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ijatsr@ug.edu.ec
University of Guayaquil
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BIM and GIS integration for construction projects. August (2022)

Hector Santacruz [1].
[1] Vera Quintana Asociados/Ecuador; hector.santacruz@veraquintana.net

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***Abstract*— Historically, most construction projects are based on CAD data, GIS information is only used to evaluate the possible project location site, which results in the non-use of a large amount of data related to the context of the project. GIS information allows us to access environmental, socioeconomic, cultural data, and historical information on both pedestrian and vehicular mobility and, most importantly, gives us the understanding, based on precise data, of what will be the real impact of a project in the environment of its site implantation. The BIM methodology is currently one of the most powerful tools for making decisions in complex construction projects based on the information analyzed during each stage of the project life cycle, but by itself, this methodology is not enough to understand the impact of a facility within a broader environment such as a region or a city, mainly because BIM focuses only on what happens with the facility and not how it affects its environment, this is where the strength of GIS becomes relevant when being able to use the information generated by BIM and extrapolate it to decision making within an environment that contextualizes several variables that through specific analysis procedures allow us to make more efficient planning decisions. In this article, the theoretical definitions will be left aside, and the definitions applied to BIM and GIS in construction projects will be reviewed separately, also make try of how these methodologies would be applied together.**

Keywords: BIM; GIS; Construction; Planning

I. Introduction

THE construction industry has been changing the way it works, not because this has been a planned change but because it was forced by several unexpected external causes in recent years. The main causes are very well known to us: the COVID – 19 Pandemic, the increasingly complex and unpredictable economic panorama, which has reduced the resources for projects in public contracting but not the requirements for private subcontractors (that is, they are asked to do more for less economic resources) and of course the exponential development of technology. This phenomenon is known as the digital transformation of the construction industry, a phenomenon that is very beneficial for the development of any industry, but in the Architecture, Engineering, and Construction (AEC Industry) industry it is carried out in a disorderly, without any planning and less medium or long-term objectives, and in the AEC industry everything is done in the short term, the duration of the project.

The inclusion and success of serious digital transformation strategies in construction companies depend on changing the way of understanding institutional planning and beginning to link the objectives of each project with the macro-objectives of each company. This paradigm shift implies not losing sight of the short-term objectives that we must meet with each entrusted project but broadening the vision of these objectives to the macro business: optimizing the way to obtain a construction budget for projects must be analyzed now as the possibility of increasing the profitability of the company in the medium term, reducing operational rework in projects should be analyzed as the opportunity to reduce operating costs, pre-construction analyzes will not only allow optimizing the expenses and times of a project but will also allow the company to be more efficient in the use of resources.

In this article, we will not analyze the implementation strategies of digital transformation solutions in the AEC industry, but we will review its main concepts, uses, and benefits. In this way, the reader will be able to familiarize himself with these concepts in a more formal way.

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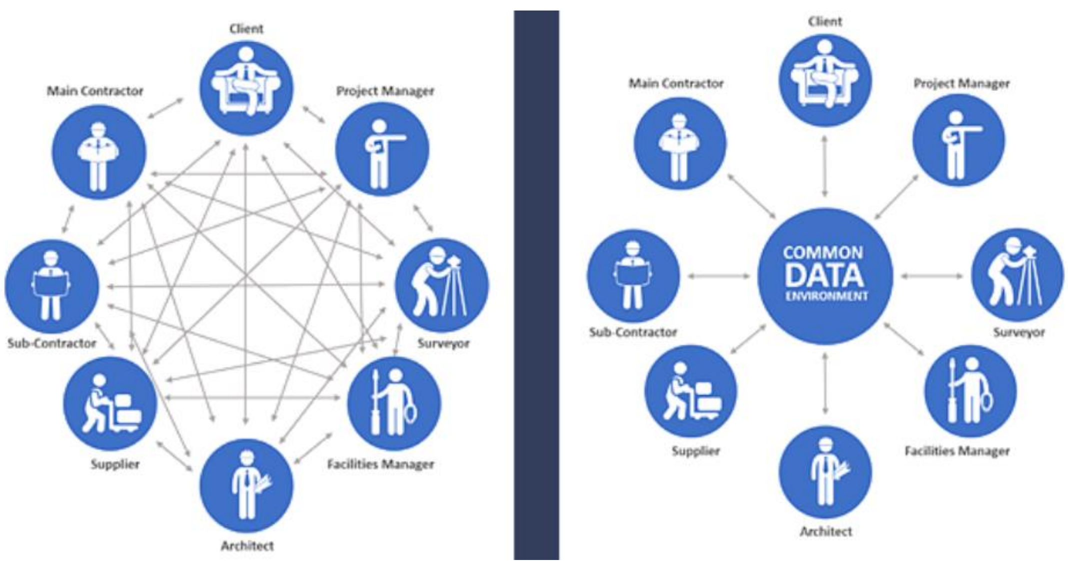
II BUILDING INFORMATION MODELING

Because the volume of information to be processed is complex and often fragmented, good communication and information exchange is necessary at all stages of the construction cycle. In construction, the application of building information modeling is one of the most important achievements in the field of information and communication technologies (ICT) in the last decade (BIM). BIM is defined as the information management of the entire life cycle of construction projects. It provides advanced digital tools and information exchange platforms to manage the entire construction project process and provides a new way to implement integrated projects [1]. Building Information Modeling should then begin to be understood as a management model that enhances project management by being based on the management of project information in its entirety and throughout its life cycle. BIM has several essential components that must work together so that information can be managed successfully, let's list the main ones:

- **Parametric Modeling.** The software is a very important tool within the work under BIM methodology and must have specific capabilities within its programming architecture that allow those involved in the project to easily edit complex elements without the need for manual reconstruction. The information must be linked through algorithms in a structured digital parametric model, in such a way that when modifications are made, the components are automatically updated in direct relation to the specified parameters.
- **Parametric Models.** The model can be defined as the graphic representation in two or three dimensions of a system, a set of elements or conceptual framework devised by the designers, represented within the computational space, the elements that make up these models should preferably meet all the conditions established under the concept of parametric modeling, depending on the need and required use, these parametric models can also be published or issued only as geometric representations in 2D and 3D, always ensuring that the base model maintains all its properties.
- **The Common Data Environment.** (CDE) as its name indicates, is a centralized information repository in which project information is managed, archived, versioned, and backed up, it is a single point of information supply that allows successful collaboration between all the members of the project and forms a crucial part of the document management processes. CDE is defined as a single source of information for any project. It functions as a digital hub for project stakeholders to collect, manage, and disseminate relevant approved project information in a managed environment. The information includes building information models, drawings, reports, and other information related to the project [2].

Figure 1 Information flux on a project



The information management process without CDE is not organized and does not allow to control the information flux.
The information management process with a CDE on the right allows to manage, archive, version and control the information flux[3].

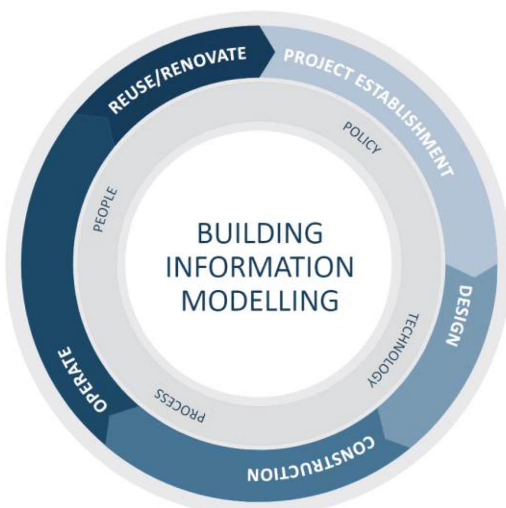
As said before the objective of this article is not to analyze the whole implementation process of BIM so it does not cover in detail the other elements without which the expected results of information management could not be obtained so merely will list them:

- Project Documentation: BIM Execution Plan, Model Element Authoring, Information Exchange Templates, BIM Uses.
- Organizational Structure: BIM Manager, BIM Leads, BIM Coordinators (only if the project qualified as "big"), BIM Modelers
- Standards: BIM Company Handbook also called BIM Procedures Manual, Local or Country Normative
- Other Documents: Matrix of Value, if the BIM methodology is going to be integrated into other agile methodologies or frameworks, the objective is to avoid repeating tasks when these frameworks overlap each other. Maturity Evaluation Matrix, List of Performance Metrics and Requirements for Compliance.

BIM was originally applied to vertical building projects but has been generalized to a wider range of areas, including civil infrastructure. Many terms are used to describe the application of model-based technologies and processes to civil infrastructure projects, such as horizontal BIM, heavy BIM, VDC (virtual design & construction), civil information modeling, BIM on its side, and BIM for infrastructure[4] but for the practical application of BIM, the most important thing will always be the establishment of the project objectives and how the correct administration of the information will allow managers, designers, and builders to make better decisions. The BIM framework does not depend on the facility type (infrastructure such as transportation infrastructure, energy infrastructure, utility infrastructure, recreational facility infrastructure, water management, buildings, process plants, or simply houses) but on what tasks, procedures, resources, and tools are going to be optimized to meet the project objectives.

BIM allows project information to be managed in a reliable, efficient, and secure manner, allowing the actors of the construction ecosystem to focus on obtaining accurate data that serves as the basis for correct decision-making before and during the execution of the construction project. These data are the result of the processing of real and controlled information that is supplied to a parametric model permanently, enabling a better understanding of the project life cycle and adding value to each of the processes required for its execution.

Figure 2 The Project Life Cycle



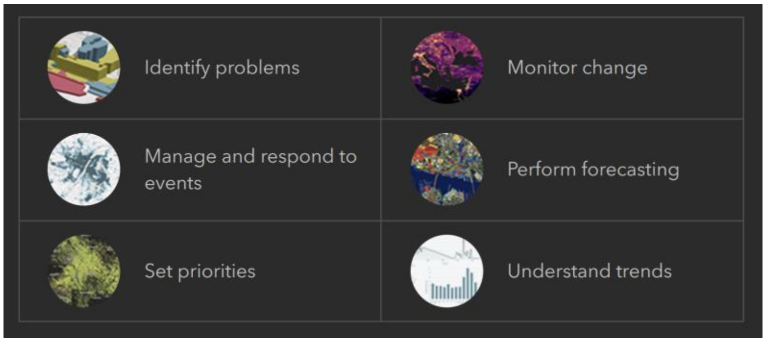
Building Information Modeling is an integral part of each of the stages of the project life cycle [2]

III. Geographic information systems.

Although most construction projects are developed using CAD documents, GIS is often a widely used tool during the planning phase of a project, especially when it comes to site selection. A geographic information system (GIS) can be defined as a system for creating, managing, analyzing and mapping different types of data. GIS connects data to maps and combines location data (where things are) with various descriptive information (where things are). It lays the foundation for graphics and analysis used in science and almost every industry. GIS helps users understand patterns, relationships, and geographic environments. Benefits include improved communication and efficiency, as well as better management and decision-making. [5]

GIS is used in municipalities, cities, and countries, especially by government agencies, which added to the fact that it is a very efficient tool in its purpose allowing it to have an extremely wide and varied application. GIS can be used to identify areas at risk from hazards such as earthquakes, floods, rural fires, and the storage and transportation of petroleum and hazardous chemicals. GIS is also used for transport planning, animal pests, and noxious plant control, the management of key native ecosystems as well as reporting on the state of the environment, to name just a few [6].

Figure 3 How GIS is used?

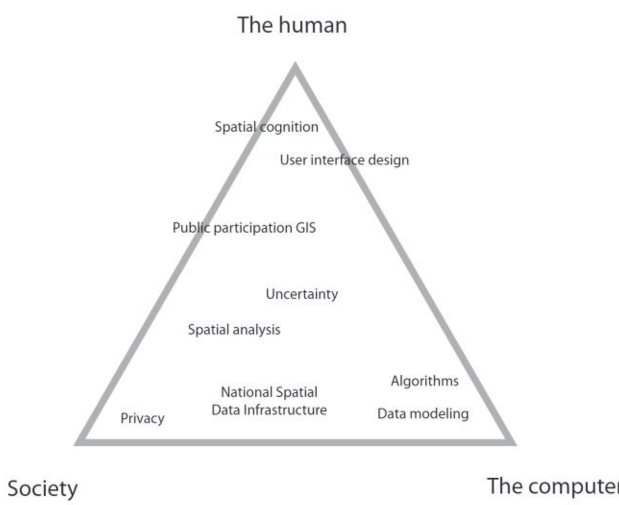


Hundreds of thousands of organizations in virtually every field are using GIS to make maps that communicate, perform analysis, share information, and solve complex problems around the world.[5].

GIS is the application of geography in combination with tools such as software and databases which give us as result a contextual understanding of the environment. The principal elements of GIS technology are:

- **Geographic Science.** The development and use of theories, methods, technology, and data for understanding geographic processes, relationships, and patterns. [7].
- **Maps.** The geographic container of data layers, historically defined as a symbolic representation of selected characteristics of a place, is usually drawn on a flat surface. Thanks to the appearance of modern technology maps are easily shared and embedded in apps, and accessible by virtually everyone, everywhere.
- **Data.** GIS integrates many kinds of data layers using spatial location. Most data have a geographic component. Examples of GIS data: Images, CAD drawings, base maps, spreadsheets, text data, etc.
- **Analysis.** GIS technology allows all these different types of information, no matter their source or original format, to be overlaid on top of one another on a single map. GIS uses location as the key index variable to relate these seemingly unrelated data so people can compare the locations of different things to discover how they relate to each other[8].

Figure 4 A conceptual framework for GIS Science



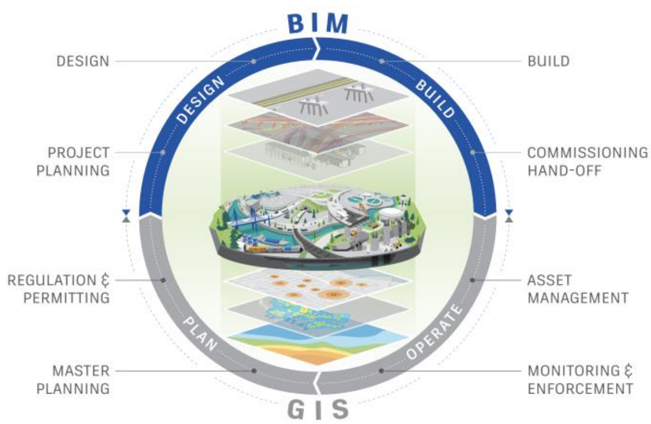
Journal of Spatial Information Science[7]

IV. BIM AND GIS INTEGRATION

Digital Transformation is one of the main trends in the construction industry the constant advancement of data collection technology: drone mapping, inverse engineering, 3D scanning, and IoT are technologies with which we work and interoperate daily, Building Information Modeling is becoming a standard of mandatory compliance in some parts of the world, GIS still have a limited role in the construction industry but is used for specific activities such as project location, regularization of municipal documentation and analysis of affected project areas. Since 2007, researchers have studied the integration of BIM and GIS using various theories and methods and demonstrated the benefits of effective BIM and GIS integration. It is especially important to integrate all information and data analysis to improve the design, construction and operation of complex structures [1].

The integration of Building Information Model (BIM) and Geographic Information System (GIS) refers to the joint solution of BIM technology and GIS technology to solve practical problems. BIM and GIS can complement each other in smart cities and digital twins. BIM is a specific source of building information, while GIS can provide powerful analytical capabilities and geospatial information. [9]. The BIM and GIS integration offers several additional possibilities related to the understanding of the projects from their context and not only from their planning, allowing us to understand the real effects of the project under study at the economic, social, and environmental impact levels. Understanding a project in context also facilitates socialization tasks, and the execution of mobility analyses with their respective affectation at the macro and micro levels, not only during its construction but also during its operation.

Figure 5 BIM and GIS Integration



Integrating BIM and GIS can result in workflows that move data seamlessly from one system to another[10].

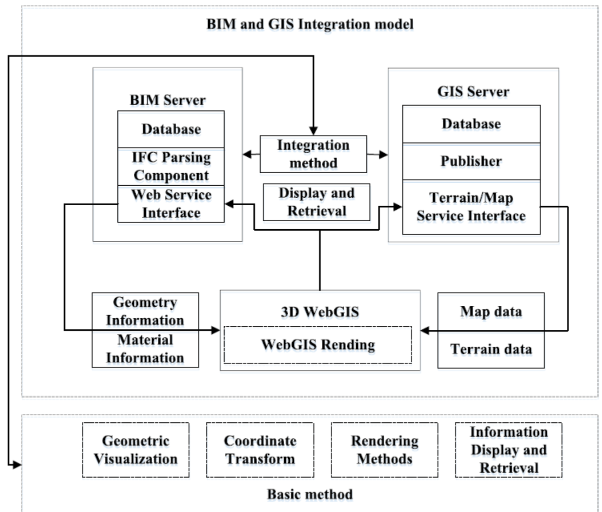
BIM was designed to model new projects in sufficient detail, while GIS was designed to describe existing facilities in a broader geographic context. BIM provides detailed information about the project, while GIS contains geographic and spatial information about the project environment. Historically, GIS and BIM have been developed in different fields and for different purposes. Although the capabilities of BIM and GIS overlap, there are still significant differences between the two technologies. It is very difficult to integrate data from two models. For example, information about project geometry is an important aspect of space planning. However, due to several obstacles, including differences in BIM and GIS representation, poorly defined BIM semantics, and a lack of tools to adequately represent 3D geospatial information, this information is not readily available for geospatial analysis in a GIS environment.[11].

BIM and GIS integration presents significant challenges at the operational level, especially in the integration of parametric and geospatial databases. Object-level data management is the natural advantage of BIM. This function ensures that the platform can clearly present the hierarchy of infrastructure and maintain the data on the object directly. The main challenges of BIM and GIS integration can be summarized:

- **Program Compatibility At the software interoperability level**, BIM and GIS programs integrate different data by understanding mutually compatible file formats or by using integration software to read files from both sides, and data communication or transmission is performed between functional units.[1]
- **Data Access. The need to interact with multiple data sources and the** ability to link and update these data sources from different software implies the need to create neutral formats with updating capacity and specific data exchange procedures.

- **Unified or ontology model level.** Unified or ontology refers to the combination of the BIM and GIS information and features into a single central model. Its advantages lie in the bidirectional conversion of data between BIM and GIS[1].
- **Data Schema Level.** It refers to the ability to integrate heterogeneous data, it is the biggest challenge of BIM and GIS integration because geometric data schemes must be solved within a web-based environment, respectively.

Figure 6 BIM and GIS Integration Model

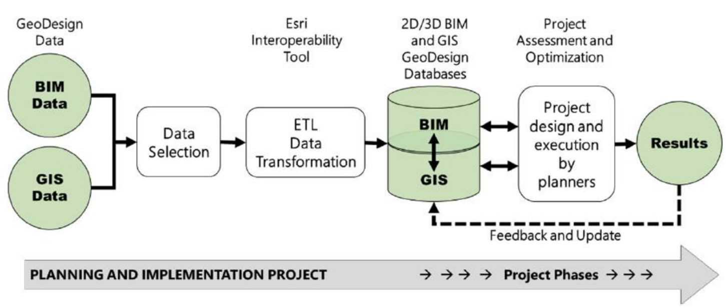


Implementation strategy model and method [1]

V. BIM AND GIS INTEGRATION APPLICATION.

An example widely used in the research literature but at the same time very educational, is the pilot project for the expansion of the A99 highway of The German Federal Ministry of Transport and Digital Infrastructure (BMVI). This project is part of the German Roadmap for the Digitalization of Construction, it is also an excellent example of what an orderly adoption process of Digital Transformation should be in the construction industry. The concept of integration is quite simple and could be easily understood with the next scheme.

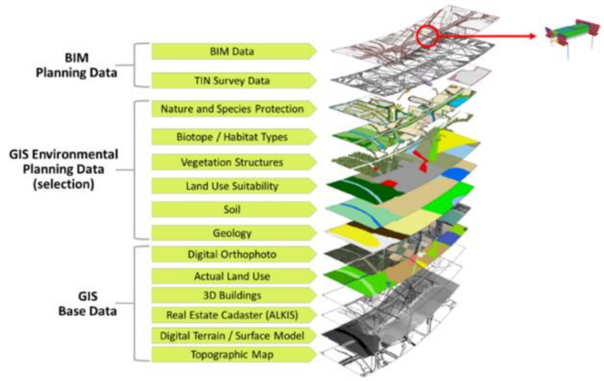
Figure 7 The Integrated data exchange concept



2D and 3D CAD and BIM data models are integrated into the GIS data model – in full or in parts – and then assessed. [12].

The integration of two databases is sought, the BIM database, whose main data sources are 2D and 3D geometry and parametric models (these data sources are used in all construction projects and come from CAD programs or parametric modeling) with the GIS database composed of several geospatial layers (satellite images, ODBC) used by those in charge of planning and environmental impact studies. By integrating the BIM planning process into the geodatabase structure of the collaborative planning system, essential information can be exchanged and processed very quickly. The method can be used in construction projects, engineering, urban planning, and especially large-scale infrastructure planning. The 2D/3D geodatabase of the A99 project combines a hierarchical (bottom-up) structure of GIS base data, environmental data, and BIM data. The GIS technology used allows combining each layer of this data set and assessing the impact between related 2D or 3D data layers. [12]

Figure 8 Schematically BIM and GIS integration



BIM and GIS planning data[12]

The visualization of the BIM and GIS integration allows us to understand the crucial importance of GIS data within the small construction project (compared to the environment of possible affectation). This integration allows a series of impact analyses to be carried out, for example: Carry out basic environmental impact assessments and compensation measures, check the clear date of the BIM construction plan according to various environmental data in the GIS database, identify conflicts that may be caused by agricultural animal and plant protection areas, create a project risk matrix, integrate potential construction risks in the design phase and improve the project socialization in the presence of vulnerable groups.

Figure 9 Visualization of BIM and GIS integration

BIM and GIS visualization data[12]

The A99 informative pilot project revealed many important benefits of integrating BIM and GIS into planning practice:

- Geographic Information: Use existing GIS data to perform spatial analysis of project areas so that planners and other stakeholders can understand the impact of project design and implementation. Conceptual designs can be optimized for compatibility with the environment even before the project begins.
- Professional data management: As a complex and professional spatial data management system, GIS plays a crucial role in the BIM process, especially for large datasets managed by multiple users.
- Modeling and forecasting: GIS provide important information for planning, not only for environmental impact assessments, but also for reviewing modeling methods of legally binding standards, such as noise limits, water quality, protected areas, etc. GIS can also provide real-time sensor information about the project and its surroundings.
- Monitoring: GIS provides continuously updated monitoring data on construction progress and environmental impact (noise, air pollution, etc.).

- Visualization and networking: 2D maps and plans, 3D network scenarios, models and dashboards facilitate effective communication between planners and other stakeholders, especially non-public professionals, throughout the planning process.

VI. CONCLUSION.

To conclude, the methods outlined in the A99 pilot project prove that BIM and GIS integration with the existing interoperability technology is possible. However, to streamline the process, standards, documentation, and interdisciplinary understanding of the involved engineers and environmental planners, as well as their requirements and workflows are necessary.[12]

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Santacruz. Hector Born in Ecuador in 1982, he has a master's degree in Project Management from the Universidad Técnica Particular de Loja in Ecuador, a master's degree in BIM Management for Infrastructure and Civil Engineering from the Rey Juan Carlos University in Spain, is also a Scrum Master Professional Certified (SMPC), he also has certifications in agile methodologies (Agile in Program Management Office) and Business Continuity.

He has more than 10 years of experience in the management of EPC projects for power generation, oil, and gas, currently working as a consultant for power generation projects. He has been developing research in the field of application of BIM methodologies as a management tool in EPC projects for more than 10 years and has been a speaker at several international conferences on the usefulness of BIM in project management. He has published the book BIM as a project management model, Ediloja, 2022.

MSc. Santacruz is a Professional Member of American Society of Mechanical Engineering and a Member of the Project Management Institute.