Citation:
Akindele, OE and Ajayi, SO and Oyegoke, AS and Alaka, HA and Omotayo, T (2023) Application of Geographic Information System (GIS) in Construction: A Systematic Review. Smart and Sustainable Built Environment. ISSN 2046-6099 DOI: https://doi.org/10.1108/SASBE-01-2023-0016

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Document Version:
Article (Accepted Version)

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Application of Geographic Information System (GIS) in Construction: A Systematic Review

Abstract

Purpose-Notwithstanding the Geographical Information System (GIS) being a fast-emerging green area of a digital revolution, the available studies focus on different subject areas of application in the construction industry, with no study that clarifies its knowledge strands. Hence, this systematic review analyses GIS core area of application, its system integration patterns, challenges, and future directions in the construction industry.

Design/methodology/approach-A systematic review approach was employed, using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. A total of 60 articles published between 2011 and 2022 were identified, thoroughly reviewed, and analysed using thematic analysis.

Findings-The analysis revealed spatial planning and design, construction-task tracking, defect detection, and safety monitoring as its four main application-based areas. The findings showed that the adoption of GIS technology is rapidly expanding and being utilised more in building projects to visual-track construction activities. The review discovered an integrated pattern involving data flow from a device and window-form application to GIS, the pathways to data exchange between platforms-to-platforms, where ArcGIS is the most used software. Furthermore, the study highlighted the lack of interoperability between heterogeneous systems as the crux impediment to adopting GIS in the built environment.

Originality/value- The research provides a deep insight into possible areas where GIS is adopted in the construction industry, identifying areas of extensive and limited application coverage over one decade. Besides, it demystifies possible pathways for future integration opportunities of GIS with other emerging technologies within the construction industry.

Keywords: Systematic literature review, GIS, BIM, GIS and BIM Integration, Digital Construction, Project Planning.

1. Introduction

In recent times, the construction industry has stepped into the usage of cutting-edge technology accompanied by different programming languages, tools, and techniques. This development has enabled construction businesses to proliferate technologically (Xiao *et al.*, 2020), leading to a rapid influx of digital solutions and opportunities (Wyman, 2018). Digital solutions like Geographic Information System (GIS), Building Information Modelling (BIM), Internet of Things (IoT), and machine learning have been identified as disruptive technologies to facilitate and enhance productivity in the built environment (Çetin *et al.*, 2021). Realizing the demand for these technologies in the building industry has expanded Information Technology (IT) and improved many construction processes. Likewise, these have birthed a lot of technological innovation and promoted transparency in communication with positive impacts recently, making field labourers more productive (Han *et al.*, 2020).

GIS is a conceptualised framework that allows capturing, storing, processing, and displaying of spatial information based on geomatic model. The system digitises and visualises abstract information, presenting them as geo-referenced maps solutions through a design schema and a functional component (Zhang *et al*., 2009). This process facilitates project success and opens new dimensions for resolving environmental challenges by reducing costs, minimizing time, and enhancing construction productivity (Yadhukrishnan and Shetty, 2015). Moreover, the integration of GIS and BIM with other systems facilitates spatial solutions towards the realisation of sustainable construction, the future of the construction industry. BIM can manage, design, and share the lifecycle data of a vertical facility such as buildings; while also capable of collecting and storing spatial data describing the urban environment (Ma and Ren, 2017). Therefore, the overlying attributes of BIM and other technologies integrated with GIS are achievable through unified data for building projects and their environment, which is beneficial to the development of the construction industry. However, these technologies only build a feature with geospatial data. For example, buildings significantly influence its surroundings, and the construction should link with the environmental aspect (Wang *et al*., 2019). Moreover, the data exchange from BIM to GIS identify areas suitable for construction and improve construction project efficiency and management (Deng *et al*., 2016; Bansal, 2020). Data integration, as enabled by the GIS, help professionals in the built environment understands geospatial information, the entire environment and the building information of the construction projects (Ebrahim *et al*., 2016).

As GIS is one of the fast-emerging green areas of the digital revolution in the construction industry, its full potential has yet to be discovered (Esri, 2021). Besides, there have been many studies on how GIS and BIM integration is being used for various processes in construction. For example, Karimi and Iordanova (2021) examined the integration of BIM and GIS for construction automation. Moreover, the integration of these two technologies has been widely studied and adopted for infrastructural planning, management, and maintenance operations in various domains of projects in the construction industry (Liu, 2017; Abd *et al*., 2020; Khan *et al*., 2021; Shekargoftar *et al*., 2022; Miano *et al*., 2022). However, this study stands out among other published articles on GIS by highlighting the key areas where GIS can be applied in different construction projects, irrespective of whether it involves BIM integration or not. As it stands, there has yet to be an in-depth review of its applications covering the integration patterns of implementation, values, and potential in the construction industry (Ma and Ren, 2017). Therefore, this paper systematically identifies GIS application research and fills the stated gap. Hence, a systematic review of papers published in the last ten years (2011-2022) summarizing the state-of-the-art of application of GIS in construction was carried out. Through the analysis of peer-reviewed literature, the objectives of this study are to:

1) systematically identify and analyse research on GIS applications in construction;
2) investigate the integration pattern of GIS implementation in construction; and
3) identify the challenges and suggest areas of future research and application of GIS in construction.

A systematic review procedural framework, following PRISMA framework, is adopted to achieve the study's aim and objectives. The subsequent section explains the systematic review methodology and how the article search, and identification were conducted. This is followed by a brief description of the GIS application's taxonomy and the integrated patterns and platforms usage of GIS in the construction industry in section 3, followed by the findings with the infographic representation of GIS integration with other platforms. The next section presents the discussion of the study and the authors' reflections on the research limitation and future research directions. The last section presents the conclusion of the study.

2. Methodology

The research adopted a Systematic Literature Review (SLR) of published papers. SLR is a scientific research approach that is useful for appraising, summarising, and presenting the findings of many research publications in a particular field of study (Wang *et al*., 2021). Moreover, SLR distinguishes itself among other reviews through its scientific and fair methodology that strives to minimise bias due to exhaustive literature searches and the provision of an audit trail of the reviewer's procedures (Tranfield *et al*., 2003). Hence, to carry out a SLR, four steps are involved: (i) Definition of the research questions, (ii) identification of database and search process, (iii) developing an inclusion and exclusion criteria, and (iv) performing data collection and descriptive analysis.

2.1. Identify the research questions

In this first step, the research question are outlined. The search question addressed by this research are:

RQ1: What are the areas of application of GIS within the construction industry?

RQ2: How can we classify the integration pattern of GIS with other systems in the construction industry?

RQ3: What are the challenges and unexplored future direction of GIS application in construction?

2.2. The Database

The main source identified for this SLR was Scopus, by Elsevier, which is considered the largest abstract and citation scientific database of peer-reviewed literature (Harzing and Alakangas, 2016). The rationale for selecting the Scopus database was that it covers nearly 22,000 titles from over 5,000 international publications. Therefore, it is possible to search for and locate a significant proportion of the published articles on GIS applications using advanced search operations.

2.2.1 Keywords and Literature identification

To avoid missing any topic related to GIS application in construction, "GIS" AND "Construction" was used as the main search keyword term in the Scopus database. According to Ferrari (2015), identifying the right keywords not only acts as a comprehensive approach towards searching for relevant publications, but also eliminates all unrelated publications that could impact the research results. This search resulted in a total of 1,982 articles, including several unrelated studies that did not meet the inclusion and exclusion criteria. After that, a Boolean operator was used for more accurate filtering of articles using keyword terms “GIS” AND “Application” AND “Construction” OR “AEC”. Moreover, the search was limited to 2011 through 2022, as shown in Figure 1. Based on this filtering, 138 articles were found relevant to the study.

Figure 1.

2.3 Inclusion/exclusion criteria

The inclusion and exclusion concept allows the researcher to focus the research on specific considerations and objectives (Meline, 2006). In this study, all articles must be on the application of GIS in construction. In addition, the finding must state the applicability and results rather than only being a proposal or conceptual, with the study reflecting how GIS is applied in the construction industry; Figure 2 shows the inclusion and exclusion criteria.

Figure 2.

2.4 Perform descriptive analysis

This SLR process resulted in 60 journal articles, as shown in Figure 1. The identified papers were then objectively reviewed, and data were extracted and examined for the following items: the research methodology, findings, and challenges and limitations. The results of this extraction were then documented in a tabular format and evaluated independently by authors to verify their eligibility. The resulting papers underwent thematic analysis to attain a classification structure in the next section. As Anderson *et al*., (2014) recommended, potential bias in thematic analysis of the extracted articles was avoided through adherence to the peer-reviewed and thematic synthesis approach. The articles were then iteratively analysed to identify the prevailing challenges and reach the best taxonomy of GIS applications.

3.0 Taxonomy of GIS application

This section addresses the RQ1 and RQ2 adopting intuitive and application-based classification approach to build the taxonomy through a systematic literature review of studies on GIS in construction as shown in Table 1. This approach is best fit for related technology use (Zheng *et al*., 2018). Moreover, identified papers are categorised and analysed, providing a taxonomy of research across the area of application of GIS. The result of the categorization yielded four application-based areas: 1) Construction task management, 2) Spatial planning and design, 3) Defect detection and 4) Safety monitoring.

Table 1

3.1 Taxonomy result

The result of the analysis of the taxonomy as presented in Figure 3 reveals 27% of GIS application in spatial planning and design with 16 articles, 5% of GIS application in defect detection with 3 articles, 20% of GIS application in safety monitoring with 12 articles, and 48% of GIS application was in construction task management with 29 articles. While for GIS projects-based areas, the reviewed articles focus more on buildings construction 29 articles (48%), while 10 articles are on road construction (20%), 4 articles are on railway construction (8%), 3 articles are on earthmoving operation (6%), 2 articles are on landscape construction (4%), and 12 articles are on heavy engineering (24%). These results support the assertion of Han *et al.*, (2020) that the usage of GIS solutions has gained expanse in several application scenarios, especially in the construction industry.

In addition, Figure 3 also reveals that there is no application of GIS in spatial planning and design on earthwork operations projects. Likewise, there is no application of GIS in defect detection on railway, landscape, and heavy engineering projects. Additionally, there is no GIS application in safety monitoring on railway and landscape construction projects. Thus, the analysis unveils a higher usage of GIS in construction task management on building projects, as presented in Table 2.

Table 2

Figure 3

3.2 Integration pattern and platform usage in construction

Based on the SLR conducted, various pathways to data exchange have been identified between GIS system and other external systems such as BIM system and other customised platforms. The result in Figure 4 reveals that 48% extracted data from a devices or window-form applications to GIS, 39% extract data from BIM and GIS to a customised system and 13% extract data from BIM to GIS system. This reveals that data transfer frequently occurred between GIS, device or window-form application as the percentage is higher than others. Ma and Ren (2017) asserted this, that data transfer and exchange processes occur between systems, devices and platforms. For instance, Petimani *et al.*, (2019) extracted data from scheduling software and CAD software to GIS system to create 4D visuals to monitor construction operations. Moreover, semantic web services platform was used to extract data from Revit and ArcGIS for preconstruction operations (Karan and Irizarry, 2015). Data integration between systems improves construction operations efficiency and collaboration among stakeholders.

In terms of platforms used for the integration, Figure 5 reveals a count of (19 items) on ArcGIS, (6 items) on Autodesk Revit, (6 items) on self-developed applications, (4 items) on AutoCAD and 3 items on WebGIS platforms. The researchers also use Virtual reality, UAV, Augmented reality, IDRISI, Google earth, DAT, Grass application, VBA, but the count of items on each platform is no more than 1. Additional information on integration pattern and platform is shown in Table 3.

Table 3.

Figure 4.

Figure 5.

3.3 GIS integration with systems at the application and operation level

In terms of application integration, the study has recognised different integration use between systems to enhance various construction operations in the built environment. From the review, the study developed an integration network framework based on the data exchange paradigm that exists between the systems and platforms. The framework consists of five components: Raw data, surface model, GIS, BIM and a customised platform, as shown in Figure 6. The integrated data flow framework shows the regimented point-to-point connection pathway across data, systems, and platforms, all to execute a construction operation. The “Raw data” depicted in the framework represent field data, high-resolution imagery collected through a device. The raw data is extracted to a surface modelling platform and BIM application for digitization, showing 3D visual representation. This process is completed through a uniform access integration between the applications, models, and techniques in each component. Whilst the data in each component is transferred or extracted to the GIS system geodatabase to create and store spatial class attributes from the non-spatial data imported from the BIM and surface model systems.

This has been a common data network path mode that exists between various platforms and systems in the reviewed articles. For example, Petimani and Vishwanath (2019) developed an integrated framework using a surface model platform, GIS, BIM and a customised application to track a construction project. The surface model application, known as CAD application data, was extracted to a GIS system where the 2D data was digitized and georeferenced into different feature classes to enhance. In contrast, the BIM system modelled the 2D data into a 3D format and exchanged the data with GIS to generate a 4D display with spatial attributes (Zhu *et al*., 2021) to support the tracking operation. Thus, data integration between GIS and other systems like BIM enables seamless modelling of data to support site selection and fire response for BIM models (Isikdage *et al*., 2008).

Figure 6.

4.0 Discussion

The systematic review shows that GIS application has expanded across all spheres of the construction project lifecycle, extensively in construction task management, spatial planning and design. This corroborated the assertion of Weerasinghe et al. (2018) that GIS is used in construction planning and management to enhance project productivity and achieve construction sustainability. Moreover, a report suggested that GIS support the construction industry, especially construction management (Bansal, 2012). In line with the area of application of GIS, the result also reveals low usage of GIS in defect detection and safety monitoring. This agrees with the assertion of Zhou *et al*. (2012) that few GIS systems and frameworks are developed to support construction safety monitoring, notwithstanding that

GIS is one of the best technologies to address construction safety when combined with a range of digital technology such as IoT, Artificial intelligence and Augmented reality.

Furthermore, the finding shows high usage of GIS on building projects, whereas usage on railway projects, earthmoving operations and landscaping projects are underrepresented in use, contradicting the previous assertion that it is used in various construction projects in the field of engineering (Palve, 2013). As it stands, GIS is yet to be fully exploited in these areas, as there is a lot of systems integration complications to facilitate construction operation in some of these projects (Bansal, 2012). Hence there is lot of opportunities around infrastructural design and construction (Mollo *et al.,* 2020). Nevertheless, some of these infrastructure projects like railway and building projects have a huge impact on human lives by providing safety, effective services, and a sustainable environment (Bansal, 2016).

GIS has become an essential for promoting sustainability in various fields, such as urban planning, natural resource management and climate change mitigation (Allawi and Al-jazaeri, 2023). With the technology capability, the impact of human activities can be understood, and the area of ecological value and sustainable land can be identified (Wang *et al*., 2019). GIS can help make an informed decision about suitable construction routes and sites (Bansal, 2016), minimise waste and reduce energy consumption during construction. Moreover, GIS technology helps in promoting sustainable development, providing vital information to create a better and more enabling environment for building construction. GIS, as a smart technology in construction, enhance sustainability. Verma and Datta (2013) assert that sustainability and smartness are intrinsically connected.

The integration of data extraction between systems like GIS and BIM has opened new possibilities for understanding the spatial pattern and relationship within large silos or set of data, leaving organisation and construction stakeholders to gain valuable insights and make better decisions during the construction initiation phase. Moreover, the review founds data extracted from window-form application to GIS as the mainstream pattern of data exchange between GIS and other systems and platforms. This is in contrast with the argument of (Liu *et al*., 2017) that data extraction is standard among BIM and GIS. The integration of GIS with other applications and devices, such as Vworld, IDRISI, AR, and UAVs, enables various construction processes to be achievable during the construction stage.

Furthermore, several studies have recognised data extraction through different systems to enhance construction operation performance. Farooq *et al*., (2017) investigated the potential of BIM in electrical system design where BIM data was extracted and transferred through a BIM application to a GIS system. Mollo *et al*., (2020) shows the potential of typological GIS to provide support for design in urban renovation projects. The research extracted historic building information modelling data to GIS. In addition, Park and Kim (2016) demonstrated an approach to construct and present a 3D model of a project site using data extracted from a Vworld system integrated to Revit. It is concluded that the observed pattern of data exchange between systems and platforms highlights the importance of integration in enhancing construction operations and processes through the life cycle of AEC projects.

Based on the SLR conducted, data interoperability between GIS and other systems has been identified as one of the key barriers that exist, despite the development of a Unified Building Model (UBM), Resource Description Framework (RDF) and Application Domain Extension (ADE). Deng *et al*. (2019) claimed that there had not been much success recorded regarding full data integration of GIS in providing satisfactory solutions regarding construction operations. As data is an essential function in GIS (Kang *et al*., 2014), data exchange between these systems is as important as establishing an operation during project execution. Wang *et al*., (2019) identified the loss of semantic features during data exchange between systems as a critical challenge during data processing. When the system data model is improbable, a good match may not be possible, resulting in the loss of detailed information. For example, Autodesk Revit and AutoCAD are limited in converting the Industry Foundation Classes (IFC) data model into the same object after conversion. Likewise, ArcGIS cannot fully integrate IFC data without data loss. This shows that the interoperability of diverse systems remains a concern in construction, requiring future attention.

Several models and platforms have been developed and suggested in the reviewed literature, and their applicability for construction projects has been demonstrated through case studies (Bansal, 2012). However, only a few of these developed systems and platforms are applied to real-life projects due to the complexity of GIS data structure. The GIS system has proven to be too difficult and unique, as users or experts are required to create a database for data attributes before any analysis can be done (Liu et al., 2017). The complexity of GIS is what makes it different from other technologies (Thill, 2000). Furthermore, integrating GIS with other technologies like BIM has compounded its complexity, as many users need help comprehending GIS system schema (Bansal, 2012). For example, when importing an IFC file into GIS, the user needs to understand how BIM information is represented in GIS model. Hence, stakeholders need to be enlightened and trained on GIS and its integration with other systems.

5.0 Recommendation for future research on GIS application in the construction industry

This section addresses Q3 based on the SLR conducted; spatial planning and design have been recognised as one of the areas of application of GIS in the construction industry. Table 1 shows this area of application and identifies other areas of usage through the review to support this section. While Table 4 shows discovered opportunities of GIS based on the current state of usage through a literature review. Bansal (2020) developed a system that uses GIS in the construction planning process to facilitate location-based spatial and non-spatial analysis. Also, a few attempts have been made to integrate GIS with other technology to support spatial-temporal design and planning in the construction industry. BUGDAY (2018) uses UAV and GIS in planning forest road construction activities and evaluating alternative routes to site. Amidst all these systems developed for spatial planning and design in the construction industry. Hence, the current system still needs more functionality to design and plan a sustainable smart city (Bansal, 2020). Therefore, future research can focus on using City Information Modelling (CIM) and BIM to capture all relevant urban and infrastructural aspects of a building to design a resilient and sustainable city. The integration of these two systems will enhance sustainability in buildings and modelling of cities, creating a more enabling environment for the future. Moreover, this can provide an integrated virtual platform in which any component of a city can be altered and analysed. This would help stakeholders looking to design iconic structures in the construction industry. Considering the application of GIS in construction task management, a few models and frameworks using GIS and integrated technology has been developed in this area. Sharafat *et al*., (2021) developed a BIM-GIS-based integrated framework for an underground utility management system for earthwork operations. Likewise, Rajadurai and Vilventhan (2021) developed an integrated model using Road Information Modelling (RIM) and GIS to facilitate an ongoing utility relocation in infrastructure projects. However, all existing systems and frameworks developed are based on different model standards and experience loss of information during conversion. Hence, there is a need for a system that can seamlessly integrate different models to perform many management-related operations with discrepancies. As a result, future research can focus on topic such developing a unified-embedded system employing a generic model and Extract-Translated-Load (ETL) data integration process to support construction task management.

Finally, defect detection has been highlighted as one of the domains of application of GIS in the construction industry. Chun *et al*., (2021) developed a system that automatically detect cracks in asphalt pavement using deep learning and GIS, a method proposed for evaluating the pavement condition based on the result extracted from the model to GIS for further inspection. Fendi *et al.*, (2014) proposed a method to establish a database for GIS for road surface cracks detection. The method uses two devices, a camera, and GPS with GIS system to aid maintenance operation. However, this method is manually performed; by one person, taking photos and location coordinates at different points, which can be challenging and expensive due to the high-end cameras and equipment required. Future research can focus on integration of IoT and GIS with ensemble model to mitigate these challenges, this in a way this would enhance operational maintenance productivity; defect detection and facilitate multi-source spatial data acquisition. The integration of GIS and IoT with Radio Frequency Identification (RFID) tags can be used to identify unsafe zone in construction site. This would also aid site risk visualization, reducing the level of exposure to risk on site.

6.0 Conclusion

In line with the current trend, there is a growing study of GIS technology in the construction industry. Consequently, GIS is proving to stretch its capabilities to the spectrum of usage where construction stakeholders within the industry could benefit from this expansion in terms of applicability. Through SLR, the study presents GIS areas of usage, integrated patterns and platforms, challenges, and future research direction of GIS technology, acknowledging the exact application-based domain where GIS is highly used and deficient in the construction industry. This makes the study stands out among other existing studies of GIS in the construction industry. Likewise, based on a comprehensive investigation of the reviewed articles, 60 journal papers were credibly identified and categorised into four areas of application in construction: spatial planning and design, construction task management, defect detection, and safety monitoring. The result shows high usage of GIS in construction task management in building construction projects.

The findings found an integration pattern, involving data flow from a window-form platform into GIS, which is the most common data exchange paradigm between systems and other authoring softwares. While ArcGIS is the most often used software, and its integration with systems or platforms enhances construction operation productivity and increases collaboration throughout project life cycles. Inclusively, it is evident that there is a noticeable gap in GIS usage, as the findings reveal low usage in defect detection.

Studies around this area of usage are few due to some systems complexities and interoperability challenges that exist between GIS, BIM and other systems and platforms. Other challenges, such as loss of semantic and geometric information during the data exchange process, have been identified through the review. Therefore, to resolve these stated pitfalls, future research should focus on fully integrating GIS into BIM and other customised systems and platforms to facilitate the comprehensive application through the life cycle of construction projects.

From the theoretical perspective, this research has been able to reveal current trends in GIS adoption. By analysing the diverse contexts in which GIS has been applied, researchers can glean valuable insights that can guide future decisions and contribute to the further development of the technology. Moreover, the research serves as a valuable resource for construction organisations seeking to deploy the use of GIS technology in the construction industry. However, the review faced several constraints, such as the inaccessibility of non-English papers, which precluded the review from engaging in some development projects.

Declaration of competing interest

The authors declare that they have no actual or potential competing or conflict of interests, namely financial, non-financial, and personal or other relationships with other people or organization.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or any other profit sector.

References

Abd, A. M., Hameed, A. H., and Nsaif, B. M. (2020). Documentation of construction project using integration of BIM and GIS technique. *Asian Journal of Civil Engineering*, Vol. 21 No. 7, pp.1249-1257, https://doi.org/10.1007/s42107-020-00273-9.

Allawi, A. H., and Al-Jazaeri, H. M. J. (2023). A new approach towards the sustainability of urban-rural integration: The development strategy for central villages in the Abbasiya District of Iraq using GIS techniques. *Regional Sustainability*, Vol. 4 No. 1, pp. 28–43. https://doi.org/10.1016/j.regsus.2023.02.004

Alshibani, A., and Moselhi, O. (2016). Productivity based method for forecasting cost & time of earthmoving operations using sampling GPS data. *Journal of Information Technology in Construction*, Vol. 21, pp. 39–56, https//www.itcon.org/2016/3.

Audu-Moses, J. A. (2019), Assessing the use of GIS tools in the Nigeria building construction industry, *International Journal of Engineering Technology Research and Management*, Vol. 4 No. 11, pp. 45-54, https://independent.academia.edu/JustinaAudumoses.

Bansal, V. K. (2011), Application of geographic information system in construction safety planning, *International Journal of Project Managemen*t, Vol. 29 No. 1, pp. 66-77. https://doi.org/10.1016/j.ijproman.2010.01.007.

Bansal, V. K. (2012). Application areas of GIS in construction projects and future research directions. *International Journal of Construction Management*, Vol. 12 No. 4, pp. 17–36 https://doi.org/10.1080/15623599.2012.10773198.

Bansal, V. K. (2016). Potential Application Areas of GIS in Preconstruction Planning. *Journal of Professional Issues in Engineering Education and Practice*, Vol. 142 No. 1, p. 06015002 https://doi.org/10.1061/(ASCE)EI.1943-5541.0000257.

Bansal, V. K. (2017). Integrated CAD and GIS–based framework to support construction planning: case study. *Journal of Architectural Engineering*, Vol. 23 No. 3, p. 5017005. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000262.

Bansal, V. K. (2020). Use of GIS to consider spatial aspects in construction planning process. *International Journal of Construction Management*, Vol. 20 No. 3, pp. 207-222. https://doi.org/10.1080/15623599.2018.1484845.

Bhandari, S., Bhandari, D., and Kumari, M. (2013). Application of Geographical Information System in Progress Monitoring of Construction Project. *International Journal of Scientific & Engineering Research*, Vol. 4 No. 12, pp.100–107. http://www.ijser.org.

Bhattacharya, A., and Neware, S. (2020). Nagpur metro tracks construction monitoring system. *International Journal of Emerging Trends in Engineering Research*, Vol. 8 No. 5. https://doi.org/10.30534/ijeter/2020/119852020.

Biljecki, F., Lim, J., Crawford, J., Moraru, D., Tauscher, H., Konde, A., Adouane, K., Lawrence, S., Janssen, P., and Stouffs, R. (2021). Extending CityGML for IFC-sourced 3D city models. *Automation in Construction*, Vol. 121, p.103440. https://doi.org/10.1016/j.autcon.2020.103440.

BUĞDAY, E. (2018). Capabilities of using UAVs in forest road construction activities. *European Journal of Forest Engineering*, Vol. 4 No. 2, pp. 56–62. https://doi.org/10.33904/ejfe.499784.

Çetin, S., De Wolf, C., and Bocken, N. (2021). Circular Digital Built Environment: An Emerging Framework. *Sustainability*, Vol. 13 No. 11, pp. 6348. https://doi.org/10.3390/su13116348.

Chun, P., Yamane, T., & Tsuzuki, Y. (2021). Automatic detection of cracks in asphalt pavement using deep learning to overcome weaknesses in images and GIS visualization. *Applied Sciences*, Vol. 11 No. 3, p. 892. https://doi.org/10.3390/app11030892.

Costa, A. L., Sousa, R. L., and Einstein, H. H. (2018). Probabilistic 3D alignment optimization of underground transport infrastructure integrating GIS-based subsurface characterization. *Tunnelling and Underground Space Technology*, Vol.72, pp. 233–241. https://doi.org/10.1016/j.tust.2017.11.027

Delgado, F., Martínez, R., Puche, J., and Finat, J. (2015). Towards a client-oriented integration of construction processes and building GIS systems, *Computers in Industry*, Vol. 73 No. 10, pp. 51–68. https://doi.org/10.1016/j.compind.2015.07.012.

Deng, Y., Cheng, J. C. P., and Anumba, C. (2016). Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison. *Automation in Construction*, Vol. 67, pp. 1–21. https://doi.org/10.1016/j.autcon.2016.03.006.

Deng, Y., Gan, V. J. L., Das, M., Cheng, J. C. P., and Anumba, C. (2019). Integrating 4D BIM and GIS for construction supply chain management. *Journal of Construction Engineering and Management*, Vol. 145, p.4019016. DOI: 10.1061/(ASCE)CO.1943-7862.0001633.

Ding, C. (2019). Application of GIS technology in the construction of urban traffic sharing multimedia information platform. *Multimedia Tools and Applications*. https://doi.org/10.1007/s11042-019-7500-0.

Ebrahim, M. A.-B., Mosly, I., and Abed-Elhafez, I. Y. (2016). Building construction information system using GIS. *Arabian Journal for Science and Engineering*, Vol. 41 No. 10, pp. 3827–3840. https://doi.org/10.1007/s13369-015-2006-1.

Esri (2021) "Architecture, Engineering, and Construction (AEC): Location intelligence for AEC", available at: https://www.esriuk.com/en-gb/industries/aec/overview (accessed 15 November 2021)

Farooq, J., Sharma, P., and Sreerama Kumar, R. (2017). Applications of building information modeling in electrical systems design. *Journal of Engineering Science and Technology Review*, Vol.10 No.6, p.119–128. https://doi.org/10.25103/jestr.106.16.

Fenais, A., Ariaratnam, S. T., Ayer, S. K., and Smilovsky, N. (2019). Integrating geographic information systems and augmented reality for mapping underground utilities. *Infrastructures*, Vol.4 No.4. https://doi.org/10.3390/infrastructures4040060.

Fendi, K. G., Adam, S. M., Kokkas, N., and Smith, M. (2014). An approach to produce a gis database for Road Surface Monitoring. *APCBEE Procedia*, Vol. 9, pp. 235–240. https://doi.org/10.1016/j.apcbee.2014.01.042.

Ferreira, T. M., Maio, R., and Vicente, R. (2017). Seismic vulnerability assessment of the old city centre of Horta, Azores: calibration and application of a seismic vulnerability index method. *Bulletin of Earthquake Engineering*, Vol.15 No.7, pp.2879–2899. https://doi.org/10.1007/s10518-016-0071-9.

Han, C., Tang, F., Ma, T., Gu, L., and Tong, Z. (2022). Construction quality evaluation of asphalt pavement based on BIM and GIS. *Automation in Construction*, Vol. 141, p.104398. https://doi.org/10.1016/j.autcon.2022.104398.

Han, Z. H., Wang, Z. K., Gao, C., Wang, M. X., and Li, S. T. (2020). Application of GIS and BIM Integration Technology in Construction Management. *IOP Conference Series: Earth and Environmental Science*, Vol 526 No.1. https://doi.org/10.1088/1755-1315/526/1/012161.

Huang, X. Y. (2012). Grid-GIS-based disaster preventing and decreasing technology in highway engineering. *Dongbei Daxue Xuebao/Journal of Northeastern University*, 33(SUPPL.2), pp.157–161.https://www.resaerchgate.net/scientific-contributions/X-Y-Huang-2094848943.

Irizarry, J., Karan, E. P., and Jalaei, F. (2013). Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction*, Vol. 31, pp. 241–254. https://doi.org/10.1016/j.autcon.2012.12.005.

Isikdag, U., Underwood, J., and Aouad, G. (2008). An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes. *Advanced Engineering Informatics*, Vol. 22 No. 4, pp. 504–519 https://doi.org/10.1016/j.aei.2008.06.001.

Jeong, J. S., and Ramírez-Gómez, Á. (2018). Development of a web graphic model with fuzzy-decision-making Trial and Evaluation Laboratory/Multi-criteria-Spatial Decision Support System (F-DEMATEL/MC-SDSS) for sustainable planning and construction of rural housings. *Journal of Cleaner Production*, Vol. 199, pp. 584–592. https://doi.org/10.1016/j.jclepro.2018.07.227.

Kang, M. W., Jha, M. K., and Buddharaju, R. (2014). Rail transit route optimization model for rail infrastructure planning and design: Case study of Saint Andrews, Scotland. *Journal of Transportation Engineering*, Vol. 140 No. 1, pp. 1–11. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000445.

Karan, E. P., and Irizarry, J. (2015). Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services. *Automation in Construction*, Vol. 53, pp.1–12. https://doi.org/10.1016/j.autcon.2015.02.012.

Karan, E. P., Irizarry, J., and Haymaker, J. (2016). BIM and GIS integration and interoperability based on semantic web technology. *Journal of Computing in Civil Engineering*, Vol. 30 No.3, p. 4015043. DOI: 10.1061/(ASCE) CP.1943-5487.0000519.

Karimi, S., & Iordanova, I. (2021). Integration of BIM and GIS for Construction Automation, a Systematic Literature Review (SLR) Combining Bibliometric and Qualitative Analysis. *Archives of Computational Methods in Engineering*. https://doi.org/10.1007/s11831-021-09545-2

Khalil, R. (2015). Credibility of 3D volume computation using GIS for Pit excavation and roadway constructions. *American Journal of Engineering and Applied Sciences*, Vol. 8 No. 4, pp. 434–442. https://doi.org/10.3844/ajeassp.2015.434.442.

Khan, M. S., Park, J., and Seo, J. (2021). Geotechnical property modeling and construction safety zoning based on gis and bim integration. *Applied Sciences (Switzerland)*, Vol. 11 No. 9. https://doi.org/10.3390/app1109400.

Kim, S.-W., Choi, J.-H., Hong, S.-H., Lee, J.-H., Cho, J., and Lee, M.-J. (2018). Monitoring the risk of large building collapse using persistent scatterer interferometry and GIS. *Terr. Atmos. Ocean. Sci*, Vol. 29 No.5, pp. 535–545. doi: 10.3319/TAO.2018.03.07.01.

Kumar, S., and Bansal, V. K. (2016). A GIS-based methodology for safe site selection of a building in a hilly region. *Frontiers of Architectural Research*, Vol. 5 No. 1, pp 39–51. https://doi.org/10.1016/j.foar.2016.01.001.

Kumar, S., and Bansal, V. K. (2019). Use of GIS in locating TFs safely on a construction site in hilly regions. *International Journal of Construction Management*, Vol. 19 No. 4, pp. 341–353.https://doi.org/10.1080/15623599.2018.1435153.

Lee, P. C., Zheng, L. L., Lo, T. P., and Long, D. B. (2020). A Risk Management System for Deep Excavation Based on BIM-3DGIS Framework and Optimized Grey Verhulst Model. *KSCE Journal of Civil Engineering*, Vol. 24 No. 3, pp. 715–726. https://doi.org/10.1007/s12205-020-1462-7.

Liu, X., Wang, X., Wright, G., Cheng, J. C. P., Li, X., and Liu, R. (2017). A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS International Journal of Geo-Information*, Vol.6 No. 2, pp. 1–21. https://doi.org/10.3390/ijgi6020053.

Loulizi, A., Rakha, H., and Bichiou, Y. (2018). Quantifying grade effects on vehicle fuel consumption for use in sustainable highway design. *International Journal of Sustainable Transportation*, Vol. 12 No. 6, pp. 441–451. https://doi.org/10.1080/15568318.2017.1385878.

Lu, G. (2013). Fast acquisition and application of spatial information of Liaoning province expressway service. *Dongnan Daxue Xuebao (Ziran Kexue Ban)/Journal of Southeast University (Natural Science Edition)*, *43*(SUPPL.2), pp. 302–306. 10.3969/j.issn.1001-0505. 2013.S2.018.

Ma, Z., & Ren, Y. (2017). Integrated application of BIM and GIS: an overview. *Procedia Engineering*, Vol. 196, pp. 1072–1079. https://doi.org/10.1016/j.proeng.2017.08.064.

Meline, T. (2006). Selecting studies for systemic review: Inclusion and exclusion criteria. *Contemporary Issues in Communication Science and Disorders*, *33*(Spring), pp. 21–27. https://doi.org/10.1044/cicsd_33_S_21.

Miano, A., Di Carlo, F., Mele, A., Giannetti, I., Nappo, N., Rompato, M., Striano, P., Bonano, M., Bozzano, F., and Lanari, R. (2022). GIS Integration of DInSAR Measurements, Geological Investigation and Historical Surveys for the Structural Monitoring of Buildings and Infrastructures: An Application to the Valco San Paolo Urban Area of Rome. *Infrastructures*, Vol *7* No. 7, pp. 89. https://doi.org/10.3390/infrastructures7070089.

Mignard, C., and Nicolle, C. (2014). Merging BIM and GIS using ontologies application to Urban facility management in ACTIVe3D. *Computers in Industry*, Vol. 65 No. 9, pp. 1276–1290. https://doi.org/10.1016/j.compind.2014.07.008.

Min, S. P., and Zhao, L. L. (2014). The application of 3D GIS technology in the whole life cycle of railway. *Journal of Railway Engineering Society*, Vol. 31 No. 10, pp. 15–20. https://doi.org/10.3969/j.issn.1006-2106.2014.10.004.

Mollo, L., Agliata, R., Iglesias, L. P., and Vigliotti, M. (2020). Typological GIS for knowledge and conservation of built heritage: A case study in Southern Italy. *Informes de La Construccion*, Vol. 72 No. 559, pp. 1-7. https://doi.org/10.3989/ic.73697.

Montaser, A., and Moselhi, O. (2014). Truck+ for earthmoving operations. *Journal of Information Technology in Construction*,ITcon Vol. 19, pp. 412–433. http://www.itcon.org/2014/25.

Ningthoujam, M. C., and Nanda, R. P. (2018). A GIS System Integrated with Earthquake Vulnerability Assessment of RC Building. *Structures*, Vol.15, pp. 329–340. https://doi.org/10.1016/j.istruc.2018.07.013.

Palve, S. N. (2013). Applications of GIS in Infrastructure. *International Journal of Structural and Civil Engineering Research*, Vol. 2 No. 4, pp. 110–122. http://www.ijscer.com/uploadfile/2015/0429/ /20150429081004.

Park, S. H., and Kim, E. (2016). Middleware for translating urban GIS information for building a design society via general BIM tools. *Journal of Asian Architecture and Building Engineering*, Vol. 15 No. 3, pp. 447–454. https://doi.org/10.3130/jaabe.15.447.

Patel, K., Patel, Tirth, and Patel, P. (2017). Application of GIS in Construction Project Management. *2nd International Conference On Construction, Real Estate, Infrastructure and Project Management (ICCRIP 2017), November*. https://www.researchgate.net/profile/Tirth-Patel-27/publication/332833320_Application_of _GIS_in_Construction_Management/links/5cc bdcc4299bf11c2a3d22b3/Application-of-GIS-in-Construction-Management.pdf.

Pedro, J., Silva, C., and Pinheiro, M. D. (2018). Scaling up LEED-ND sustainability assessment from the neighborhood towards the city scale with the support of GIS modeling: Lisbon case study. *Sustainable Cities and Society*, Vol. 41, pp. 929–939. https://doi.org/10.1016/j.scs.2017.09.015.

Petimani, V. S., Awati, V., and Rashmi, J. V. (2019). Monitoring the construction project by 4D application of GIS. *International Journal of Recent Technology and Engineering*, Vol. *8* No.2,pp. 2994–2999. https://doi.org/10.35940/ijrteB2718.078219.

Rajadurai, R., and Vilventhan, A. (2021). Integrating road information modeling (RIM) and geographic information system (GIS) for effective utility relocations in infrastructure projects. *Engineering, Construction and Architectural Management*.Vol. ahead-of-print No.ahead-of-print. https://doi.org/10.1108/ECAM-04-2021-0295.

Safaei, M., Sundararajan, E. A., Driss, M., Boulila, W., and Shapi'i, A. (2021). A systematic literature review on obesity: Understanding the causes & consequences of obesity and reviewing various machine learning approaches used to predict obesity. *Computers in Biology and Medicine*, Vol. 136, p.104754. https://doi.org/10.1016/j.compbiomed.2021.104754.

Sharafat, A., Khan, M. S., Latif, K., Tanoli, W. A., Park, W., and Seo, J. (2021). BIM-GIS-Based Integrated Framework for Underground Utility Management System for Earthwork Operations. *Applied Sciences*, Vol.11 No. 12, p.5721. https://doi.org/10.3390/app11125721.

Shekargoftar, A., Taghaddos, H., Azodi, A., Nekouvaght Tak, A., and Ghorab, K. (2022). An Integrated Framework for Operation and Maintenance of Gas Utility Pipeline Using BIM, GIS, and AR. *Journal of Performance of Constructed Facilities*, Vol. 36 No. 3, p.4022023.https://doi.org/10.1061/(ASCE)CF.1943-5509.0001722.

Song, W., and Wu, C. (2021). Introduction to advancements of GIS in the new IT era. *Annals of GIS*, *27*(1), 1–4. https://doi.org/10.1080/19475683.2021.1890920.

Tegtmeier, W., Zlatanova, S., Van Oosterom, P. J. M., and Hack, H. R. G. K. (2014). 3D-GEM: Geo-technical extension towards an integrated 3D information model for infrastructural development. *Computers & Geosciences*, Vol 64, pp. 126–135 https://doi.org/10.1016/j.cageo.2013.11.003.

Thill, J.-C. (2000). Geographic information systems for transportation in perspective. *Transportation Research Part C: Emerging Technologies*, Vol. 8 No.1–6, pp.3–12. https://doi.org/10.1016/S0968-090X(00)00029-2.

Tiedong, L. (2013). Based on GIS technology of urban gardening and greening layout optimization model. Research Journal of Applied Sciences, Engineering and Technology, Vol. 6 No. 12, pp. 2166–2170. https://doi.org/10.19026/rjaset.6.3841.

Togawa, T., Fujita, T., Dong, L., Ohnishi, S., and Fujii, M. (2016). Integrating GIS databases and ICT applications for the design of energy circulation systems. *Journal of Cleaner Production*, Vol.114, pp. 224–232. https://doi.org/10.1016/j.jclepro.2015.07.020.

Tranfield, D., Denyer, D., and Smart, P. (2003). *Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review* Vol. 14 No 3, pp.207-22. https://doi.org/10.1111/1467-8551.00375.

Tsai, M. K., and Yau, N. J. (2014). Using mobile disaster response system in bridge management. *Journal of Civil Engineering and Management*, Vol. 20 No.5, pp. 737–745. https://doi.org/10.3846/13923730.2013.802731.

Verma, S., and Datta, A. (2013.). *GIS-driven renewable energy framework for smart and sustainable cities-India Geospatial Digest*, Available: http://geospatialworld.net/article/gis-driven-renable-energy-framework-for-smart-and-sustainable-cities (accessed 02 May 2023).

Vilventhan, A., and Rajadurai, R. (2019). 4D Bridge Information Modelling for management of bridge projects: A case study from India. *Built Environment Project and Asset Management*, Vol 10 No. 3, pp. 423–435. https// doi.org/10.1108/BEPAM-05-2019-0045.

Wang, H., Pan, Y., and Luo, X. (2019). Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. *Automation in Construction*, *103*(February),Vol.103, pp.41–52. https://doi.org/10.1016/j.autcon.2019.03.005.

Wang, S., Zhang, F., and Qin, T. (2021). Research on the Construction of Highway Traffic Digital Twin System Based on 3D GIS Technology. *IOP Conference Series: Earth and Environmental Science*, Vol.1802 No. 4, p. 042045. https://doi.org/10.1088/1742-6596/1802/4/042045.

Wang, J., Wei, J., Zhang, W., Liu, Z., Du, X., Liu, W., and Pan, K. (2022). High-resolution temporal and spatial evolution of carbon emissions from building operations in Beijing. *Journal of Cleaner Production*, Vol. *376*, p.134272. https://doi.org/10.1016/j.jclepro.2022.134272.

Weerasinghe, M. D. G., Rupasinghe, A. R., and Jayasooriya, S. D. (2018), *Application of GIS in Construction Management*, International Research Conference Proceedings, General Sir John Kotelawala Defence University, Sri Lanka, pp. 35-38. http://ir.kdu.ac.lk/handle/345/2465.

Wu, H., Tao, J., Li, X., Chi, X., Li, H., Hua, X., Yang, R., Wang, S., and Chen, N. (2013), A location based service approach for collision warning systems in concrete dam construction. *Safety Science*, Vol. 51 No. 1, pp. 338–346. https://doi.org/10.1016/j.ssci.2012.08.006.

Xiao, Q., Tan, S., and Yu, S. (2020). Research on the Construction of Cutting-Edge Technology Monitoring System Based on Multi-Source Heterogeneous Data. *MLIS*, pp. 127–135.doi:10.3233/FAIA200774.

Xu, H. (2013). XThe Application of 3S Technology to the Tsukuba Bailin Landscape Project. *International Journal of Online Engineering*, Vol. 9 No. 4, pp. 49-51 https://doi.org/10.3991/ijoe.v9i4.2935.

Yadhukrishnan, A. V, and Shetty, A. (2015). A Review on GIS based Construction Project Management. *International Advanced Research Journal in Science, Engineering and Technology*, Vol. 2 No. 6, pp. 137–141. https://doi.org/10.17148/IARJSET.2015.2629.

Yan, L., Xu, H., and Guo, Q. (2012). Design and implementation of railway operation monitoring system based on cloud computing and WebGIS. *Zhongguo Tiedao Kexue/China Railway Science*, Vol. *33* No. 1, pp.132–138. https://doi.org/10.3969/j.issn.1001-4632.2012.S1.23.

Zheng, Z., Xie, S., Dai, H.-N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: A survey. *International Journal of Web and Grid Services*, Vol. 14 No. 4, pp. 352–375. https://allquantor.at/blockchainbib/pdf/zheng2018blockchain.pdf.

Zhou, W., Whyte, J., and Sacks, R. (2012). Construction safety and digital design: A review. *Automation in Construction*, Vol. 22, pp.102–111. https://doi.org/10.1016/j.autcon.2011.07.005.

Zhu, J., Tan, Y., Wang, X., and Wu, P. (2021). BIM/GIS integration for web GIS-based bridge management. *Annals of GIS*, Vol. 27 No. 1, pp. 99–109. https://doi.org/10.1080/19475683.2020.1743355.

Table 1

Reviewed Articles

Authors	Area of Application	Objective	Results	Challenges
Petimani et al. (2019) [1]	Construction task management (Building)	Proposes a 4D model of GIS for monitoring construction project activity.	Model output provides better visualisation for construction work progress to reduce cost overrun and rework.	Interoperability defect.
Bansal, (2020) [2]	Spatial planning and design (Building)	Proposes a GIS system for geospatial analysis to support construction planning process.	The system facilitates location-based analysis both spatial and non-spatial aspects on a single platform.	System Complexity
Bansal et al. (2011) [3]	Spatial planning and design (Building)	Proposes a GIS tool for CPM scheduling with a 3D component to visualise the buildability on a computer screen.	Establishment of dynamic linkage between schedule and corresponding 3D component in GIS.	System Complexity
Kumar & Bansal, (2019) [4]	Safety monitoring (Building)	Develop GIS-based framework for locating temporary facility (TF) on a construction site in hilly regions.	A framework developed identify proposed infrastructure facilities which were located at adverse locations.	Complexity of system
Ebrahim et al. (2016) [5]	Construction task management (Building)	Propose the use of GIS in building information system in building construction.	GIS establish information system for building construction and create an archive for project documentation.	Interoperability defect
Fendi et al., (2014) [6]	Defect detection (Road)	Propose a customized system for road surface distress detection and reporting.	The system eliminates continuous re-measurement of road pavement distresses at each update and reduce cost to re-inspect the rad in subsequent years.	Complexity of system
Bhandari et al. (2013) [7]	Construction task management (Building)	Present the concept of integrating GIS with construction project management to provide a better solution for progress monitoring.	Project schedule data was integrated with GIS technology for visualisation of project progress	Interoperability defect
Palve (2013) [8]	Construction task management (Building)	Proposes GIS technology for planning, design and construction phase of infrastructure project.	Results shows spatial interface and information for project tracking.	System Complexity
Audu-Moses, (2013) [9]	Construction task management (Building)	Proposes the use of GIS and project management software for tracking of construction activity progress.	Project management software and GIS was integrated for progress real time tracking.	Interoperability defect
Patel et al. (2017) [10]	Construction task management (Building)	Proposes integrated system for construction progress tracking.	The system facilitates the successful execution of projects reducing cost and time.	Interoperability defect
Lee et al. (2020) [11]	Construction task management (Building)	Proposes a model for monitoring risk variation during deep excavation.	The model predicts time series of displacement from site to monitor risk.	Interoperability defect
Kim et al., (2018) [12]	Safety monitoring (Building)	Application of Persistent scatterer method and GIS to monitor the displacement of multiple building in downtown areas.	The result show that the method is effective for analysing the displacement of large buildings in downtown	System Complexity
Ningthoujam & Nanda, (2018) [13]	Defect detection (Building)	Develop a methodology to assess visual screening score sheet for seismic vulnerability assessment for buildings.	The platform generation and displacement damaged buildings and identifies areas with potential heavy damage.	System Complexity
Ferreira et al., (2017) [14]	Safety monitoring (Building)	Proposes a simplified seismic assessment method to address traditional masonry building.	The assessment integrated GIS tool to mitigate the risk vulnerability index supports safety and emergency.	Unintentional destruction of information
Costa et al., (2018) [15]	Construction task management (Heavy Engineering)	Proposes an innovative probabilistic alignment tool for underground tunnel construction.	The approach aids risk management and 3D alignment optimization of underground tunnel construction.	System Complexity
Bansal (2016) [16]	Safety monitoring (Building)	Proposes a GIS- based methodology for safe site selection.	The model locates a suitable and safe site that satisfies various spatial aspects.	System Complexity
Alshibani & Moselhi (2016) [17]	Construction task management (Earthmoving Operations)	Proposes automated Wed-based system for estimating actual productivity, forecasting cost and time of earthmoving operation in real- time.	GPS and GIS for tracking and controlling earthmoving operations.	System Complexity

Park & Kim (2016) [18]	Spatial planning and design (Building)	Proposes a middleware-based GIS platform for building design.	The platform guides open data and provides environmental information to building design.	Interoperability defect
Kumar & Bansal (2016) [19]	Safety monitoring (Building)	To explore the potential area of GIS in preconstruction planning.	GIS application in preconstruction stage increase the level of productivity, safety and sustainability.	Interoperability defect
Ma et al. (2013) [20]	Safety monitoring (Heavy Engineering)	Proposes a quantitative risk analysis process for urban gas pipeline networks, using GIS.	The application strengthens the risk analysis model for urban gas pipeline frequent inspections.	System Complexity
Khalil (2015) [21]	Spatial planning and design (Road)	Proposes the use of GIS for volume estimation and earthwork calculation of borrow pit and roadway construction.	Techniques generated a raster GRID to represent accurate volume and computed volume.	System Complexity
Karan & Irizarry (2015) [22]	Construction task management (Building)	Proposes semantic web techniques for transforming preconstruction information during the construction planning and design phase.	Semantic web technology enable interoperation between building and geospatial data.	Interoperability defect
Mignard & Nicolle (2014) [23]	Construction task management (Building)	Proposes a platform for urban facility management that allows the emergence of new business disciplines.	Platform supports the life cycle of urban environment from the design to recycling of buildings.	Interoperability defect
Chun et al., (2021) [24]	Defect detection (Road)	Develop a system that automatically detects cracks from images of pavement using deep learning and GIS	The system model showed high detection accuracy for pavement images with cracks with few false positives in pavement images without cracks.	Complexity in system
Kang et al. (2014) [25]	Spatial planning and design (Railway)	Proposes a model to facilitate cost effectiveness in rail infrastructure planning and design.	The model performs optimization, which helps integration of GIS for land search.	Complexity in system
Xu (2013) [26]	Construction task management (Landscape)	Proposes 3S technology for planning and managing landscape projects.	The technology increases the efficiency of interoperability in construction projects.	Interoperability defect
Bansal (2012) [27]	Construction task management (Building)	Explore potential application of GIS technology for the construction industry.	GIS application meet construction project requirements at different stages.	Interoperability defect
Yan et al. (2012) [28]	Construction task management (Railway)	Proposes a cloud computing and Web GIS model for railway operation monitoring system.	Cloud computation information processing aid railway operations	Complexity of system
Irizarry et al. (2013) [29]	Construction task management (Building)	Proposes an integrated model to improve visual monitoring of construction supply chain management.	The model integrated BIM-GIS for supply chain visualisation.	Interoperability defect
Huang (2012) [30]	Safety monitoring (Road)	Proposes a system called Grid-GIS to prevent highway disasters.	The system updating highway disaster data for decision on geologic hazard.	Complexity in system
Tiedong (2013) [31]	Spatial planning and design (Landscape)	Proposes GIS-based technology for unban gardening and green layout optimization.	Establishes green garden, landscape construction and management of information.	Interoperability defect
Deng et al. (2013) [32]	Safety monitoring (Building)	Proposes an application for earthquake emergency building foundation information database.	The application gives effective data support to earthquake emergencies.	Interoperability defect
Lu (2013) [33]	Safety monitoring (Road)	Proposes spatial information solution for highway construction.	GIS realize road property survey, disaster prevention and emergency rescue.	Complexity in system
Min & Zha (2014) [34]	Construction task management (Railway)	Proposes theories, software tools for improving railways information construction.	3D GIS application technology route-oriented railroad industry.	Interoperability defect
Tsai & Yau (2014) [35]	Safety monitoring (Heavy Engineering)	Proposes integrated mobile information techniques using GIS for disaster response.	System improvement and disaster recognition between a construction engineers and disaster engineers.	Interoperability defect
Ding (2019) [36]	Construction task management (Road)	Proposes a geographic multimedia information system for urban intelligent traffic road construction in China.	Improvement and efficiency of urban road construction and management.	Complexity of system
Jeong & Ramírez-Gómez, (2018) [37]	Spatial planning and design (Building)	Proposes a Web-based model to facilitate sustainable rural housing planning and construction.	Collaboration and communication of spatial design and visual impact facilitate sustainable housing.	Interoperability defect

Pedro et al. (2018) [38]	Spatial planning and design (Building)	Proposes a method using GIS as a tool for strategic urban planning construction.	The model evaluates sustainable level of urban construction and identifies key infrastructure.	Interoperability defect
Loulizi et al. (2018) [39]	Spatial planning and design (Road)	Develop a procedure which highway engineers could estimate the effect of a geometrical design features.	Establish freeway layout with terrain profile less than 10% to avoid massive earthwork activities.	Complexity of system
Farooq et al. (2017) [40]	Spatial planning and design (Heavy Engineering)	Investigate the potential of BIM application on electrical system design and analysis.	GIS & BIM facilitate electrical grid construction and optimization of city	Interoperability defects
Togawa et al. (2016) [41]	Spatial planning and design (Heavy Engineering)	Proposes integrated database application for designing an energy circulation system.	Application facilitates better management, reporting and verification of materials	Interoperability defects
Vilventhan and Rajadurai (2019) [42]	Spatial planning and design (Heavy Engineering)	Develop a 4D BrIM model for the management of bridge project	The application of the model benefits the project team in material delivery planning.	Interoperability defects
Han et al. (2020) [43]	Construction task management (Heavy Engineering)	Proposes an integrated platform for hydraulic and hydropower engineering projects.	Platform offers a satisfactory scheme for resolving inconsistencies.	Interoperability defects
Bhattacharya & Neware, (2020) [44]	Construction task management (Railway)	Proposes an application that shows the progress of construction activity.	The approach to detection and portrait of the correspondent metro network image.	Complexity of system
Fenais et al. (2019) [45]	Construction task management (Heavy Engineering)	Proposes an integrated AR-GIS for mapping and capturing underground utilities using a mobile device.	The integration produced an efficient solution for data collection.	Interoperability defects
BUĞDAY (2018) [46]	Spatial planning and design (Road)	Proposes the use of Unmanned aerial vehicles (UAVs) and GIS tools for planning forest road construction.	Found that UAV and GIS advantageous in capturing higher quality and higher resolution imagery	Complexity of system
Li et al (2017) [47]	Construction task management (Heavy Engineering)	Proposes a Super Map object application for monitoring a subway construction system.	Application process information for safety monitoring of highway tunnel projects.	Complexity of system
Delgado et al. (2015) [48]	Construction task management (Building)	Proposes development of web 3D visualizer for building construction process.	The application allows professionals to identify delays during building construction processes.	Interoperability defects
Montaser & Moselhi (2014) [49]	Construction task management (Earthmoving operations)	Develop an automated system that integrates GPS and GIS for earthmoving operations.	The system capture data to track and monitor the productivity of earthmoving operations.	Complexity of system
Wu et al. (2013) [50]	Safety monitoring (Heavy Engineering)	Proposes a warning service system for dam construction.	System shows feasible option in fulfilling collision warning function and automating dam construction process	Complexity of system
Mollo et al. (2020) [51]	Spatial planning and design (Building)	Proposes a typological GIS system for knowledge and conservation of built heritage in buildings	Potential in building design provides support for urban renovation.	Complexity of system
Rajadurai & Vilventhan, (2021) [52]	Construction task management (Road)	Develop an integrated model to assist early identification of utilities and effective coordination during relocation in infrastructure projects	The evaluation of the developed models shows that the RIM-GIS model approach enabled early planning and coordination and facilitates effective management of utility relocations.	Interoperability defects
Khan et al., (2021) [53]	Safety monitoring (Earthmoving Operation)	Integrated GIS and BIM for modelling geotechnical property and safe construction zones based on soil type	3D digital model provides information on surface and subsurface model for construction planners and managers to identify best construction practices for safe construction	Interoperability defects
Biljecki et al., (2021) [54]	Construction task management (Building)	Proposes Application Domain Extension (ADE) to support retaining building information	ADE application automatically converts IFC to CityGML, visualising structure and added value in a use case	Interoperability defects
Sharafat et al., (2021) [55]	Construction task management (Heavy Engineering)	Develop an integrated system (GIS-BIM) for underground utility management	The system provides real-time 3D spatial information during construction process, act as as-built information.	Interoperability defects
Abd et al. (2020) [56]	Spatial planning and design (Building)	Integrated GIS and BIM data for creating digital representation of real-world scenarios	Visualization process shown in 3D as well as different formats to compile case studies with in one environment	Interoperability defects
Wang et al., (2022) [57]	Spatial planning and design (Building)	Develop a method using GIS to calculate carbon emission from building operations	The system provide help for planning quick and reduction of carbon emission	Complexity of system

Han et al., (2022) [58]	Construction task management (Road)	Develop framework to perform real-time process quality evaluation of pavement construction	The framework combined BIM and GIS to provide good information environment for construction quality	Interoperability defects
Miano et al., 2022 [59]	Construction task management (Building)	GIS integrated with Differential Interferometric Synthetic Aperture Rader (DinSAR) for structural monitoring of buildings	The result highlighted strategy to correlate the DinSAR-monitoring ground settlement with damage scale.	Complexity of system
Shekargoftar et al., (2022) [60]	Construction task management (Heavy Engineering)	Developed integrated system employing BIM, GIS, AR and application programming interface (API)	The system: pipeline operation and maintenance management system is efficient in improving data collection, communication among stakeholders, and perception of as built subsurface utility.	Interoperability defects and Complexity of system

Table 2

Categories of GIS key application domain in the built environment

Category	No of Papers	Reference
Spatial planning and design	16	Bansal,et al., 2011;Bansal, 2020; Park & Kim, 2016; Khalil, 2015; Kang et al., 2014; Tiedong, 2013; Jeong & Ramírez-Gómez, 2018; Pedro et al., 2018;Loulizi et al., 2018; Farooq et al., 2017; Togawa et al., 2016; Hartman et al., 2012; BUĞDAY, 2018; Mollo et al., 2020; Abd et al., 2020; Wang et al., 2022
Construction task management	29	Petimani & Vishwanath Awati, 2019; Ebrahim et al., 2016; Bhandari et al., 2013; Palve, 2013; Audu-Moses, ; Patel et al., 2017; Lee et al., 2020; Costa et al., 2018; Alshibani & Moselhi, 2016; Karan & Irizarry, 2015; Mignard & Nicolle, 2014; Xu et al., 2013; Bansal, 2011; Huang, 2012; Irizarry et al., 2013; Min & Zhao, 2014; Ding, 2019; Han et al., 2020; Bhattacharya & Neware, 2020; Fenais et al., 2019; Liu et al., 2017; Delgado et al., 2015; Biljecki et al. 2021; Sharafat et al. 2021; Rajadurai & Vilventhan 2021; Miano et al., 2022; Han et al., 2022; Shekargoftar et al., 2022
Defect detection	3	Fendi et al, 2014; Ningthoujam & Nanda, 2018; Chun et al, 2021
Safety monitoring	12	Bansal, 2016; Ferreira et al., 2017; Kumar & Bansal, 2016; Wu et al., 2013; Kumar & Bansal 2019; Ma et al., 2013; Huang, 2012; Deng et al., 2013; Lu, 2013; Tsai & Yau, 2014; Khan and Park, 2021; Kim et al., 2018

Table

Integration pattern and platform of reviewed literature

Integrated pattern	**Platform**	**Literature**
Extract data from Window-form application to GIS	ArcGIS, AutoCAD, MSP ArcGIS, AutoCAD, VR. AutoCAD, ArcGIS ArcGIS, (VBA), WebGIS/F DEMATEL/MC-SDSS Grass GIS, ArcGIS Augmented reality (AR), ArcGIS, Revit Unmanned Aerial Vehicles (UAV, ArcGIS WebGIS, ArcGIS Revit, ArcGIS	[1,2,3,4,7,9,10] [13,14,8,16,20,31,32,36,39 33,21,11,34] [12] [19] [37] [44,60] [45] [46] [28, 59]
Extract data from BIM system into GIS/vice versa	ArcGIS, AutoCAD BIM-GIS, WebGIS, ArcGIS,	[27,40,51] [43,53,56] [47]

Extract data from BIM and GIS or GIS into another system /vice versa	Self-developed, ArcGIS	[5,49]
	VB, ArcGIS	[6]
	ArcGIS, Decision Aids for Tunnelling	[15]
	ArcGIS	[17,25,29, 57]
	Vworld, AutoCAD, Google earth, Autodesk Revit	[18]
	ArcGIS, Autodesk Revit, Self-develop, Geo-Tool	[23,58]
	ArcGIS, IDRISI	[24]
	ArcGIS, Self-develop	[26]
	ArcGIS, AR application, Mobile 3-D	[30]
	ArcGIS, Self-develop	[35,38]
	Self-developed platform	[41,42,48,50,52,54,55]
	Self-develop, ArcGIS, Autodesk Revit	[22]

Table IV

Recent stage of GIS technology and area of future research within the construction industry

Area of Application	**State- of -the- art**	**Potential opportunities**
Spatial planning and design	Spatial analysis for location and site selection. [2] Visualization of construction buildability [3]	-CIM-BIM based system to design and plan resilient sustainable built environment.
	Vworld middleware for better decision-making for building design [18] Computation of construction excavation accuracy [21] GIS for calculating building carbon emission [57]	-CIM and IoT integration for intelligent decision-making to support design and planning.
	GIS optimization for suitable routes in rail infrastructure planning and design [25] GIS for establishment of urban landscape green space optimization [31]	-IoT and GIS for suitable routes selection for road construction projects
	Web graphic model with fuzzy decision-making tool to regulate sustainable rural housing problem [37]	- Point cloud model for urban landscape optimization and design.
	Scaling up LEED-ND and GIS for urban redevelopment and decision-making support [38] Rail Transit Route Optimization Model integrated with GIS for verification and layout design [39]	- Geo-Analytics server and BIM for urban housing design and planning
	Seamless integration of GIS and BIM for electrical grid optimization and city modelling [40] Integration of GIS database and ICT application [41] Large environmental visualization via a web platform [42]	-IoT, BIM and GIS integration for real-time spatial visualisation and analytics
	Unmanned Aerial Vehicle for capturing high quality and resolution data for planning forest road construction [46] Typological GIS technology for knowledge and conservation of built heritage [51]	-Integration of google earth and Web-GIS for environmental analysis
	Generation of digital representation of real-world scenarios in various formats [56]	-Image resolution processing and capturing for real-world scenarios -Geo-BIM data driven IoT platform for smart building construction operations

Construction task management	Integrating BIM and GIS to support preconstruction operations [22] Integration of BIM and GIS to support information management in buildings [23] 3S technology for engineering design and management [26] Cloud computing (WebGIS) for railway operation monitoring and visualization and security management [28] GIS technology for road construction intelligent management [36] Combination of BIM and GIS for construction management [43] Satellite imagery data to facilitate construction monitoring system [44] BIM/GIS integration to support data conversion to end application [47] BIM-AR-GIS+API for utility pipeline operation management [60] 3DSIMOS technology for integration, different stages with 3-D model of a building browsed 3-D to WebGL rendering decision support [48] Integrated system (Truck+) utilized for estimation, monitoring and forecasting in earthmoving operation [49] Integrated BIM/GIS system for visual representation of construction operation [29] Innovative integrated approach of tunnel construction simulation [15] Integrated GIS and AR for underground mapping underground Utilities [45] 3D-GIS technology railway management [34] Report on potential areas of GIS technology in construction project [27] GPS data integration to GIS for Construction task management operations [17] Risk management system based on GVMm, BIM-3DGIS framework [11] Marriage of AutoCAD, MSP AND ArcGIS for construction progress tracking [10,9,7,1] GIS new technology models eliminate data redundancy, miscommunication, and cost conversion [8] Building Construction Information System (BCIS) using GIS used for all stages of construction from project design to project handover [5]	-Development of GIS-BIM based framework using Extract-Translated load (ETL) for managing construction operation -Model integration for intelligent visualization and management -Integration of internet of things (IoT), Artificial intelligent and GIS for intelligent management of construction operations -Development of construction management system using ArcGIS online, High-precision GNSS and UAVs to view progress of construction. -GIS-BIM based framework for measurement project performance modelling using Big data -GIS driven IoT platform for construction simulation - Mapping and tracking simulation of underground utility using IoT and GIS -Big data and GIS integration for real-time analysis in construction to establish auto-generation of structural element in building. -AI assist Geo-BIM based system for tunnel construction simulation. -Risk assessment during excavation process using GIS-IoT. -Big data analytics-based GIS system for data conversion -Machine learning and GIS system for prediction and identification of utilities and effective coordination of infrastructural project

	Early detection model for road management using integrated road information modelling and geographic information system (RIM-GIS) [52] GIS+DinSAR for structural monitoring damage assessment [59] GIS-BIM integration for asphalt pavement quality evaluation [58] Develop Application Domain Extension (ADE) to support, retain and extend IFC information to CityGML [54] Integration of BIM and GIS framework to support earthwork operation [55]	-Natural Language Processing (NLP) for auto-conversion and dataset demystification in models -GIS-BIM for real-time 3-D of spatial information visualization of earthwork operations
Defect detection	Integrating GIS and Multiple Objectives Decision (MCDM) to support highway decision making and alignment determination [24] GIS database to automate process of recording and reporting road surface distresses [6] GIS technology to identify areas with damage on existing buildings [13]	-Deep learning and GIS using python in building defect detection -Integrating machine learning and GIS in training spatial data for building and road defect recognition and classification. -GIS and Big data in predictive analytics and generation of real-time spatial data
Safety monitoring	Application of remote sensing technology for earthquake emergency support [32] Mobile platform for disaster response system in bridges [35] Design algorithm technological approach for warning and guiding potential hazards [50] Quantitative risk analysis integrated with GIS technology [20] Grid-GIS system offering reliable highway information [30] GIS technology spatial information solution to address emergency [33] GIS framework for safety detector in construction site [4] Persistent scatterer interferometry and GIS approach for risk monitoring of buildings [12] GIS technology in risk assessment and mitigation [14] GIS model in safe site location [16] GIS application in construction safety and sustainability [19]	-IoT-GIS data exploration for site risk identification and emergency response -Mobile app to exploit disaster service -Real time risk forecast with Web-GIS based technology -GIS-IoT and RFID for safety zone identification

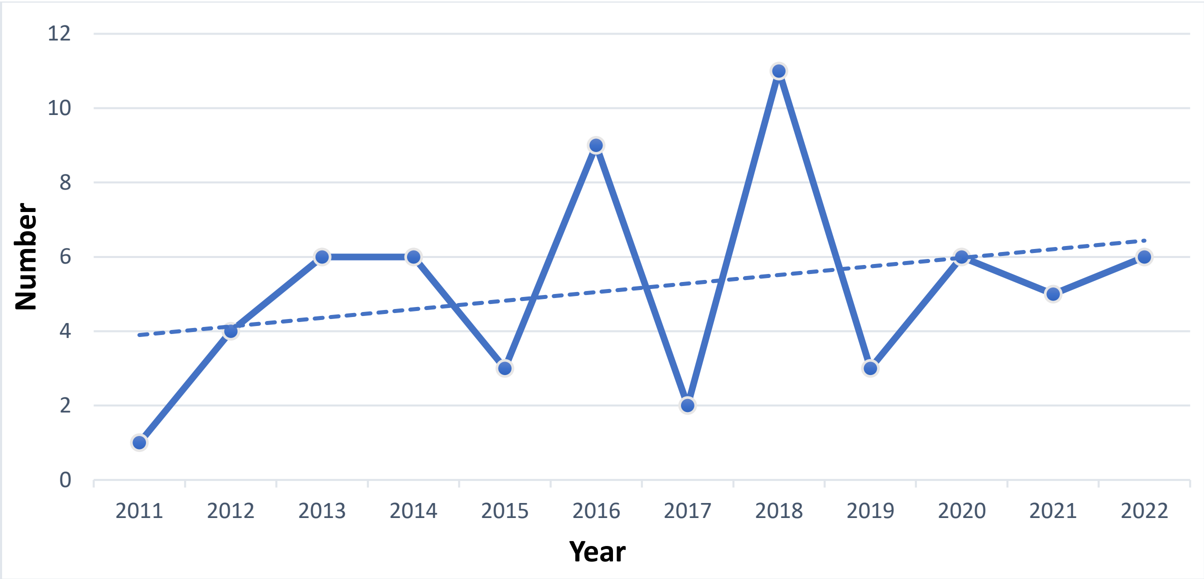


Figure 1. Number of relevant papers published in each year between 2011 and 2022.

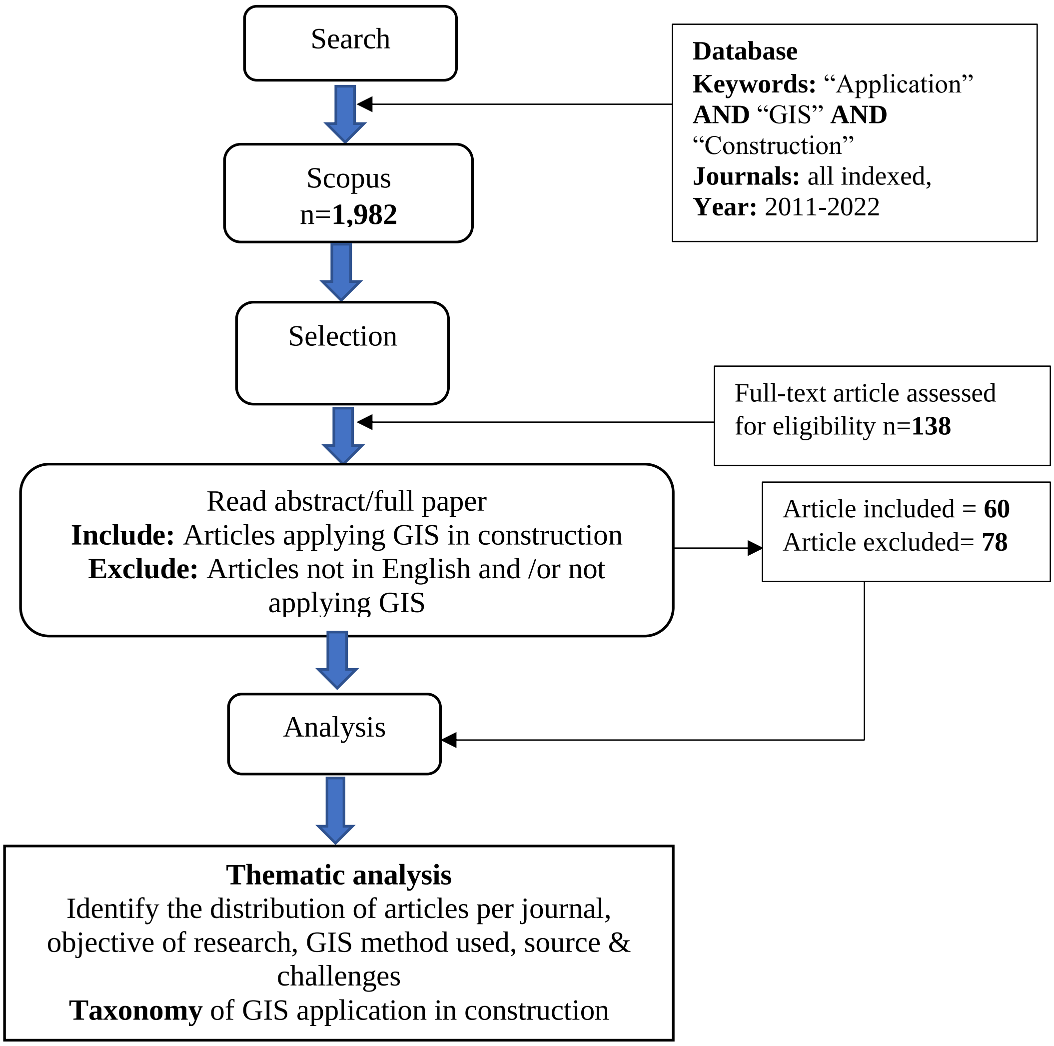
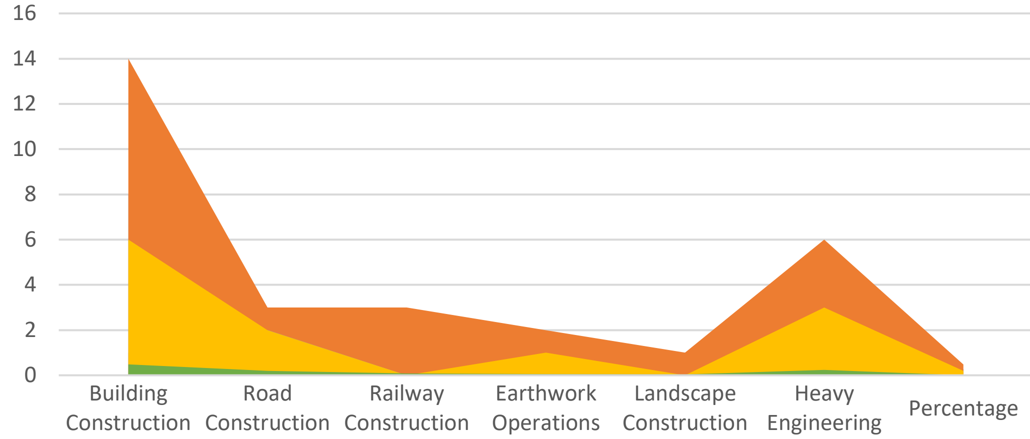


Figure 2. Systematic Literature Review Process



	Building Construction	Road Construction	Railway Construction	Earthwork Operations	Landscape Construction	Heavy Engineering	Percentage
Spatial Planning and Design	8	3	1	0	1	3	27%
Construction task Management	14	3	3	2	1	6	48%
Defect detection	1	2	0	0	0	0	5%
Safety monitoring	6	2	0	1	0	3	20%
Percentage	48%	20%	8%	6%	4%	24%	

Figure 3. Taxonomy of GIS application in construction

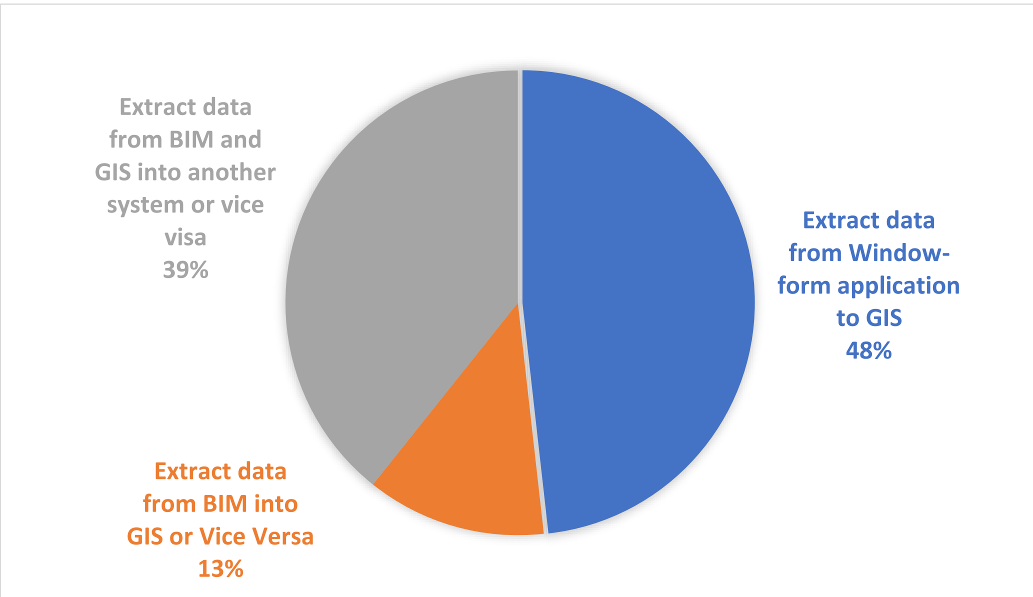


Figure 4. Integration pattern distribution

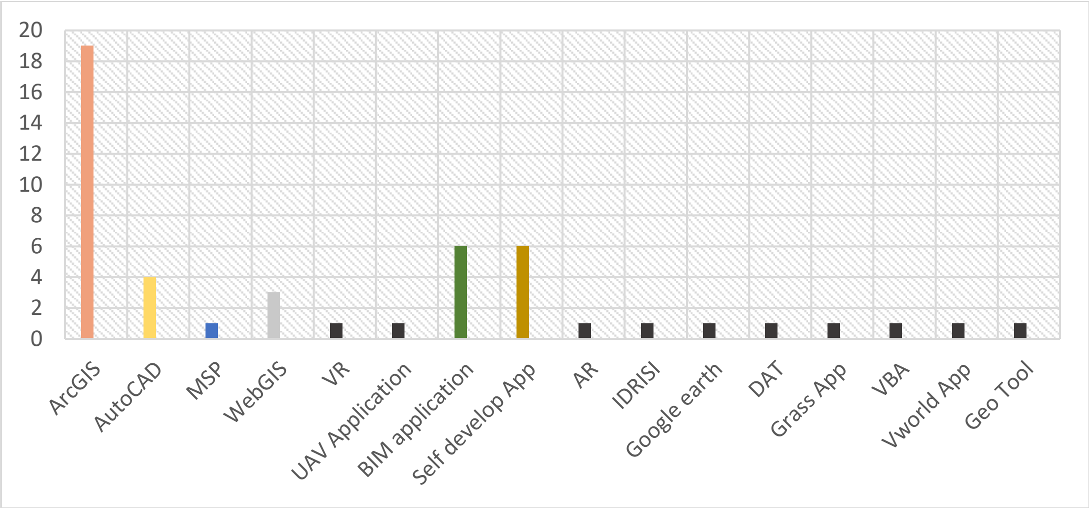


Figure 5. Platform distribution

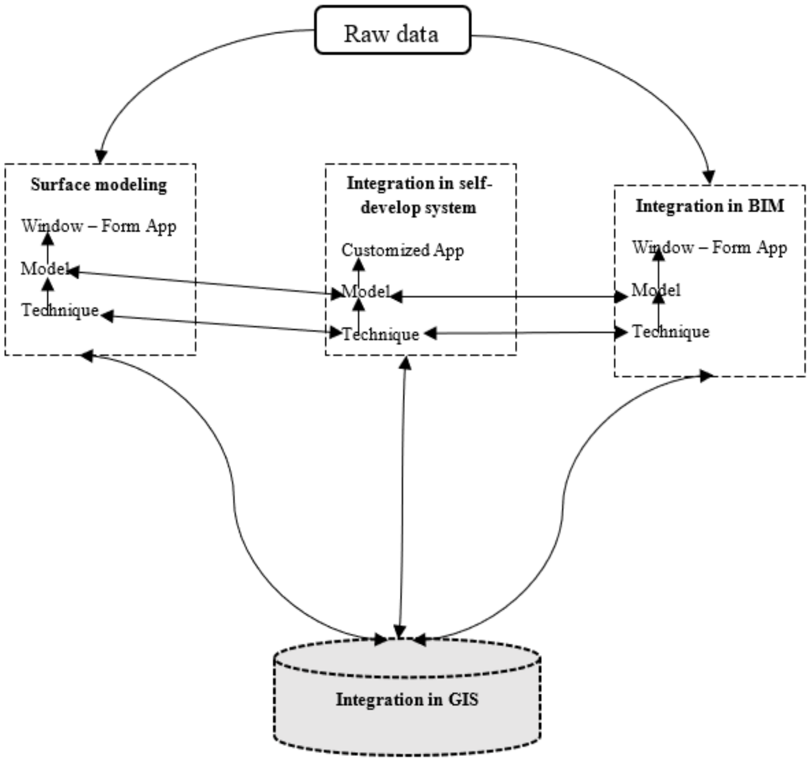


Figure 6. GIS integration network framework