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Cross-sectional SWOT Analysis of BIM and GIS Integration

Abstract: The integration of BIM (Building Information Modeling) and GIS (Geographic Information System) technologies allows for added value in many fields; starting from the construction industry to administrative operations. However, the issue of integration is currently quite challenging. This is due to the lack of consistency (inter alia, a lack of standards) in the integration of both technologies. It is the result of the different primary use of BIM and GIS. The use of BIM and GIS integration has great potential, especially in the construction industry. Therefore, it was decided to analyze the strengths and weaknesses of integration as well as the opportunities and threats in the future by performing a SWOT analysis. The analysis was performed cross-sectionally based mainly on the existing literature. Finally, six strengths, five weaknesses, five opportunities, and four threats were identified and described.

Keywords: BIM, GIS, integration BIM&GIS, SWOT, GeoBIM

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1. Introduction

The construction industry needs positive incentives to grow, as its stagnation causes several setbacks, resulting in reduced efficiency, increased environmental impact, or higher lifetime operating costs [1]. The need for change is important because, according to a McKinsey report, the contribution of the construction industry to global GDP (Gross domestic product) will increase from around 12% (2020) to over 19% (2035) in the coming decades. This will stem from an increase in population and the need for infrastructure or buildings [2, 3].

One response to these problems is the implementation of new technologies such as BIM (Building Information Modeling), the search for new GIS (Geographic Information System) applications in the AEC (Architecture, Engineering, Construction) industry or the creation of new management solutions tailored directly to the construction industry. The word "new" is relative here, as these solutions are often technologies or methods used in other industries, but their universal characteristics allow for adaptation to new conditions. An example of this is the concept of the Digital Twin, which was initially used mainly in the manufacturing industry [4]. The adaptation of this technology in the construction industry can be used in supporting the management of a construction object during its entire life cycle [5].

This article focuses on the area of BIM and GIS integration, as there is no current publication in the literature that has analyzed it in depth (identifying strengths, weaknesses, opportunities, and threats of integration). Articles usually focus on: one issue, analyzing the applicability of integration for a particular area, e.g. for bridges [6], describing one integration problem from one perspective, e.g. file georeferencing [7] or information exchange between technologies using characteristic formats [8], or need to be updated as a result of new solutions or reports from standardization bodies, such as ISO (International Organization for Standardization). A holistic view of the problem makes it possible to analyze integration in terms of adapting solutions from some applications for other purposes. Some solutions used in one branch of the construction industry can be implemented in another. In addition, developments in technology have created new opportunities for integration, relative to the analysis of integration in [9] or [10]. Reports and technical specifications of ISO working committees have also been published. Therefore, the aim of this paper is to look at the integration of BIM and GIS technologies from a further perspective. Thus, the strengths, weaknesses, opportunities, and threats of integration were assessed by performing a SWOT analysis. The questions that the research tried to answer is: what are the strengths and weaknesses of BIM&GIS integration? And what are the threats and opportunities of BIM&GIS integration in the future? The paper is structured as follows. In first section BIM and GIS technologies are described. Section 2 identifies application areas for integration and analyses current applications. The next part of the paper is a SWOT analysis, where the method is described. The fourth section specifies the strengths and weaknesses of integration, as well as future opportunities and threats. Finally, results are discussed and the whole paper is summarized.

2. BIM and GIS – Differences, Similarities and Applications

BIM and GIS and the management processes associated with these technologies can add value even when used separately [11]. Using BIM and GIS technologies separately does not allow the information they contain to be used to their full potential. This becomes evident in the management of extensive areas or in large infrastructural projects. These projects or processes are characterized by the need to have the most accurate and wide range information. Integration allows the decision-making process to be contextualized and supports this process throughout the entire life cycle of the facility. This is the very essence of BIM and GIS integration. An example of a project, where integration has been used as part of the decision-making process is the large Crossrail infrastructure project in the United Kingdom. In this way, the right information can go to the right person at the right time [12]. The problem that occurs here is the use of BIM and GIS data within a single tool (e.g., CDE – Common Data Environment platform according to ISO 19650 standards [13]). This is because of the originally created applications of both technologies, which will be explained later in this paper.

The integration of BIM and GIS is a relatively new idea that has arisen as software, computer processing power, and information storage standards have developed [14]. Integration provides opportunities to look at the construction investment process or geospatial data from a broader perspective. BIM (Building Information Modelling) is a technology which presents an object in digital form. It is comprised of two main layers: geometric and informational. The geometric layer refers directly to the storage of the 3D model and the visual representation of the object (at a specified level of detail). On the other hand, the information layer is all the descriptive information about the components that make up the object. However, BIM is not only a 3D model that allows for reduction of clashes or analyses of the schedule of works [15]. BIM is also about processes correlated with the entire investment [16]. These include processes of information exchange, data revision, agreeing on the location of components or clash detection. The currently applied ISO 19650 standard indicates the areas in which the processes described above should be introduced [13].

An approach that supports the implementation of investments is the idea of openBIM. The principal of this idea is use of open standards for information exchange such as the IFC (Industry Foundation Classes) format (ISO 16739-1:2018 [17]), the semantics of which is currently mainly adapted to cubature objects [18], and its limitations in notation cause complications in recording of data in infrastructure projects [19]. As the integration of BIM and GIS seems to have the greatest potential in relation to more extensive objects (which is particularly evident in the operational phase of a facility [20]), lack of standardization regarding the recording of infrastructure data in IFC format is a problem. This requires the use of special classes such as IfcBuildingElementProxy, which makes it difficult to manage the information itself during the implementation of an investment based on the BIM methodology [19].

It also results in the difficulty in converting files to formats acceptable by GIS technology, and thus the difficulty of the integration itself. However, there is an opportunity to improve the situation, as the organization responsible for developing the IFC format, buildingSMART, is currently working on creating a standardization to extend the IFC format to include object classes specific to infrastructure projects [21].

Compared to GIS, BIM data are definitely more detailed, but cover a smaller area. GIS can be defined as a system for entering, managing, analyzing and sharing data located in space, which also has descriptive attributes – metadata [22]. The greatest advantage of this type of system is the possibility of various types of analyses, which can be carried out at different levels of complexity. Starting from the simplest actions like intersecting two layers or metadata analysis, to using machine learning techniques and solving complex problems. The possibilities of analysis depend on the type of data. However, it is possible to combine and analyze them together (e.g., vector data, raster data, TIN – Triangulated Irregular Network, grids or 3D models). The characteristic format for storing 3D objects, currently the most widely used, is CityGML (City Geography Markup Language). It can be said to be equivalent to the IFC format in GIS. This format is developed by the Open Geospatial Consortium (OGC) and is based on the GML (Geography Markup Language) language for notation of various objects in the form of object classes at a defined level of detail [23]. An analogy with the earlier description of IFC can be seen here. An important point to note is the divergence in detail levels used and terminology between BIM and GIS technologies, which can often lead to mutual misunderstanding [24].

From the perspective of the information stored in both technologies, BIM data stores precise data concerning only the object to which the investment relates and possibly some residual data on the surroundings of the object. GIS, on the other hand, stores generalised but more extensive data and creates a more open system, in addition, located in global space (global coordinate system). The data related to a building are usually reduced to the form of a solid, which can be created, for example, on the basis of aerial laser scanning [25]. The lesser need for data accuracy is due to the application area, which was already described in the previous chapter. Of course, there are now possible extensions to GIS with more accurate structures, for instance, using IndoorGIS [26] or CityGML ADE (Application Domain Extensions), so that the information in the GIS atabase can be more accurate (have more instances of object classes), but this is a tedious and labor-intensive process. A review of existing extensions to the CityGML format has been done in [27].

The following figure (Fig. 1) shows the common points in the recording of information in both technologies. Points of commonality relate primarily to the storage of data related to local medium-scale objects. BIM does not store information about, e.g., the unemployment rate of European countries or the precise location of material suppliers, while GIS does not have in its structures data on individual, detailed components of a given object. Indoor GIS solutions allow for navigation or simple analytical activities, but any detailed cost estimation must be based on the

BIM model. The very semantics of data recording for the previously described data exchange formats characteristic for these technologies (BIM – IFC, GIS – CityGML) confirms the above thesis, and the difference in recording is shown in the figure below. Both technologies are heavily dependent on metadata that is linked to the objects being described. Figure 1 and Figure 2 were made on the basis of previously cited literature, mainly on [10].

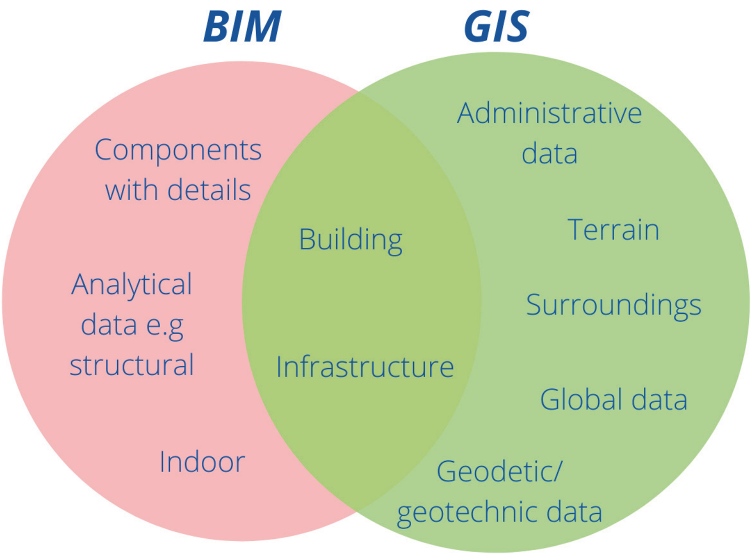

Fig. 1. Comparison of data stored in BIM and GIS technology

The integration of BIM and GIS can also be considered from a time perspective, when looking at the use of integration during investment projects. The information provided in the life cycle of an object from the perspective of the individual project phases and the resolution of this information are different. In the initial phase, GIS provides information on the project surroundings, for example: Digital Terrain Model (DTM), Digital Surface Model (DTM), land cover information or geotechnical data. This data tends to vary in terms of temporal and geometric resolution as it depends on the method used to obtain the information. BIM, on the other hand, gives information developed by the designer or architect with a certain LOD Level of Detail) on how the area will look in the future in relation to the present (data obtained, for example from measurement). Thus, we see that there is information coverage here primarily considering the present state. In the construction phase, GIS again presents data from the past and the present, for example obtained using remote sensing techniques. On the other hand, from a BIM perspective, information is provided and stored about the past – how the object was originally planned, the present – what changes have occurred in relation to the planned object, how the model of this object looks today (Digital Twin), and the future – how the object will look after the changes. In the operation and maintenance phase, both technologies provide information about the past and the present. Here, we are dealing primarily with the use of various types of sensors that can track the state of the object. It is also possible to predict the behavior of an object through estimation basis on available GIS and BIM data. However, such analyses are usually characterized by relatively high uncertainty and do not directly represent the future situation. Therefore, it was decided not to include them in the figure below.

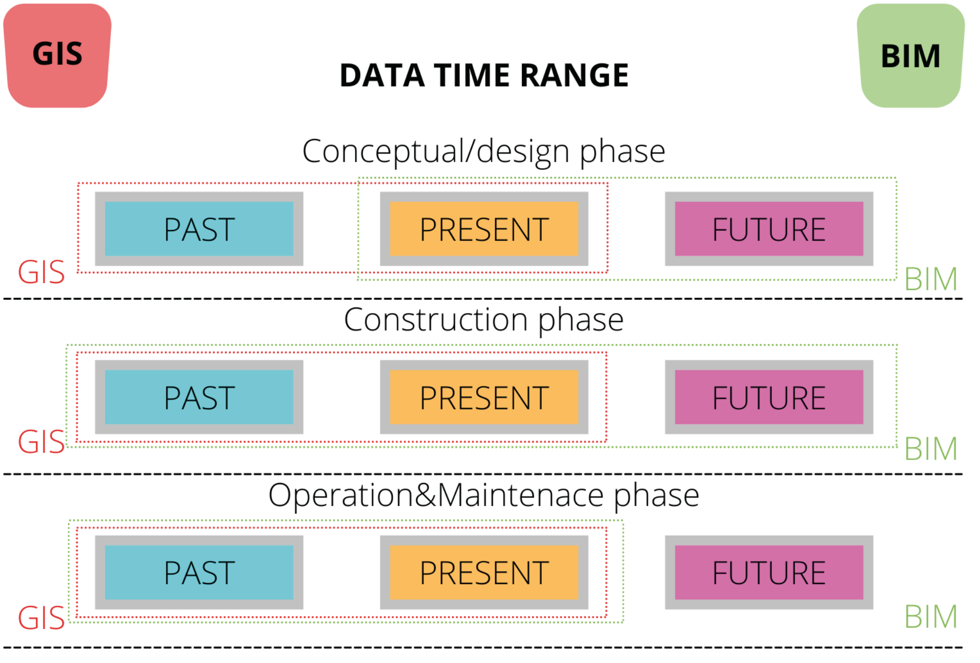

Fig. 2. Time range of data providing by BIM and GIS technologies in different phases of building life cycle

The areas of application can be divided according to their source. First, applications can be mentioned in the direction of activities improving the operation and management of data in the area of infrastructure. This is particularly relevant for the operational phase and for carrying out Asset Management and Facility Management processes in an appropriate manner. Among the examples, in addition to the Crossrail project discussed earlier, it is worth mentioning here: the development of information management systems for hydropower [28], optimization of the road route based on defined factors such as the geology of the terrain, the cost of implementation and the environmental impact [29, 30], modeling geotechnical properties [31] or management of utility networks [32, 33].

A second source of applications is the area of cubature construction. It should be noted here that the possibilities of integration are much more limited, among other things, due to differences in the level of accuracy between technologies and different need for information than in large-scale infrastructure projects. However, examples of applications for building engineering include: risk management in the operational phase of a facility [34], visibility and shading analysis of the designed building [35], fire risk management, assessment of potential fire effects [36], creation of integrated navigation systems for indoor and outdoor use [37, 38].

A third area of application is the use of integration in public administration work. Starting with the idea, which is being developed in several countries, of creating national digital twins [39] and administrative services based on 3D models [40]. The process of issuing building permit on BIM and GIS data, which has been implemented in several European countries, may also serve as an example [41]. Also, the management of urban space management, which has so far been based mainly on inaccurate 2D documentation, can be transferred to a 3D space, together with metadata about objects. Also, for this application area, applications related to combining BIM, GIS with IoT (Internet of Things) sensors [42] or remote sensing data can be developed, which can allow the implementation of SmartCity solutions. The management of urban spaces based on real-time data can increase safety and efficiency. Publications on this topic include: a description of the integration of IFC-CityGML formats for macro-planning and building scale work [43], creation of an urban space management system based on a platform ACTIVe3D [44] or the concept of using BIM-GIS integration as a support for Smart Cities planning considering energy planning aspect [45].

The essence of integrating BIM and GIS is their complementarity. Where BIM has limitations in terms of the information it can provide, GIS helps to fill this information gap. It can be concluded that knowledge of the object's environment (GIS data) and the object itself (BIM data) can create coherent and complete information about the investment, which makes it easier to identify risks, assess the profitability of the investment, monitor or make key management decisions. The above sentence is a goal which should be pursued during the implementation of investments. The integration and complementation of each other is the source of the synergy that arises from the use of these technologies together. Examples of positive impacts and combined application of these technologies are numerous in the literature, including [10, 46–48], and the potential for their combined use does not yet appear to have been fully utilized. This is mainly due to the problems that are described later in this paper.

3. Methodology

To analyze the integration of BIM and GIS, it was decided to use the SWOT method. As written in the Introduction, most of the papers on the problem in question usually deals only with single aspect under the acronym SWOT or addresses single application area.

SWOT analysis (acronym: Strengths, Weaknesses, Opportunities, Threats) is a tool for analyzing internal and external factors. It is considered in two different time periods: the present and the future. This tool is often used to assess the strategic position of a company in the market and to define its strategy [49, 50], but it is also possible to perform an analysis for a service or process. This is undoubtedly the case with BIM-GIS integration. In this way, the strengths, weaknesses, opportunities, and threats of the analyzed subject are identified.

In the literature related to BIM and GIS integration, SWOT analysis is found relatively rarely. A SWOT analysis for the implementation of BIM using elements of the geospatial environment was carried out in [9]. Another example of performing SWOT analysis is the study of opportunities for BIM implementation in Poland with reference to the state of the construction industry [51]. Also using this tool, the use of BIM for infrastructure facilities was analyzed throughout the life cycle of the facility [52]. Whereas [53] presented SWOT analysis for BIM is based on bibliographic research for different stages of the project and from the perspective of different stakeholders.

For the analysis, scientific publications in the field of BIM and GIS integration were mainly used. Reports and standards dealing with this topic were also used. Identifying them was done by selecting keywords related to the topic of this publication. Source material searches were conducted in general academic databases, including the Web of Science Core Collection, Google Scholar Citations and the Scopus database. 169 publications from 2007–2021 (paper, conference proceedings, standards and reports) directly related to the topic of BIM and GIS integration were analyzed. Factors were then selected according to the three-stage work description below. Own suggestions were also subject to evaluation.

The classification followed the following scheme:

- Stage I
  Identification of: positive and negative factors influencing integration or processes; areas that can be improved by applying integration, elements influencing inconsistency of integration. Questions: What is the added value of integration? Why is integration not always effective?
- Stage II
  Evaluating the identified factors for use in the analysis. A logical condition was applied: 0 – less important factor, 1 – more important factor. The evaluation was based on the descriptions of the individual publications or own suggestions. Question: Is the identified factor important?
- Stage III
  Classifying individual factors, consolidating and drafting: strength or weakness, opportunity or threat to integration. Question: Is the identified factor strength, weakness, opportunity or threat?

The analysis was conducted from the broad perspective of the construction industry, for example, executives involved in implementing integration in construction companies or companies with asset maintenance units throughout the life cycle of a facility. The perspective of software developers was not included in the analysis as they were found to have different objectives than those listed above. When identifying the factors, the following criteria were given the most attention: technological – current integration problems at technology level, e.g. data exchange formats between technologies, management – how integration affects the management of the project investment process and standardization – what standardization activities are or are not undertaken.

4. Results

The various strengths and weaknesses identified, and the opportunities and threats of BIM and GIS integration are discussed below. All of the factors are also summarized in a table (Tab. 1).

Table 1. SWOT Matrix of BIM and GIS integration

Strengths	Weaknesses
– A broader view of the design and environment of the subject site. Support of decision-making processes. Integration of data from multiple sources. – Ability to monitor, control and optimize resources in the project. – Improve stakeholder, risk and cost management across the building life cycle. – Greater accuracy in decision-making. – The ability to conduct in-depth spatial analyses for the subject site in conjunction with data describing the surrounding space. – Improving Asset Management (AM)/Facility Management (FM) processes	– Lack of a unified standard for information exchange and ambiguity of terms used during integration. – Loss of information during. integration process (e.g., conversion of BIM data into GIS data). – Giving a global spatial aspect to BIM data – problems with georeferencing this type of data. – Technological level: need for high computing power to transform data into target information, limitations of existing software/tools. – Gaps in awareness among higher levels of decision makers about the benefits of using BIM-GIS integration
Opportunities	**Threats**
– Application potential – finding new ways of using integration in different areas. – Development of standards for storage of integrated data and information. – Appearance of systems combining BIM and GIS data on a large scale – e.g., emergence of CIM (City Information Model), coherent infrastructure management systems. – Integration of BIM, GIS data with IoT sensors. – Use of integration at national or local government level – development of e.g., 3D cadastre, planning decision support processes, building permit review and issuing processes	– Termination of work in developing standards. Failure to develop standards. – Lack of support from software developers. Development of native data formats. – Emergence of other technologies or development of BIM and GIS separately. – Continued lack of understanding and awareness of the benefits of integration. Legislative constraints causing stagnation in development

4.1. Strengths

A Broader View of the Design and Environment of the Subject Site. Support of Decision-Making Processes. Integration of Data from Multiple Sources

One of the strongest points of BIM and GIS integration is the ability to take a broader view of an investment or facility throughout its life cycle. This makes it possible to support the decision-making process. Regardless of whether this aspect is considered from the investor's side or from the side of the general contractor, integration makes it possible to have more data (and thus information). However, the mere possession of data does not mean anything. It has to be processed properly in order to obtain a depth of information on the desired topic. Thanks to this, it is possible to detect risks or irregularities faster and mitigate them. Additionally, data not strictly related to the facility and its environment, such as monitoring the supply chain through a dedicated management panel connected to a 3D model and spatial data, can allow detection of possible delays and an appropriate response. This also makes it possible to implement lean solutions, such as just-in-time delivery of building materials.

By combining spatial data with a BIM model and appropriate data management, it is possible to increase safety or plan a construction site appropriately [54]. An example of this is the identification of risks resulting from incorrectly located cranes [48] or material storage areas. In addition to the strictly safety aspect on the construction site, this approach also allows to eliminate waste related to the use of resources in an inappropriate way and, what is often derived from this, to reduce the impact on the environment.

Visualization of some problems extends the spectrum of decision analyses. The publication [55] describes the management of an infrastructure project based precisely on the use of spatial data and BIM data. The greatest advantages of such a solution include greater efficiency and better project management.

In the operational phase, when managing assets such as roads, railways, or underground infrastructure, integration can help to realistically monitor their condition. Decision-making can again be preceded by various types of analyses. An example described in the literature is an underground infrastructure management system [32]. Based on a database containing BIM and GIS data, it is possible to predict various types of problems that may occur and conduct preventive actions.

This strength of integration is the most general and seems to be the most important. Therefore, in the next ones identified, reference will be made to the one described above.

Ability to Monitor, Control and Optimize Resources in the Project

Controlling the supply chain for large investments, be it building or infrastructure, requires continuously tracking the progress of subcontractors delivering the resources. Equally important is the cost estimation using spatial data (e.g., estimation of material transport costs) [56, 57]. Such an approach enables greater control over the project and control by the project manager as well as his superiors who decide on the strategic activities of the company.

The use of Business Intelligence tools combined with BIM and GIS allows for even more precise verification of the correctness of project implementation. Due to this, such a prosaic aspect as communication during various meetings can be more effective. All kinds of visualizations allow for a much more efficient exchange of information and better understanding between, for example, the investor and the contractor.

An important part of integration is also the ability to reduce environmental impact by reducing material waste. An example of this is [58].

Improve Stakeholder, Risk and Cost Management across the Building Life Cycle

Visual representation of a given issue, in this case, for example, in the form of 3D models and DSM (Digital Surface Model), is definitely more effective than the use of traditional methods such as documentation presented as a 2D layer. Additionally, the model provided with data surrounding the implemented object can allow stakeholders to understand the given problem, e.g., during public consultations for a complex infrastructure project. Considering the example of route variants, the BIM model combined with GIS data can allow us to estimate the cost-effectiveness of the implementation, create lists of corridor occupancy and plots from the land and building register, or make preliminary environmental impact assessments. Large infrastructure projects are often associated with the obligation to resettle people or animals living in the areas intended for investment. The analysis of variants at the initial stage of investment based on BIM and GIS data makes it possible to take a better decision, optimal from the point of view of the investor and other stakeholders.

This description mainly concerns the stage of conceptual work. However, also thanks to the combination of BIM and GIS data, for example, in the form of a single CDE platform, it becomes easier to perform processes related to more administrative activities, such as billing or responding to requests for information [59].

Greater Accuracy in Decision-Making

What is undoubtedly related to the strengths of integration described above and below is the greater accuracy of decisions. With broader, more up-to-date, and more accurate knowledge, making the optimal decision is certainly much easier. The ability to run different simulations of options, using tools that integrate BIM and GIS supported by machine learning technology, allows managers at every level to support their decisions. In [60], a survey was conducted on a group of professionals involved in BIM and GIS. Among the results for both categories, the most frequently mentioned advantage was the sentence "better decision-making process". This shows the potential of both technologies.

The Ability to Conduct In-Depth Spatial Analyses for the Subject Site in Conjunction with Data Describing the Surrounding Space

Thanks to the conversion of BIM data into GIS databases, it is possible to perform various types of analysis concerning investment. Beginning with the problem of transporting a component, for example, the analysis of whether a component with large dimensions can be delivered to the construction site or how it should be delivered (environmental or economic analysis). Furthermore, the choice of sub-suppliers can be analyzed taking into account various factors (e.g., time or cost). The entire supply chain can be tracked, and individual sub-suppliers monitored to mitigate the risk of project delay. Looking a little closer at the investment, using various types of GIS data, it is possible to perform in-depth analysis of the impact of the investment on the environment (e.g., analysis of deforestation), location analysis of individual objects supporting or performing construction works. Moreover, the detection of various types of clashes between e.g., the planned and the existing infrastructure may allow for a much greater fluidity of the project during the execution phase of the facility. Another area of analysis may be to consider BIM and GIS in 4D. This approach is described, among others, in [61]. Spatial analysis can improve safety on a construction site by identifying risks while work is being carried out.

An example of spatial analysis for optimal location can be an algorithm that analyses the designed object, optimizes the location of tower cranes [48], or optimizes the position of an object under certain conditions [46].

Also, in the operational phase, various types of spatial analysis can be implemented. These mainly concern more general issues, e.g., the aspect of navigation within objects [62] or noise pollution analyses [63].

Improving Asset Management (AM)/Facility Management (FM) Processes

The storage of information and the ability to use it in the operational phase is a very important aspect. Having an Asset Information Model to manage a facility allows to use it in a much more efficient way, with less capital involvement and less risk of information loss (e.g., by destruction of paper documentation). Planning of repairs, inspections, estimation of their costs allows for estimation of the cost-effectiveness of facility maintenance.

There are already quite a few examples in the literature of the use of integration in the support of AM and FM processes. In addition to the infrastructure publications mentioned in the first part, it is worth mentioning [59], where a description of processes for FM support based on BIM and GIS integration is presented, or a proposal for a system also based on integration for FM processes [60].

4.2. Weaknesses

Lack of a Unified Standard for Information Exchange and Ambiguity of Terms Used during Integration

According to [47], the BIM and GIS integration process can occur at three levels: application, process, and data. Each of these levels has certain imperfections in the form of data loss, difficulties in operation, and time-consumption. The lack of developed and fully functional interoperability standards causes new solutions to emerge, but they are not always sufficient. The limitations of existing software are also a result of this weakness. Full coherent integration of heterogeneous data is not a trivial task, but it is certainly worth investing time and capital to develop solutions that can bring benefits to the whole construction industry, society, and the environment.

Loss of Information during the Integration Process (e.g., Conversion of BIM Data into GIS Data)

The interoperability of systems that integrate BIM and GIS at the data level has many shortcomings. One of the elements that causes the biggest problems is the loss of information during conversion. The most common errors during conversion of BIM data to CityGML format are the loss of non-geometric information, semantic classification errors, omission of information, or distortion of geometry seem to be the most important ones [8].

This causes a number of complications for the use of integration-based systems later on, for example in the operation phase of a facility such as a highway, as the data may be incomplete [64].

Giving a Global Spatial Aspect to BIM Data – Problems with Georeferencing This Type of Data

When formulating and creating the technologies, both BIM and GIS were envisioned for other applications. Their linkage, as mentioned, has not been present since the inception of both technologies. Hence, at the moment, deficiencies that cause problems in integration become apparent. One of them is the recording of BIM data in global space, so that the data is not distorted. This problem was described in detail by S. Jaud et al. in [65]. Admittedly, this problem can be neglected for smaller projects (less extensive), but for large infrastructure projects, for which the application potential seems to be the greatest, this aspect cannot be neglected.

The levels of georeferencing defined by Ch. Clemen and H. Görne indicate what one should aim for when georeferencing BIM models in IFC format [66]. Unfortunately, the survey shows that the existing software does not support georeferencing at higher levels [7]. For integration in large infrastructure projects, this can have a big impact, for example when trying to identify clashes between BIM data and GIS data.

Technological Level: Need for High Computing Power to Transform Data into Target Information, Limitations of Existing Software/Tools

BIM and GIS data, especially with higher geometric accuracy and high information saturation, create the need for large disk spaces to store these data and high computing power to produce a product that can serve as an element of decision support or model creation. This problem has been addressed in several publications [53, 67].

Additionally, when data are converted from IFC format to CityGML at the same level of detail, the volume of data increases.

When analyzing existing software that supports integration, the number of programs, that allow one to combine BIM and GIS data, is limited. ESRI's software allows loading of BIM data, but ArcGIS has, mainly, a desktop version and has some limitations in real-time collaboration between stakeholders. ESRI's collaboration with Autodesk [68] may result in a number of integration benefits in the future, but this is still in the use of native formats, which have limitations and complicate the availability for application developers to create new applications.

SafeSoftware's FME software allows BIM data to be converted to GIS and combined in a defined format, but it is not strictly for collaboration within, for example, a single platform. It is mainly used to process data and prepare the final product, rather than to display and analyze it.

Bentley's OpenRail/Roads Designer/OpenStation or Autodesk Infraworks or Civil 3D software allows the importing of GIS data in the form of point clouds or WMS services, but these are tools used mainly for design and do not have the ability to perform spatial analysis (or it is limited).

Therefore, it can be seen that there is a lack of tools, both for collaboration and design that have the main elements and tools of BIM and GIS. BIM and GIS data, within a single CDE platform, must be displayed separately or have a reduced amount of information.

Gaps in Awareness among Higher Levels of Decision Makers about the Benefits of Using BIM-GIS Integration

Support for integration must come from top-down regulations that could make it an obligatory element, for example, when carrying out investments in public procurement. For this to happen, there is a need for greater awareness of those at that level. The current lack of awareness of the benefits of integration certainly limits its development.

This problem has been pointed out in several articles in the literature, among others [40] or [60].

4.3. Opportunities

Application Potential – Finding New Ways of Using Integration in Different Areas

Example applications of the integration of BIM and GIS have already been presented in the earlier parts of the publication. This section presents ideas for even deeper integration and the use of various solutions that are currently not found in the literature.

The first element is the use of remote sensing data, especially those acquired from satellite imagery. Satellite imagery is classified as GIS data because it contains data about and is defined in space. Raster data from, e.g., the Sentinel-2 mission can allow the analysis of the progress of works (comparison with the 4D BIM schedule) or verification of various hypotheses presented during the works.

The second element is the use of open spatial data to integrate BIM and GIS, especially in the conceptual phase. The awareness of the availability of such free data among railway or road routes designers in Poland can be assessed as low. This type of data includes point clouds for virtually the entire country, orthophotos with a field pixel of up to 5 cm or objects in the Topographic Database. Of course, it should be kept in mind that the timeliness of such data may vary, but its accuracy is usually sufficient for conceptual and preliminary design work [69]. The supply of open spatial data in the European Union will grow. This is due to regulations set by the European Commission [70].

Another area of application for integration could be to use it as a basis for project management. The implementation of management methodologies from other industries, based on agile philosophy, would certainly allow for increased efficiency, whether in the design phase or already in the construction phase. It would be necessary to verify whether the flow of information, its understanding, by the client (investor), thanks to integration, is at a higher level, and the final product itself allows for greater satisfaction thanks to joint development of the final product (e.g., design of the facility). A natural place for data collection in the BIM methodology is the CDE. Supporting the platform with GIS spatial data and frameworks known from the industry, e.g., IT (Information Technology), generates great potential to create management and decision-making procedures, tailored directly to construction projects, especially infrastructure ones.

Development of Standards for Storage of Integrated Data and Information

One of the conversion problems described above was the lack of existing standards for information exchange between BIM and GIS technologies. Hence, the obvious opportunity for increased interoperability between the aforementioned technologies in the future seems to be a narrowed cooperation between the organizations dealing with them: buildingSMART International (bSI) – development of standards related to BIM and Open Geospatial Consortium (OGC) – development of standards related to GIS or through standardization activities carried out by ISO committees.

The first effects of this work can already be seen in the form of the results of the work of ISO committees published in May 2021: technical report ISO/TR 23262:2021 and technical specification ISO/TS 19166:2021 created in cooperation with the committees ISO/TC 59/SC 13 – ISO/TC 211 WG: GIS-BIM interoperability. The former document describes areas where geospatial BIM can be improved [71]. The second refers explicitly to the conversion of BIM data to GIS and presents the concept of mapping data schemas. However, the technical specification only presents a framework for mapping data exchange formats; it is not a ready-made schema. The schema depends on the intended use of the integration [72].

However, all this leads us to believe that the development of standards offers the possibility of further coherent interoperability in the future, which again is linked to the popularization of BIM and GIS integration.

A similar document to those produced by the ISO committees is the IDBE (Integrated Digital Built Environment) report, which analyses the IFC, CityGML, and LandInfra formats. The publication describes the advantages and disadvantages of each format and identifies opportunities for integration development through the aspect of data storage [73, 74]

The above description was about integration at the data level. However, newer and newer IT developments give hope for a better future of integration. In particular, new IT solutions are worth mentioning here. Using of web applications or unified databases provides opportunities to create systems integrating BIM-GIS data, e.g., for CDE platforms.

Appearance of Systems Combining BIM and GIS Data on a Large Scale – e.g., Emergence of CIM (City Information Model), Coherent Infrastructure Management Systems

The idea of creating Smart Cities, which is currently being developed, is one of the key aspects concerning the evolution of cities toward sustainable areas, above all in environmental terms. However, accurate city models saturated with relevant information are needed to accomplish these tasks. Therefore, another opportunity for the integration of BIM and GIS has been identified. Knowledge of not only the spatial positions of buildings but also what is beneath the ground is undoubtedly important in city planning processes. In addition, information on what an object is made of can serve as a determining element for decisions taken on, for example, a long-term city management strategy.

Another aspect is the integration service for security purposes. Thanks to the integration of BIM and GIS, security services can plan a mission much more quickly, for example, the evacuation of a burning building or the firefighting process itself.

Already now we can see single applications (described in one of the previous chapters) in this field, but it seems that in the future they will become an integral part of the cities of the future based on the Smart City idea.

Another opportunity somewhat related to the creation of CIM is the implementation of infrastructure management systems by the organizations in the country responsible for this. Along with the implementation of further investments in BIM technology, it is necessary to think about the fact that models that have information about components "do not die", but serve during operation. GIS tools can be used for this.

Another proposal is to create coherent systems for real-time infrastructure management. Combining BIM and GIS data with systems controlling, e.g., track geometry or general condition of the infrastructure may make it possible to assess the condition of the managed infrastructure and, as a result, plan repairs based on the available data.

At present the main problems which do not allow the implementation of this type of system are limitations in computing power and shortages in the current state of technology in the integration and mutual conversion of data. However, it seems that in the coming years this branch of integration will be increasingly developed and cities and infrastructure facilities will have their digital twin to serve their entire communities.

Integration of BIM, GIS Data with IoT Sensors

In addition, the integration of BIM and GIS with IoT sensors, providing data on, for example, pollution or traffic flow through BIM and GIS-based systems, can undoubtedly be helpful. Further areas of facility management support should be sought here. Installed sensors can transmit different types of information in real time. Looking, for example, at bridges and SHM (Structural Health Monitoring) class systems, it is possible to track many objects at the same time and verify the correct behavior of the structure over time, depending, for example, on weather conditions.

In the second section, the currently encountered applications in this field in the literature have already been mentioned. However, they are mostly of conceptual or pilot character, so it was decided to qualify this feature as an opportunity in the future and a direction for development.

Use of Integration at National or Local Government Level – Development of e.g., 3D Cadastre, Planning Decision Support Processes, Building Permit Review and Issuing Processes

This application area seems likely to have the greatest impact on the development of BIM and GIS integration as it relates to national strategies for spatial data development. The more initiatives that originate at this level, the more capital and attention will be given to the development of integration. The process of digitization of surveying and construction work, described above, which is developing in several countries, is an example of this.

It seems that an equally great opportunity, and something that may in some time be crucial for a correct real estate management policy, is the 3D cadaster. Concepts of how such systems could work are already described in the literature, among others in [75–77]. Undoubtedly, one of the components of such systems, in addition to descriptive, administrative, or legal data, would be data related to the building (for example, based on IFC to CityGML conversion), the object environment (strictly GIS data) or infrastructure.

Further areas of work are the development and digitalization of urban planning processes or concerning the above-described processes of issuing building permits. Digitization and automation of some of the processes, which are currently carried out manually by officials, may allow to accelerate the execution of works and increase their accuracy.

All of the above-mentioned applications form, so to speak, a single ecosystem, where the building permit process combines local development plans and urban planning, while the 3D cadastre feeds information on the more legal side of individual properties. Implementing all of these components together can allow for a much more efficient management of spatial information at the administrative level of the individual units responsible for it. Together, all these components can feed or co-create the National Digital Twin, which can support the management strategy even at the governmental level.

4.4. Threats

Termination of Work in Developing Standards. Failure to Develop Standards

One obvious threat to the further integration of BIM and GIS is the lack of development of final/functional standards. At this point in time this threat seems to be rather unwarranted, but further continuous work should be pursued in producing uniform integration standards and then updating and improving them.

Lack of Support from Software Developers. Development of Native Data Formats

If standards are created, another risk is that they will not be supported by existing software, or indeed by their developers. New standards will contain publicly available schemes of information exchange, which will have to be implemented in software. Such action may be economically unprofitable for software vendors, so we can expect, in a way, boycott of the standards. Although such a scenario is unlikely, it is possible.

Native data formats will always be limited to some extent, especially when viewed from the perspective of information exchange between different industries or project stakeholders.

Emergence of Other Technologies or Development of BIM and GIS Separately

Another threat identified is the emergence of other technologies or the development of existing technologies. This type of threat can only be treated individually for integration. It is currently difficult to imagine a technology that could replace the integration of BIM and GIS, but the continuous development of information technology, may bring a new tool that will supplant the integration of BIM and GIS. For the construction industry itself, it seems that such an event would be an opportunity, however, looking only at the aspect of integration in the SWOT analysis, it is undoubtedly a threat. Moreover, the development of any of the technologies separately, could result in the abandonment of integration. This is especially possible through the future use of machine learning methods e.g., to generate objects through tools implemented in GIS type software.

Continued Lack of Understanding and Awareness of the Benefits of Integration. Legislative Constraints Causing Stagnation in Development

A publication [40] identified lack of awareness of the benefits of integration as one of the main challenges faced by BIM-GIS integration. This is especially true for senior decision makers deciding on the direction of development of individual industries. The lack of support in individual countries for integration will certainly not accelerate its development. The more organizations dealing with and developing common standards, the greater chance for integration. In the event of further lack of support, solutions may be commercialized and available only to a narrow group of recipients, which is probably not beneficial to the whole community.

An element that should undoubtedly support not only integration, but also implementation of BIM and GIS technologies even separately, are legislative conditions. The requirements of using BIM first and then integrating BIM and GIS in public investments would certainly accelerate the development of integration. Their absence, however, may at some point cause stagnation in the development of BIM and GIS integration.

4.5. Discussion and Conclusions

The above analysis shows the direction which should be followed by scientific units, software developers or institutions defining the standards for the exchange of BIM-GIS information. Undoubtedly, there is considerable potential in BIM-GIS integration, which can allow for better planned and scheduled investments, better estimated budgets, without exceeding them or reducing the impact on the environment. The possibility of further integration with IoT sensors or the creation of Digital Twins for cities, can allow for more efficient management of urban spaces, again creating greener areas. It can therefore be concluded that integration is in line with the sustainable development goals set by the United Nations. To further emphasize this, reference can be made to a report created in 2020 on the integration of spatial data with GIS, which shows many case studies from around the world, where it is precisely through integration that it is possible to reduce, for example, environmental impact or limit the impact of environmental phenomena on anthropogenic areas [78].

However, the risks and their monitoring should be kept in mind at all times. The development of final, fully functional standards, the implementation of which, inter alia, in CDE cooperation platforms, should be a priority task, and the solution of the problems described in the following publication will give a chance to reduce the problems related to the loss of information about the investment.

However, it should be noted here that the identified strengths, weaknesses of integration and threats and opportunities in the future were considered as key and most probable. It is possible to carry out an analysis at an even greater level of detail, for example for individual project phases or individual stakeholder, but this may be the subject of a separate publication.

Also worth noting is the need to support integration from the top level. The creation of new applications and the implementation of prototypes that appear in the literature should be reflected in real life. The implementation of such applications may bring measurable benefits, both for citizens (digitization of processes) and for administrative units, which will have information contained in e.g., databases, and the advantage of such solutions over paper documentation does not need to be mentioned. This should also have a positive impact on the AEC industry, which is correlated with administrative actions. Digitization of the various administrative processes related to the construction industry may allow, for example, a reduction in project duration.

To sum up the assessment, it seems that the realization of opportunities is much more probable than the realization of threats. Therefore, it should be believed that the integration of BIM and GIS should be continuously developed and funded.

In conclusion, the BIM and GIS integration has much greater potential for applications in the management of large areas like infrastructure or a set of facilities. Of course, as mentioned, cubature objects can also be served by systems based on integration, but this applies to large complexes of objects such as university campuses or hospitals or individual applications at the stage of conceptual or design work, e.g., for shading or sunshine analysis.

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