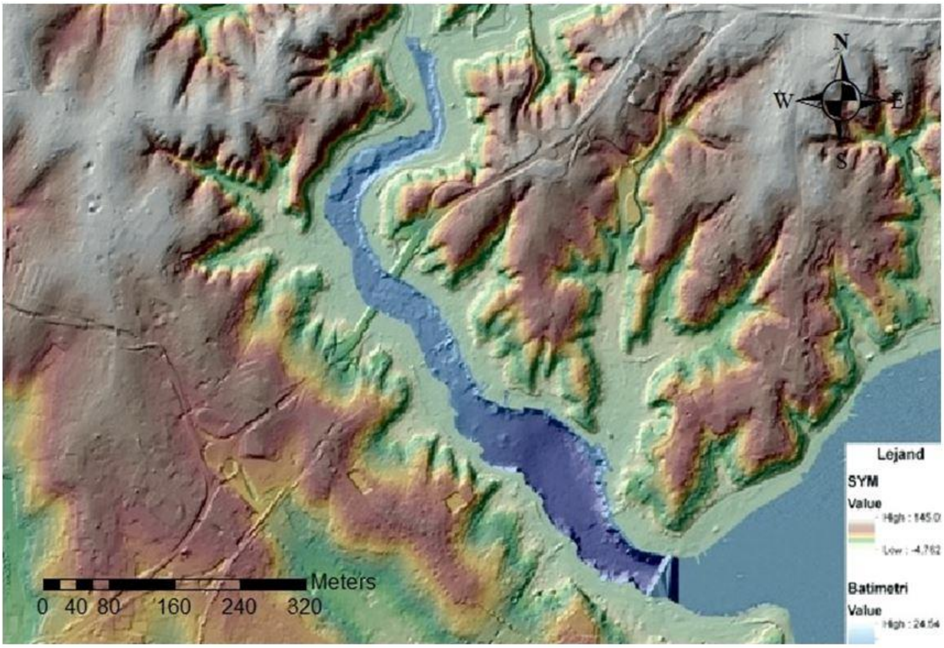

Figure 6. Hill-shaded map of the study area

4. RESULTS

The main objective of this application was to create a 3D city model of the study area to be used in the development of a coastal information system through the integration of different types of data. The use of a 3D city model is considered an alternative to 2D planning data. 2D CAD data is integrated into GIS and allows for 3D evaluation providing the decision-makers with the opportunity to conduct a temporal analysis on or update the data. Fig. 7 presents a workflow diagram of the 3D city model data types used in this study.

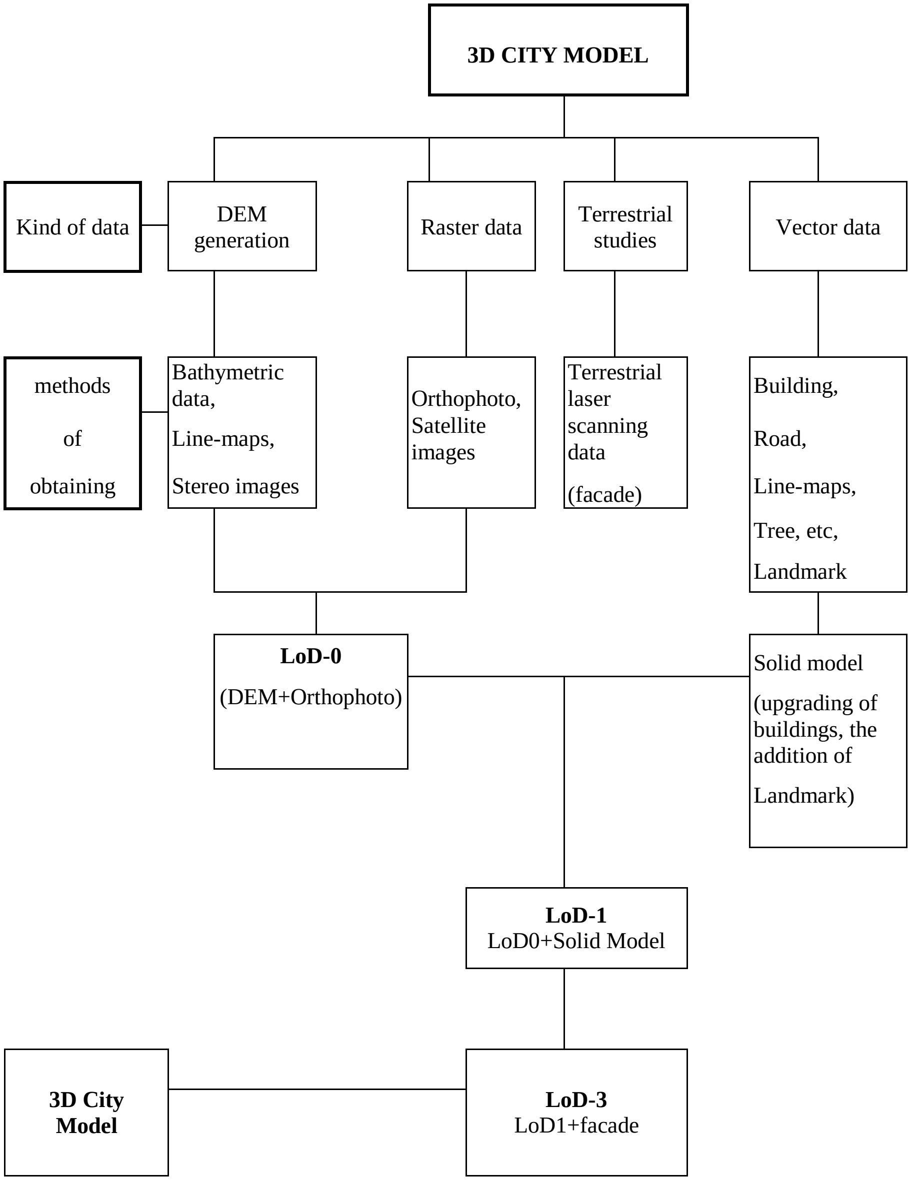

Figure 7. Flowchart schema of the 3D city model

4.1. 3D city model at LoD1

The LoD1 product was generated from the building outlines available in the vector map with the building heights being extracted from the information on the number of storeys over the horizontal surface plane (Fig. 8). For an interactive visualisation of 3D models on the internet, photo-realistic models should be converted from 3ds max to standard file formats (e.g. VRML).

This virtual model allowed a navigation, simulation, and visualisation of the appearance of the city to be created and the identification of the environmental issues. The modelled bridge (Landmark) is added to the model in Fig. 9a. and to the 3D city model in LoD1 for the entire estuary in Fig. 9b.

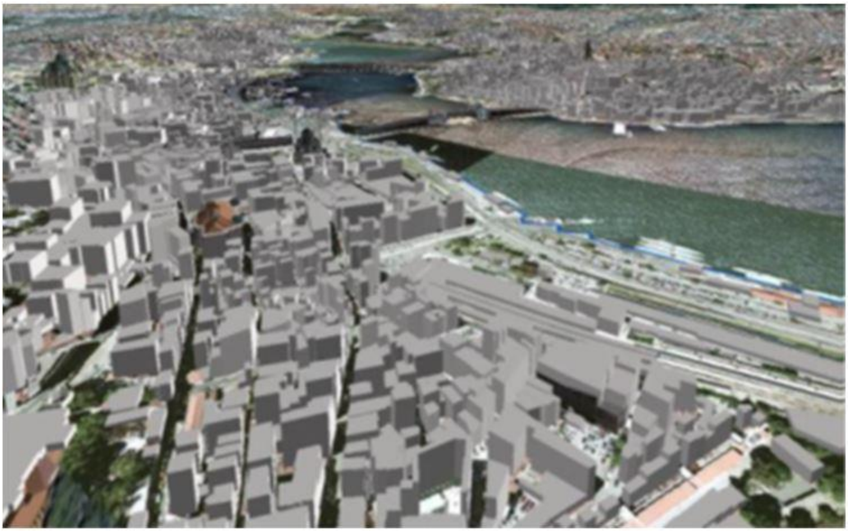

Figure 8. Part of the 3D city model in LoD1

Figure 9. Example of the landmark (a), an overview of the Golden Horn in LoD1 (b)

4.2. 3D city model at LoD2

The 3D city model of the study area at LoD2 was created by combining the block model with the roofs. Roofs can be derived from stereo images on the drawings. Since drawing roofs is expensive, may present with some problems and is not essential for sustainable coastal zone management, it was not included in the present study.

4.3. 3D city model at LoD3

LoD3 is a high-quality product, which was generated from the detailed map of roofs and building facades including photo realistic texture mapping of each building. In this study, the modelling was performed based on 2D drawings; however, the existing situation could also be modelled using the facade drawing data, which was generated from laser scanning data (Fig. 10a.). The combination of terrestrial laser scanning data and aerial imagery to derive a new 3D model at LoD3 aimed to facilitate analysis on coastal zones by integrating the bathymetric DEM into the generated model (Fig. 10b).

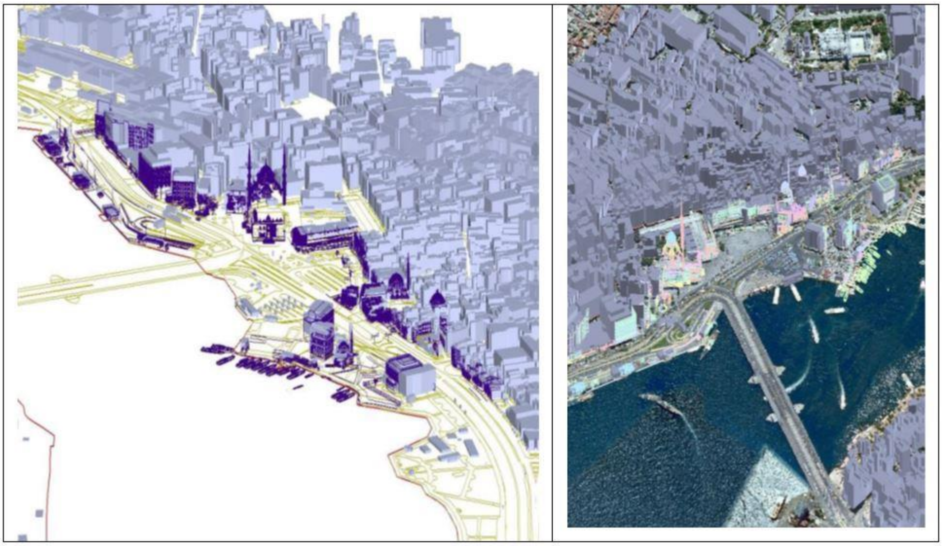

Figure 10. LoD3 (solid model and facade drawing) (a), 3D model at LoD3 (b)

The LoD4 model was created combining the LoD3 model with the stage model of the interior surfaces of buildings. Internal surfaces are not required for coastal areas and thus they were not significant for 3D modelling for the purpose of coastal zone management.

At this point, it is useful to present some examples related to the design and development system of 3D city models. The first example concerns the determination of the impact of water level rise on the coastal areas; in particular the area on the shores of the Golden Horn where settlement seems to be close, but not so dense as to be intertwined with water. The water level in the analysis in ArcGIS 1 m, 2 m, 3 m elevation of the case study shows the impact on the coastal areas. Using the ArcMap ArcGIS software component, the Spatial Analyst reclasser creation process was performed. For this analysis, 1 m resolution DEM bathymetric data for the land portion was used. The areas that would be affected when the water level increases are indicated in Fig. 11b. Another analysis revealed that, a water level rise of 1 m would submerge an area of 234 839 m^2, and for a 2 m rise , this would be 1,163,429 m^2, and a 2,475,292 m^2 area would be submerged following a water level rise. Fig. 11a shows the area that would be affected by the rise at various water levels.

The integration and combination of geoinformatic technologies created new knowledge and understanding of the area's geographical characteristics in order to help increase the effectiveness of planning and management of urban coastal zones. Well organized decision support system must provide a common, shared information basis, framework and language for dialogue and negotiation all branch of who interesting urban coastal zones (Fedra and Feoli, 1998). Geoinformatic techniques not only provide practical decision support requires a new approach but also supports participatory decision making process on urban coastal zones.

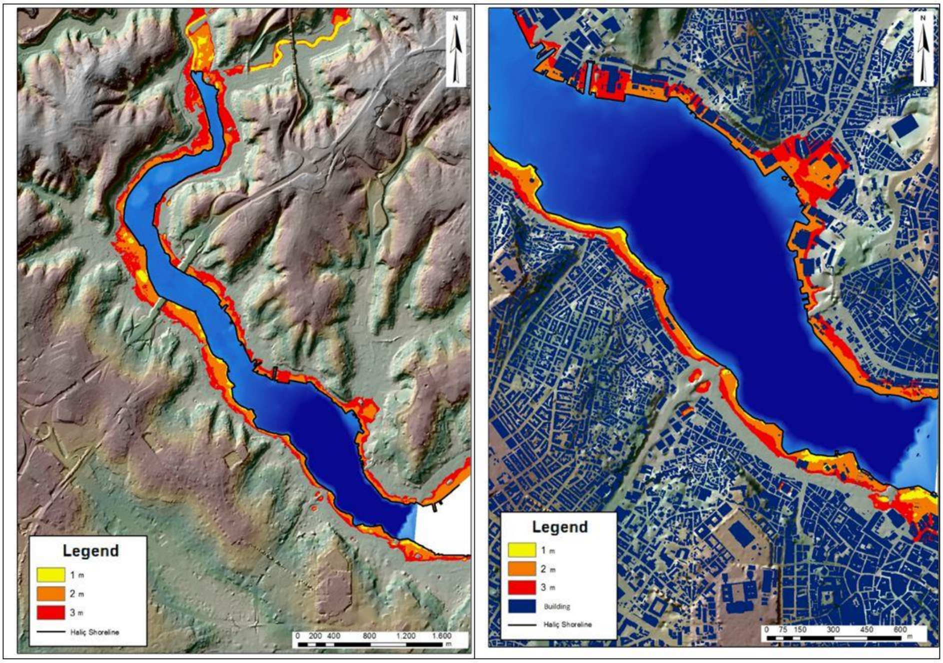

Figure 11. Area affected by elevated water level (a), Structures affecting water level (b)

In this study, 3D City Model has been created via using Remote Sensing and GIS technologies which is also name is geoinformatic techniques. It is possible to make a lot of analysis not only today both also next time predictions (likes as Fig.11) for preserving historical coastal zone management. On the other hand, the paper shows how could be created 3D ICMZ for coastal zone areas. Finally, 3D city model is very important components for tracing and preserving of coastal zone management.

5. INTEGRATED COASTAL ZONE MANAGEMENT

Coastal zone environmental research and state assessment often requires the integration of physical, chemical, geological, biological, social, economic, governance and management dimensions of the environmental system [31]. Integrated Coastal Zone Management schemes must address both human and natural elements of the coastal environment [32]. Integrated Coastal Zone Management and Urban Planning have made important progress in recent years [33]. According to Timmerman and White [20] observed earlier that "*coastal* cities research is rather scarce, although curiously both the management of urban areas and coastal zones have been objects of extensive research over the past three decades". Even today, the situation has not changed. This is an important but neglected area as the need for ICZM in urban coastal zones arises often due to inadequate or inappropriate land use planning practices. In a general sense, coastal zone management refers to spatial management, which means the distribution and allocation of space, ultimately of parcels of land, (with our without water covering it) to alternative uses or activities, or the control of processes that in turn may affect space, such as flood effect. The city ecosystem and the coast ecosystem will have different, but connected, cycles of operation. The scale relationships both temporal and spatial between these will also be complex. The ecological reasons why cities were originally located on coastal zones are under threat [34].

Many of the underlying processes within the domain of environmental (both physical and ecological) modelling can be represented by spatially distributed models that describe environmental phenomena in one (in rivers or estuaries), two (land, atmospheric and water quality models, models of population dynamics), or three dimensions (again air and water models). The increasing development and use of spatially distributed models replacing simple spatially aggregated or lumped parameter models is, at least in part, driven by the availability of more and more powerful and affordable computers [35, 36]. On the other hand, integrated coastal zone management (ICZM) is an inherently and increasingly complex task (Fig. 12.) To provide support for a formal yet practical decision requires a new approach, involving a more open and participatory decision-making process. A new paradigm of man-machine systems is needed where the emphasis is no longer on finding an optimal solution to a well-defined problem, but rather on supporting the various phases of problem definition and solving process.

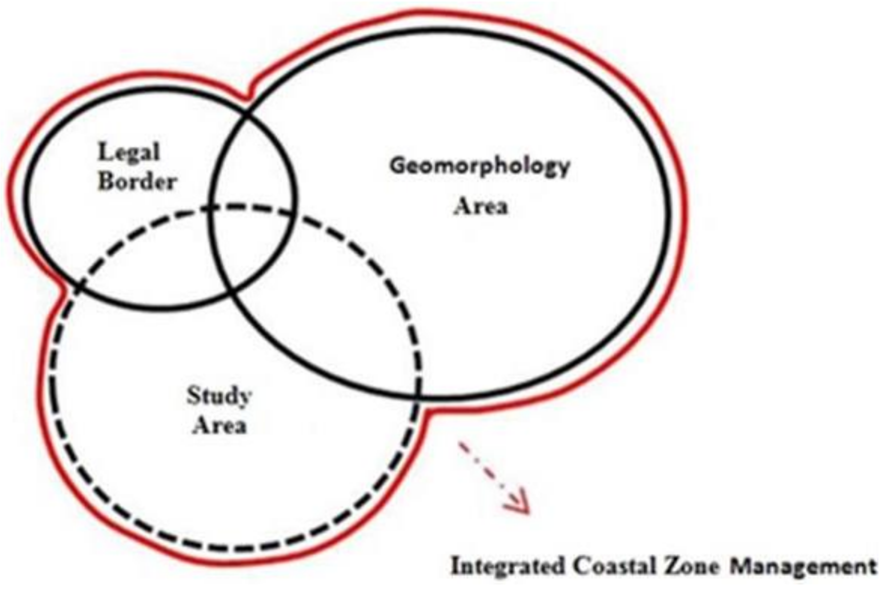

Figure 12. Integrated coastal zone management

Before creating information systems that would allow for ICZM as shown in Fig. 12, it is essential to determine the exact current situation of the area. Initially, a full survey of the geomorphological aspects of designated areas should be undertaken. Furthermore, the existing laws pertaining to coastal areas should be investigated and suggestions should be made for additional or new legislation to be implemented [37].

ICZM has a spatial attribute which comprises a large portion of the data and information used for supporting decisions at the administration level. It is combined with GIS to develop a user-defined structure that allows displaying a large amount of data. The advantages of ICZM based on GIS include:

1. Early identification of coastal zone problems,
2. Making stakeholders aware of coastal issues,

3. Providing information for decision-making processes related to coastal zone management [38, 39].

GIS can be used for the evaluation and continuous monitoring of environmental conditions. The information technology (such as GIS) tools to be applied to this range of problems include: Dynamic land use simulation modelling for long-term predictions of land use and land cover changes; a dynamic state-transition model based on transition probabilities, dynamic external driving forces including policy, zoning, master plans, regulatory guidelines and first-order production rules that can modify the primary transition rules and probabilities [17]. ICZM in terms of performance measurement and evaluation is performed through the development indicators. It also helps achieving consensus among stakeholders [40]. Once the spatial data is collected, it can be processed based on scenario modelling to priorities the issues that are important for comprehensive coastal management, which avoids disputes in the decision-making and planning process. ICZM requires tools that cope with interdisciplinary, spatial, temporal or organizational scales and knowledge from various sources [41].

There are new opportunities to use the features of geomatics technology on coasts and shorelines. This is especially useful in older cities such as Istanbul, where the shoreline is no longer natural and has been encroached upon by buildings and other structures. New technology based on 3D GIS city modelling uses virtual reality to facilitate successful town planning. Visual reality tracking technology providing stereoscopic visualisation of 3D structures assists the user to better comprehend the complex data sets and to utilise this information to ensure that buildings are safe from the threat of rising sea levels [42].

In this study, the design and development of 3D modelling was undertaken to be used in ICZM. 3D modelling was chosen to help prevent potential design errors and provide a better understanding of the study area. Moreover, it is considered that the 3D designs can be better compared with each other. Briefly, the use of 3D technology makes it easier to communicate and process information during the planning stage, and allows the preparation of a more transparent and better design. Since there are several environmental, political and other factors affecting the planning decisions, 3D modelling is the best choice in terms of allowing changes to the design and updating the models at different scales. 3D modelling also reduces the time and cost involved in planning.

6. CONCLUSION

Integrated Coastal Zone Management is globally one of the important research fields. ICZM must be sensitive to the nuances of the all types of ecological variables for urban coastal ecosystems and aid in suitable human utilization of coastal areas. In large and historic cities such as Istanbul, coastal zone management is of great importance particularly in terms of urbanization and city modelling. This study aimed to present the design, development and implementation of a 3D model of the Golden Horn in Istanbul to contribute to coastal zone management of the area.

The difficulty of such complex work derives from the fact that these different systems are studied by different disciplines that have little in common. The human population is still growing rapidly; rural to urban migration continues in developing and under develops countries and most of the world's cities still lie in the coastal zone.

The international importance and changing nature of coastal management and the necessity of increasing sustainability in coastal development should be central to the pursuit of global coastal area sustainability. ICZM must be based on sound scientific information from a range of disciplines before decisions can stand up to legal and political challenges. Such challenges are sure to be raised by those concerned, whose activities may be affected by the ICZM process. It is recognised that different types of information are required at different stages. In general, several types of data and information are used in supporting the decision-making process in ICZM by identifying areas to be developed, protected or conserved. One of the main concerns before a decision is reached on a certain area is the impact of development to the coastal zone. GIS allows gathering all the related geographic information to help in this process. In this study, a solid model was successfully generated in all the coastal zones of the Golden Horn at LoD1. Terrestrial laser scanning application was completed at LoD3, at which the existing situation could be modelled using the facade drawing data, generated from the laser scanning data of the selected area of the Golden Horn. The sub-bottom morphology of the Golden Horn (bathymetric data) was combined with geo-informatics methods. These products can be used by decision makers who are in charge of planning historically the most valuable region of Istanbul. These products can also be provided as 3D instead of 2D for decision makers.

Finally, in this study, the 3D model was designed and developed using remote sensing and GIS. The laser data was converted to CAD data and data integrity was ensured by integrating GIS with ArcGIS software along with other raster and vector data. In addition, ArcGlobe and ArcScene were utilised in the creation of the 3D environment. In this study, the collection and use of data from 3D city models was investigated. Furthermore, the paper demonstrated the level at which the model can be associated with the current data and that a 3D city model can be created with the available data. All other data except for LoD4 that displays the inner surface of the building and the roof details that make up LoD2 and 5 can be obtained to create the 3D city model. Thus, a 3D city model comprising LoD0, 1 and LoD3 was created and this presents an innovation in itself for the management and protection of coastal areas.

Obviously the city ecosystem and the coast ecosystem are dissimilar. Not only temporal but also spatial correlation is complex. The methodology is notable for its low cost, precision, practicality and thoroughness, and can be applied to the entire Golden Horn historical heritage and their features. The documentation system provides a flexible, precise and easily-applied instrument for recording the full appearance, materials, stratification palimpsest and conservation status, in order to identify restoration criteria and intervention priorities, and to monitor and control the use and conservation of Golden Horn historical heritage and their features. This modelling process contributes to the information on which planners and associated people can base their development decision-makers. Consequently, this study demonstrates the benefits of this technique that can be applied to other coastal areas of Istanbul.

We believe that this paper highlights the potential of three-dimensional (3D) models as an integrated tool to assess, visualize and possibly value future coastal landscapes through the use of high quality, yet dissimilar, data related to management of the urban coastal zone.

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