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BIM AND GIS INTEGRATION: LESSONS LEARNED FROM MULTIPLE CASE STUDY

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Abstract

Building information modelling (BIM) and geographic information systems (GIS) are two key concepts for the digital built environment vision. Although they provide digital representations and are complementary, they have different focus and purposes. There is a lack of research particularly on a macro level for their practical integration. This study adopted multiple case study as its research strategy to explore the BIM and GIS integration at a multinational design and consultancy company. The paper contributes to knowledge by outlining the benefits, challenges and lessons learned for the BIM and GIS integration from a management, technical and process perspective.

Introduction

Researchers and practitioners in the built environment have long been discussing how to capitalise on digital innovation to effectively manage information by leveraging digital technologies. In recent decades, a remarkable effort for the systematisation of the information management within the built environment has been undertaken. Two key concepts underpin this: building information modelling (BIM) and geographic information systems (GIS).

BIM is the process for digitally representing the physical and functional information of a built asset as a shared database that can facilitate managing the whole asset life cycle, from design to demolition (Sacks et al., 2018). BIM can contain detailed and semantically rich information about a built asset and its components. With its features, BIM has found many applications in design optioneering, clash management, project cost and schedule control, logistics management, progress monitoring, and asset maintenance and operations (Li et al., 2017). Geographic information systems (GIS) are computerised systems based on geography, cartography, and remote sensing for managing geo-referenced spatial information and data about the Earth's surface (Wang et al., 2019). GIS can be used in regional planning, disaster monitoring, agriculture, infrastructure design, construction and maintenance, land surveys, cadastral and environmental management, and GIS-based simulations for spatial decision making and optimisation (Zhang et al., 2009).

Although both BIM and GIS provide digital representations of the built environment, their foci are different. BIM focuses on built assets themselves and their internal components, while GIS are more concerned with location specific geospatial features surrounding the built assets. In this regard, their combined use, which is sometimes called GeoBIM (Arroyo Ohori et al., 2020), provides integrated data for the assets and their surrounding environment. This integrated data is also necessary to obtain a complete digital representation of the built environment (Ma and Ren, 2017). Therefore, BIM and GIS are complementary toward the digital built environment vision (Noardo et al., 2020). The GeoBIM integration is used for applications such as 3D cadastres, location-based services, asset and heritage management, site selection and layout planning and urban environment analysis (Liu et al., 2017). It also is particularly relevant for the delivery of built assets distributed over a large geographical area such as infrastructure assets (e.g., highways, railways, pipelines, utilities etc.) (Garramone et al., 2020). Despite this, research in the BIM and GIS integration has been insufficient both at macro level (e.g., processes, project management, commercial and organisational dynamics) and micro level (e.g., technical integration) (Wang et al., 2019). As stated by Sacks et al. (2020), the conceptual understanding of the possibilities and visionary views of a digital future through these promising concepts have often outstripped the practical, technical, commercial, cultural, and organisational constraints. This paper aims to present findings, including challenges, lessons learned and benefits, from a BIM and GIS integration effort at a multinational design consultant over multiple projects.

Literature Review

BIM and GIS integration

After systematically reviewing the GeoBIM literature, Wang et al. (2019) concluded that there are three modes of BIM and GIS integration in practice based on the different dominant positions of the two technologies and their role in the integration: (i) BIM leads and GIS supports, (ii) GIS leads and BIM supports and (iii) both BIM and GIS are equally involved. When (i) BIM leads and GIS supports, a particular asset is in the focus for preservation, reconstruction, design, construction and maintenance of specific asset components with BIM models being dominant, and GIS models are auxiliary for additional data (Borrmann et al., 2015). In these applications, GIS-based vector data and information systems are imported to a parametric 3D-BIM platform (Wang et al., 2019). While these applications can better represent a particular asset and its internal information, they lack the ability to integrate with information from other assets or the surrounding environment.

When (ii) GIS leads and BIM supports, geospatial analysis and terrain modelling are in the focus (e.g., preconstruction spatial planning) with GIS being dominant. Industry Foundation Classes (IFC) used in BIM are converted into GIS formats and are used to consider the effects of built assets on their surroundings. Using GIS-based methods, mapping IFC into the city geography markup language (CityGML) standards, adopting open standards such as XML and using programming application interfaces (APIs) underpin these applications (Wang et al., 2019). While these applications provide advanced spatial data processing capabilities, they lack detailed attribute information for built entities.

When (iii) both BIM and GIS are equally involved, a detailed and balanced combination of information from the built asset itself and its surrounding space can be obtained. The applications require interoperability between the BIM and GIS models, and integration of data from these two models generally on third-party platforms (Deng et al., 2016). The applications focus on asset life-cycle management, energy management, and urban management by combining BIM and GIS into a geospatial information model (IGIM), for example integrating IFC and CityGML, and implementing automatic data mapping between IFC and CityGML at different level of details (LODs) and level of information needs (Wang et al., 2019). In fact, there are different formats that can support GIS and design software interoperability. Whilst these applications provide more complete data, the integration process is cumbersome, increasing the computer processing needs.

Integration challenges and requirements

BIM and GIS integration is a promising yet complex area. The complexity is due to their dissimilarities, which pose various challenges for the integration (Liu et al., 2017): different users, different application focus, different development stages, different spatial scales - GIS scaling hierarchically from the world to asset spaces, and BIM scaling hierarchically from asset infrastructure to components. Different coordinate systems, different semantic and geometric representations, different levels of information granularity, and different information storage and access methods can be added to the dissimilarities (Liu et al., 2017). However, the overlap between them has expanded recently, particularly on the infrastructure, building, and space level in line with the digital built environment vision, which has propelled the integration efforts.

Currently, technical solutions to the integration can be categorised into three levels: (i) data level, (ii) process level and (iii) application level (Amirebrahimi et al., 2015). The data level involves introduction of new standards (e.g., InfraGML, IndoorGML, Unified Building Model), revision of old standards (e.g., revisions in IFC and CityGML for better mutual compatibility), or the conversion/translation of data formats (e.g., the semi-automatic Extract Transform Load process). Although effective, this type of solution requires great deal of effort and provides solutions for specific spatial scales. Also, data loss is expected during the transformation process.

The integration at the process level keeps the data formats and structures distinct and intact. Semantic web-technologies, with which a reference ontology is generally used for seamless integration, and service-based approaches using web-services come to the fore at this level (Karan et al., 2016). The process level integration is bidirectional for both geometric and semantic information. However, it requires human intervention, and not being considered time and cost efficient.

The application-level integration is case-based by extracting specific information (e.g., noise information) from GIS and BIM to process for a specific purpose (Liu et al., 2017). Although time and cost efficient, it is concerned with a very particular aspect of information depending on the case.

Alongside the technical requirements, an open and collaborative attitude among GIS and BIM users is key to their integration. Efforts toward the integration occur particularly when it is demand-driven, where the BIM and GIS integration is necessary for the successful realisation of a relevant purpose (e.g., project site selection and layout planning), or a concept (e.g., smart cities) (Liu and Issa, 2012). Government and client initiatives are also key drivers to their integration (Saygi and Remondino, 2013). Standardisation and optimisation of integration workflows, work processes and communication channels are also important in the practical realisation (Zhang et al., 2009).

It is clear from the literature that the focus of the discussions in the GeoBIM domain has predominantly been on the technical side of the integration efforts demonstrating frameworks, systems, platforms, data models, algorithms, and plug-ins for this purpose (Wang et al., 2019; Karimi, S. and Iordanova, 2021). The lessons-learned presented in this paper from various case studies across the world are deemed complementary to the technical integration discussions and will provide an overview of the integration in practice, bridging some gaps in the technical-requirements-heavy GeoBIM literature.

Research Method

Case study is the research method adopted in this investigation. According to Yin (1994), a case study analyses a contemporary event and its context, especially when the boundaries of the event and context are not clear. The research was carried out at an international design and consultancy company through a Knowledge Transfer Partnership (KTP) project. KTP is a partially government-funded programme in the UK sponsored by Innovate UK, to support collaboration between a knowledge base and company partner. This particular KTP project investigated the integration of Lean and digital design.

It consisted of the development and critical analysis of Esri's ArcGIS GeoBIM platform (https://www.esri.com/en-us/arcgis/products/arcgis-geobim/overview) implementation by the company. ArcGIS GeoBIM is a web-based platform for collaboration on BIM projects, allowing data from multiple systems to be used in a geospatial environment. It is a geo-enabled platform built on ArcGIS and functions through a user type extension, in which teams can work with linked data and documentation in configurable web apps, integrating data from Esri's Cloud environment ArcGIS Online, the Autodesk Cloud environment Autodesk Construction Cloud (ACC - https://construction.autodesk.co.uk/) and BIM 360 (https://www.autodesk.com/bim-360/).

The aim is to improve the understanding of how GeoBIM could be applied in engineering projects, capturing the learning from this process by describing the best practices and identifying key technical requirements when implementing the GIS and BIM integration. The ultimate goal is standardising the implementation through all the company project types and scales where Autodesk software, i.e., ACC and BIM360, is adopted:

Research Design

The investigation is limited to five case projects. The study was conducted in 4 stages (Figure 1): (1) implementation of the ArcGIS GeoBIM platform within the projects, following the discover, prepare, and deploy steps; (2) lessons learned and process modelling exercises with case studies A, B and C (see Table 1), considering the overall design process and the technical aspects of its implementation; (3) overall review and evaluation of the benefits, challenges and lessons learned for all case study projects through a virtual workshop; and (4) development of a guidance document addressing the lessons learned and dissemination to the wider community within the company. It was developed in close collaboration with Esri Inc's Professional Services Division, which provided support and guidance throughout the investigation. The duration of the case studies was approximately 6 months.

During stage 1, the teams from each case study (A, B, C, D, E) went through various BIM and GIS integration workflows using their project data with the end goal of creating an ArcGIS GeoBIM Project that contains apps to be used by project stakeholders and end users. Stage 1 and 2 were iterative, allowing the refinement of the process, addressing the lessons learned from other case studies while still implementing the platform. Five versions of the ArcGIS GeoBIM process map were developed. The lessons learned were captured regarding the management, technical and process aspects.

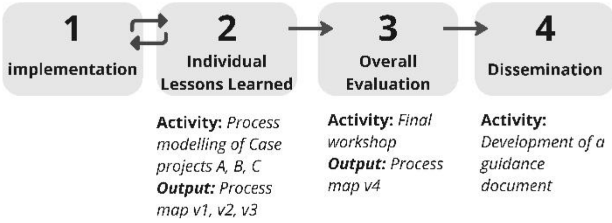

Figure 1: Research Design

The main sources of evidence are: (i) case study meetings to discuss the implementation of ArcGIS GeoBIM within the projects with the team and with the Esri representative; (ii) continuous improvement meetings with each case study project team to map the ArcGIS GeoBIM process and how it impacted the design process, as well as to capture the lessons learned; (iii) workshops with all case study projects, i.e. kick-off workshop and final workshop; (iv) a small survey to collect initial lessons learned, challenges and benefits, which were assessed and discussed through the final workshop; and (v) guidance and lessons learned document developed and disseminated within the case study projects and wider within the company.

Case Description

BIM and GIS integration has been investigated and implemented within the company for some years. However, data conversion between BIM and GIS is still required, e.g., by creating copies or snapshots of a situation or design, to provide input in both directions. Although this process is time consuming and requires a lot of effort to keep information up to date, it supports improved decision-making, being beneficial to the project development. The expectation with the new platform is to create a 'live connection' between both BIM and GIS data, by adopting standards that will render the integration between both technologies easier.

The cases were initially selected through a top-down approach by the company's ArcGIS GeoBIM steering group, identifying relevant business areas and project types, i.e., railway, water, environmental, building design projects, based in different countries, i.e., Belgium, UK, USA, Netherlands, and Australia. Teams from each region identified a relevant project where the integration of BIM and GIS data could be assessed in a meaningful way. Table 1 describes the case studies. The project size was defined according to the complexity of information management (e.g., BIM stage required), project complexity (e.g., number of disciplines involved), and project fee value.

Table 1: Cases description

Case	Location	Project type	Project size	Project phase
Case A	UK	Water	Large	Design
Case B	Belgium	Railway	Medium	Planning and conceptual design
Case C	USA	Environ mental Design	Large	Design
Case D	Netherla nds	Building	Small	Planning and conceptual design
Case E	Australia	Building, Rail	Medium	Planning and conceptual design

The key stakeholders involved in this investigation can be described as: (i) case study sponsors, accountable for the steering group (responsible for directing and coordinating the pilots) and executive sponsors; (ii) implementation champions, such as BIM and GIS leads, responsible for facilitating the project setup, training and support, as well as monitoring the success; (iii) project champions, i.e. project BIM and GIS staff, responsible for the project setup, configuration and implementation; (iv) Esri consultant serving as a point of escalation and assisting in the development and implementation of the ArcGIS GeoBIM platform; and (v) continuous improvement and research team supporting with the lessons learned and process mapping activities. The company stakeholders' roles can be summarized as: (i) GIS and BIM coordinators, managers, and consultants; (ii) geoscience data consultant; (iii) geospatial consultant; (iv) data analyst; (v) design engineer and CAD technician; (vi) associate and senior technical directors; (vii) digital lead; global leaders for design & engineering and the Autodesk platform; (viii) and ArcGIS Enterprise server manager; and (ix) lean and continuous improvement manager.

ArcGIS GeoBIM process

The aim of the cases (A, B, C, D and E) was to integrate BIM models with a spatial GIS environment through the integration of BIM360 and ACC with ArcGIS Online through the adoption of ArcGIS Pro. The ultimate goal is to connect the online GIS environment with the BIM360 or ACC cloud environment by using ArcGIS GeoBIM. As discussed by Wang at all (2019), the first challenge to focus on, is the integration of BIM and GIS at the technical level, because BIM and GIS data are used (e.g., created, managed, analysed, stored, and visualised) in different ways considering the data structure, coordination system, and range of focus. Thus, there are incompatibilities between the two sets of data.

Considering the current scenario, a process mapping exercise was carried out alongside the development of the case studies to capture the key activities on a technical level of the implementation, but also to identify how it was affecting the design processes, e.g., by removing waste or improving the quality of the delivery. Mapping and documenting the process supported the implementation (and has the potential to support future implementations) by formalising hidden steps, identifying flows, and aligning with international standards. This exercise also helped in capturing lessons learned, benefits and challenges according to the management, technical and process aspects.

Figure 2 shows the key steps undertaken for the GeoBIM implementation. The process consists of eighteen steps but can be summarised in: (1) kick-off meetings and strategy definition; (2) georeferencing; (3) BIM to GIS transformation; (4) GeoBIM process; (5) app creation for the users.

For a successful BIM and GIS integration, including a successful GeoBIM Project deployment and well-used GeoBIM apps, it is strongly recommended that BIM designers, GIS technologists and other stakeholders convene at project inception to agree on various topics pertaining to the work, i.e., defining the georeferencing strategy (step 1). Additionally, some technical aspects such as licensing and technical abilities should be considered before starting. This pre-work effort will allow for smoother workflows, less inefficiencies along the way, and less rework.

The Apps in ArcGIS GeoBIM are highly configurable, and they can serve a multitude of purposes for a wide array of users. For efficiency purposes and in order to create a well-designed app that is used often, relevant topics should be considered, such as identifying end users and their technical abilities as well as the Level of Information Need (quality, quantity and granularity of information).

The second step, georeferencing or geolocating (2) a BIM model, ensures that the model has assigned coordinate values representing some real-world coordinate system, by georeferencing the documents (2.1) and defining the projection file (2.3). Followed by the BIM to GIS transformation (3), creating a BIM cloud connection (3.1), bringing BIM data to ArcGIS Pro (3.2), transforming data into a geodatabase (3.3), creating and publishing building

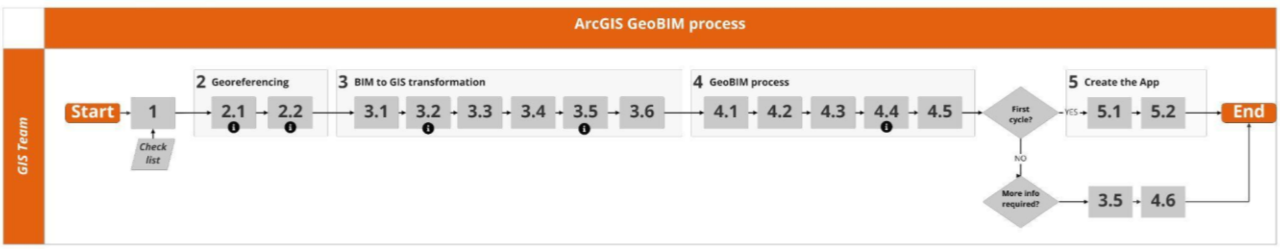

Figure 2: ArcGIS GeoBIM process

layers to share the BIM data across the ArcGIS platform (3.4, 3.5, and 3,6). The GeoBIM process (4) consists of accessing ArcGIS GeoBIM (4.1), creating a new project and account (4.2 and 4.3), configuring the tools, such as ‘locate issues’, ‘locate engineering documents’ and ‘create BIM project boundaries’ (4.4), and adding links between the BIM and GIS information (4.5). Finally, a new viewer app should be created, customised, and shared with the users (5.1 and 5.2). Iterations might be required in future cycles when new data needs to be added, adding the new data to the scene, and creating additional links (3.5 and 4.6).

Key challenges, lessons learned, and benefits

Key challenges, lessons learned, and benefits were identified through the survey and final workshop. The following section will further describe the key points identified which are related to the technology, processes, and management aspects.

The teams faced challenges when implementing the ArcGIS GeoBIM platform, such as complexity of creating the apps or publishing, due to the number of steps required. The complexity was also associated with the technical aspects, e.g., some of the functionalities were not easily or fully adopted, such as the scheduling tool, which enabled the planning of activities, but did not consider the project complexity and recurrence of activities. The users also had challenges in understanding how to use the platforms and its apps, due to its technical user interface. Further training might be required to increase the awareness and understanding of the technical requirements and functionalities. Because of the many iterations between the BIM and GIS data required, early communication and agreement among both BIM and GIS teams was a challenge (and an opportunity for improvement), as well as the lack of clarity in early stages of the implementation of how the new platform would be adopted within the project. Thus, it was recognised that it could take time to set up the platform, however, it is expected by the company to save time throughout the project development after setting up the platform and apps.

Considering the challenges mentioned above, recommendations and lessons learned were recorded aiming to guide future implementation within the company. First, the importance of having a clear purpose and understanding of who will be using the platform, e.g., managers, design team, client, was outlined to develop the interface aligned with the user expectation. It could be used for different purposes and present different interfaces, considering the different functionalities available due to the highly configurable characteristic of the platform. For instance, project managers could use it during meetings (with the client or the team) as a visualisation device to support decision-making and have a project overview. This would be facilitated by having all the information needed in one place, without too many technical details. On the other hand, designers might use it to find more information about the design itself. Thus, depending on the purpose, more or less data will be required, and more or less functionalities will be used. Designers might still use the BIM software to visualise cross-sections of buildings, while project managers might use the ArcGIS GeoBIM platform for the visualisation purpose. A clear understanding of the information required by end users is essential.

Considering the platform was adopted in different projects and different design stages, the teams agreed ArcGIS GeoBIM is most beneficial in the planning and concept design stages, due to the lower Level of Information Need.

Early and initial planning emerged as one of the key lessons learned to improve the ArcGIS GeoBIM adoption. A step (‘kick-off meetings and strategy definition’) was highlighted and a checklist was proposed with key topics to be discussed and agreed by the BIM and GIS managers in early stages. It aims to ensure the key requirements and expectations for each team are considered. Three aspects were considered: (i) georeferencing strategy (e.g., are there BIM/GIS standards in place?); (ii) design and technical integration (e.g., Who are the end users? What are the users’ technical abilities? What is the Level of Information Need required? Is it possible to simplify and have a lower Level of Information Need? What is the publishing frequency? What data should be shown? What BIM software is used? etc); and (iii) software, hardware, and licensing (e.g., system requirements, proper user types, permissions and licensing with ArcGIS GeoBIM, appropriate software version, authorisation of ArcGIS Pro on the BIM cloud repository, etc). By emphasising the need for better communication in early stages of the process, the connections between the BIM and GIS teams have been enhanced within the company, which was a positive side effect.

In addition to this, it was agreed that decisions in the design process affect the interoperability and collaboration between BIM and GIS. Thus, preconditions should be clear in the design processes when adopting the new platform, because if BIM data is not configured considering the GIS software and end user requirements, the data cannot be used in ArcGIS GeoBIM.

Therefore, default processes were identified as a requirement to implement GeoBIM in a project, as a way to standardise and formalise the key activities. Further in the project there could be manual activities and manipulations of the data needed to optimise the use of GeoBIM and having clarity of the key steps would support this.

The integration with the common data environment (CDE) platform was also a key aspect to be considered and this even limited the implementation in some sectors of the company, e.g., highways, as the platform does not support integration with CDE platforms by other software vendors. Further investigation and improvements are required here.

The key benefits for the BIM and GIS integration were found to fall in the areas of information management and data integration, collaboration and communication, visualisation and optioneering. These key benefit areas are discussed in the following.

Information management and data integration

It was identified by the company stakeholders that a key benefit for clients and internal stakeholders is associated with having all the information in one place, i.e., a single source of data. The platform presents the opportunity to be a single portal with easy access to GIS and BIM data (see Figure 3a). However, the data itself will be stored in separate proprietary elements of the CDE. In this respect, the platform is an interface that allows the users to view previously disconnected parts of the CDE.

The integration with other documents, e.g., pdf files and images, was also highlighted as a relevant functionality regardless of the project Level of Information Need (see Figure 3b). The ArcGIS GeoBIM platform was considered to be the place where the team would find all required information, and if more detailed information was needed, the platform would guide the users to the right location. This enables maintaining the source data (or its links) available during the entire design process, avoiding duplication of information, and therefore, design errors.

Collaboration and communication

ArcGIS GeoBIM requires more direct communication between GIS and BIM teams and more collaboration in early stages to ensure the expectations of both teams regarding data were met. The new approach was also classified as easier when communicating live or updated project information (containing contextual information) with external parties.

Visualisation

The platform allows visualisation of the latest model, as well as the environment and surroundings, as demonstrated in Figure 3. It facilitates understanding of contextual information, even more for large scale projects. By connecting BIM and GIS data, all stakeholders, including external parties, have easy and online access to the latest information. The information is available over a web browser, eliminating the need for installing software for the end user. It was also identified as a benefit to the project managers and planners, who could easily find and understand information due the data integration and connectivity to live models. It added value to the locating aspect, allowing all types of information to be located, even the information that was not previously considered. For instance, PDF inspection reports or pictures from field inspections, which could be previously imported into the GIS environment, become available on a screen with the geographical location on the ArcGIS GeoBIM platform.

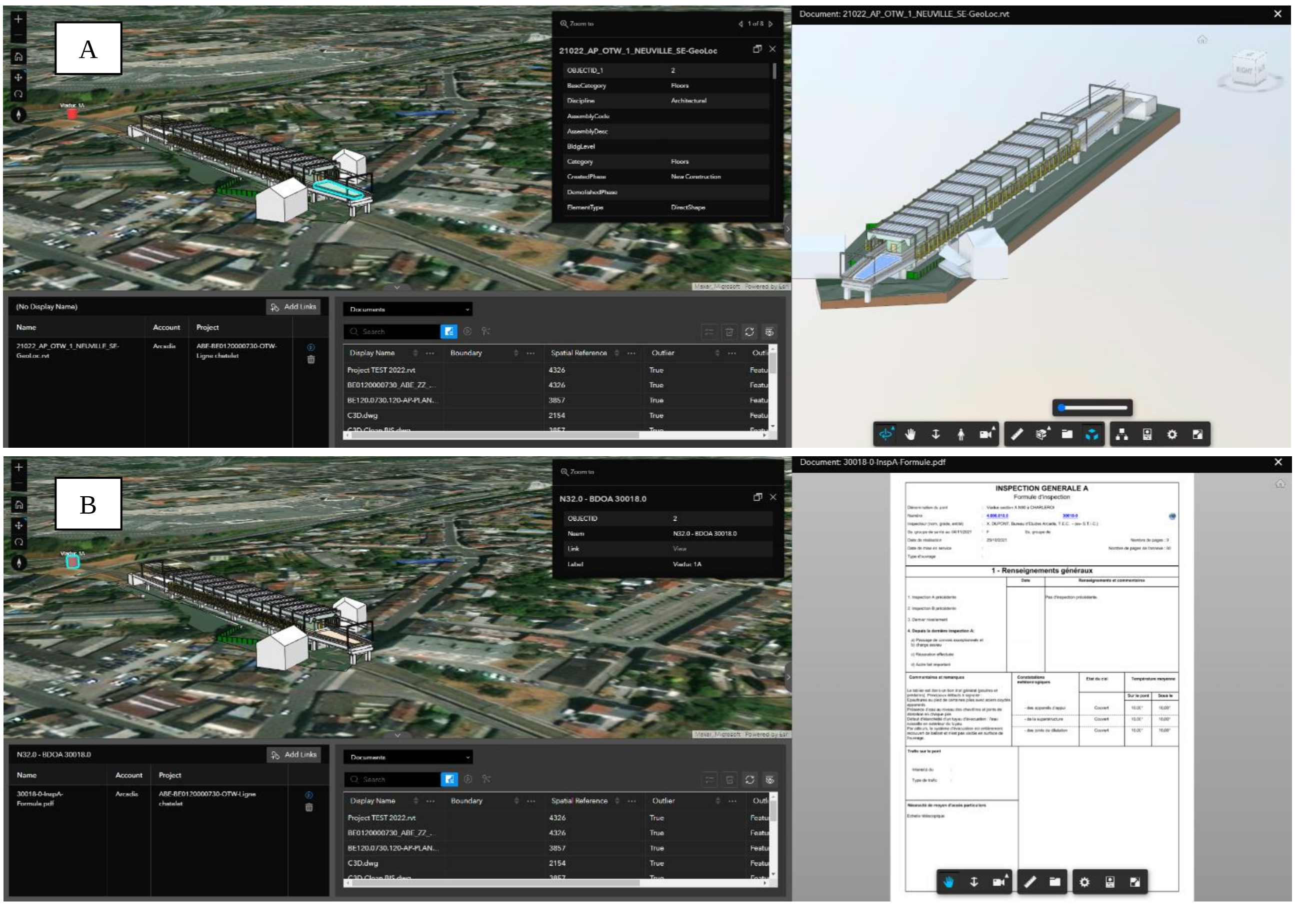

Figure 3. GeoBIM Platform interface used in Belgium

In addition to this, there was a dynamic interaction where the design issues identified within the BIM software were updated or visualised in the GIS environment. Those issues were linked and visualised in a dashboard facilitating the coordination and decision-making process.

Optioneering

ArcGIS GeoBIM supported design optioneering by duplicating models to different locations, or sites and different rotations. This was made possible by ensuring the model was georeferenced to the actual location. This benefits the design team by eliminating design steps and saving time, but also the client, who will be able to visualise the design options in early stages of the process.

Discussion

Depending on application purpose, different types of BIM and GIS integration could be identified, as outlined by Wang et al. (2019). When there is a lack of clarity related to the key modes of collaboration adopted in a project, other aspects could be affected, for example the quality of data integration. This could also lead to additional steps within the design process, without achieving the expected outputs (or the output aligned with the specific purpose). One of the key modes identified within the case studies was the 'Both BIM and GIS are equally involved', considering GIS provided easily accessible integrated data through the ArcGIS GeoBIM WebApp, whereas BIM contributed with well-defined and prepared data. While ArcGIS GeoBIM offers multiple functionalities, it also increases the data processing needed. Therefore, identifying to what detail and sophistication/granularity the model elements will synchronise is important. This can increase the effort required to process data depending on the design stage, e.g., detailed design, and the number of iterations required between different stakeholders. In practice, the needed level of detail and consequently, the data processing needs may be reduced on GeoBIM integration platforms as the BIM representation will be linked to the live, most up-to-date and often detailed level of information and detail of the model.

The various challenges related to the different users and application focus, as argued by Liu et al. (2017), can potentially be overcome by having an early collaboration of BIM and GIS users. Ensuring technical buy-in from the wider project team, specifically the design team and their technical leadership and the project managers is also critical. A clear integration strategy, defined in early stages of the design process, can support the collaboration by identifying standards required for the georeferencing activities, as well as considering the design and technical integration, software, hardware, and licensing aspects.

As discussed by Zhang et al. (2009), standardisation, workflows optimisation, and communication are also essential aspects to support the practical realisation of the BIM and GIS integration. Having those elements in place, can potentially support a standardised application of BIM and GIS through several types and sizes of projects. This is also aligned with the case studies' ultimate goal, which was partially achieved, and represented a first step towards the standardised implementation.

In that respect, a GeoBIM execution plan (i.e., GBEP) much like a BIM execution plan (BEP) for the integration of BIM and GIS, covering the key requirements and responsibilities, can be drafted at the outset of projects. This not only will standardise the requirements, modes of collaboration, and data and Level of Information Need arrangements required to execute a specific project through the BIM and GIS integration but also will serve as a reference document for future efforts. This can be driven also by clients and in contracts. The GBEP can be included in the main BEP as an extension, particularly for projects where BIM leads. Requirements and content for the GBEP for different modes of application in practice (i.e., BIM leads, GIS leads, BIM and GIS equally lead) need further research.

The study outlined and documented some key benefits (i.e., information management and data integration, collaboration and communication, visualisation and optioneering) of the BIM and GIS integration, particularly in early design stages. However, alongside the key requirements, other issues such as compatibility with the CDEs and appropriate user interface design for different applications should be taken into account. In this sense, a legacy IT and user requirements study are advised while planning the integration.

Mapping (e.g., swim lane mapping or value stream mapping) and improving the integration process from a lean and continuous improvement perspective were proven to be effective in the practical integration. Therefore, it can be concluded that practitioners should not overlook the process design and improvement side of the integration. Including process improvement and lean practitioners in the integration process can be useful in that regard.

As for future applications, the teams identified Internet of Things (IoT) and live mapping services to track transportation and hauling progress during construction as high-potential technologies and applications that could benefit from the BIM and GIS integration. IoT was also identified as a facilitator for this integration.

Conclusions

BIM and GIS, as the two key underpinning concepts for digitalisation of the built environment, are complementary with their different focus. Their integration (i.e., GeoBIM) has found several applications recently. However, this integration in practice is complex and difficult on multiple levels due to the differences between BIM and GIS. Also, the extant literature is mostly concerned with overcoming the technical challenges of the integration at a micro level.

This paper presented the benefits and lessons learned from a practical BIM and GIS integration effort at a multinational design consultant organisation from multiple case study. The study documented several integration benefits, challenges, and suggestions for practical implementation from a management, technical and process perspective on a more macro level.

It is advised that practitioners working on the integration review the findings to justify and plan their GeoBIM integration efforts. Opportunities for future research, such as outlining the requirements and content for a GBEP document for different integration modes were also identified. More research into the GeoBIM integration dynamics on a project and organisational level is needed. Efforts in quantifying the GeoBIM benefits will be also useful for the business case of the integration.

Acknowledgments

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References

Amirebrahimi, S., Rajabifard, A., Mendis, P. and Ngo, T. (2015) A data model for integrating GIS and BIM for assessment and 3D visualisation of flood damage to building. Locate, 15(2015), pp.10-12.

Arroyo Ohori, K., Diakité, A., Krijnen, T., Ledoux, H. and Stoter, J. (2018) Processing BIM and GIS models in practice: experiences and recommendations from a GeoBIM project in the Netherlands. ISPRS International journal of geo-information, 7(8), p.311.

Borrmann, A., Kolbe, T.H., Donaubauer, A., Steuer, H., Jubierre, J.R. and Flurl, M. (2015) Multi-Scale Geometric-Semantic Modeling of Shield Tunnels for GIS and BIM Applications. Computer-Aided Civil and Infrastructure Engineering, 30: pp. 263-281.

Deng, Y., Cheng, J.C. and Anumba, C. (2016) Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison. Automation in Construction, 67, pp.1-21.

Garramone, M., Moretti, N., Scaioni, M., Ellul, C., Re Cecconi, F. and Dejaco, M.C. (2020) BIM and GIS integration for infrastructure asset management: a bibliometric analysis. In ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (Vol. 6, No. 4/W1, pp. 77-84). ISPRS.

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, 30(3), 04015043.

Karimi, S. and 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, 28(7), pp.4573-4594.

Li, X., Wu, P., Shen, G.Q., Wang, X. and Teng, Y. (2017) Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. Automation in Construction, 84, pp.195-206.

Liu, R. and Issa, R.R.A., 2012. 3D visualization of sub-surface pipelines in connection with the building utilities: Integrating GIS and BIM for facility management. In Computing in Civil Engineering (2012) (pp. 341-348).

Ma, Z. and Ren, Y. (2017) Integrated application of BIM and GIS: an overview. Procedia Engineering, 196, pp.1072-1079.

Noardo, F., Ellul, C., Harrie, L., Overland, I., Shariat, M., Arroyo Ohori, K. and Stoter, J. (2020) Opportunities and challenges for GeoBIM in Europe: developing a building permits use-case to raise awareness and examine technical interoperability challenges. Journal of Spatial Science, 65(2), pp.209-233.

Sacks, R., Eastman, C., Lee, G. & Teicholz, P. (2018) BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers. John Wiley & Sons.

Sacks, R., Girolami, M. and Brilakis, I. (2020) Building information modelling, artificial intelligence and construction tech. Developments in the Built Environment, 4, p.100011

Saygi, G. and Remondino, F. (2013) Management of Architectural Heritage Information in BIM and GIS: State-of-the-art and Future Perspectives. International Journal of Heritage in the Digital Era, 2(4), pp.695-713.

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, pp.41-52.

Zhang, X., Arayici, Y., Wu, S., Abbott, C. and Aouad, G. (2009) Integrating building information modelling and geographic information systems for large-scale facilities asset management: A critical review. In Proceedings of the Twelfth International Conference on Civil, Structural and Environmental Engineering Computing, Stirlingshire, UK.