Indian Journal of Science and Technology, Vol 9(39), DOI: 10.17485/ijst/2016/v9i39/92774, October 2016
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Research Directions on GIS Database Design and Management

Venkateswari Pichaimani[1]* and K. R. Manjula[2]

[1]SRC, CSE, Sastra University, Kumbakonam – 612001, Tamil Nadu, India; venkat_eswar2000@src.sastra.edu
[2]School of Computing, SAP, CSE, Sastra University, Thanjavur - 613401, Tamil Nadu, India; manjula@cse.sastra.edu

Abstract

Objective: Geospatial Information System (GIS) is predominantly used in urban planning, and improves quality of people living in an area in many ways. Even though so many hardware and software systems are employed in GIS, the database gains the greatest significance. The intension is to progress a spatial database that should be used as a representation or model of the world, particularly to design for a very specific application. **Analysis:** The GIS data framework is the methodology proposed to promote an application specific spatial database. It comprises of integrating heterogeneous type of data, followed by constructing a semi-structured multi dimensional data model which directs to design a spatial database. **Findings:** The novelty in this GIS data framework is Building Information Model (BIM) integrated with the traditional data in support of answering indoor spatial queries. Moreover, this framework worked with BigData to support heterogeneous type of data and to automate decision support system. **Enhancements:** The views focused on the case studies in this paper help to travel in a new direction of GIS specification, utilization and research from the routine methodologies. This paper widens the scope of research directions in order to establish new techniques in each diverse field.

Keywords: Big Data, BIM, GIS, Spatial Database

1. Introduction

Geospatial Information System is a computing technology that analyzes geographical data and stored in a well structured format. Next it supports manipulation of stored data which may be helpful in visualizing geographical map as a more informative one. To provide solutions to geographic problems require spatial thinking. Through spatial thinking the clear and simple solution through analysis of data become simple. Through this information of each and every place on earth's surface can be provided. The knowledge about a place such as "what is where and when" can be gained. In day to day life GIS makes a great impact on our life style which may be realized (implicitly or explicitly) or not even realized. To an individual to start a day by checking the climatic condition and to be guided with GPS navigation, GIS provides more crisp solutions. In public service from ambulance dispatch to crime identification the services render by GIS are unavoidable.

To be lucid, the integration of geography with data is termed as GIS. Each and every moment our environment is keep on changing rapidly. Keeping track of this rapid change in spatial data is a challenging task. By recording these kinds of temporal information leads to decision support systems. That is the main utility of GIS. It helps to open new avenues for scientific inquiry and creates spatial data infrastructure in which no restrictive boundaries are available. We are living in two types of environment namely natural and manmade which is illustrated in Figure 1. The first one is powerful and self regulated and the other is created and managed by human being. These two environments increase conflicts in their own way in terms of controlling them. The common vision of GIS is to develop abstraction of earth surface as a "Digital World" which is illustrated in Figure 2. This "Digital World" provides better way to understand the features of earth's surface. It treats earth as a system to represent, control and communicate. The systems such as measurement, planning and

*Author for correspondence

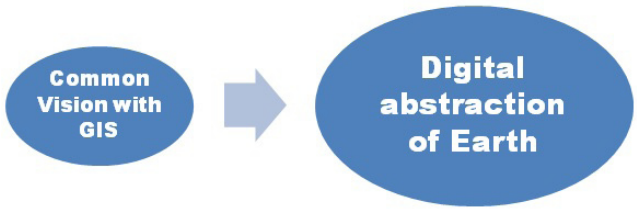

Figure 1. Our environment.

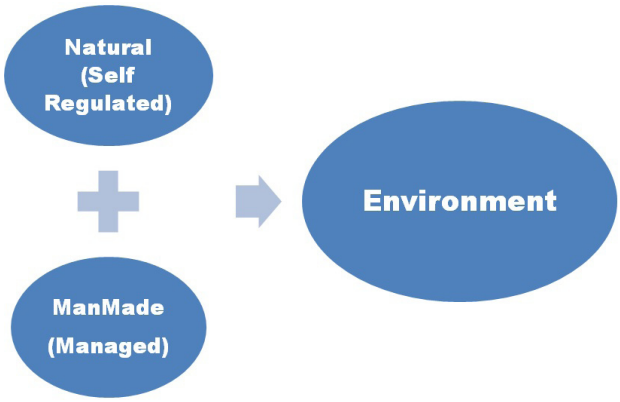

Figure 2. Vision of GIS.

modelling are developed which provides services such as management, decision making and monitoring.

2. Applications of GIS

GIS is used for different purposes by adapting recent trends and technologies which is described in Figure 3. During climatic change conditions, flood is one of the main factors that affect the people from their routine work. The Spatial Integrated Policy Infrastructure[1] is an integrated tool of information management as well as decision ability with recent technologies. In control of atmospheric pollution, emission and recycling of Carbondioxide[2] near power plants are handled efficiently and cleverly by sophisticated database system generated by GIS. In health care[3], GIS based tools are created to monitor atmospheric five main air pollutants for hospitalization cases. The selection of site for coal-fired power plant[4] is suggested after analysing so many spatial factors. The GIS alone can be the powerful tool to organize all spatial factors in a centralized manner. To increase effectiveness and robustness in site selection the fuzzy programming (interactive) and Genetic Algorithm-II (non-dominated sorting) techniques is applied along with GIS framework. The optimal

Figure 3. Applications of GIS.

location selection of Photo Voltatic panels[5] in energy supply system is the major role for municipal service in a city. The same especially for a campus[6] roof selection which also plays as a considerable role. GIS identifies suitable roof tops and maximizes the utilization of Photo Voltatic installations. The assessment of wind energy resource[7] in offshore is to manage energy production and operational costs. The parameters such as potential of energy production, maintenance and operational cost are considerably supported by GIS.

The GIS modelling framework provides serviceability to keep archaeological sites[8] from harmful anthropogenic and natural hazards. In coastal vulnerability approach[9] the spatial and temporal progression of oil spill avoidance and providing alertness. In health and place, GIS is useful in community integration[10] research what are all the things happening related to community and where. A visual environment is presented to query and identify locations based on their activities and interaction on community basis. To create environment feel like to be a part of a family or community.

In the field of land slide study area, GIS modelling is a better acceptable solution than the grid overlay method[11] which is an exhausting and time consuming process. It can be extended for earthquake[12] triggered landslides. In site selection GIS has considerable application in organic farm land selection[13] and seismic station installation[14]. The former supported by GIS along with analytical

hierarchal process. The latter is to observe vibration of earth with seismic noise survey. GIS is a profitable and beneficial approach for Spatial Planners and geographers to make decision support tool. In urban planning GIS simulate transportation network model[15] to avoid traffic congestion and transportation delay which is a challenging task. It provides simulation model and optimization techniques for several functionalities. GIS is an effective tool which plays a central role in wide range of applications and supports all kinds of data. In urban area, due to the increased population growth the environmental pollutions and traffic congestions are the threatening issues which are handled effectively by GIS. The GIS tied with remote sensing data plays a wonderful role to manage land use, land cover changes and vegetation cover of a National Park. The added advantage of park management is for monitoring of ecological heritage and distribution of exotic or invasive species[16]. The drastic increase of population and development of mega cities are one of the major factors for the climate change especially in rain fall[17]. The analysis of long term trend of rainfall data with GIS techniques capable of predicting increasing or decreasing of rainfall.

3. Role of Computer Science in GIS

To solve anything with GIS, computing plays an indivisible portion for GIS analysts which can be referred in Figure 4. The thing observed from the survey of the past decade on the basis online and offline the professionals from computer science gained GIS oriented jobs rather than geography. The same reflected in research scope of GIS along with Computer Science which is evidenced from the chart in Figure 5. The graphics display techniques such contour lines, shadings etc. as are used to display abstraction of the world in a topographic maps. The entire analysis and all location based functionalities are carried out in the form of visualization which leads to the success of GIS.

The GIS data are stored in a centralized manner for flexible access and to manage in geo databases. These data can be leveraged in web or mobile environments. The application design provides a platform to design, configure and integrate various services or functionalities. The system administration is a field in which management of hardware, software, storage, server and security

Figure 4. Role of computer science in GIS.

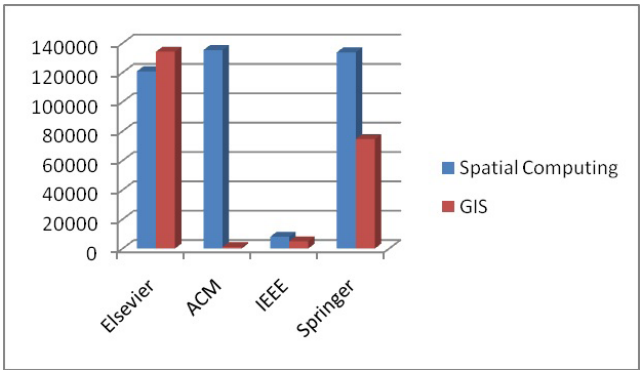

Figure 5. Journal evidence of GIS.

are maintained. The system administrator provides the responsibilities to manage the entire data and leverage the power of access. The role of application designer and system administrator are two extreme opposite end but tied together to make up a full pledged system.

Obviously, security is to be provided if there is an information system. In internet, the hacking and malware are the serious threatening issues in data security. In GIS data transmission internet is the predominant mode and data authenticity can be succeeding with water marking techniques[18]. Lot of research scope can be involved in GIS data security because it gaining importance almost in all fields from lower (buildings) to higher scale (cities).

4. Relevant Technologies

GIS is a special kind which is entirely different from other related systems such as DBMS, CAD/CAM, Automated

Mapping and Scientific visualization System. In case of DBMS the implicit information such as names of countries, states, cities, etc. and their zip codes can be recorded. But there is no recording of geographical coordinates and query related to this are difficult. The location search or identification of an object by its longitude is found to be difficult. For example, a spatial query "to identify petrol bunk around 100 N or across town from 300 E Main?" could not be processed which lacks in geographical data management.

The automated mapping is a cartography tool which supports two dimensional graphical design and display which has limited database facilities. The facility management integrates different sources of data but lacks in spatial analytical tools. The CAD is mandatory for engineering design and display system which supports 3D graphics. It deals with shapes and dimension but lacks in reference of geographical location. The CAD refers earth as digital cube where as GIS refers as digital world. The database management system existing in CAD but it is limited to non-spatial data. So many visualization systems are there which concentrate on different views and projections. Mainly they all lack in database support and spatial analysis tools.

5. Importance of Database in GIS

What actually needed for information system is database to implement. Being GIS is a special kind of information system also requires database which should integrate spatial as well as non-spatial data. The GIS database contains data about spatial features, activities or events which is described by means of points, lines or polygons (areas/surfaces). GIS manipulate queries on these kinds of data and retrieve spatial information. A decision making system is achieved with set of automated functions. Information system is a management of data for sharing between people by adopting latest technology in data maintenance and communication network. The main two types of GIS are spatial and non-spatial data (attribute data). The spatial data describes location of a geographic feature in the form of coordinates and projections. The attribute data describes properties of spatial entity and characteristics of spatial feature and not deal with location information so called non-spatial data. To distinguish the two the location of a city is spatial data whereas coverage, pattern of roads, number of buildings etc. are non-spatial data. GIS identifies quick patterns and able to answer challenging questions. In urban growth plans and policies various changes and patterns can be observed to suggest growth models. To do so the integration of remote sensing data and GIS techniques is supportable and Shannon's entropy model helps to identify urban sprawl[19].

6. Research Scope in GIS Database System

The Oracle and ESRI[20] are the leading industry which deals with spatial database management systems. The Oracle helps to cover the nature and properties of spatial data with new set of data types. The Environmental System Research Institute (ESRI) is an international software industry which provides training, support and services for geographical information system. It is a supplier of wide variety of software products such as ArcGIS, ArcView, ArcGISServer, ArcIMS, ArcSDE, ArcGISMobile, ArcPad to fulfil different requirements. The ESRI[21] is a geo technology developed by adopting young technologies such as Cloud computing, BigData analytics etc., in computing. The Geo Spatial Design civilizes the Geo visualization and Geo analytics by easy and flexible integration of the above mentioned computing technologies. The open source softwares such as PostgreSQL, MySQL, Cassandra and MongoDB contribute their roles in spatial data development and management. The Cloud computing[22] provides a platform for data storage and computation in ubiquitous manner. The availability of Internet made this technology a successful one. Its usage various from simple mail services to Google map with Flickr. The ESRI tools are made available in online by using this cloud services. By doing so the mapping services such as creation, interactivity and sharing are possible without any limits.

The representation of geographical location and dimension of things with 3S (RS, GPS, GIS) technology is used for spatial modelling[23]. The data gathered from Internet of Things is processed and managed which improves data intelligence with analysis and mining.

The uncertainty issues in data set decreases the performance of clustering large data set and quality can be improved by using Voroni, Mahalanobis and Clara technique or by combining all the three together[24]. The SOA (Service Oriented Architecture) supports for monitoring and managing information from utility networks (electricity, sewage, water, gas, communication networks etc). BigData capable of handling large set of disparate data[20]

especially raster data set which is a challenging task. The storage of large geographical data set of past and future is not only the issue but integration and management of diverse information is also handled by Hadoop file system. It supports rapid retrieval and provides hope for interactive processing as well as analysis of large volumes of satellite data.

Usually GIS application is preferable for public administration, urban planning and larger organization. Its application may even be extended to various types of building with large landscapes and amenities. The integration of spatial and non-spatial data of a building leads to a smart building. The combination of buildings with landscape structure leads to a smart city which can be further extended to country and world (refer Figure 6). The types of buildings with large landscapes (wiki) with its examples are illustrated in the figure 7. GIS is a major keyword for smart city projects. So, every private and public institution starts adopting GIS standards in the management system which make smart city projects easy and worthy one.

The BIM (Building Information Model) standards are incorporated into management system which provides structured data and information. The integration of BIM and GIS plays a considerable role for the development of smart projects for an initial building level. The size of BIM increased drastically every year in terms of Terabytes by extending so many Infrastructure model. So, BigData analytics[25] may be the preferable option for storage and management of building information in terms of Terabytes. The detailed description of landscape along with buildings can be useful for next level like smart city projects.

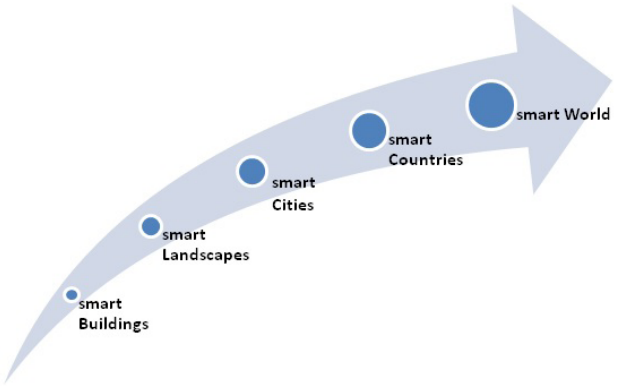

Figure 6. Formation of smart World.

Figure 7. Research scope in types of buildings.

The GIS based models can be created for each specific types of building which describes both indoor (BIM) and outdoor views (GIS). This kind of database management of both spatial and non spatial data creates a new platform for further research scope in knowledge reasoning and discovery as well as in data mining to identifying pattern trends. A semi structured multidimensional model can be incorporated with the database system to provide various web and mobile oriented services. The architectural diagram to create such model and database management system is described in Figure 8.

The sources of GIS data may be non-spatial data of a spatial location, geographic features described on a thematic map, remote sensing of satellite or aerial images, shape and dimension of CAD data, GPS coordinates, survey measurements of boundaries, surface modelling, utility and transport system etc. The integration of these data and migration are possible with data conversion tools and collected in dataware house. The integration of BIM with GIS is solved with so many preferable solutions. The main issue is the mapping of IFC (Industry Foundation Class) with CityGML (City Geography Markup Language) is a challenging and critical task. The one to one mapping of integration is not at all possible because in CityGML four LODs (Level of Details) are there. A user perspective simplified surface model[26] could be generated which is easier to load and process building information on GIS.

Once the data becomes ready it's an initial way to construct a structured data model which used to understand what the problem is. GIS data modelling is a needy way to "think spatially". It helps to represent our world in a GIS. The functional patterns that are visible in geographic space are identified and spatial relationships between them. As always a structure is helpful to combine them together and drive

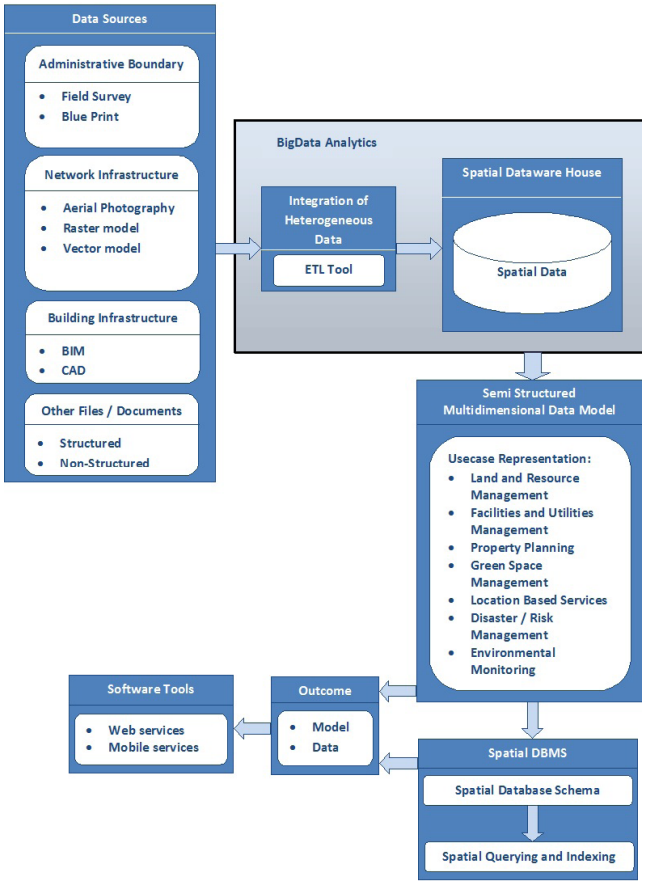

Figure 8. GIS database design and management (architecture).

meaningful models. The major objective of the GIS modelling is to study and understand the phenomena of spatial objects in the real world. Its purpose is to represent meaningful features, events and processes in geographical space. Moreover, it could be split into several layers such as land and resource management, facilities and utilities (energy saving) management, property planning, green space management, transportation network, disaster management and environmental monitoring. The formal model established with CASE tools[27] decreases complexity and increases flexibility as well as extensibility. Using this GIS modelling the generation of spatial database schema is easier to build which in turn helps to develop spatial databases.

Spatial databases are used in a wide variety of real word applications. The main purpose is to manage and integrate spatial and non spatial data. The GIS data can be uniformly stored, managed and accessed in a centralized manner. The main advantage of this spatial data management is to leverage spatial information more effectively. The way of GIS storage is in the form of vector and raster data. The vector data is stored as thematic layers of feature classes. In vector data the feature class is the collection of geographic features in the form of geometric types like point, line and polygon, attributes (non spatial) and coordinate positions. The feature data set is a collection of feature classes and to define relationships between them. The raster data is stored as its own thematic layer and multiple raster images are grouped as a raster catalogue.

The spatial query is a statement or logical expression that identifies geographic features based on a location or its relationship. As spatial database is a representation of points, lines or polygons, the spatial query might answer which points are contained within a polygon or set of polygons. They are also capable of answering features within a specified distance of an object or adjacent object's features. There are three main categories for spatial queries based on spatial relationship takes place between various features and they are direction, distance and topology. The first one deals with orientation of features and next one asks features within a specified distance of others. The last one queries about geometric features of spatial objects and how it related spatially. There are two forms in distance query that are nearest neighbour queries (kNN) and range queries. The range queries[28] inquire for certain objects within a predictable distance. The coverage of the interested objects is identified by forming regions (as polygons) and finding centroids.

The GPS technology led to the plenty of applications impacting every aspect of recent trendy life style. It is an essential element for road networks to carry through geo-positioning.

In k-Nearest Neighbour[29], the Spatial Keyword Query (SQK) enhances the road network proximity and relevance objects identification and at the same time filters out the unqualified objects efficiently. The spatial query types and examples are formulated in the Table 1.

The spatial indexing is a mandatory technique required to perform efficient spatial query processing. Actually the main objective is to speed up the query process. The data structure which is more prominent to optimize spatial queries is tree structure. The proficiency[30] of indexing is evaluated based on the size, answering capability and efficiency in time taken to construct.

7. Back Bone of Geo-Database Development

The primary and indispensable step of Geo-Database is 'modelling'. The term 'spatial modelling' is quite common

Table 1. Spatial queries with examples

Spatial Query Types	Example Queries
Direction	• What cities are east of Chennai? • Which cities are south of Cauvery origin? • From which directions birds arrive to vedanthangal?
Distance	• How many cities are there within 10 km of seashore? • How far is it from Chennai to Trichy? • How far apart are all the earthquakes with magnitude of 7 or greater?
Topology	• Do any two lines share boundaries? • Is any point contained within any polygon? • Is any line cross other?

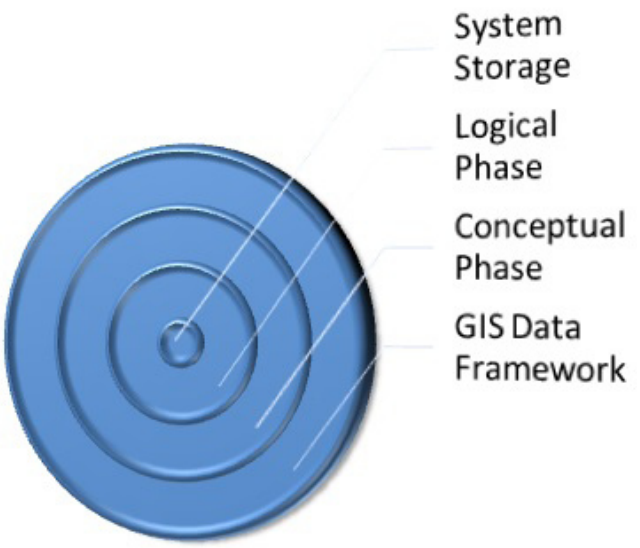

Figure 9. Modulating GIS data framework.

in different application areas. So it is highlighted as 'Geo-spatial modelling' which is focused on geographical data. The pieces of data modelling, structures and its applications comprise the GIS environment. Initially, spatial data is structured and modelled without temporal information. Once the implementation is succeeded it can be extended with temporal details. The GIS data framework is comprised of three approaches namely conceptual, logical and system storage[31] which are illustrated in Figure 9.

The first one deal with design phase (i.e. modelling) and the next one deal with implementation phase. The final stage represents the system internal storage and access. The data elements in the data model are integrated one from different data sources which is mentioned earlier. Next the relationships among them and rules and operation on these data are to be defined. There are different data model representations such as relational, network, hierarchal models, object oriented etc. Among these models mentioned the object oriented data model[32] illustrates the real world entities clear and flexible. The main advantages are extensible and reusable and its benefits are list in the Table 2. Because the GIS data is dynamic in nature these advantages make the GIS framework stronger.

The spatial data infrastructure provides a framework for the generation, implementation, maintenance and distribution of geographical information at national or global level. The entire basic structure is changed into spatial infrastructure as a development of GIS trends. The necessary tool to implement spatial data infrastructure that is described above is illustrated in a table in Figure 10.

Table 2. Object oriented features with benefits

Object Oriented Features	Benefits with GIS terms
Encapsulation	The spatial data (geometric plus thematic) and operations are encapsulated to represent the state of a spatial object and its behaviour.
Classification	The abstract definition of a spatial object.
Inheritance	It maintains parent – child relationship and its main advantage is reusability which is more important for spatial features.
Generalization and Specialization	The classes having common properties and behaviours are organized in a hierarchal order as a general class. Among these the classes having unique features other than common is term as specialization. Example: 'Highway road' and 'Subway road' are considered as a general Road and the reverse is considered as specialization.
Association	The collection of many other objects and it may be homogeneous or heterogeneous. Its special form is aggregation and restricted form is composition.
Aggregation	The list of objects which make up an object is termed as aggregation. Example: A 'city' is made up of other objects as roads, buildings and trading centres.

GIS Formation	Tools Required
Conversion of Raster Model to Network Model	PostGIS/ ArcGIS
Integration of BIM with GIS	Talend ETL Tool
BigData Analytics	Hadoop
Spatial Data Modelling	CASE Tools (UML)
Spatial DBMS	PostGIS / Oracle Spatial

Figure 10. GIS formation and its tools requirement.

8. Case Studies for GIS

The residential apartments and military services are two different extreme end applications. The GIS plays an important and inseparable role in these two fields. Nowadays the residential apartments are attracted with so many good and sophisticated services. So GIS management and services may gain good impact on real estates. As a case study, take up the information system for a well equipped apartment with various amenities. It views geographical layouts and physical data as two different forms. The aim of GIS is to make different sources of data as a unified system. The group of homogeneous features are grouped as GIS layer. This layer represents map structure and various utilities such as buildings, road network, water supply, sewage, phone supply, etc. The integration as a single system capable of achieving functionalities such as construction, green space management, route layout, entrance of a block and lift, reconstruction suggestions, wi-fi or surveillance camera foot coverage etc. The spatial queries such as inner and outer queries and location of external amenities such as swimming pool, party hall, ATM centre, etc. can also be carried out.

In the case of military services, the GIS implementation is vital one to manage information under one roof. The different categories of buildings in military services are castle, barracks, arsenal etc. The castle is a large building covered with thick compounded wall which withstands against attacks. The barracks are nothing but group of residential building of soldiers. The arsenal is a place where collection of weapons and equipment are stored. The entire geographical information system can be organized and managed efficiently by GIS. It solves the existing complexity and structural issues. The alternate suggestions can be provided for inadequate of space to house soldiers, security to the arsenals and castle by monitoring and route map for pedestrians, cycling or vehicular circulation.

9. Conclusion

In this proposed GIS data framework BIM and BigData are acting together to develop a GIS database to automate answering of indoor as well as outdoor queries. The GIS, BIM and BigData are the key ideologies which draw special attention in research of database. In future, algorithms and techniques can be derived to enhance identification and extraction of data from BIM to handle indoor queries. Moreover, research can be narrowed down to design a system to a dedicated application for sophistication. It opens new avenue for numberless research in spatial data processing, management, mining and analysis.

10. References

1. Ran J, Nedovic-Budic Z. Integrating spatial planning and flood risk management: A new conceptual framework for the spatially integrated policy infrastructure. Computers, Environment and Urban Systems. 2016; 57:68–79.
2. Gouareh A, Settou N, Khalfi A, Recioui B, Negrou B, Rahmouni S, Dokkar B. GIS-based analysis of hydrogen production from geothermal electricity using CO_2 as working fluid in Algeria. International Journal of Hydrogen Energy. 2015; 40:15244–15253.
3. Wang W, Ying Y, Wu Q, Zhang H, Ma D, Xiao W. A GIS-based spatial correlation analysis for ambient air pollution and AECOPD hospitalizations in Jinan, China. Respiratory Medicine. 2015; 109:372–378.
4. Xu J, Song X, Wu Y, Zeng Z. GIS-modelling based coal-fired power plant site identification and selection. Applied Energy. 2015; 159:520–39.
5. Camargo LR, Zink R, Dorner W, Stoeglehner G. Spatio-temporal modelling of roof-top photovoltaic panels for improved technical potential assessment and electricity peak load offsetting at the municipal scale Computers, Environment and Urban Systems. 2015; 52:58–69.
6. Kucuksari S, Khaleghi AM, Hamidi M, Zhang Y, Szidarovszky F, Bayraksan G, Son YJ. An integrated GIS, optimization and simulation framework for optimal PV size and location in campus area environments. Applied Energy. 2014; 113:1601–13.
7. Cavazzi S, Dutton AG. An Offshore Wind Energy Geographic Information System (OWE-GIS) for assessment of the UK's offshore wind energy potential. Renewable Energy. 2016; 87:212–28.
8. Agapiou A, Lysandrou V, Alexakis DD, Themistocleous K, Cuca B, Argyriou A, Sarris A, Hadjimitsis DG. Cultural heritage management and monitoring using remote sensing data and GIS: The case study of Paphos area, Cyprus. Computers, Environment and Urban Systems. 2015; 54:230–9.

9. Nelson JR, Grubesic TH, Sim L, Rose K, Graham J. Approach for assessing coastal vulnerability to oil spills for prevention and readiness using GIS and the blowout and spill occurrence model. Ocean and Coastal Management. 2015; 112:1–11.
10. Chan DV, Helfrich CA, Hursh NC, Rogers ES, Gopal S. Measuring community integration using Geographic Information Systems (GIS) and participatory mapping for people who were once homeless. Health and Place. 2014; 27:92–101.
11. Raghuvanshi TK, Negassa L, Kala PM. GIS based grid overlay method versus modelling approach – A comparative study for Landslide Hazard Zonation (LHZ) in Meta Robi District of West Showa Zone in Ethiopia. The Egyptian Journal of Remote Sensing and Space Sciences. 2015; 18:235–50.
12. Xu C. Preparation of earthquake-triggered landslide inventory maps using remote sensing and GIS technologies: Principles and case studies. Geoscience Frontiers. 2015; 6:825–36.
13. Mishra AK, Deep S, Choudhary A. Identification of suitable sites for organic farming using AHP and GIS. The Egyptian Journal of Remote Sensing and Space Sciences. 2015; 18:181–93.
14. Qaddah AA, Abdelwahed MF. GIS-based site-suitability modelling for seismic stations: Case study of the northern Rahat volcanic field, Saudi Arabia. Computers and Geosciences. 2015; 83:193–208.
15. Huang B, Pan X. GIS coupled with traffic simulation and optimization for incident response. Computers, Environment and Urban Systems. 2007; 31:116–32.
16. Zafar SM. Spatio-temporal analysis of land cover/land use changes using geoinformatics (A Case Study of Margallah Hills National Park). Indian Journal of Science and Technology. 2014 Jan; 7(11). DOI: 10.17485/ijst/2014/v7i11/47792.
17. Meena PK, Khare D, Shukla R, Mishra PK. Long term trend analysis of mega cities in Northern India using rainfall data. Indian Journal of Science and Technology. 2015 Feb; 8(3). DOI: 10.17485/ijst/2015/v8i3/59580.
18. Aybet J, Al-Saedy H, Farmer M. Watermarking spatial data in Geographic Information Systems. H. Jahankhani, A. G. Hessami and F. Hsu, editors. ICGS3 2009, CCIS. Berlin Heidelberg: Springer-Verlag. 2009; 45:18–26.
19. Al-sharif AAA, Pradhan B, Shafri HZM, Mansor S. Spatio-temporal analysis of urban and population growths in Tripoli using remotely sensed data and GIS. Indian Journal of Science and Technology. 2013 Aug; 6(8). DOI:10.17485/ijst/2013/v6i8/36357.
20. Lopez M, Couturier S, Barrera K. Design scheme for spatial database of climatic and environmental variables in Mexico integrating BigData Technology. Procedia Computer Science. 2015; 55:503–13.
21. Wilson MW. On the criticality of mapping practices: Geodesign as critical GIS? Landscape and Urban Planning. 2015 Oct; 142:226–34.
22. Vance TC. A primer on cloud computing. Cloud Computing in Ocean and Atmospheric Sciences; 2016. p. 1–13.
23. Hu M, Li C. Design smart city based on 3S, Internet of Things, grid computing and cloud computing technology. Y. Wang and X. Hang, editors. IOT Workshop, CCIS 312; 2012. p. 466–72.
24. Manjula KR, Keshari AK, Pahlazani A. An approach to perform uncertainity analysis on a spatial dataset using clustering and distance based outlier detection technique. Indian Journal of Science and Technology. 2015 Dec; 8(35). DOI: 10.17485/ijst/2015/v8i35/71972.
25. Correa FR. Is BIM big enough to take advantage of BigData analytics? Proceedings of the 32st ISARC; Oulu, Finland. 2015. p. 1–8.
26. Kang TW, Hong CH. A study on software architecture for effective BIM/GIS-based facility management data integration. Automation in Construction. 2015; 54:25–38.
27. Bedard Y. Principles of spatial database analysis and design. 1999. Available from: http://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch29.pdf
28. Taniar D, Rahayu W. A taxonomy for region queries in spatial databases. Journal of Computer and System Sciences. 2015; 81:1508–31.
29. Luo C, Junlin L, Li G, Wei W, Li Y, Li J. Efficient reverse spatial and textual k-Nearest Neighbour queries on road networks. Knowledge-based Systems. 2016; 93:121–34.
30. Wei-Kleiner F. Tree decomposition-based indexing for efficient shortest path and Nearest Neighbors query answering on graphs. Journal of Computer and System Sciences. 2016; 82:23–44.
31. Worboys MF, Hearnshaw HM, Maguire DJ. Object-oriented data modelling for spatial databases. International Journal of Geographical Information Systems. 1990; 4(4):369–83.
32. Pinet F. Entity-relationship and object-oriented formalisms for modelling spatial environmental data. Environmental Modelling and Software. 2012; 33:80–91.