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Research Article

Integrating Building Information Modelling and Geographic Information System to Achieve Energy Efficiency in Buildings and Urban Areas

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Abstract: Climate change and global warming are the biggest challenges facing the world. They are caused by different human activities, especially in urban areas, such as construction, industry and transport. The research explores the possibility of integrating new technological tools in the process of construction and planning phases with the aim of reducing energy consumption and increasing energy efficiency at the level of the building, neighbourhood, and city to achieve sustainable development. The research starts by reviewing the literature that addresses the importance of energy efficiency in sustainable development. It also identifies two new technological tools: building information modelling (BIM) and geographic information system (GIS). Then, it explores their ability to enhance energy efficiency and rationalise consumption to improve the built environment at different city levels. The research also reviews and analyses several case studies that have applied these two technological tools to raise energy efficiency. It aims at identifying the required data (input and output), steps, and procedures necessary to apply these tools at the different city levels. In conclusion, the research proposes guidelines for the integrated use of BIM and GIS to raise energy efficiency in urban areas. It defines the main actions and requirements to perform an energy assessment with input and output data for BIM and GIS. Applying these methodologies, whether in new or existing neighbourhoods, will significantly contribute to energy conservation, reduce harmful emissions, preserve the environment, and achieve sustainable development.

***Keywords*:** energy efficiency, energy use mapping, BIM, GIS, energy assessment, energy simulation

1. Introduction

Human activities in the fields of construction, industry and transport have a negative influence on the environment and urban sustainable development. Burning fossil fuels causes large amounts of greenhouse gases that trap heat in the planet's atmosphere, preventing it from escaping into space. These gases act as a warming blanket around the earth, causing an increase in the amount of heat from the sun that leads to the greenhouse effect, resulting in climate change and global warming.

Climate change has wide-ranging effects on the environment, society and economy, such as on water resources, agriculture, food security, people's health, and biodiversity [1]. Climate change is caused by human activities, especially in urban areas. Energy consumption is one of the primary causes of climate change, and an effective way to address the impacts of climate change is to enhance energy efficiency and reduce energy consumption in buildings. Energy efficiency not only slows climate change; it also saves money, boosts job creation, and limits harmful environmental

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pollution [2].

New technologies can help experts calculate the energy consumption of buildings, perform energy analysis, and then define a set of alternatives for energy conservation. This study explores the possibility of integrating new technological tools in the process of construction and planning phases to reduce energy consumption and increase energy efficiency at the level of the building, neighbourhood, and city to achieve sustainable development.

The research starts by reviewing the literature that addresses the importance of energy efficiency in sustainable development. It also identifies two new technological tools: building information modelling (BIM) and geographic information system (GIS). Then, it explores their ability to enhance energy efficiency and rationalise consumption to improve the built environment at different city levels.

"*BIM is the technology to generate and maintain information that is produced during the whole life cycle of a building, from design to maintenance, and is applied to various fields*" [3]. It is a tool used to help the architecture and construction industries become more sustainable, both economically and environmentally. It uses the building's information to calculate the energy use throughout the building and produce alternatives for energy efficiency [4]. GIS is useful in the geographic visualisation and analysis of data related to energy consumption at the district or city level. It is capable of assessing the energy behaviour of the existing built environment [5] and identifying areas with high energy use to address policies to improve energy efficiency in these areas.

The research also reviews and analyses several case studies that have applied these two technological tools to raise energy efficiency. It aims at identifying the required data (input and output), steps, and procedures necessary to apply these tools at the different city levels. In conclusion, the study proposes guidelines for the integrated use of BIM and GIS to raise energy efficiency in urban areas by producing maps of current energy consumption to develop plans for the urban energy sector and identify energy efficiency opportunities. It defines the main actions and requirements to perform an energy assessment with input and output data for BIM and GIS. Applying these proposed approaches, whether in new or existing neighbourhoods, will significantly contribute to energy conservation, reduce harmful emissions, preserve the environment, and achieve sustainable development. Figure 1 illustrates the framework of the study and defines the sequence of its flow.

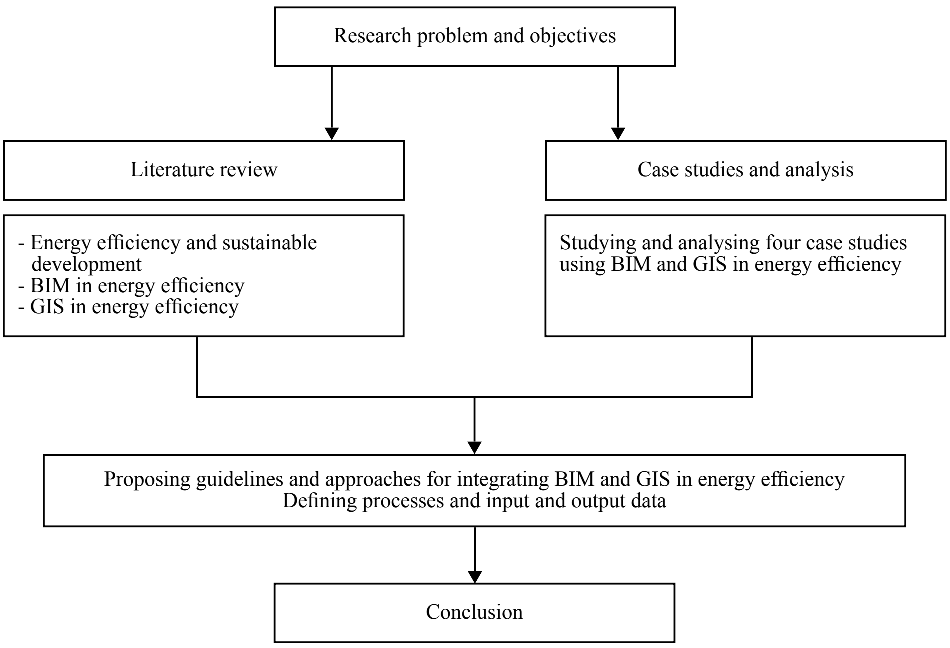

Figure 1. The study framework

2. Energy efficiency and sustainable development

Sustainable development is a way of meeting the needs of today without sacrificing the ability of future generations to meet their own needs. Sustainable development goals focus on balanced economic growth, conserving natural resources, protecting the environment, and promoting social equality. Energy efficiency can contribute to achieving some of these goals.

Energy efficiency has important benefits for the environment; it reduces greenhouse gas emissions, limits climate change, limits the consumption of natural resources, and improves public health. To ensure sustainable development, energy must be used efficiently. Increasing energy efficiency obtains the maximum economic output from the energy used and minimises the harm to people and the environment as it reduces environmental pollution.

Energy is one of the essential elements required for urban, social, and economic development [6]. Without energy, people cannot accomplish most of their work or operate their devices and machines, which have become essential parts of their lives and which they cannot live without. Unfortunately, it is also an essential reason for pollution and climate change. Therefore, there are initiatives in many countries to conserve energy and increase energy efficiency. Energy efficiency is essential for achieving sustainable development, as it has some environmental and socio-economic factors.

Many countries are attempting to reduce their energy consumption because of concerns about the high price of energy and its side effects on the earth. The cheapest, fastest, and most environmentally friendly way to achieve sustainable development is to increase energy efficiency [7].

There are many benefits of energy efficiency in sustainable development. In the environmental field, energy efficiency reduces greenhouse gas emissions and other pollutants, decreases water use, and helps achieve a clean environment. In the economic field, energy efficiency can reduce personal utility bills, generate jobs, and support settling down the price of electricity by lowering overall electricity demand. In the health field, energy efficiency can enhance the quality of life and indoor living environments and improve air temperatures, quality of air, and humidity levels [8, 9].

3. BIM and GIS for energy efficiency

BIM and GIS systems are technologically different and they are designed for different purposes [10]. Each system has its capabilities in terms of energy efficiency and the outcome of one system can be used as an input in another system.

Presently, BIM and GIS are important technologies dealing with three-dimensional (3D) models. These two technologies develop building models in different fields for different purposes. BIM provides detailed and rich 3D building models with many details, but it lacks information about the surrounding environment [11]. On the contrary, GIS gives georeferenced information and allows spatial queries and analysis at the district and city level, which is important for the suitability, urban, and energy planning. It lacks information about building details such as indoor settings, windows, and door openings.

Integrating BIM and GIS is useful for exporting building details from BIM as input data to the GIS. The exported data may contribute to the accuracy of urban analysis and decision-making [11]. This integration produces georeferenced buildings with high accuracy and rich information at the urban scale that is necessary for energy analysis and simulation.

3.1 *BIM capabilities in energy efficiency and sustainable development*

"*BIM is the holistic process of creating and managing information for a built asset based on an intelligent model and enabled by a cloud platform*" [12]. BIM integrates all types of data in a structured process to produce a digital representation of the construction through its lifecycle, starting from the design, construction, operation, and maintenance [12].

BIM has many dimensions - three, four, five, six, and seven dimensions - each dimension is used for a specific purpose. Six-dimensional BIM is used for sustainability and energy efficiency. It helps analyse the energy consumption in the building. BIM is an essential tool to improve energy efficiency and the built environment. It improves energy efficiency in the design and construction phases by assessing energy consumption at each stage. BIM uses the building information stored to calculate energy use and define optimum efficiency throughout the building [4].

Environmentally, BIM can assist in optimising the energy consumption of the building and reducing its carbon footprint. Economically, it can reduce the energy consumption of a building and the cost of construction and maintenance by up to 20% [4].

BIM is capable of estimating the energy demand of the building by producing alternatives for efficient design. It is also capable of preparing energy simulations and analysing the performance of the building in the design phase [13]. It has the potential to calculate the energy consumption of an existing or new building and propose alternatives to reduce the energy consumption at different levels of intervention.

3.2 *GIS capabilities in energy efficiency and sustainable development*

GIS is a system that stores, analyses, manages, and maps all types of georeferenced data. GIS links geographical data (spatial data) with descriptive information (tabular data). GIS can arrange many different processes and help users understand patterns, relationships, and geographic context.

GIS is capable of mapping energy consumption at the city scale rather than the building scale. It will give the planners an overview of how energy efficiency is disseminated at the urban level [14]. The potential of visualising energy consumption at that level will allow planners and city officials to read the distribution of energy consumption and improve their current energy vision to support future planning actions as a main preference in the city's development. Gaspari et al. [14] stated that "*despite the scientific literature offering consolidated knowledge on surveying energy efficiency at the building scale, experiences at district or city scales are still limited*".

3.3 *Integrating BIM and GIS for energy efficiency*

Integrating BIM and GIS has many benefits in data collection, analysis, visualisation and management in evaluating the energy consumption at the building and district scale [15]. Figure 2 shows the stages in both BIM and GIS and the integration between them.

GIS has the capability of storing both spatial and tabular data, which are exported from the BIM software. It can store the BIM data related to the building components, such as walls, pillars, floors, windows, materials, energy consumption, user information, etc., in the GIS. At the district level, all previous data is stored per building; queries and analysis can be applied at that level. To reduce energy consumption at the district level, queries such as the selection of buildings with high energy consumption can be asked. Action can be taken against the selected buildings to reduce their energy consumption and enhance the occupant's environment.

In GIS, the sources of data used for energy analysis can be energy consumption data gained from the readings of metering systems or energy bills or data obtained from energy performance analysis done in BIM for the buildings, either new or renovated ones, based on the building characteristics [14].

GIS and BIM can create 3D data models that offer useful information about buildings and their surroundings, as shown in Figure 3. Data in GIS can easily be stored and updated. The analysis results can be presented on the maps [14]. GIS is used to analyse and visualise building consumption to address retrofitting actions for buildings with high consumption and prepare any energy initiatives [14].

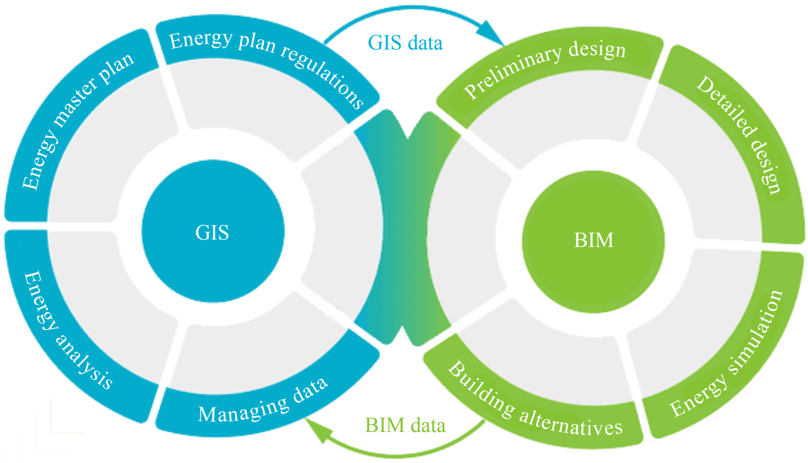

Figure 2. Integration of BIM and GIS for energy efficiency [16]

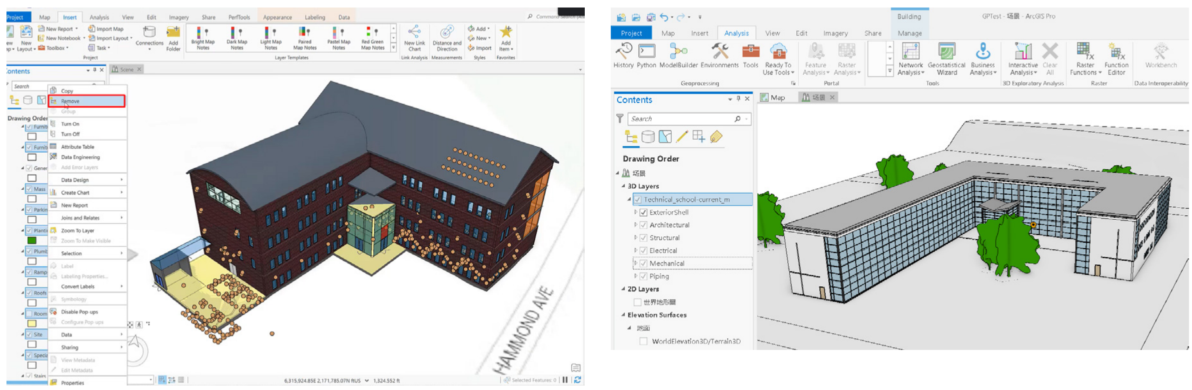

Figure 3. Examples of importing BIM data directly into ArcGIS Pro [17, 18]

4. Case studies of the use of BIM and GIS in energy efficiency

Several case studies were studied in the field of utilising BIM and GIS technologies for energy efficiency. Four case studies were chosen to be presented in the research: one for BIM application, one for integration of BIM and GIS, and two for GIS application. The first two case studies are for existing buildings; one used BIM tools for energy analysis and to improve the building's energy performance, and the other used BIM and GIS tools for energy analysis. The other two case studies are the applications of the GIS tools to analyse the energy consumption of two cities, Massachusetts and Bologna.

4.1 *An educational institute building case study*

This case study studies and analyses the energy performance of an existing building to improve its energy efficiency. Two main software programmes were used to select the optimal materials for the building components. Autodesk Revit and Green Building Studio were used to develop proposals to make buildings more efficient and reduce the excessive expense of energy use in the building's life [19].

a) Building description: The building is an educational institute situated in Alexandria, Egypt. The total area of the building is 5,021 m^2, distributed over six floors, whereas each floor has an internal height of 3 m [19].

b) Data needed and collected: All information about the building was collected. Information about the building use, location, architectural, civil, and electro-mechanical plans, building materials, heating, ventilation, and air conditioning (HVAC) systems, weather stations, and climate databases are the input data for the analysis phase [19].

c) Architectural and 3D building model: To measure the operating energy consumption of the building, a 3D architectural model of the examined educational building was created. The model was created with Autodesk Revit software.

d) Energy model and analysis: The energy analysis phase studies the parameters that may affect the energy consumption of the building and these parameters are building location, building types, weather station, building materials, building systems (HVAC), and internal loads [20, 21].
The analysis output from Autodesk Revit was transferred to Green Building Studio, a web service that studies the environmental impacts of the building parameters in the design phase [22]. The analysis output from Green Building Studio contains information related to the energy use per month and year about thermal performance, solar radiation, total fuel, electricity cost and demand, water use and carbon emission.

e) Evaluating energy consumption and cost: The Green Building Studio was used to calculate the operational costs and the amount of energy consumed in the whole building through materials, HVAC, and orientation parameters. Meanwhile, BIM Revit 2018 was used to calculate the amount of heating and cooling loads that are gained or lost from building components during the operating year.

f) Wall alternative: Green Building Studio analysed and compared eight alternative wall construction components with the initial design [19].

g) Roof alternatives: Green Building Studio analysed and compared different types of roof materials with the initial design to choose the optimum type.

h) HVAC systems: HVAC systems have an important influence on the energy use of the building life cycle. Green Building Studio analysed and compared several options for HVAC with the initial design [19].

Table 1 shows the energy evaluation analysis process for each of the suggested parameters compared to the initial design.

Table 1. Energy evaluation analysis for the parameters compared to the initial design [19]

Parameters	Electricity (%)	Fuel use (%)	Energy cost (%)
Whole-building energy	28.20	42.70	22.30
External orientation	10.00	18.47	7.32
External walls	20.16	19.10	21.00
Internal roof	13.36	23.35	11.00
HVAC systems	24.00	40.12	19.14

The building location and orientation are considered substantial parameters that have an important effect on energy consumption and can influence the total energy used. BIM tools have the capability of comparing different types of parameters with the initial parameter to create several alternatives and develop the optimum solution at the lowest cost.

In this case study, one of the important parameters that can save a lot of energy and money is the building's orientation. It can save on heating, cooling, and lighting costs through better utilisation of solar radiation.

4.2 *A campus-building case study*

This case study studies and analyses an existing historical building (a campus) that needs renovation and retrofitting. Experts were needed to get a comprehensive vision of the building to develop a retrofit plan. Autodesk Revit and Green Building Studio were used to create 3D models, conduct energy analysis, develop alternatives to improve the building's efficiency and choose the optimal alternative to achieve the best energy efficiency solution for retrofitting.

4.2.1 *Building description*

The building is a historical campus constructed in 1913. In 1935, the building was renovated and several renovation projects were implemented to replace the existing building materials [23].

4.2.2 *Data needed and collected*

Two types of data were needed for the energy analysis: as-is geometric data and as-is data. The software programmes used were Google SketchUp and Autodesk Revit; they produced 3D geometric data for energy performance analysis. GIS was used for data analysis and mapping.

The following building data were gathered to analyse energy use and create retrofit models [23]:

a) 3D drawings of buildings
b) Energy performance data and emissions
c) Water production
d) Waste production
e) Indoor environmental conditions
f) Indoor air quality
g) Evaluating the behaviour, attitude and satisfaction of the occupants

4.2.3 *Architectural and energy model*

Google SketchUp was used to create the 3D model of the building by using the photo-matching technique. Then, the model was imported into Autodesk Revit.

4.2.4 *BIM and GIS integration*

Output data from BIM, information about the structure, materials, installation and appliances, and the collected data about operation and service, survey observations, and a pre-retrofit survey were saved into the GIS to perform analysis and produce energy maps.

In the GIS, each type of data imported from BIM was assigned a unique identification number that was linked to each space (spatial data) in the building to give environmental information about that space and produce useful pre-retrofitting maps.

Several building data maps were prepared using GIS according to the data available in the database. The following data maps were produced:

a) Indoor environment
b) Hygro-thermal conditions
c) Indoor air quality
d) Lighting conditions
e) System equipment and layout
f) Detected problematic points

According to the previous factors, maps were created to illustrate the zones per floor that face problems in temperatures, humidity, illumination, etc., as shown in Figures 4(a) and 4(b). From the analysis and calculations, some findings indicated that action was needed to improve the energy efficiency of the building [23]:

a) Finding: Thermal discomfort.
   Action: Renew the existing heating and cooling system with efficient HVAC systems.
b) Finding: Drafts from windows.
   Action: Replace old windows with new, efficient ones.
c) Finding: Lighting levels were higher than needed.
   Action: To minimise energy consumption, the current lighting system should be replaced with efficient and dimmable lamps.
d) Finding: Predominantly higher CO_2 levels.

Action: The number of air changes per hour should be increased.

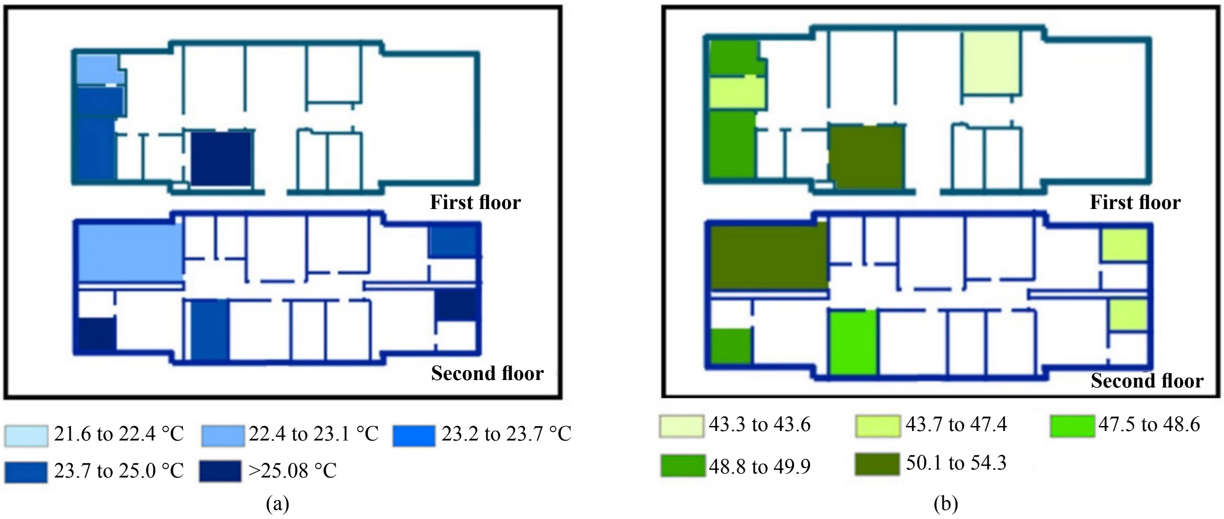

Figure 4. Spatial mapping of (a) temperature and (b) relative humidity for each zone on each floor [23]

The integration of GIS with BIM is useful for visualising and mapping building data. The pre-retrofit model developed a deep environmental understanding of the building. It was used to perform several scenario comparisons and to choose the optimal renovation decision based on economic and environmental factors.

4.3 *Massachusetts City case study*

4.3.1 *Introduction*

The municipality of Massachusetts wanted to understand the energy consumption of their city. Therefore, Massachusetts Programme Administrators (MPA) used GIS to understand their energy consumption and evaluate spatially the distribution of energy use, energy savings, and customer evolution in the past years. GIS was used to visualise geographically the zones and locations with high consumption and the locations of commercial and industrial energy customers that are participating in energy efficiency programmes.

4.3.2 *Data and software*

MPA collected data from the electricity bills and from their programme for tracking energy efficiency. They used ArcGIS and QGIS for the GIS software.

4.3.3 *How the system works*

The first step for analysis is to save the data in a working spatial format (GIS format) and link tabular data with spatial data (geographic). Several datasets were collected over different years. Massachusetts commercial and industrial billing data were collected for years 2011 and 2012 [24].

4.3.4 *GIS analysis*

GIS was used to analyse the previously collected data and produce several maps. A dot map for Massachusetts was produced to present nearly 400,000 commercial and industrial electric customers and 12,000 commercial and industrial electric energy efficiency projects [24].

Analysis was done to produce maps presenting areas with energy savings (in kWh and percentage) of town consumption, as illustrated in Figures 5(a) and 5(b). It was obvious that zones with a lower population have lower consumption and lower savings.

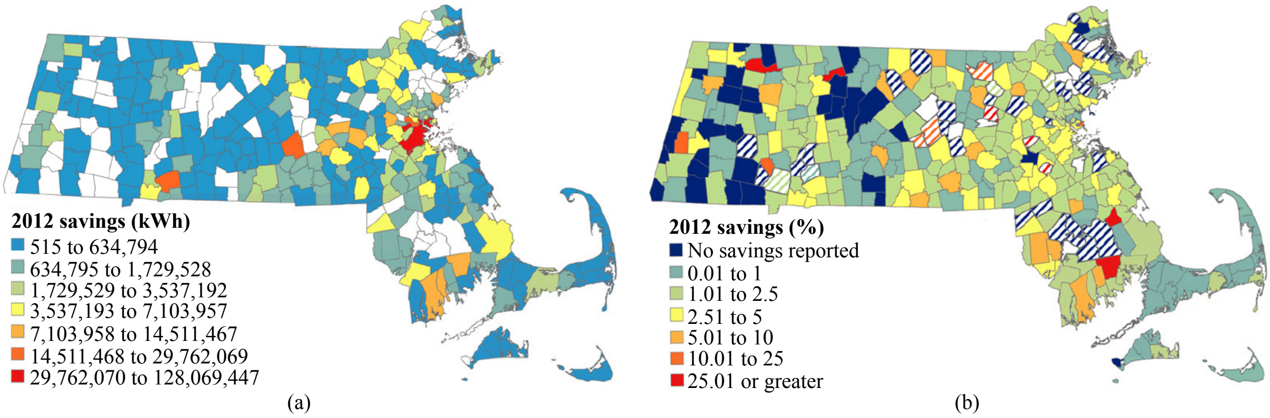

Figure 5. Savings of town consumption in (a) kWh and (b) percentage [24]

MPA wanted to get a better picture of which towns have the highest energy consumption and savings. GIS was used to analyse and select these towns. It was also used for more detailed analysis to define the type of commercial and industrial business and evaluate normalised savings for one town versus another.

This analysis allows the municipality to better understand which areas obtained high savings compared to the state mean and how the municipality concentrates its awareness and efficiency offerings in particular places. It also gives a thorough vision into which zones are over or under performing and even a starting point for looking at what types of end users and customers are key targets for new efficiency offerings and can help MPA continue to deliver the targeted innovative programmes that made Massachusetts the most energy-efficient state in the United States in 2013 [24].

4.4 *Bologna City case study*

4.4.1 *Introduction*

The objective of the case study was that Bologna municipality, Italy, needed to update Emilia-Romagna regional urban planning regulations and prepare an action map with regard to the energy efficiency of homogeneous urban parts defined by the general urban plan. The municipality used GIS to support future planning actions, easily analyse and visualise energy consumption and distribution, and prepare an updated energy map for the municipality of Bologna. Their focus has been on shifting from the building scale to the district scale to identify areas with large and homogenous energy use to address policies and plans to improve energy performance levels at the city scale.

The potential of visualising an energy zoning map presenting the current way of energy demand at the city blocks will allow Massachusetts Administrators (MAs) to improve their basic understanding and increase their effectiveness while preparing future urban regulations.

4.4.2 *Data and software*

All data regarding energy consumption was collected. There were limitations in collecting the data because individual information about energy consumption is confidential and protected. Therefore, there was another way to obtain energy consumption from energy performance certificates (EPCs), which must be associated with any new or renovated building unit. Energy consumption can be predicted by using a formal calculation code depending on the characteristics of the building, including technical and constructive factors. Several indirect estimation methods have been developed to overcome the lack of direct consumption data [14].

Two types of input data were used: vector data representing the buildings on the map and tabular data representing the energy consumption.

4.4.3 *GIS analysis*

GIS was used to produce maps providing all the information representing the estimated data of energy consumption (kWh per m² per year) at the cadastral parcel scale, as shown in Figure 6. It was used to represent the vision of energy consumption at the city level. These maps can support decision-makers and designers in making any decision regarding energy plans. It can also be used to easily communicate with citizens and end-users and improve awareness about this issue [14].

GIS has been useful in the shift from single-building energy performance to a broader urban energy consumption observation, which has been the main requirement for updating regional regulations. This will help put in mind the growth of buildings' energy consumption over time, focusing on aggregate demand and city-wide distribution and supporting insights into the impacts of national and external influences.

Figure 6. Energy consumption (kWh per m² per year) at cadastral parcel scale [14]

Energy efficiency is normally examined at the building scale by analysing the building envelope, the technical installations, and the energy performance of the entire building. However, this does not reflect the scope of the regional law request, which is directed at understanding how energy efficiency is distributed at the city level. In this case study, the municipality of Bologna shifted studying energy efficiency from the scale of the building to the district scale. GIS was the solution for energy mapping, studying the city's energy consumption and producing maps visualising the energy consumption at the district level to help the municipality boost energy savings measures and also update the energy map of Bologna municipality for the general urban plan.

4.5 *Analysis of case studies*

After studying the previous case studies, they were analysed and classified into some themes, as shown in Table 2.

Table 2. Analysis of case studies according to specified themes

	The educational institute	The campus-building	Massachusetts City	Bologna City
Data required	Building use Location Architectural, civil, and electro-mechanical plans Building materials HVAC systems Weather and climate data	3D drawings of buildings Energy performance data and emissions Water production Waste production Indoor environmental conditions Indoor air quality Occupants' behaviour	Electricity bill data Tracking energy efficiency data	Energy consumption data is collected from EPCs. There were limitations in collecting the data, so energy consumption data was predicted.
Programmes used	Autodesk Revit Green Building Studio	Autodesk Revit Green Building Studio Google SketchUp ArcGIS	ArcGIS QGIS	ArcGIS
Main analysis	Architectural and 3D building model Energy model and analysis Evaluating energy consumption and cost	Architectural and 3D building model Energy model and analysis GIS analysis	GIS analysis	GIS analysis
Outputs	Alternatives for the building's elements and components	Alternatives for improving the building's efficiency Maps presenting: - Indoor environment - Hygro-thermal conditions - Indoor air quality - Lighting conditions	Map presenting: - Commercial and industrial customers - Commercial and industrial energy efficiency projects - Areas with energy savings - Savings as a percentage of town consumption	Maps representing - Estimated data on energy consumption - Vision of energy consumption at the city level - Urban energy consumption

5. Approaches for the integrated use of BIM and GIS in energy efficiency

The case studies studied were classified into BIM and GIS case studies. They were analysed according to the types of data needed for analysis, steps and stages of analysis. The paper defined and classified the types of data needed to be applied to the BIM and GIS tools. Then the paper defined the processes, input data, and output data for achieving energy efficiency for both BIM and GIS tools, as shown in Table 3.

The paper also proposed two approaches dealing with BIM and GIS applications in achieving energy efficiency, shown in Figures 7 and 8. The approaches defined the steps and stages for implementing energy simulations and analyses in buildings and urban areas. The first one flows from BIM to GIS, and the second one flows from GIS to BIM.

Working with BIM and GIS for energy efficiency in buildings can start with BIM, and then the output can be exported to GIS or vice versa. The choice depends on the availability of data, the scale (building or district scales), and whether the buildings are new or existing.

The first proposed approach flows from BIM to GIS consists of six stages:

Stage 1: Specify the data and software needed

- Energy assessment needs data to be analysed; they must be well-defined and collected to achieve a reliable simulation and correct outputs.
- The software selection: The objectives and outputs of the energy assessment should be defined, and depending on the analysis needed, the software should be selected.

Stage 2: Modelling

- Building modelling is the main foundation stone for an energy assessment. The designers must specify the location and orientation of the building.
- Assign the materials and information to the building elements.
- Define the characteristics of the interior spaces of the model.
- Define HVAC systems.

Stage 3: 3D models

- Create 3D models for the building. The 3D architectural model must at least be created to perform the energy assessment on it.

Stage 4: Simulation

- Simulation outputs differ from one building to another depending on the objective of the energy analysis mentioned in Stage 1.
- The output of the simulation can be presented in charts or numerical tables. After performing an energy simulation, results must be validated against a recognised calculation method [25].

Stage 5: Export or convert from BIM to GIS

- Convert BIM files containing architectural and civil elements (if they exist) with all elements holding their data to GIS software.
- Some GIS software, such as ArcGIS Pro, can import BIM data directly into the software without converting the data.
- Check the geometry and coordinates (spatial data) of the building to confirm that they are correct. Check all elements and spaces to confirm that they are holding their information in the database (tabular data).

Stage 6: Energy analysis in the GIS

- If the drawings and databases are correct and complete, the user can perform all the analysis and queries needed for energy assessment at the building scale and the district or city scale.
- The latter analysis can be visualised in different types of output: maps, tables, and charts.

Table 3. Process, input data, and output data for energy efficiency

	Process	Input data	Output data
BIM	Developing 3D modelling	Architectural drawings Civil drawings Electro-mechanical drawings	Develop 3D building model in BIM
	Creating energy simulations	Data related to: - Location - Orientation - Weather - Materials - Assignment of spaces - Space loads - HVAC systems - Number of occupancies	Perform: - Energy simulation - Operational costs - Amount of energy consumed per room, floor or building monthly and annually - Heating or cooling loads - Electricity cost - Fuel cost - Water use - Carbon emissions
	Optimal proposal	Energy simulation for different elements of the building	- Proposals and comparisons to achieve the lowest consumption - Calculating the cost (energy, electricity, heating, fuel, water use, etc.) for each proposal
GIS	Produce energy maps at district and city scales	Data related to: - Energy consumption - Electricity bills - Water use bills	Perform analysis and queries to produce energy maps at district and city scales, defining places with high and low energy consumption.
	Produce energy maps at building, district, and city scales	Data imported from BIM (all information about building elements mentioned above)	- Perform analysis and queries to produce energy maps at the building level, defining rooms with high energy consumption. - Energy maps at district and city scales define buildings and zones with high and low energy consumption.

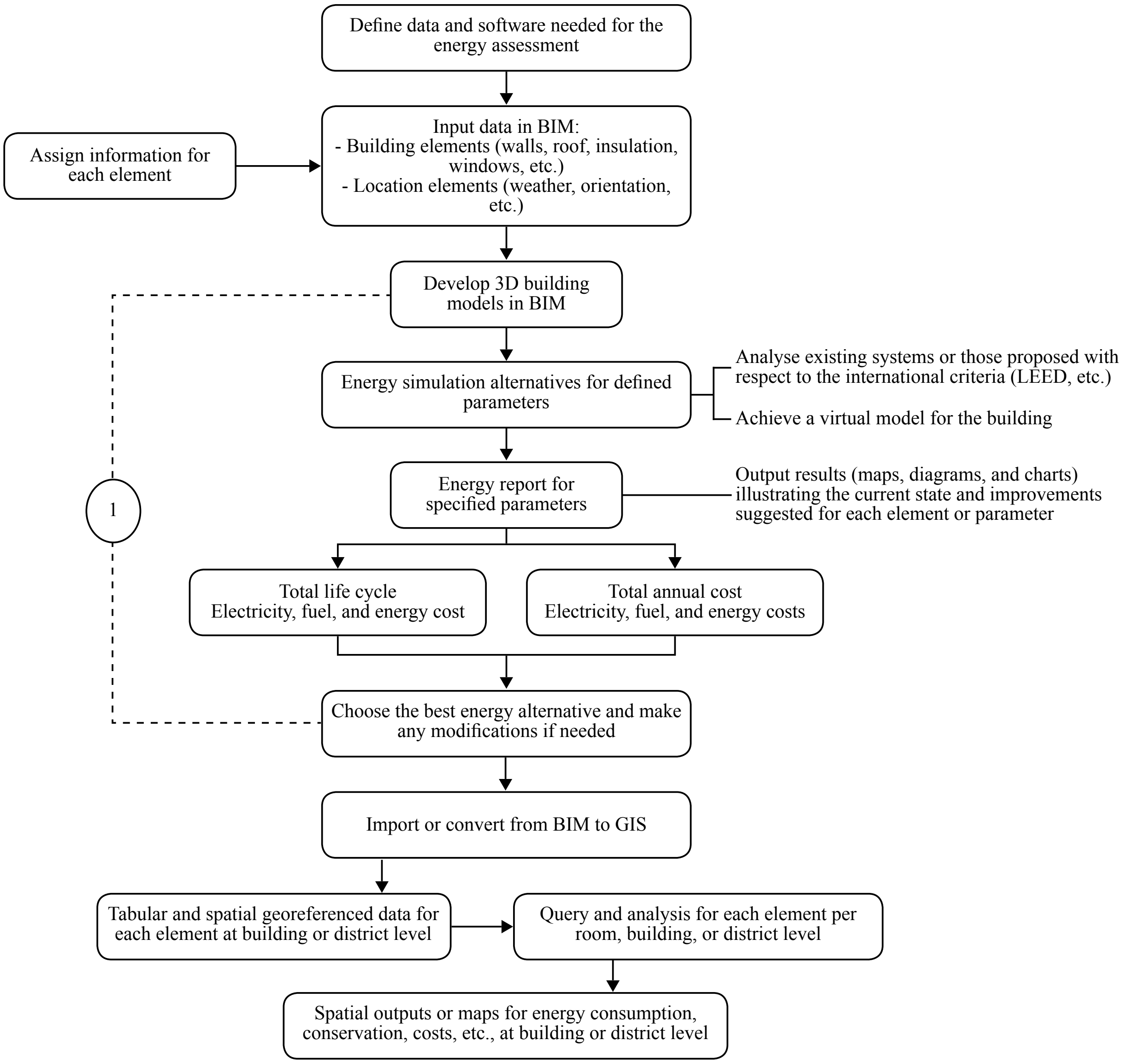

Figure 7. The proposed approach for the integrated use of BIM to GIS in energy efficiency

The second proposed approach from GIS to BIM consists of six stages:

Stage 1: Data entry

- Define, collect and enter the data needed for energy assessment in GIS software.

Stage 2: Data analysis

- Through the capabilities of the GIS, analysis can be done to define the buildings or zones at the district level with high energy consumption.

Stage 3: Define the buildings that need retrofitting

- From the output of the previous stage, energy experts can identify the buildings that need retrofitting to decrease the energy consumption of the district.

Stage 4: Export or convert from GIS to BIM

- Data about buildings that need retrofitting can be exported or converted from GIS to BIM.

Stage 5: Provide as-built drawings

- Provide as-built drawings for the buildings that need retrofitting.
- Define the current building elements (walls, roof, insulation, windows, etc.).

- Define the current HVAC systems.
- Define the occupancy of the rooms in the building.

Stage 6: 3D models and simulation

- Create 3D models for the building. The 3D architectural model must at least be created to perform the energy assessment on it.
- Simulation outputs differ from one building to another depending on the objective of the energy analysis mentioned in Stage 1.
- The output of the simulation can be presented in charts or numerical tables. After performing an energy simulation, results must be validated against a recognized calculation method [25].

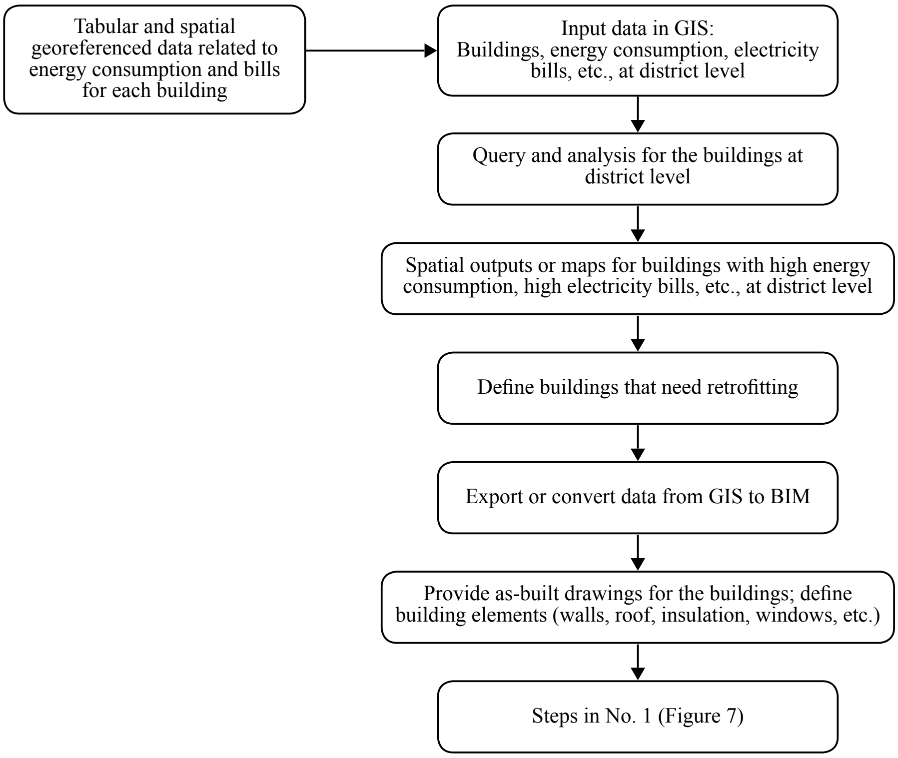

Figure 8. The proposed approach for the integrated use of GIS to BIM in energy efficiency

6. Discussion

The world is facing many problems with environmental deterioration, and among the major reasons for this deterioration is the high consumption of fossil energy in the construction and operation of urban areas, from the building level to the city level. This energy consumption has negative effects on the environment, the most important of which is global warming and climate change. Therefore, raising energy efficiency is one of the factors that can contribute to reducing climate change. For that reason, this research proposes taking advantage of both BIM and GIS as tools for enhancing energy efficiency and rationalising energy consumption by proposing guidelines and methodologies that can be applied to new or existing buildings as well as other levels of the city.

Aiming to contribute to the emerging literature on this topic, the paper has reviewed and studied several case studies that applied BIM and GIS for enhancing energy efficiency. The findings of the paper indicated the potential values of integrating BIM and GIS at the district scale, which has not been widely documented so far. Certain connections between the values of these technologies at the two scales were also discussed.

Due to the limited number of case studies analysed in this paper, it is hard to reach a definite percentage of reduction in energy used in buildings or other levels of the city if the two technological tools are used, but the paper identified an overall positive effect and reduction in energy consumption. Other effects that can be attributed to the use of BIM and GIS include users' thermal comfort, especially in outdoor areas, which is not included in energy efficiency. Thus, the actual benefit of using the tools might be greater than what has been summarised in this paper.

There are several outcomes for this study. First, the study defined the types of data needed for analysis in the case of BIM and GIS applications. Second, it defined the processes needed for enhancing energy efficiency and the input and output data for each process. Third, it proposed an approach to be applied from BIM to GIS for building energy efficiency. The guidelines and stages of this approach are well discussed. This approach is mainly used for new buildings that have not yet been constructed; in the designing phase, it is easy to modify any element in the design, such as orientation, building materials, HVAC, etc. Fourth, the study proposed an approach to be applied from GIS to BIM for enhancing energy efficiency. This approach is mainly used for buildings with high energy consumption. The findings of the study will be very useful in achieving energy efficiency and lowering energy consumption in the construction field.

By achieving energy efficiency, many goals of sustainable development will be achieved. Less energy will be consumed, and therefore natural resources will be conserved for future generations. Preserving the environment by reducing harmful emissions can reduce global warming. Reduce the money paid in electricity bills, and the return will accrue to the government and individuals.

Some challenges faced by this paper are the amount and kind of data that need to be available so that such technological tools can be utilised. Data production, the high soft costs of producing such data, and the concern that such data might be difficult to circulate are some of the apparent challenges.

Also, among the difficulties raised by this paper is the relation between BIM and GIS and their effect on energy efficiency and the rating systems or certification of buildings and neighbourhoods.

The outcome of this study can be used by the local government, construction investors, and individuals as an attempt to boost the performance of buildings in urban development by applying energy efficiency measures for sustainable development as a value-added contribution to this research. Applying these methodologies can be obligatory to achieve a building permit as a gateway for environmental conservation and sustainable development.

There are some limitations that the user may encounter when applying these methodologies. First, the lack of data regarding the constructed building. Second, the availability of BIM and GIS programmes. Third, the unavailability of experts to utilise these specialised programmes, especially in developing countries. Fourth, the fact that constructing or achieving energy efficiency in buildings initially costs more than conventional buildings discourages many people, especially investors, from applying this concept.

7. Conclusion and recommendations

Energy conservation in buildings has levels and this intervention depends on its ability to change. It may be something simple, such as changing the glass of the windows or changing the building orientation (in the design phase). It could be bigger, such as changing the current HVAC systems to a new system with higher efficiency or insulating the walls. The change could be greater, such as changing building materials.

BIM technology has shown big potential in the architecture, engineering and construction (AEC) industry. There is a quick increase by institutions and municipalities in the use of BIM because of its capabilities in saving all information about the building and its elements in one place, along with its great ability to coordinate and communicate between different disciplines. In addition to being able to perform energy simulation, BIM is also able to calculate energy costs and make suggestions for reducing energy costs.

GIS is capable of integrating different types of data from different sources in one place. It can run many analyses at the district level about buildings with high energy consumption and electricity bills. GIS helps in evaluating and identifying the potential for energy improvements concerning energy performance.

Integrating BIM with GIS is useful to utilise the capabilities of BIM in energy efficiency inside the GIS at the district level instead of only focusing on improvements to individual buildings. Accordingly, the output results of the urban energy analysis maps are beneficial for a wide and general review of the energy performances in the city. The integration of these two important technologies can produce useful outputs regarding energy efficiency, which is now an important issue all countries are concerned with.

This research recommends:

- Apply the proposed approaches to future research and real buildings.
- For local governments, applying these methodologies to new buildings becomes mandatory if possible.
- Propose future research defining different ways and techniques for achieving data related to the proposed approaches.
- Propose future research defining the different types of software and identifying the most suitable for applying the proposed approaches in BIM and GIS.

Conflict of interest

The authors declare no conflict of interest in this study.

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