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Developing Building Management System Framework using Web-based-GIS and BIM Integration

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Abstract: Building Information Modeling (BIM) and Geographic Information systems (GIS) are two digital system innovations advantageously applied in the Architecture, Engineering, Construction, and Operations (AECO) sectors. GIS and BIM integration development is indispensable in building and infrastructure management. This integration promises several benefits for the operational phase of buildings and infrastructures. However, it faces challenges in data transformation and collaboration. This study proposes a framework and model for a web-based building management platform. The framework is developed by transforming BIM data into the GIS environment using the latest technology from ArcGIS. It allows data-sharing and collaboration among stakeholders, help build management, and is valuable for decision-making. The stakeholders, who do not need a BIM-GIS expert, could virtually see the report and updates of this building model every time.

Keywords: Building management; BIM-GIS; framework; ArcGIS Online; web-based.

Introduction

Technology is one of the success keys in building and infrastructure management. Governed by Indonesian Law no. 2 of 2017 [1] concerning Construction Services, the Central Government encourages the construction industry to accelerate technology and innovation developments. Two technological innovations that can be applied in the construction sector are Building Information Modeling (BIM) and Geographic Information Systems (GIS). BIM is a growing collection of concepts and tools that have been linked to transformative capabilities in the Architecture, Engineering, Construction, and Operations (AECO) industry. It can visually compare deviations between plan and actual performance [4,5].

GIS captures, stores, analyzes, manages, and presents data connected to a single geographic location [2]. It helps users understand geographic patterns, relationships, and contexts. It also supports users in improving communication, efficiency, and better management and decision-making [3]. The scope of spatial and related attribute data is extensive. It covers various industries such as utilities, transportation, petroleum, insurance, banking, real estate, retail, environmental consulting, and healthcare. It is also often combined with other technology for instant Global Positioning System (GPS), Radio Frequency Identification (RFID), sensors, mobile wireless communications, handheld devices, and LIDAR. [4].

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As information technology platforms, BIM and GIS have differences and similarities. GIS has multiple users with global spatial data, while BIM focuses on the detail components geometry [5–7]. On the other hand, both can combine attributes and geometries, create 3D models indoors or outdoors, and change spatial and non-spatial data [7,8].

The integration of GIS and BIM is promising; it can improve data interoperability and the data management process. This feature entirely solves sharing data problems among users [9,10]. Hence, it is necessary to have GIS and BIM integration technologies to support the construction industry [11].

However, GIS-BIM integration still faces many challenges [3]. It is necessary to know both standard data formats, such as .ifc in BIM and .shp in GIS, to understand their integration methods and data exchange mechanism [12]. The use of BIM and GIS commonly has focused on buildings (73.1%) rather than other infrastructure (12.2%). Therefore research on platforms throughout the life cycle is suggested [13], while maintenance management information is the most critical factor in building facility management [14].

This study summarized many potential methods and challenges to get the most commonly used and practical platform. Hence, it is necessary to deeply observe the previous latest research related to BIM-GIS integration beforehand. This study aims to create a practical framework of BIM-GIS integration for building life cycle management, determine its potential benefits and propose its implementation in a web-based building management model.

The Study Method

This study started with reviewing the literature to get a historical perspective on each research area and an

Table 1. List of Literature Related to BIM-GIS Integration

No	Ref	Integration Area	Life Cycle Phase	Platform	Integration Method	Challenges
1	[17]	Building life cycle management	FS, P, D, C, OM, DM	Autodesk Revit, Navisworks, ArcGIS	BIM to GIS	Data transfer
2	[6]	Data Integration	FS	Autodesk Revit, Talend, BG ETL	BIM and GIS to another system	Data/ information interoperability
3	[18]	Knowledge transfer process	FS	Autodesk Revit, ArcGIS, SketchUp, AutoCAD	BIM to GIS	Database management systems used in GIS do not support 3D databases
4	[19]	Visualization and Cost Estimation	FS, P	AutoCAD	BIM and GIS to another system	Huge data assumptions to define the cost estimation.
5	[20]	Sustainable Environmental Planning	FS, P	AutoCAD, ArchiCAD, Autodesk Revit, Active3D, BIM4GeoA, CityEngine	BIM and GIS to another system	Two types of models need to be upgraded using the third platform
6	[21]	Underground utility visualization	FS, P	Autodesk Revit, Autocad, Civil 3D, ArcMap	GIS to BIM	Necessary to include larger datasets
7	[22]	Documentation of construction project	FS, P, D	Autocad, Autodesk Revit, ArcGIS, Autodesk Infraworks	BIM to GIS	Data documentation and collaboration
8	[23]	Highway alignment planning, Cost optimization, Hazard Mitigation	FS, P, D	Autodesk Revit, Civil3D, Naviswork, ArcGIS, ArcMap, ArcEngine, SQL	BIM and GIS data into another system	A large amount of data and collaboration
9	[24]	Indoor geo-visual analysis	P	Autodesk Revit, Naviswork, ArcGIS	BIM to GIS	Data transformation
10	[25]	3D visualization model of the water distribution system	P	Autodesk Revit, Infraworks, AutoCad, SketchUp, ArcGIS, CityGML	BIM to GIS	Data loss
11	[26]	Indoor 3D modelling and spatial analysis	P	Autodesk Infraworks, ArcGIS	BIM and GIS data into another system	Data validation
12	[27]	Visualization and Flood damage assessment	P	Autodesk Revit, ArcGIS	BIM and GIS to another system	Data quality
13	[28]	Design for energy saving	P, D	AutoCAD, Autodesk Revit, Google Earth, Energy Plus	BIM and GIS to another system	The difference in standards and data description needs data conversion
14	[29]	Design for energy saving	P, D, OM	Autodesk, BEMS, SCADA, BACnet, WSN, OGC OWS-4	BIM and GIS to another system	Decision-makers mindsets have to transform
15	[30]	Planning development	P, D	Matlab, OpenStreetMap, QGIS	BIM to GIS	Visual Data model integration and georeferencing
16	[31]	Site Layout Planning	P, D	Autodesk Revit, ArcGIS	BIM to GIS	Limited attributes to be transferred
17	[32]	Integrate Site Planning and Building design results	P, D	Revit, ArcGIS, MongoDB database	BIM and GIS data into another system	The data is not uniform
18	[33]	3D noise map in urban environments	P, D	Autodesk Revit, ArcGIS, VBA	BIM to GIS	Model Updating
19	[34]	Flood damage assessment	P, D	Autodesk, ArcGIS	BIM to GIS	Detailing the use cases based on stakeholders
20	[35]	3D Data Visualization	P, D	Autodesk Revit, ArcGIS, Google Earth, VWorld middleware	BIM and GIS to another system	Interoperability and sharing of data
21	[36]	Fire-fighting simulations	P, D	Self-Developed system	BIM and GIS to another system	Data transfer
22	[37]	Urban Facility Management	P, D, C, OM, D	AutoCAD, ACTIVe3D, Self-Developed system SIGa3D	BIM and GIS to another system	Data heterogeneity
23	[38]	Emergency route planning	P, D, OM	Autodesk Revit, ArcGIS	BIM to GIS	Data collection and geometric transformation
24	[39]	3D city models assets database	P, OM	Autodesk Revit, Dynamo Revit Plug-in, ArcGIS Pro, Oracle	BIM to GIS	A large amount of data

Note: (FS) Feasibility Study, (P) Planning, (D) Design, (C) Construction, (OM) Operation and Maintenance, (DM) Demolition

Table 1. List of Literature Related to BIM-GIS Integration (continue)

No	Ref	Integration Area	Life Cycle Phase	Platform	Integration Method	Challenges
25	[40]	Geometry Data Transformation	D	Feature Manipulation Engine (FME), Data Interoperability Extension for ArcGIS (DIA)	BIM to GIS	Geometry transformation
26	[41]	Geometry Data Transformation	D	Autodesk Revit, DIA, AMG, Feature Manipulation Engine (FME), Open-Source Approach (OSA).	BIM to GIS	Geometry Data Exchange
27	[42]	Data Transformation	D, C	Vworld Desktop software and Autodesk Revit, MySQL, IFCOpenShell plugin, Cesium.js	BIM to GIS	Exporting data
28	[43]	Flood damage assessment	D, OM	ArcGIS, Autodesk Revit	BIM to GIS	Data-level integration and collaboration
29	[44]	Construction Supply Chain Management	C	Google Earth, ArcGIS, Autodesk Revit	BIM to GIS	Data integration and software interoperability
30	[45]	Construction Supply Chain Management	C	Autodesk Revit, Naviswork, ArcGIS,	BIM to GIS	The data quality and manual input
31	[46]	Equipment location optimization	C	Autodesk Revit, ArcGIS	GIS to BIM	Lack of interopera-bility between GIS and BIM.
32	[47]	Minimize construction disruption	C	AutoCAD, Degree 3D, GeoServer, MS SQL	BIM and GIS to another system	BIM-GIS data open-interoperability
33	[48]	Information sharing	C	Autodesk Revit, ArcGIS	BIM to GIS	Data transformation and collaboration
34	[7]	Decision-making scenarios & clash detection	C	Synchro, Autodesk, CesiumJS, ArcGIS Pro, Oracle Primavera	BIM to GIS	Data interoperability and collaboration
35	[49]	Transfer Knowledge	C	Autodesk Revit, ArcGIS Pro, FME Desktop, IfcGeoRefCHec-ker, CSTBeveBIM, FZK Viewer	BIM to GIS	Georeferencing and Conversions
36	[50]	Visualization and Time Control System	C	Autodesk Revit, Google Earth, MS Project, MS Access	BIM to GIS	Data interoperability
37	[11]	Technology in Construction Management	C, OM	No Description	BIM to GIS	The standards are not unified, need collaboration
38	[51]	Energetic efficiency for hospitals	C, OM	QGIS	BIM to GIS	Data transformation
39	[52]	Environmental Decision-Making Process	OM, D	Autodesk Revit, Infraworks, ArcGIS	BIM to GIS	Data format interoperability
40	[53]	Evaluation of building performance	OM, D	Autodesk Revit, ArcGIS	BIM to GIS	Data collaboration and quality
41	[54]	Integrated pre-retrofitting	OM	Autodesk 123D, Autodesk Revit, Google Sketch Up, ArcGIS, AutoCAD	BIM to GIS	Lack of support for BIM systems
42	[55]	Reuse of existing facilities	OM	Open BIM and Open GIS	BIM to GIS	BIM and GIS data interoperability
43	[56]	Monitoring of historic buildings	OM	AutoCAD, ArcMap, Autodesk Revit	BIM to GIS	Geometric documentation data
44	[57]	Web GIS-based management	OM	Open CASCADE, ArcGIS Pro, ArcGIS Online	BIM to GIS	Geometry transformation
45	[58]	Heritage monitoring and documentation	OM	Autodesk Revit, ArcGIS, QGIS, FME	BIM to GIS	Data interoperability
46	[59]	3D Evacuation Planning	OM	Autodesk Revit, FME Revit Plug-in, and ArcGIS Pro	BIM to GIS	Data interoperability
47	[60]	Documentation and restoration of historical monument	OM	Autodesk Revit, Infraworks, FME	BIM to GIS	A large number of database
48	[61]	Digital documentation and model concerning	OM	Autodesk Revit, Open Source GIS, Feature Manipulation Engine (FME), PostGIS, ArcMap, QGIS	BIM to GIS	Data loss
49	[62]	Data documentation and sharing	OM	Autodesk 123D Catch, MS Access, Autodesk Revit, ArcGIS	BIM to GIS	Interoperability and sharing of data
50	[63]	District Modeling	OM	Autodesk Revit, ArcGIS, Autodesk Infraworks, Self-Developed system DIMMER	BIM and GIS to another system	Database and data collection
51	[64]	Indoor emergency response	OM, P	Autodesk Revit, ArcGIS	BIM to GIS	Lack of data resources
52	[65]	Demolition waste management	DM	Autodesk Revit, ArcGIS	BIM to GIS	Data interoperability

Note: (FS) Feasibility Study, (P) Planning, (D) Design, (C) Construction, (OM) Operation and Maintenance, (DM) Demolition in-depth account of future research efforts [15]. Fifty scientific research related to BIM-GIS technology integration was thoroughly reviewed. Some theoretical frameworks of BIM-GIS integration were studied to underlie the proposed framework. The framework will be analyzed whether it follows the results of previous studies. Next, a BIM-GIS integration model was created in the WebGIS platform to enable effective integration of data management [16].

Defining Parameters

Research articles related to BIM and GIS Integration within the last ten years were selected and reviewed based on their study parameters. The parameters included Integration Area, Lifecycle Phase, Integration Platform, Integration Methods, and Challenges are shown in Table 1.

Results and Analysis

The output of this study is focused on proposing a simple and practical framework for BIM-GIS integration based on many related literature recommendations, especially regarding the integration method and platform. The model was created as an initial validation of the proposed framework.

Potential Area of BIM-GIS Integration

The content of previous research related to the integration of BIM and GIS technologies was classified based on predetermined parameters and life cycle stages. Table 2 shows the life cycle stages of reviewed literature.

The BIM-GIS integration has been commonly developed in every life cycle phase. The feasibility study is commonly used to view building life cycle management for the upstream process. The interaction between a project and its surroundings and their environmental impacts is essential to understanding the landscape of work done and its utilization in various stages of the building lifecycle [17,18].

The planning and design phase is commonly used for visualization, site layout, route, and alignment planing. This integration reduces the data gap between site planning and building design to improve the collaborative design [32]. It potentially overcomes the limitations and better understands vulnerabilities in the building, and facilitates effective decisions [43]. It is also commonly used for construction monitoring and data collection during the construction phase. Having a clear case for the collection and ongoing use of information is fundamental because the same information can be repeatedly used and minimize the cost [7].

Table 2. Application of BIM-GIS Integration in the Building Life Cycle

Life Cycle	Integration Area
Feasibility Study	Building life cycle management [17,18]
	3D Utility Visualization [6,21]
	Knowledge transfer process [18]
	Sustainable Environmental Planning [66]
	Documentation of construction project [17, 22]
	Alignment planning [23]
	Cost Optimization [23]
	Hazard Mitigation [23]
Planning	3D visualization and database [25–27,32]
	Indoor 3D modelling & spatial analysis [26, 27,35]
	Flood damage assessment [27,34,43]
	Design for energy saving [28,29]
	Site Layout & Route Planning [31,32,36]
	3D urban environments [30,33,37,39]
	Urban Facility Management [37]
Design	Data Transformation [40–42]
	Design for energy saving [28–29]
	Flood damage assessment [27,34,43]
Construction	Supply Chain Management [44–45,47]
	Equipment location optimization [46]
	Minimize construction disruption [47]
	Information sharing & knowledge transfer [7,43,48,49]
	Decision making scenarios & clash detection [7,27]
	Visualization & Time Control [7,48,50]
Maintenance and Operation	Flood damage assessment [27,34,43]
	Urban Facility Management [30,33,37,39]
	Emergency route [28–29,64]
	3D city models assets database [11]
	Energy efficiency [29,51–53,67]
	Environmental Decision-Making [52]
	Building performance Evaluation [53–58]
	Monitoring and Documentation [56–68]
	Web GIS-based facility management [35, 42,57]
	Reuse of existing facilities [55]
	3D Evacuation[59]
	Data documentation and sharing [60–63]
Demolition	Demolition waste management [65]

Building performance monitoring, operation, and collaboration are required during the operation and maintenance phase. Therefore an integrated system is essential. It gives information regarding the current state of preservation for the decision-making towards selecting the necessary materials and minimizing the threats and risks of the past [56]. Moreover, it provides stakeholders with a dynamic and holistic virtual assessment of the building's performance [29]. Concerning building demolition, the technology can be used to manage the waste after the demolition.

WebGIS is an integrated product of GIS and Internet technologies; in WebGIS, internet technologies are linked with GIS to take advantage of their particular characteristics. WebGIS makes it possible to retrieve and analyze spatial data through websites. The Internet also provides a medium for processing information related to geographic data [69]. In addition, WebGIS analyzes data from various sources and allows widely sharing of spatial and geoscientific data models [70].

The BIM-GIS integration has been researched and implemented in various project areas, but most previous studies have been developed for the operation and maintenance (OM). The phase with the highest number of stakeholders is the OM phase [74]. Table 3 shows which building life cycle stages are usually directly included in the interested parties' considerations.

Table 3. Stakeholders' Involvement in Project Lifecycle [71]

Upstream process	Planning and Design	Construction	Use	Demolition
D, G, S	O, De, D, F, G, S	O, De, D, C, S, F, G	O, D, C, S, U, FM, I, Re, G	O, D, C, S, U, I, G

Note: Owner (O), Developer (De), Designer (D), Constructor (C), Supplier (S), User (U), Facility Manager (FM), Financer (F), Insurance (I), Real Estate broker (Re), Government (G)

Moreover, knowing how long the OM phase takes and costs more than 58% of the life cycle cost [72], this technology integration is better implemented for the OM phase for the building management purpose as an initial approach.

Integration Method and Platform

Liu et al. classified BIM and GIS integration into three categories: data, process, and application-level [10]. The integration bridges the process between the source of heterogeneous information models. The extension methods, interlinking, and merging prevent information loss during direct conversion [73].

They were adapted from Ma and Ren [13]. Platforms for BIM and GIS have been defined into three areas: Extracting data from BIM systems into GIS, extracting data from GIS into BIM systems, and extracting data from BIM and GIS systems to other systems. The platform's recommendation is summarized in Table 4.

There are several methods integrating BIM and GIS. The methods are categorized into three patterns based on which one leads and supports [66].

Traditionally, many studies in the civil and construction industry use pattern one. BIM leads and GIS support in the design until the operational phase since BIM provides more detailed data in the first place. This pattern can better express the building's internal information; moreover, it could monitor at the elementary level in BIM geometry objects. The GIS data and map strengthen the geometry data to give spatial information easily. The integration improves communication with stakeholders, provides geospatial analysis capability, and facilitates understanding of the impacts of a building on its surroundings [17].

Table 4. The Supportive Platform of Integration

Integration Method	Integration Platform
BIM to GIS	Autodesk Revit: [17], [18], [22], [24], [25], [31], [33], [38], [39], [41]–[45], [48]–[50], [52]–[54], [56], [58]–[60], [62], [64], [65], [74] Autodesk Navisworks: [17], [24], [45] AutoCAD: [18], [22], [25], [54], [56] Autodesk Infraworks: [22], [25], [52], [60] ArcGIS: [7], [17], [18], [22], [25], [31], [33], [34], [38]–[40], [43]–[45], [48], [49], [52]–[54], [57]–[59], [61], [62], [64], [65] QGIS: [51], [58], [61] OpenSteetMap: [25], [30], [40] Google Earth: [44], [50] PostGIS: [61] Vworld Desktop [42] Matlab [30] VBA [33] MySQL [42] Cesium [7], [42] Open CASCADE [57] Synchro [7] Oracle Primavera [7], [39] MS Project [50] MS Access [50], [62]
GIS to BIM	Autodesk Revit [21], [46] Autocad [21] Autodesk Civil 3D [21] ArcGIS [21], [46]
BIM and GIS to other systems	Autodesk Revit [6], [20], [23], [27], [28], [35], [63] AutoCAD [19], [20], [28], [37], [47] Autodesk Civil3D [23] Autodesk Naviswork [23] Autodesk Infraworks [26], [63] Google Earth [28], [35] CityEngine [20] ArcGIS: [23], [26], [27], [32], [35], [63] MySQL: [23], [47] Self-Developed system: [6], [20], [29], [32], [36], [37], [47], [63]

Pattern two, which GIS leads and BIM supports, is dominated by the GIS model and is often used for city planning or other feasibility studies because of its excellent spatial data processing capabilities. Unfortunately, this pattern lacks detailed attribute information for building entities. The BIM model is used only to provide data support.

At last, the third pattern takes BIM and GIS equally involved and emphasizes the interoperability between the BIM dan GIS model. This pattern is what the future of these two technologies would expect. This method will achieve an excellent combination of capabilities in the building and the surrounding space. While all data can be compatible, interoperability will be achieved. However, enormous data volume could increase the burden of computer processing. The third pattern is expected to combine BIM and GIS technologies to be visualized in a modern web browser without plugins [66].

Therefore, the first pattern could be best developed for the initial integration step in the construction industry, especially in the building's operation phase.

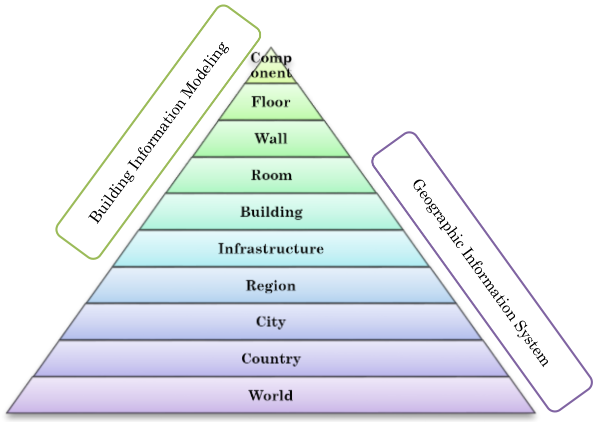

Figure 1. BIM and GIS Overlap (adapted from [8,10])

As shown in Figure 1, the infrastructure, building, and room are where BIM and GIS overlap. At this level, both information systems complement each other to support the organization's management and decision-making, starting from the 3D component to the more complex components and the environmental data. The information data is divided into geometry and property data.

The BIM geometric information has detailed information regarding specific building components. It needs to be extracted to the GIS environment as a multipatch. Next, it will be uploaded to the database as a shapefile containing the property information. The information could be selected and displayed in the GIS viewer according to the user's demands.

This study proposes a framework integrating the BIM model inside the GIS environment through georeferencing the BIM in Revit to match the map coordinates. The process is to export the BIM data integrated with GIS and import those shapefiles into the GIS database using online GIS software.

Many previous studies have used various software, plugged-in, and self-developed platform for integration. To achieve high interoperability, a high level of detail, and avoid data loss, the 3D model data in .rvt or .ifc must go through several more data transformation processes using Feature Manipulation Engine (FME) or other converting software. Thus, relying on several commercial software is the main requirement for an effective BIM-GIS integration solution.

Revit was the most common BIM platform, while ArcGIS was decisively the most common GIS platform. The .ifc BIM file using Autodesk Revit software is a compatible data format commonly used with the GIS environment, while shapefile (.shp) using ArcGIS Software is commonly used as the GIS sharing format. Shapefile is the most-used exchange data format in the GIS industry that supports 3D geometry and can easily be exchanged with other 3D BIM software [41]. Moreover, Revit has other advantages with the .rvt format, which could be directly exported to ArcGIS Pro without a complex transformation step beforehand. Shapefile can hold BIM models, even complex entities such as windows, doors, and stairs [40]. Extracting data from GIS into a BIM system is unlikely to be used in the AEC industry, especially for developing a website platform. GIS provides a more extensive, lighter, and more flexible database than BIM has. The third is extracting data from BIM and GIS systems to other systems. It can also be performed but needs more programming skills and longer steps or processes because it usually uses the self-developed platform.

Therefore, this study will use Autodesk Revit and ArcGIS with the latest technology for data sharing and collaboration to make a more feasible framework in the building management web-based platform.

Implementation Challenges

Each integration method and platform's strengths and weaknesses become crucial issues for proposing a better framework. The previous studies found that many challenges during integration must be noticed and prevented to make a seamless integration (Table 5). The most common challenge found in the previous study is the data compatibility or interoperability between BIM and GIS. One of the foremost apparent irregularities between the two systems is georeferencing. It is a common long-run practice in GIS and 3D city models; however, it may be new in BIM [49].

Mismatch information shows the difference in a standard format, different users, different application focuses, development stages, spatial scales, coordinate systems, geometric representations, storage, and access to various information [10]. More study about data transformation promises the broad potential of further integration. Some software packages and systems are not always compatible, requiring extra data transformation steps [5]. The semantic web technologies and service-based methods give high effectiveness, extensibility, and effort; therefore, collaboration and openness are the keys to BIM and GIS integration [10]. The web is a mesh of information linked up in such a way to be easily processable by machines on a global scale [37]. Emerging technologies such as cloud computing, semantic web technology, web-based communication, and mobile BIM-GIS technologies extend the framework implementation [17].

Table 5. Highlighted Challenge

Challenge	Solution
System	
- The system is not compatible with each other - BIM standard is .ifc while GIS standard is .shp or CityGML	- Do the performance test on the operating system [75] - The system needs an extra data transformation step [40,41]
Data	
- Data formats not compatible with each other - Georeferencing - Database	- Using plugin or middleware to transform the data format [35,40,49] - Export the BIM model directly to ArcGIS [57] - Georeference is the geometric model to match the location [65] - Using ArcGIS to make geodatabase [39]
Collaboration	
- Not all users understand the system - Data sharing	- Using WebGIS for collaboration and data sharing [42] - ArcGIS has a supportive Web Application [76]

Proposed Framework

Based on the reviewed literature, some potential integration challenges and solutions regarding data-sharing and transformation are observed and listed in Table 5.

The data transformation has been the most critical challenge since some information can be lost during the integration process [25,61]. Some software packages and systems are sometimes incompatible and require extra data transformation steps [5]. These problems are due to a lack of interoperability between different platforms. While the semantic web technologies and service-based give high effectiveness and extensible effort, collaboration and openness become the keys to BIM and GIS integration [10]. This study proposes the simplest BIM-GIS integration method using Revit and ArcGIS in a web-based platform. Web GIS integrated methods can collect more valuable information from distributed sources (e.g., the public and all building facilities) [20]. The most common integration pattern is conducted by extracting BIM data from Autodesk Revit and transforming it into a GIS environment through the ArcGIS platform.

The second challenge is related to data collaboration. Therefore, the proposed framework is prepared to optimize data-sharing features using a web-based GIS application to perform broader collaboration. It optimizes the sharing data process through ArcGIS Online, the most flexible and easy-to-use GIS environment platform. ArcGIS Online is the latest technology of ArcGIS, a cloud-based mapping and analysis solution for data sharing, analysis, and collaboration. It is possibly made into web applications with various app builder templates with minimal configuration requirements [76].

The highlighted features of the proposed framework are as follows:

1. Focus on building and facility management purpose
2. Use an integration pattern that extracts the BIM data to the GIS Environments
3. Optimize data sharing and collaboration through the web-based platform
4. Utilize the application from ArcGIS's latest technology (ArcGIS Online, Experience builder, and ArcGIS Survey123)
5. Do not require advanced IT or programming
6. The website platform is easily adjusted and developed based on the organization's demand

The framework is specially developed for building management's operational phase, which supports collaboration among stakeholders through flexible data sharing. Figure 2 shows the use-case of the framework, while Figure 3 illustrates its integration.

The use case is a scenario about the expected behavior of a system regarding the stakeholders' needs. It will be used as the basis of the required functionalities and the data needs for the application. From the use case provided (Figure 2), the system level had been divided into three primary users: Admin, Building Manager, and User/ stakeholders.

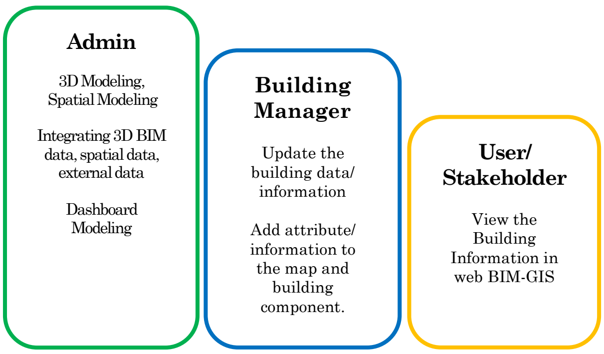

Figure 2. The Use-Case Scenario for the Framework

The system process can only be edited by the admin, which does not have to have advanced IT or programming knowledge through this platform. The organization could make a web app using a variety of app builders application templates with minimal to no configuration required [76].

At the same time, the building manager has the authorization to give updates on specific information, such as maintenance reports for the building components and updated external data. The user or stakeholders can see this Web BIM-GIS if the admin sets the data sharing format as public data. It will benefit many relevant stakeholders, for instance, the building maintenance vendor, consultant, room tenant, the building operator, or other external stakeholders.

Autodesk Revit is the most common platform for 3D geometry data modeling, while ArcGIS models the map and the integration platform. The spatial modeling and the extraction process from .rvt to multipatch are using ArcGIS Pro. The environment and multipatch data are then shared to the ArcGIS online database as a web map.

Moreover, ArcGIS Online provides many supporting online application packages that could be used to support the use-case scenario. The proposed framework will be developed using the other ArcGIS supportive application such as ArcGIS Experience Builder to model the website dashboard and ArcGIS Survey123 to add or ArcGIS FieldMap to update the existing data or attributes.

The proposed framework (Figure 3) uses the semantic web integration method to extract BIM data in the GIS environment. The adapted use-case scenario to perform the framework is as follows:

1. The 3D BIM objects had been modeled in Autodesk Revit (Desktop), and the geometry attributes were added
2. The user logs into the GIS Server with the account in ArcGIS Pro (Desktop)
3. The user observes the object's location on the GIS map and adds the spatial data needed (Spatial Modeling)
4. The user selects a BIM object to use and exports it to ArcGIS Pro as a multipatch
5. The user georeferences the location of BIM and moves to the destined position on the GIS map.
6. Share the BIM-Map from desktop to ArcGIS online database (Website)
7. Choose an ArcGIS application to make a front dashboard: ArcGIS Experience Builder or ArcGIS Dashboard (Website)
8. Design the layout and choose the map that has been uploaded to the ArcGIS online database
9. Create a survey form with ArcGIS Survey123 and connect to the Dashboard
10. Add more data and information needed to ArcGIS Online.
11. Set the data as private or public to be shared.
12. Share the dashboard website address so everyone can easily access the BIM objects in a GIS map.

At this point, the framework can be performed to make a WebBIM-GIS building management platform. The advantages of using the ArcGIS Online support application are the attractive user interface, the flexibility of data sharing, and ease of use. As previously discussed, the biggest challenge of the integration is the data complexity, which involves highly specialized skills from civil, knowledge, and ICT engineering [77]. However, an organization without advanced IT and programming knowledge could easily develop this platform through this framework. The validation of the proposed framework

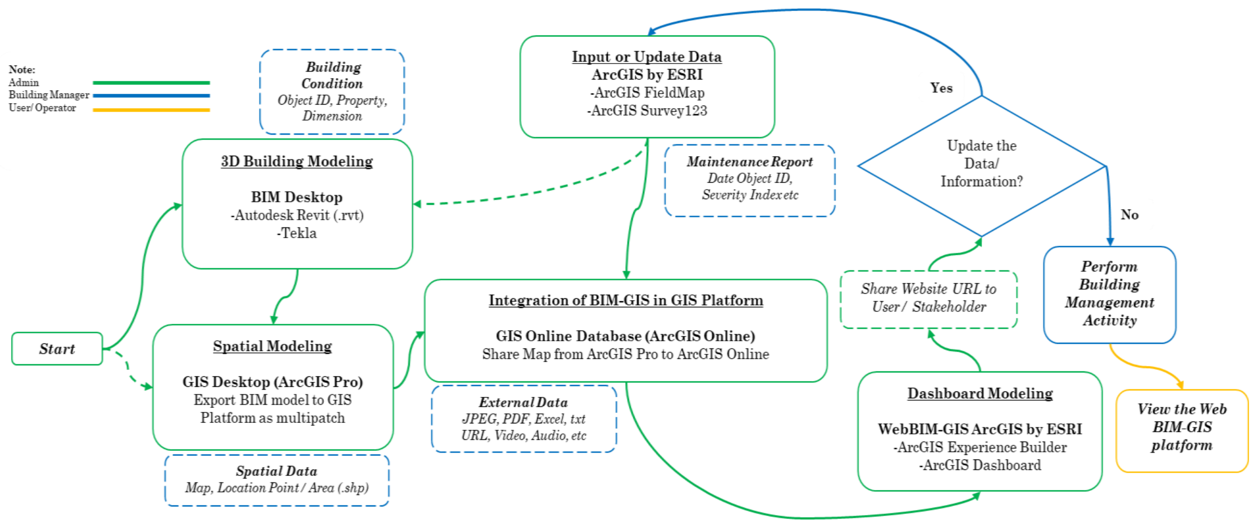

Figure 3. BIM-GIS Technology Integration Framework for Building Management

is using case study modeling. The model is a web-based application developed using Autodesk Revit and ArcGIS Online. The model platform has been visualized and explained in the WebBIM-GIS Model Platform section.

WebBIM-GIS Model Platform

The framework can be a practical guide for creating a web-based GIS and BIM technology integration platform. This platform is developed to validate whether the proposed framework can work and be implemented. This platform is in the form of a model created using ArcGIS (with the supporting application package) and Autodesk Revit to provide an overview of building management applications.

This platform is practically developed in the ArcGIS environment, accommodating the online web-based GIS. ArcGIS Online and the support application store various forms and types of data in its database. Later, the data sharing and collaboration can be adjusted following the organization's needs.

The ArcGIS Experience Builder is a web-based application developed by ArcGIS which works as a website. The user can easily adjust the website's contents because it provides many widgets and features to connect to the data in ArcGIS Online. The model's Dashboard of the building management platform developed using the ArcGIS Experience Builder can be seen in Figure 4. The Dashboard can show general information to the public. The data sharing or privacy can be managed in a public, private, or organizational setting.

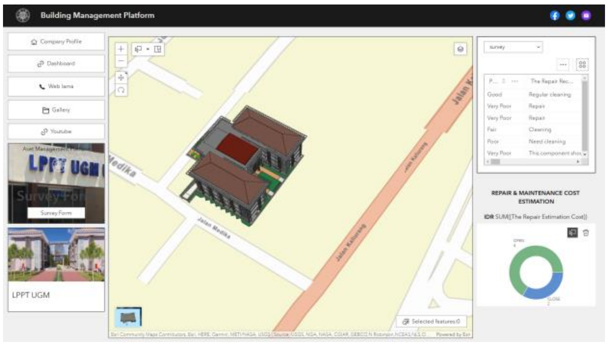

Figure 4. Web BIM-GIS Dashboard

In Figure 4, the information shown on the Dashboard is the spatial data, geometry data, and other supportive data. The highlighted of this Dashboard shows the BIM 3D Revit model, which has the most crucial information for the building management's process. The geometry data example is the building model previously developed in Revit.

The spatial data is the map of the building area with supporting information or attributes, such as street names, building names, building areas, location markers, and other important information. The data in .rvt must be transformed into .shp or multipatch in ArcGIS Pro. Then it has to be georeferenced to meet the exact locations or the global coordinates. The other supportive data can be the picture, the table, the charts, the Uniform Resource Locator (URL), and other formats. Only through this one window can the user receive much information through this platform. The following window in Figure 5 is a BIM modeling containing geometric information of the elemental level of detail, integrated into the GIS platform via ArcGIS Online. This integration allows detailed visualizations and access to a building model's attributes through the website address. The user does not need to open the model through the desktop. The stakeholder could virtually see the building's details only through this website application.

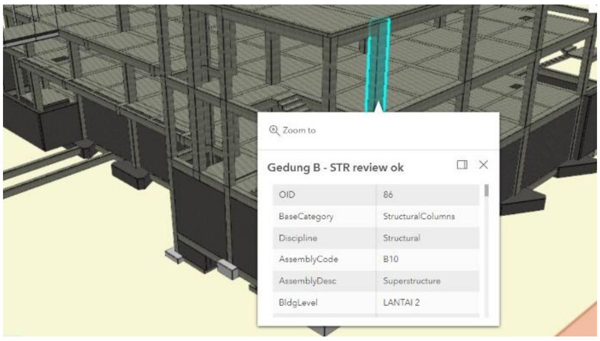

Figure 5. The BIM/Geometric Attributes' Information

This detailed 3D model visualization highlights this platform, which is decisive for the building's stakeholders following the use-case scenario. The user could virtually jump into the 3D model through this integration platform to know the detail by clicking/selecting the desired components.

Detailed information of every building component can be seen, such as the objectID, object name, material, dimension, severity index, and more attributes can be added to the geometry's attribute. The information input and collection are adjustable following the organization's purpose.

ArcGIS Survey 123, a supportive survey application provided by ArcGIS, is also a part of this framework. ArcGIS Survey123 works as a data collector, which can be connected to the Dashboard in real-time to update and create new reports. In Figure 6, there are several questions to gather the data needed by the building's manager. The workers do not have to do the paper works anymore because the inspection's survey can be done digitally. Therefore, all historical changes and reports could be stored in the database. The historical data could benefit the building's manager's working process. ArcGis Field Maps could be the alternative to input and edit the existing data because it can directly edit the feature/ geometry data.

After the data collection and update process, the data can be visualized in more attractive forms, such as the bar chart shown in Figure 7. A bar chart entitled "Building Component Condition" is extracted from the survey result in a table. The table summarizes the survey result collected from the ArcGIS Survey123 (Figure 6).

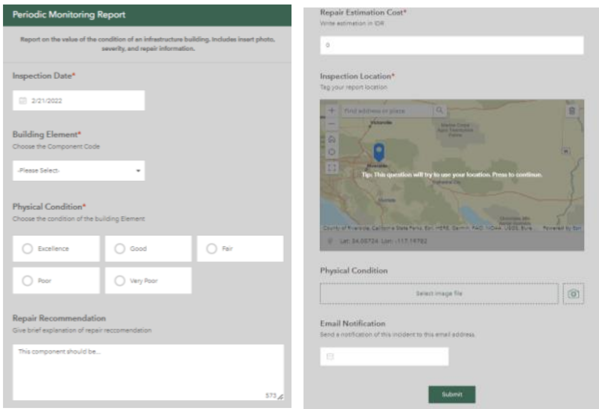

Figure 6. The Building Monitoring form using ArcGIS Survey123.

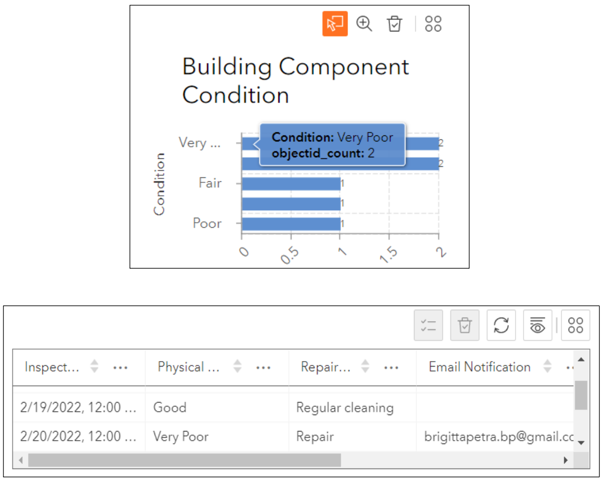

Figure 7. The Web-monitoring Report

There are limitations of the model:
1. The model only uses the structural and architectural BIM data as an initial model.
2. The data quality has not been a concern as it emphasizes how to practically collect, transform, and share the BIM data in the GIS environment.
3. This model has not performed the data analysis, such as the building condition index.
4. The organization needs a license since Autodesk Revit and ArcGIS are commercial products.

Despite the limitations, this web-based platform is easy to adjust and can accommodate the organization's needs, in which this web-based platform has customized widgets to adjust the layout and contents. For instance, the user can filter which data should be shown or hidden, visualize the data in a bar chart or piechart, and edit the existing or add data with the provided features. This platform can also accommodate the organization's needs by displaying the desired data such as spatial, geometry, and other data formats. The Revit building 3D model transformed into the ArcGIS platform as important geometry data for the building management. The user could explore the information within the building 3D model through this website. The information within the building components' attributes can be stored in the web-based platform, while the updates and historical data reports are required for the building management.

In fact, the framework feasibly supports the extensive development of the model. It has been providing the general guidance for the most straightforward integration. However, it does limit the possibility of more complex development with other software packages or plugins. Thus, it can be developed more broadly based on the needs of the data and information management process from various relevant stakeholders.

Conclusion

This study explored the potential BIM-GIS integration to manage building-life cycles. It is found that the integration could be applicable in every building phase. However, many studies have claimed that BIM-GIS integration will be significantly valuable for the operation and maintenance of buildings and infrastructures, especially for facility monitoring and evaluation management. Autodesk Revit and ArcGIS Pro have become the most commonly recommended commercial platform for developing the BIM-GIS integration.

This study has conducted a general review and given a practical framework validated by providing the initially applied model in a case study. The case study constituted a general building whose business process involved admin, building manager, and users. The model was applied on a web-based ArcGIS Online platform with the ArcGIS support applications: ArcGIS Experience Builder, ArcGIS Survey123, and ArcGIS Field Maps. The model was successfully developed, and the building-related data, especially the 3D BIM data, was successfully transformed following the use-case scenario of the framework for a building management system. It supports data-sharing and collaboration among stakeholders. The stakeholders are not necessarily proficient in operating the BIM-GIS software; they could virtually see the report and update this building model. These platform's features help build good management and support the decision-making policy.

The applied model is valuable; the organization could effortlessly monitor and evaluate the building operation. However, it still needs improvement, as the WebBIM-GIS integration output and the framework has not profoundly considered the data quality and details. Hence, further studies need to be carried out to implement this theoretical framework into actual projects and involve the relevant stakeholder demands.

Further Direction

We are developing the framework into an actual project, considering the real stakeholder needs and the building facilities as our subsequent research. A pilot survey is being conducted, and the prototype is being developed and presented.

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