Integration of Geographic Information Systems (GIS) in Civil Engineering: A Review of Applications, Challenges, and Future Direction

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Abstract

This study aims to give information systems researchers an overview of geographic information systems (GIS) and a research framework. The article includes a study framework for GIS and summarises the key features, capabilities, and functions of GIS. Furthermore, a number of study avenues are recommended, including those pertaining to GIS management, organisational effects, cooperative problems, assessments of the efficacy of decision-making and social implications in both developed and developing nations. An increasing amount of research is demonstrating the benefits that come from integrating Geographic Information Systems (GIS) with Building Information Modelling (BIM). For a variety of reasons, the two systems' integration is challenging. The most important of them is data incompatibility since coordinate systems, areas of interest, and data formats differ in how BIM and GIS data are generated, managed, examined, saved, and displayed. In order to: (1) identify the most pertinent data models used in BIM/GIS integration and comprehend their benefits and drawbacks; (2) take into consideration the possibility of other data models that are available for data level integration; and (3) offer guidance on the future of BIM/GIS data integration, this paper will review the pertinent research papers.

Keywords— Building Information Modelling (BIM), Geographic Information System (GIS), Integration, Data Interoperability.

INTRODUCTION

Geographic Information Systems (GIS) and Building Information Modelling (BIM) originate from distinct fields of expertise. Through the integration of heterogeneous spatial data and various attribute data, as well as the derivation of knowledge through various spatial analysis tools and modelling approaches, GIS analyses and visualises location-related problems in geospatial science, environmental science, and natural resource management. BIM serves the Architecture, Engineering, and Construction/Facility Management (AEC/FM) domain by providing detailed 3D building models that could be used throughout the lifecycle of Both BIM and GIS have developed quickly in recent years. Since the introduction of the first widely used GIS programme, Canada Geographic Information System (CGIS), in 1966, GIS technology have been around for more than 50 years. Throughout this time, GIS has developed from a little, specialised technology to one with wide applications and influence in several fields. For instance, the governments of wealthy nations in North America and Europe heavily rely on GIS for disaster management. The global GIS market was valued at $8.98 billion in 2016 and is projected to increase at a compound yearly growth rate of 10.1% to reach $17.51 billion by 2023, according to a new analysis by P&S Market Research. Similar to GIS, the field of BIM is growing. By 2022, the worldwide BIM market is projected to have grown from $3.16 billion in 2016 to $7.64 billion. Many nations, such as the UK, Japan, and those in the EU, have mandated or specified the use of BIM for publicly financed construction and building projects due to the rising significance of BIM. GIS technology was extensively used in the AEC industry prior to the realisation that BIM and GIS needed to be combined. ArcSite was created to identify the best position for temporary facilities on building sites, and Cheng created a GIS-based system for tracking the erection process in real-time in conjunction with barcodes. Li managed on-site supplies and machinery using GIS to cut down on waste and boost productivity. In addition, GIS has been used to enhance safety during construction and optimise the placement of tower cranes on building sites. Combining GIS with BIM is becoming more and more common. The total number of citations each year about BIM/GIS integration from 2009 to 2017 is shown in Figure 1. There have been 100 times as many citations since 2009 from only 3 in 2009 to 313 in 2017. The relevance of this issue is further evidenced by the increased interest of scholars in BIM/GIS integration, which is behind the rising curve.

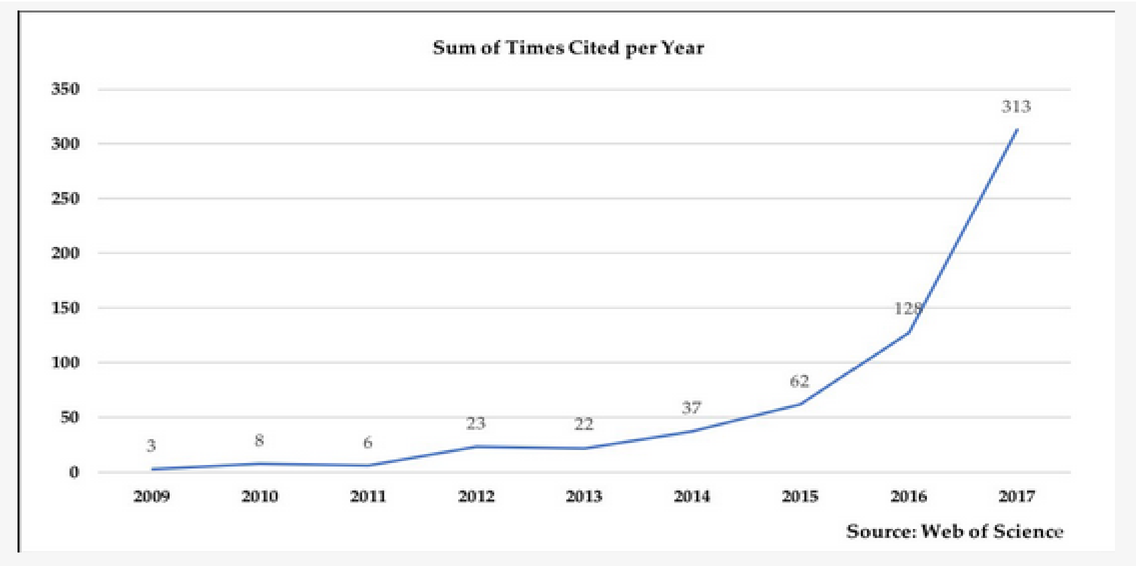

Figure 1- Sum of times cited per year from 2009 to 2017 regrading BIM/GIS integration

GEOGRAPHIC INFORMATION SYSTEM (GIS)

Defining GIS is a sensible first step in any discussion of the topic. It should be understood that GIS is more than just a tool for creating presentation visuals and creating maps. For instance, a number of spreadsheet programmes now come with GIS features that let users create map presentations. These features are helpful for making presentation visuals and other comparable presentations, but they don't fully capture the potential of full-function GIS. GIS should thus be seen as much more than just a straightforward mapping tool. While there have been a number of definitions of GIS proposed we favour the following: An accurate cartographic representation of things in space is the basis for all data collection, management, analysis, modelling, and display capabilities offered by a geographic information system (GLS), a computer-based information system. In light of this definition, it should be acknowledged that GIS differ from other information systems in a number of ways. To begin with, GIS are made to facilitate the creation of maps. There are several ways to create maps. These include scanning paper maps into digital format, creating maps from satellite or aerial photos, and gathering map coordinates with the use of global positioning systems (GPS) or surveying methods. These methods are either labor-intensive or need for specific tools and knowledge. Thus, in many respects, one of the trickier and more expensive parts of putting a GIS into practice may be acquiring data. Second, GIS are tools for managing spatial databases. Stated differently, they are capable of gathering and organising data that is specified by space. The first step in data management is to establish a connection between attribute and map data. The practice of tying attribute data to the spatial coordinates on a map is called geocoding. For instance, if a user wanted to map the locations of her customers' establishments, she might specify the points that would be used to represent each customer's location by geocoding each customer's address against the map's coordinates. Each address's longitude (location X-value) and latitude (location Y-value) are created as fields in the attribute database during the geocoding process. The connection that results creates a geographic database that combines the two data sets (i.e., the attribute and map data) in a way that works well together. This database gives the user a lot more information than each data set would if utilised independently for the majority of applications. GIS may be used to query data based on geographical criteria, criteria generated from the attribute data, or combinations of these criteria once these databases are created. Questions like "where is this house?" and "what is located at this intersection?" may be addressed with the use of spatial queries. While it is feasible to do searches like this using attribute data alone, GIS offers an integrated framework for doing so. Additionally, queries containing notions like "next to," "contained within," and other spatially-referenced questions which are frequently inaccessible with conventional database management systems can be executed using GIS. For instance, GIS includes tools that let users query data by pointing to objects, defining polygons, or selecting records within a specific distance from a location. While both types of database systems and GIS offer tools that let users perform queries based on attribute data, like an address or a zip code, GIS incorporates these tools more than other database systems. The ability to show geographic data falls into a third area of GIS skills. Put otherwise, a GIS may be used to represent maps. Furthermore, it is possible to see and show many sets of data at once.

GIS APPLICATIONS

The majority of businesses utilise information systems for one or more of the following essential functions: internal management and control, planning and decision-making, operations, inventory management, and transaction processing. Because GIS has features that are similar to those of other information system types, it may be used for these and other purposes. But GIS also have special features that set them apart from other types of information systems. Mennecke et al, for example, provided a framework that outlines the connections between GIS features and the business application areas where GIS may be employed (refer to Figure 2). This framework is helpful in establishing research possibilities and determining applications for GIS. Four fundamental GIS functions are outlined in the framework: database administration, design and planning, decision modelling, and geographic visualisation. The basic GIS capacity to depict data and information inside a geographically specified coordinate system (such as a map) is known as "spatial imaging." The database management function serves as a symbol for GIS's capacity to access, store, and modify data. The potential of GIS to offer analytical tools that can assist in decision making is represented by the decision modelling tool. Lastly, the GIS tools that are available for creation, design, and planning are represented by the design and planning function. The model depicts a number of particular GIS applications in addition to the fundamental GIS functionalities that may be used with them. Surveying and mapping, facility management, market analysis, logistics, transportation, strategic planning, decision-making, design, and engineering are some of these uses. Every one of these application areas makes use of every one of the fundamental GIS features, in one way or another. Every application, however, also depends more or less on one or more of the fundamental GIS functions; as a result, each application is displayed next to the core function or functions that are most crucial to it.

One of the first uses of GIS is automated mapping (AM), which is the process of surveying and mapping. Because AM enables businesses to produce geographical data internally, it is a crucial commercial tool. Furthermore, since the paper map is no longer the primary data source, GPS and remote sensing may be utilised to create maps with greater accuracy. Despite this, one of the most challenging aspects of using a GIS is acquiring maps. For example, data can cost more than twenty percent of the total cost of implementing a GIS, and data accuracy might pose serious issues. Defining positional accuracy (i.e., is the object where the map indicates it is?), attribute accuracy (i.e., is the object described and classed correctly?), and completeness (i.e., are all the relevant objects shown?) are some of the reasons why errors might occur. Furthermore, interpretational concerns might make data gathering more difficult as an object's classification can rely on both the user's intended use for the map (i.e., which items should be coded) and interpretative considerations (e.g., is this a tree or a bush?). Another factor that may limit an organization's capacity to create maps is the fact that a large number of business staff lack the cartographic expertise required to create maps. WI-Facilities management is a second commercial use for GIS. (FM). Because GIS give managers the capabilities to enable real-time facility and resource monitoring, they are helpful for FM applications. Organisations that are reorganising or that have regionally dispersed resources should pay much more attention to this. The database management and geographical visualisation features of GIS are crucial to FM. To put it another way, the majority of FM programmes manage or monitor facilities using historical or transaction (real-time) data. Additionally, they mostly rely on GIS's imaging capabilities to depict the spatial organisation of data items. To give organisations a method for creating, organising, and using maps and other spatial data, the AM and FM features of GIS are frequently integrated. These systems are known as AM/FM Systems.

Market analysis is the third use case for GIS. Understanding the consumer is market analysis's main goal. Because it offers a platform for visualising the geographical relationships between the market's suppliers, rivals, and customers, geographic information systems (GIS) are an effective tool for market analysis. The database management and decision modelling features are the main GIS features utilised in market analysis. Stated differently, the majority of market analysis software employ decision modelling, support tools, and historical or transactional (real-time) data to examine the marketing environment of the company.

Transportation and logistics issues make up the fourth application area for GIS. Because logistical challenges nearly always involve geographical data, GIS is helpful in solving these kinds of difficulties. In this situation, decision modelling may be carried out on a GIS platform, and analysis findings can be shown. There are several specialised GIS applications in this field, including as navigation, production control, inventory management, dispatch, and truck routing. The decision modelling function [S] is the essential component of logistical GIS and transportation. These systems make use of algorithms including material flow models, adjacency models, proximity models, transportation network models, and facility layout models.

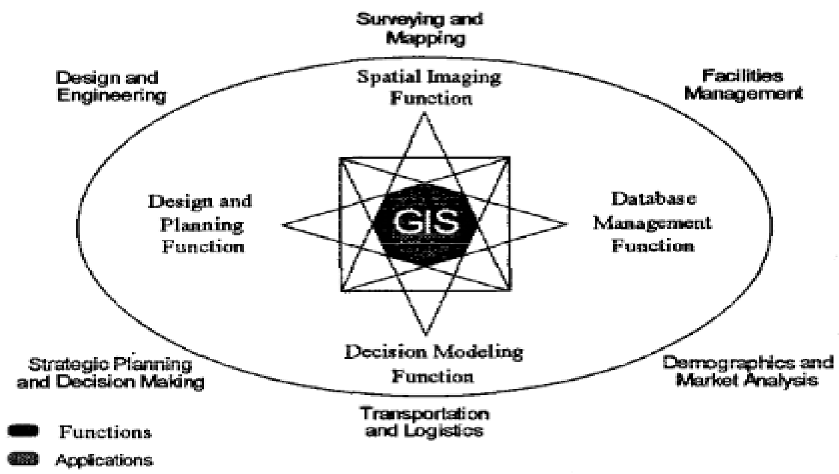

Figure 2- GIS Functions and Applications

DEVELOPING OF GIS

GIS and other information system types like management information systems and decision support systems are comparable in many aspects. GIS must be correctly managed in order to be used, much like these other systems. Scholars researching information systems have a wealth of material at their disposal that may be used to investigate GIS. For example, one of the main worries that management has when implementing new technology is whether or not employees would use and accept it. However, not much research has been done on GIS acceptance and dissemination in the commercial setting, for an overview of many case studies of GIS adoption in the public sector], the process of developing GISs, and cost/benefit tradeoffs. Up until now, the majority of research on GE development and implementation has been published with an emphasis on public sector organisations and technical, as opposed to behavioural, aspects influencing success. There is a wealth of literature in the information systems research community that details the adoption and spread of novel ideas that may be used in GIS research. For example, a number of academics have used surveys and anecdotal case studies to look at how technology is implemented in various organisations. The idea that diffusion is a multistage process and that organisational and behavioural elements will probably have significant effects on the implementation's effectiveness is a common thread that unites many of these research. There hasn't been a published comprehensive research of GIS application across several corporate organisations as of yet. Specifically, Onsrud and Pinto noted that previous research in this field has solely concentrated on single-site, retrospective assessments of successful systems after their examination of the GIS-related implementation research. This clearly restricts how far this study stream may be applied. Furthermore, there is still much to learn about how user acceptability of GIS varies from that of other information technologies. The degree of training and GIS expertise of the user will probably have an impact on their adoption of the system and, consequently, its success. The fundamental technologies of GIS are founded on geographic and cartographic ideas, which are likely unfamiliar to many people. This sets GIS apart from conventional information systems.

INTEGRATION OF GIS

(i) Levels of Integration- There are several stages at which BIM and GIS integration may take place. Relevant studies were divided into two levels by Irizarry, Karan, et al.: the basic level and the application level. These levels are connected. While the application level is focused on creating new techniques that make the most of BIM and GIS, the basic level is concerned with data exchange standards and compatibility at the data level. Based on comparable subject terms, Kang and Hong categorised them into five groups: schema-based, service-based, ontology-based, processes-based, and system-based techniques. A three-level approach, however, was provided by Amirebrahimi, Rajabifard, et al. that divides those research into application, process, and data level categories.

(ii) Typical Data Formats Involved- Data format is a subject that cannot be ignored at the data level. Every time data moves from BIM to GIS, or the other way around, the data structure (data format) changes. 3D geometry may be stored in a variety of data formats, including.3ds,.skp, Openflight (.flt), Collada (.dae), VRML and GeoVRML (.wrl), and 3D Studio Max (.3ds). Nonetheless, multipatch (shapefile), City Geography Markup Language (CityGML), and Industry Foundation Classes (IFC) are the most pertinent 3D data formats used in BIM/GIS integration.

(iii) Data Interoperability- The ability of GIS and BIM to communicate data is referred to as data interchangeability. The ideal kind of data interoperability would be able to transfer information from BIM to GIS or vice versa without sacrificing either geometry or semantics. This must come to pass before BIM and GIS may be combined at the application level.

CONCLUSION

This paper's goals were to define GIS and investigate the methods information systems researchers might use to investigate this technology. The primary GIS features, capabilities, and functions were outlined in the study. Furthermore, a number of GIS applications were explored. A discussion of a suggested framework that identifies the fields on which information systems faculty members should concentrate their research efforts brought the study to a close. Though few people in the information systems academic community have actively studied this technology, GIS is rapidly entering the corporate sector. There are many of chances to do study. For example, further data regarding GIS management during the implementation and operation stages of its life-cycle is required. Research must also look at problems with collaboration, the organisational effects of GIS, the efficacy of decision-making, and elements influencing human perception and cognition. Ultimately, a great deal of work still has to be done to investigate how GIS affects society in both wealthy and developing nations. Because GIS is probably going to be a crucial component of many information systems, it is significant. Since most business challenges have substantial geographical components, GIS is a useful tool that may help decision makers ask and answer questions that they were previously unable to.

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