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Can the integration of BIM and GIS enhance information management for large scale linear infrastructure projects?

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Abstract – The integration of BIM and GIS is the subject of considerable research, particularly as the two coalesce for the purpose of information management. Large scale infrastructure projects require best practice in terms of how information is managed given the volume of information generated throughout the project lifecycle and the numerous parties requiring access to project content. This paper investigates whether the integration of BIM and GIS can enhance information management on large scale linear infrastructure projects. The research comprised a literature review and interviews with a number of BIM/GIS professionals actively working on linear infrastructure projects across the world. Some of the key findings to emerge from this research include the use of GIS web platforms to act as 'gateways' to project content, the importance of the CDE for information management, the use of ETL tools for moving data between BIM and GIS and finally the criticality of skilled personnel for ensuring the tools and workflows are applied correctly. The key findings resulted in a proposed implementation strategy for BIM-GIS integration for large scale linear infrastructure projects such as MetroLink. This research demonstrates that BIM and GIS complement each other when it comes to information management and the synergies between them strengthen the case for further integration.

Keywords – BIM; GIS; information management; infrastructure; integration

1. Introduction

Over the course of the past decade Building Information Modelling (BIM) has emerged as a key tool in Digital Construction. BIM provides a framework to enable the creation of a digital equivalent of the built environment throughout all stages of the project lifecycle. However, despite the promise of BIM, the Engineering and Construction (E&C) sector has been described as struggling to adopt digital workflows and embrace the opportunities that advances in digital technology and ICT offered [1, 2].

In contrast, utilising digital workflows and technologies which have been demonstrated to deliver benefits to project delivery have become essential tools to successful project outcomes [3]. A significant issue on construction projects irrespective of scale, concerns access to authoritative data to enable project teams work in an efficient and productive manner [4]. At the beginning of a new decade it is certain that advances in digital technologies and workflows will need to be more readily adopted by the E&C industry. Only then will the benefits from applying these new ways of working help deliver cost savings and efficiencies to how we design, construct, maintain and operate the built environment.

The term "mega-project" has been used to describe large-scale complex projects that can take years to design and build and typically cost in excess of one billion dollars [5]. Given the scale of construction activity and the economic and societal impacts of these types of projects, the information management associated with these projects is even more critical in ensuring successful outcomes.

The MetroLink project, as one of the largest infrastructure projects ever undertaken in the Irish state, is an example of a "mega-project". The project consists of approximately 19 kilometres of urban railway of which a large proportion of the route will be underground, comprising 15 new metro stations, a Park & Ride facility catering for 3,000 vehicles and a Depot facility for vehicle stabling, servicing and also incorporating a command and control centre.

In November 2017 the Irish Government announced a strategy seeking to increase the use of digital technology on key public works contracts [6]. The twin objectives of the strategy are to manage the adoption of BIM in an orderly fashion across the publicly funded capital programme and secondly act as a catalyst for the wider adoption of BIM across the industry generally. The strategy has tasked public bodies with establishing

BIM requirements for the design, construction and operation of public buildings and infrastructure over the course of the next four years. As a result, publicly funded infrastructure projects such as MetroLink have been developing and implementing BIM workflows and technologies as part of their information management strategy.

Both BIM and GIS have developed for the purpose of creating and managing information in a more efficient manner. While GIS technology has been utilised in infrastructure projects for some time [7], the application of BIM technologies and workflows on linear infrastructure projects presents a different challenge in terms of information management [8].

The purpose of this research is to critically appraise the application of information management solutions, specifically BIM and GIS, on large scale linear infrastructure projects and to assess whether the integration of these two disciplines can enhance information management on projects of this type. This work will build on published research in the area of the integration of BIM and GIS and will critically appraise those findings relative to the requirements of large-scale infrastructure projects.

To achieve this, subsequent sections of this paper are set out as follows: Section 2 sets out the research objectives and associated methodology. Section 3 contains a Literature Review, addressing the need to critically evaluate previous approaches and research in this area. Section 4 presents a critical appraisal of existing best practices and lessons learned in BIM-GIS integration for linear infrastructure assimilated through interviews with professionals working in the area of BIM/GIS/Information Management on projects of similar scope and scale to MetroLink. Section 5 describes a proposed framework for integrating BIM and GIS while Section 6 outlines how such a framework can be applied to the MetroLink project. Finally, Section 7, the conclusion, presents the key findings of this work and identifies some areas that may be worthy of further research.

2. Objectives & Methodologies

Objective 1: Critically evaluate the current status of the integration of BIM and GIS.

Research Methodology: undertake a comprehensive review of the literature in the area of BIM and GIS integration.

Objective 2: Critically appraise the role of GIS and BIM in the context of information

management on large scale linear infrastructure projects.

Research Methodology: undertake a comprehensive literature review in the area of the utilisation of BIM and GIS technologies, workflows and processes on infrastructure projects for the purpose of information management.

Objective 3: Determine the factors key to the success of BIM and GIS integration on linear infrastructure projects.

Research Methodology: Undertake qualitative research via semi-structured interviews with individuals who have worked on or are working in the area of BIM/GIS/Information Management for infrastructure projects similar in scale to MetroLink. Using a thematic analysis methodology, the interview responses will be analysed to develop a set of common factors across these projects that have yielded positive outcomes for BIM and GIS integration.

Objective 4: Develop and appraise proposals for an implementation strategy for BIM-GIS integration to determine its suitability for applying to a large-scale infrastructure project using MetroLink as a test case.

Research Methodology: undertake Action Research by developing a workflow to publish BIM models to a GIS Web platform to determine which approach yields the best outcomes for the MetroLink project.

3. Literature Review

3.1 Background

Over the course of the last decade there has been a noticeable increase in published literature focussing on the integration of BIM and GIS [9-11]. Proponents of both BIM and GIS espouse the information management capabilities of each and phrases such as ‘single source of truth’[12] and ‘authoritative data’ are commonly used in describing both. Despite their different origins and applications, BIM and GIS share the aspiration to develop authoritative datasets, realize the value of project information and enhance how information is managed throughout the project lifecycle. To fully understand the merits around the integration of BIM and GIS it is critical to understand each.

3.2 What is BIM?

ISO19650-1:2018 describes BIM as “the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions” [13]. The management of information as part of the delivery phase of assets described in

ISO19650-2:2018 also clearly states the applicability of the standards to built assets and construction projects of all sizes, including infrastructure networks [14]. The information contained in BIM models is progressively developed throughout the project lifecycle in order to accurately depict all facets of the building with the intention of transitioning some of the content contained in the Project Information Model (PIM) across to the Asset Information Model (AIM). The Common Data Environment (CDE) is the repository for all content created throughout the project consisting of documentation, graphical models and non-graphical data. Information is managed in the CDE in a controlled manner supporting the re-use of trusted and approved content across the project team. Information accumulated throughout the Operation and Maintenance phase of the asset results in a 'cradle to grave' representation of all aspects of the built environment. The application of BIM is often undertaken with the intention of delivering a "digital twin" of the built environment.

3.3 What is GIS?

GIS is a decision-support tool comprising of hardware, software, people and data and can be defined as "a computerised system for capturing, managing, manipulating, integrating, analysing, visualising and disseminating spatial data" [15]. Using the spatial analyses capabilities of GIS, it is possible to overlay data from various sources representing a variety of themes and identify new relationships between these datasets based on the shared characteristic of location. Associating supplementary information in the form of attribution further enhances the capability to analyse and manage information in GIS. The application of GIS in transportation has been evident for some time [7], [10], [16]. GIS has been used as part of infrastructure projects for route planning, environmental applications and utility management [17].

In recent years the shift from 2D to 3D in GIS is very much to the fore [18]. Capabilities have emerged over the course of the past decade in terms of the ability to build and share 3D scenes across web browsers which is leading to a change in approach to how spatial information is being managed, analysed and disseminated. There has also been an explosion in recent years in terms of our ability to create and share spatially referenced data. In the construction sector alone the use of geospatial technologies such as Laser Scanning, UAVs and Virtual and Augmented Reality tools have all significantly advanced the cause of GIS and spatial information management and

future advances are likely to transform digital workflows in construction projects [19].

3.4 The Integration of BIM and GIS

Considerable research has been undertaken in recent years investigating the integration of BIM and GIS. Given the applicability of both BIM and GIS throughout every stage of the construction lifecycle, the characterisation of both BIM and GIS as information rich, decision-support tools used to make better, more informed decisions about assets, this research is clearly merited. In recent years the boundaries between BIM and GIS are becoming less distinct. Most GIS solutions now provide the capability to work with detailed 3D data [18, 20]. Where GIS has traditionally been associated with mapping and managing information representing the 'outside world', some GIS solution providers are now applying GIS technology to indoor environments [21], the traditional domain of BIM. The rise of Smart Cities lends further weight to the integration efforts underway in GIS and BIM [22]. The creation and development of intelligent building models where information is progressively added has the capacity to enhance existing models of Smart Cities [18]. This approach will also help eliminate unnecessary duplication in the creation of content for Smart Cities as BIM models can be used for any new or updated model of a building. The cumulative growth of building models across a district or region can then be further analysed using the spatial analysis capabilities of GIS.

Another shared trait of both BIM and GIS is their use for environment-related applications. The growing trend towards more sustainable and environmentally friendly construction in the built environment, delivering on the objective of reducing carbon emissions is an area that can benefit from the integration of BIM and GIS. While BIM has enabled more efficient design and optioneering for buildings, particularly in terms of their green credentials [23], the fusion of BIM and GIS creates the possibility of enabling environmental factors such as wind speed, wind direction, solar paths, air pollution, traffic noise and a myriad of other factors to be considered as part of building design.

Further evidence of the growing trend towards GIS – BIM integration is provided as part of the research undertaken for the GeoBIM project [24]. The GeoBIM project involves eleven National Mapping and Cadastral Agencies (land ownership) along with four academic

institutions. The motivation behind the GeoBIM project stemmed from the clear overlap that exists between BIM and GIS and the opportunity to use the strengths of both in responding to the multi-disciplinary challenges of the built environment. The case put forward by the authors is that the more detailed BIM data can be used to feed the GIS data and the GIS data can be used to provide context that is typically missing from BIM. In reviewing the state of play with regard GeoBIM across Europe [20], the authors identify strong potential for GeoBIM with examples of GeoBIM for planning applications and managing national cadastral (land ownership) systems.

The authors also report an absence of national focus on the subject and a somewhat fragmented approach to implementations of GeoBIM but outline future work of the GeoBIM project in the area of operational tasks. In the context of infrastructure projects where the operational phase is considerably longer and more costly than the construction phase, the GeoBIM research into this phase of the project lifecycle has the potential to deliver significant benefits.

While there are many examples of positive outcomes from BIM-GIS integration, it is not without issue [9]. Examples of some of the issues and incompatibilities include the use of BIM for buildings and GIS for areas, the use of local coordinate system in BIM versus a projected coordinate system in GIS and utilisation of 3D in BIM and 2D in GIS. Considering these incompatibilities, it is worth noting recent advances in both BIM and GIS capabilities have ameliorated some of these issues.

A number of papers have comprehensively reviewed particular approaches to the integration of BIM and GIS. The approaches to the integration of BIM and GIS that have been investigated to date include identifying commonalities between exchange formats [25], approaches to modelling in 3D common to both GIS and BIM [16] and focussing on integration at the data level [10]. The integration of BIM and GIS is described as cumbersome [26] and challenging noting key differences between the two such as scale of use, Levels of Definition and representations of geometry. In his paper, Amirebrahimi et al. [26], go on to categorise the integration efforts into three major groups namely integration at application, process and data levels, a categorisation which is also used and expanded upon by Zhu et al. [10] particularly for the data level.

- **Application Level,** refers to the development of functionality that extends or enables software applications to incorporate the functionalities of both BIM and GIS. This approach may require software reconfiguration or extending functionality through custom tools or extensions. Integration at this level has been described as "most difficult and time consuming" [10, 27]. However, there has been some recent developments in this area such as the ESRI-AutoDesk partnership outlined below.

- **Process Level:** efforts at integration focus on employing both BIM and GIS as part of a collaborative workflow where each solution still manages information independently resulting in no change to the data. The application of semantic web technologies to enable integration between BIM and GIS facilitates 2-way exchange of information between BIM and GIS [28] and does present some promise. However, it is still at an early stage of development.

- **Data Level:** most of the focus on the integration of BIM and GIS has been at data level [10, 25, 27, 29]. Integration at data level refers to the ability to exchange information between both solutions without data loss [10]. It may also mean the introduction of new or updating of existing standards or converting data formats [27]. In terms of moving data from BIM to GIS and vice versa, the most popular formats in use are IFC for BIM and CityGML for GIS.

The integration of BIM and GIS is hampered by the lack of a fully formed exchange protocol between the two disciplines [30]. Efforts to exchange information between BIM and GIS based on the common exchange formats of both namely IFC and CityGML results in data loss during translation, an issue which is noted in numerous works [25, 29, 31]. Given the core characteristic of information management applicable to both, this information loss must be remedied in order to facilitate truer integration between the two solutions.

The use of Extract Transform Load (ETL) tools is another area that is being used to translate from BIM to GIS or GIS to BIM [30] but the knowledge of the operator is critical when undertaking these translations. There are a number of tools available in the market to undertake these translations, with one of the most popular being FME by Safe Software [32]

It would appear that along with the published research regarding the integration of BIM and GIS, industry is also clearly adopting the approach that the two technologies should be seen as complementary rather than competing [33]. Numerous online publications further develop the proposition of the integration of GIS and BIM [34], [35] and particularly in the case of infrastructure [36, 37]. In November 2017, a strategic partnership was announced between AutoDesk and ESRI, two leading technology solution providers in the BIM and GIS industries [38]. Both companies have committed to continue working on the integration of their technology platforms (platform level integration) and envision a future of City Information Modelling (CIM) built from BIM and GIS and becoming the bedrock for Smart Cities [39].

3.5 Differences & Similarities between BIM & GIS

GIS applications, in order to undertake spatial analysis and effectively work with spatial data, require that data to be assigned to a map projection. A map projection is used to mathematically model a 3D real world surface onto a 2D planar representation. Assigning a map projection to the data defines where the data is located and enables data to be analysed in a geographical context. BIM on the other hand is usually modelled in a local coordinate system and in the absence of information about the surrounding area. This can lead to issues when trying to federate BIM and GIS data. A related issue is that of scale with the tendency of GIS to model and manage information for large extents when compared to BIM, which is focussed on a building [11]. This issue is even more pronounced in infrastructure where the extents of the works may be measured in kilometres while detail on a bridge or building structure can be modelled to millimetre precision.

One of the key components of a BIM workflow is a Common Data Environment (CDE), which is described as the single source of truth for all project information. From a GIS perspective one of the stated objectives of GIS has always been to establish authoritative datasets in order to ensure any analysis or output is trusted. Implementing a CDE solution should present an opportunity to promote the integration of BIM and GIS. With the CDE acting as a repository of project or asset information, developed from early design throughout each stage of the project lifecycle this would appear to be an obvious location to store GIS data as well enhancing the integrity of all data [40]. The requirement to develop the single

source of truth for a project is a key objective of both solutions. However, it is apparent that both cannot lay claim to being the authoritative dataset unless that dataset is one with shared access.

A notable issue associated with the exchange of information between BIM and GIS is the differing interpretations of Levels of Definition (LOD) between the main exchange formats of IFC and CityGML [10] which hampers the exchange of information. The IFC files typically contain much more information than the CityGML format and the data loss needs to be fully understood to assess its impact.

Another area where BIM and GIS differ is in how geometry and topology related issues are managed. In GIS, topology refers to a set of rules and behaviours that model how points, lines and polygons share coincident geometry. Topology rules enforce these behaviours and ensure the integrity of the geometric data. The absence of these rules in BIM can result in issues when trying to migrate content from BIM to GIS [41] and particularly when attempting to migrate content from IFC to CityGML [42].

3.6 BIM & GIS for Infrastructure

Infrastructure projects require information technology solutions and information management workflows to support the various disciplines engaged on the project and to ensure appropriate sharing of information. Large scale infrastructure projects such as metro systems, major road and rail schemes present a challenge in terms of information management. As has been mentioned previously, issues relating to the size and scale of the work coupled with the appointment of multiple parties working across different disciplines at different times make a coherent and effective information strategy essential [40, 43-45].

When considering the focus of this work, an integrated BIM-GIS framework would appear to be logical fit for infrastructure projects. Considering the extent and impact of large infrastructural projects, where both the natural and built environment are affected, integrating the best aspects of both solutions in a complementary manner presents a strong case. Both solutions are already used throughout various stages of infrastructure projects [27]. In the case of large-scale infrastructure projects, GIS analysis and tools have been employed for some time. Examples of the use of GIS and BIM in infrastructure projects include route selection, environmental impact assessment, utility management [17], asset management and the delivery of Safety

Files and As-Built information at scheme handover and scheme closeout.

The utilisation of BIM on infrastructure projects has been demonstrated to be applicable across the life cycle of transportation infrastructure. Comprehensive examples of BIM as part of the planning, design, construction and maintenance phase of infrastructure works across a variety of transport modes is provided, as is the utilisation of BIM for As-built documentation [43]. The application of BIM technologies and workflows on linear infrastructure projects presents a different challenge in terms of information management [8]. The spatially dispersed nature of a linear infrastructure project is very different when compared to that of a building site. The BIM models created to represent the design and construction progress for building sites or vertical construction are very different from those used to represent linear infrastructure that typically extend horizontally [28, 43]. In the context of infrastructure where construction can be multiples of kilometres in length with numerous sites e.g. stations along a rail line, it is quite common to split a project into multiple contracts and as a consequence, work is undertaken by numerous construction teams each with the potential to interpret client requirements in a different way.

The use of collaborative working environments based on BIM technologies and workflows on infrastructure projects are becoming more prevalent. Particular emphasis is being placed on developing asset-centric approaches to information management particularly in the case of large-scale linear infrastructure projects [44]. A whole-of-life approach is critical to developing the right strategy for managing information, particularly as infrastructure projects are constructed for the long term and effective management of the asset throughout the operational phase needs to be considered.

4. Interview Findings

In order to further develop the research into the integration of BIM and GIS integration on large scale linear infrastructure projects, a number of semi-structured one-to-one interviews were completed. This approach was used as it enabled interviewees to freely express their views and opinions on the subject matter and also facilitated the gathering of reliable and comparable data. The purpose of the interviews was to examine the content posited in the literature review and attempt to better understand if key items identified as part of the literature review reflected real-world practice. The

interviews followed a structure where two key topics were discussed along with a selection of both closed and open-ended questions, the purpose of which was to determine a comprehensive response from the interviewees.

The individuals selected to participate in the interviews were identified based on their involvement in information management for large scale linear infrastructure projects. In targeting individuals to participate in the interviews a conscious effort was also made to draw on international expertise from different types of infrastructure projects to assist in developing a more comprehensive understanding of the role of BIM and GIS in large scale linear infrastructure projects. Those interviewed have participated in developing information management strategies on linear infrastructure such as road, rail and large-scale utility projects. In presenting the findings from the interviews, all interviewees have been anonymised in order to protect their identity and confidentiality.

The interviewees consisted of the following people:

1. Interviewee 1 – [IRE-ENG-BIM], an Engineer for an Irish-based engineering consultant leading the company's transition to BIM workflows for projects in roads and utilities.
2. Interviewee 2 – [EU-BIM/GIS], a GIS/BIM Co-ordinator working on a major rail project in eastern Europe.
3. Interviewee 3 – [UK-ENG-BIM], a U.K.-based consultant working for one of the world's leading engineering consultants predominantly in the area of information management as part of highway engineering.
4. Interviewee 4 – [CAN-ENG-BIM], a Canadian-based consultant working for one of the world's leading engineering consultants as a BIM lead with experience of major rail infrastructure projects such as CrossRail and HS2.
5. Interviewee 5 - [UK-GIS-SA], a U.K.-based Solutions Architect working for a world-leading GIS solution provider in the area of AEC & BIM.
6. Interviewee 6 – [USA-GIS-PM], a U.S.A.-based Product Manager for AEC workflow integration at a world-leading GIS solution provider.

The assigned code for each of the interviewees is listed within square brackets above and summarised in Table 1

below. In synthesising interviewee responses to the interview process, the assigned codes are used to help the reader understand the perspective of the interviewee.

Interviewee	Assigned Code
Interviewee 1	IRE-ENG-BIM
Interviewee 2	EU-BIM/GIS
Interviewee 3	UK-ENG-BIM
Interviewee 4	CAN-ENG-BIM
Interviewee 5	UK-GIS-SA
Interviewee 6	USA-GIS-PM

Table 1: Interviewee Codes

a) Information/Asset Management

The interviewees were asked to outline their experience of the application of BIM and GIS on linear infrastructure projects that they have been involved in particularly in the area of information and asset management. All of the respondents referenced the use of both BIM and GIS as key tools in the structured management of project information. CAN-ENG-BIM referenced the utilisation of GIS on infrastructure projects in the 'pre-BIM' days. The use of GIS in infrastructure projects has a long history, as demonstrated in the literature review [7].

While the question asked of interviewees distinguished between BIM and GIS in the context of information management and asset management, UK-ENG-BIM was quite resolute in not distinguishing between BIM and GIS, "I just see it as data and information management, I don't differentiate BIM and GIS". This type of vernacular certainly appears to have emerged in more recent times amongst transport authorities where digital information strategies such as those published by Victorian Roads (Australia) [46], Transport New South Wales (Australia) [47] and HS2 [48] appear to be working towards a situation where BIM and GIS are strands of the overall information management strategy and are being used as tools or workflows in achieving this outcome.

IRE-ENG-BIM cited BIM as the reason his organisation established a more structured approach to information management, in part out of recognition for the role BIM would play in future contracts but also in understanding the value of utilising best practice in information management for engineering contracts they were bidding for. USA-GIS-PM emphasised the importance of having an asset management framework in place so that design and construction teams know what they are working to.

b) Lead tool

This question asked of the interviewees was if BIM or GIS was considered a 'lead tool' with regard information management. Notably 3 of the 6 interviewees described BIM as the lead tool from the perspective of

implementing a framework for the management of digital information. CAN-ENG-BIM recounted the experience of working in the area of information management utilising GIS before the widespread adoption of BIM and "struggling to gain traction" in the area of information management. This perspective would lend support to the role and purpose of BIM in terms of helping move the AEC industry to digital workflows. IRE-ENG-BIM described the conscious decision by the business to adopt BIM and how it has been used to lead to the business approach to a structured framework for information management with GIS being used in parallel. UK-ENG-BIM expressed the view that that the process very much drives the technology and as a result, BIM workflows take the lead.

The other interesting point to note with regard to the use of either BIM or GIS as a lead tool is dependent on the stage the project is at. Both UK-ENG-BIM and CAN-ENG-BIM made clear reference to the fact that the use of BIM and GIS tools largely depended on the stage the project was at, with GIS being more prevalent at stages like planning, preliminary design and during operations but with BIM tools and workflows very much to the fore during the Detailed Design and Construction stages.

c) Single Solution

Given the utilisation of both BIM and GIS throughout all stages in the project lifecycle [13] and the recent application of GIS to indoor environments [49] the question was asked of all interviewees whether they could see a situation where BIM and GIS tools become a single solution for information management or would they always function independently of each other.

Three of the interviewees did not discount the possibility that this might happen at some point in the future but cited a number of barriers preventing this occurring such as the complexity of CAD and BIM geometry versus GIS [41] and the file based nature of BIM as opposed to the database oriented approach of GIS solutions. Contrary to the view that BIM and GIS could become a single solution, the other three interviewees were resolute in this not transpiring with the common view of specialist tools for specific jobs.

The nature of linear infrastructure was identified by IRE-ENG-BIM as a key potential driver behind the development of a single solution. However, there was also a clear reference to the use of GIS at specific stages in the project lifecycle. A

similar point was made by UK-ENG-BIM in advocating the right tools for the right job at specific stages of the project, so use BIM software for the tasks they are strongest at and GIS software for what they do best.

Three of the interviewees described an approach of using GIS as a means of engaging with project information through the creation of project portals in a GIS platform. These platforms act as a doorway to access project content on linear infrastructure projects by linking between GIS, BIM and other enterprise solutions to give the appearance to the end user of a single solution when in fact it is a number of linked enterprise systems.

d) Role of the CDE in integration

The CDE is at the heart of the BIM workflow and central to information management. During the course of the discussions with IRE-ENG-BIM and EU-BIM/GIS references were made regarding GIS and BIM operating in parallel. This type of approach was also suggested by CAN-ENG-BIM who stated that content could be "mastered in one and mirrored in the other". These statements give an impression that content has to be replicated in both solutions which runs counter to the practice of developing a 'single source of truth'. This may in part be down to the understanding or perception of what constitutes a CDE. UK-ENG-BIM, CAN-ENG-BIM, and USA-GIS-PM were also clear in stating that the CDE is a collection of systems or solutions such as document management systems, databases, GIS and other information management solutions with USA-GIS-PM stating a preference for the term "Connected Data Environment" as opposed to Common Data Environment. The key characteristic is that the information repository has to be the authoritative data source to qualify as part of the CDE.

e) Information Exchange

The literature review outlined the considerable research that has been undertaken with regard the integration of BIM and GIS at data level. The more popular exchange formats are IFC for BIM and CityGML for GIS and, as identified in the literature review, there is an issue with data loss [25, 29, 31] during translation between these formats. During the course of the interviews four of the interviewees referenced IFC for the purpose of exchanging files. IRE-ENG-BIM indicated that this was more as a result of projects using generic EIRs and asking for as many file formats as they could. CAN-ENG-BIM referenced the use of IFC for cost

models but also stated that "in infrastructure IFC is still a bit early in its evolution in its templates so it's not always possible". EU-BIM/GIS alluded to issues with the format on a current infrastructure project stating "IFC creates additional problems" while interview 6 also referenced the limitations of IFC formats for infrastructure applications. Over the course of the interviews, none of the interviewees referenced CityGML as a deliverable or data format used on the work they had been involved in. This is notable considering a number of papers focus on BIM-GIS integration based on the use of IFC and CityGML formats [20, 29, 42].

f) Direction of exchange

In the context of the direction of flow of information interviewees were asked if the exchange of information occurs in a uni-directional (i.e. BIM to GIS or GIS to BIM) or whether it was bi-directional representing an over and back movement of data. Based on the responses provided there was no conclusive answer. The interviewees provided some examples with UK-ENG-BIM stressing the importance of not duplicating content as a result of the exchange of information and describing the use of web referencing to consume data from GIS into a BIM design tool. CAN-ENG-BIM reiterated the view of "the right tool for the right job" to somewhat mitigate against the actual transfer of data from BIM to GIS or vice versa, while UK-GIS-SA described the use of hosted web services as a means of limiting the actual movement of content out of the 'master source'.

g) Use of ETL tools

The role of Exchange Translate and Load (ETL) tools [30, 32] was identified in the literature review as a means of moving content between BIM and GIS. Interviewees were asked as to the use of such tools with regard the integration of BIM and GIS. CAN-ENG-BIM was effusive in his recommendation of the use of a tool like FME stating it is "absolutely critical to the success of this, you can't do without it". EU-BIM/GIS, UK-GIS-SA and USA-GIS-PM also described using a similar ETL tool, ESRI's Data Interoperability tool for the purpose of translating data between data formats. While the use of ETL tools may be required to enable the movement of BIM data to GIS or GIS data to BIM, it does require a strict data management policy to avoid unnecessary duplication or loss of content.

h) Lessons learned

In the context of the interviewees experience in the area of BIM and GIS, the final question asked of them related to lessons learned on past projects. Interviewees were presented with the scenario of starting a project over without budgetary or time constraints and asked what steps they would take to ensure a successful outcome with regard the use of BIM and GIS on the project. Four of the six interviewees identified people as key to ensuring success. As one of the interviewees stated you can have all of the software and processes in place but if people do not engage with and buy into these then success will be limited. Training was also referenced as a key factor to a successful outcome. Ensuring that people are trained in terms the purpose and role of the information they are responsible for producing will help in achieving the overall project objectives.

5. A framework for BIM-GIS integration

Based on the literature review and an analysis of the interviews undertaken as part of this research, a critical assessment of the findings was undertaken to synthesise what BIM-GIS integration currently looks like on linear infrastructure projects across the world. The key findings can be summarised as follows:

a) BIM and GIS both have key roles to play in effective information management on linear infrastructure projects. The literature review and the interviews have established that both are currently being used on linear infrastructure projects for the purpose of enhancing information management. BIM has established a framework around which key tools and workflows are implemented and GIS is one such key tool. A number of interviewees described how the utilisation of GIS is more prominent at earlier and latter stages of the project lifecycle because its seen as the most effective tool to access and manage project content.
b) Integration does not mean consolidation of BIM and GIS to a single solution with the functionality of both. Over the course of the interviews it became apparent that the distinction between the two exists because they have evolved from different disciplines and have specialised

tools and capabilities appropriate to those disciplines.

c) The Common Data Environment is at the core of the Information Management for BIM workflows. Over the course of the interviews a number of people stressed the point that a CDE should be thought of more as a Connected Data Environment. A Connected Data Environment can be described as a collection of information management solutions, containing authoritative enterprise data which can be associated by means of database management software or the use of web services for surfacing content.

d) The exchange of content between BIM and GIS has been the subject of considerable research, the main focus has been on the exchange of content at data level. It is also clear that the exchange is not without issue [10], with research identifying data loss occurring when the exchange of data takes place [25]. However, the literature review and the practical experience on the ground as evidenced in the interviews states a clear role for the use of ETL tools and their importance in contributing to the exchange of information between BIM and GIS.

e) A common theme emerging from the interviews was the use of GIS as a portal for accessing project content. Typically, these take the form of GIS Web Portals with the capability to link project information contained in enterprise solutions. EU-BIM/GIS, UK-ENG-BIM, UK-GIS-SA and USA-GIS-PM referenced the use of GIS portals on infrastructure projects they have worked on as a key tool in enabling access to project information, particularly in the case of linear infrastructure where the project extent is over a large area.

f) Of particular note was the findings of the Lessons Learned question where four of the six interviewees articulated the importance and value of ensuring the right people were working on the project and are trained to be fully aware of their obligations regarding information management on the project. Workflows and technology are only as effective as the people implementing them.

6. Applying the Recommendations to MetroLink

Having synthesised the findings of the literature review and the interviews completed as part of this research into a framework for BIM-GIS integration, the next stage of this research sought to apply the key aspects of the framework to the MetroLink project. The following five items have emerged from this research as key recommendations for the application of BIM-GIS integration framework to the MetroLink project;

6.1 Role of BIM & GIS

Both GIS and BIM have a key role to play in information management for large scale linear infrastructure projects. Throughout the project lifecycle there will be stages where each will lead in the context of information management. The literature review and interviews undertaken as part of this research reinforce this view. Typically, in the early stages of a linear infrastructure project, numerous surveys are undertaken to de-risk the project and ensure in-depth knowledge of the corridor through which the project is being built. Environmental, geotechnical, geophysical, topographical surveys are examples of such surveys. For this work the GIS is critical. As the project progresses throughout the design and construction stages the use of BIM is more prevalent in order to ensure model content is updated to reflect the latest design or construction changes and to facilitate the accurate transition of content from the Project Information Model (PIM) to the Asset Information Model (AIM). The MetroLink project will need to encapsulate the role of both BIM and GIS as part of the overall information management strategy and reflect the strengths of both as information management solutions.

6.2 Common Data Environment (CDE)

Establishing and managing the Common Data Environment (CDE) early in the project is critical for information management and to the overall success of the project. The CDE is not just a single solution, rather it is a collection of information management systems. As revealed at the interview stage of this research, the term Connected Data Environment might be considered a more appropriate term. A clear strategy setting out how information is managed needs to be developed, identifying how content in each system is related and ensuring clear delineation between the tools used for

information management. This approach should help ensure that the CDE is developed and managed in line with best practice. A point worthy of note, particularly for publicly funded projects, is the need to ensure the CDE is in place as early as practicably possible and to consider any procurement related issues that may arise. With the project CDE in place, the project standards and rules required to establish and embed the practice of structured management of information across all members of the project team can be implemented.

6.3 GIS as a 'gateway' to content

The use of 'GIS Portals' as tools for facilitating access to project content has emerged as a key finding from this research. The ability to display and interrogate BIM models using GIS web platforms is becoming a much more common means of interrogating and disseminating project information. This is particularly the case for linear infrastructure projects due to the large project extents. This view was demonstrated in the findings of the literature review and corroborated in the interviews. GIS Portals are being used as the access point or gateways to project information. The geographical context that they provide enhances the ability to access project content by navigating to the area of interest to discover information of interest. The MetroLink project uses GIS web portals to provide access to project content and has also published Revit BIM models to its GIS Portal.

6.4 Exchange, Transform & Load (ETL) Tools

The exchange of content between BIM and GIS and vice-versa is heavily reliant on the use of Exchange Transform & Load (ETL) tools such as FME. The ability of these tools to exchange content from one format to another greatly enhances the projects ability to surface and share content. On a project as large as MetroLink, it is highly likely that numerous data formats will be encountered and the use of ETL tools can greatly assist in the management of project information. Key to the successful deployment of ETL tools is ensuring the people responsible for undertaking the data exchange and transformations are familiar with the underlying data formats and are aware of the implications of data exchange, such as data loss.

6.5 People at the heart of good data

Technological advances have been transformational in our ability to design and model the built environment. Our ability to capture, analyse and disseminate

digital content continues to progress and shows no sign of abating. However as proffered by a number of the interviewees, people are key to ensuring successful outcomes. In the context of any major linear infrastructure project and particularly with reference to the integration of BIM and GIS, a highly skilled, highly trained information management team is essential. The information management team can ensure that the production of information throughout the project lifecycle is done according to project standards and content can be trusted by all members of the project team. The size and budget of large-scale infrastructure projects demands that adequate attention is afforded to the value of digital information. The utilisation of BIM and GIS solutions can further strengthen the project team's capacity to share project information and enhance integration with existing enterprise solutions.

7. Conclusion

This purpose of this research was to develop an implementation strategy with regard to BIM and GIS integration for the MetroLink project, set against the research question "Can the integration of BIM and GIS enhance information management on large scale infrastructure projects?".

A comprehensive literature review assessed the current status of BIM-GIS integration and the role of GIS and BIM in the context of information management for large scale infrastructure projects. Based on the findings of this research there is clear evidence that the utilisation of both BIM and GIS technology and workflows are being used for such projects and positively contribute to the information management practices of these projects.

It has also become evident over the course of this research that the integration of BIM and GIS, or GeoBIM, continues to advance at a significant pace. Across the spectrum of academia and industry, research and development continue to enable new methods of integration and enhance existing approaches to BIM-GIS integration. Presently, BIM and GIS solution providers such as Autodesk and ESRI are actively enhancing the integration capabilities of their respective solutions through collaborative research and development.

The Open Geospatial Consortium (OGC) and buildingSMART consortium published a whitepaper in May 2017, establishing the Terms of Reference between the two organisations to find solutions to increase the interoperability between data for the geospatial and built environments. The International Standards

Organisation (ISO) in June 2018 announced the establishment of a new joint working group on BIM and GIS, which will develop a technical report on the interoperability of BIM and GIS. This evidence suggests that there is likely to be ongoing advances in the field of BIM-GIS integration over the coming years.

The literature review and interviews undertaken as part of this research determined the factors key to the success of BIM and GIS integration on linear infrastructure projects by critical appraisal of a number of use cases and approaches. Clear evidence supporting an integrated BIM-GIS approach emerged from projects such as CrossRail, HS2 and Rail Baltica along with major road schemes in the U.K. These examples demonstrate how approaches to BIM-GIS integration have worked and helped determine factors key to the successful integration of BIM and GIS for linear infrastructure projects.

The characteristics of successful BIM-GIS integration for linear infrastructure projects based on the findings of this research were then synthesised to recommend a framework for BIM-GIS integration on the MetroLink project.

In the case of large-scale publicly funded infrastructure projects, BIM and GIS solutions are critical to delivering effective information management solutions. Both BIM and GIS have proven to be instrumental in the overall information management process and recognising that increased integration will undoubtedly yield further benefit it is highly likely they will be at the forefront of information management on large scale infrastructure projects into the future.

During the course of this work a number of areas worthy of further research were encountered. The issue of data loss during translations between BIM and GIS was highlighted in a number of papers. This issue highlights some of the incompatibilities between BIM and GIS and further research into developing a more comprehensive exchange mechanism is merited. In the context of linear infrastructure projects, the use of IFC as an exchange format requires further investigation. buildingSMART are developing the “IFCRail” project and further research to evaluate the potential benefit this open format will bring to BIM-GIS integration on linear infrastructure projects is required. Finally, while the workflow for publishing Revit models to a GIS Web platform were proven to work and are successfully being used on the MetroLink project, potential future research is recommended with regard how BIM models published in a GIS Web

platform can further integrate with enterprise management systems as linear infrastructure projects advance towards the operational stages of the project lifecycle.

[1] McKinsey. "Imagining constructions digital future." McKinsey. (accessed April, 2018).
[2] BCG. "Digital in Engineering Construction : The transformative power of building information modelling." The Boston Consulting Group. (accessed April, 2018).
[3] EU BIM Task Group, "Handbook for the introduction of Building Information Modelling by the European Public Sector," EU BIM Task Group, http://www.eubim.eu/wp-content/uploads/2017/07/EUBIM_Handbook_Web_Optimized-1.pdf 2017.
[4] M. Poljansek, "Building Information Modelling (BIM) standardization," European Commission, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109656/jrc109656_bim.standardization.pdf, 2017. [Online]. Available: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109656/jrc109656_bim.standardization.pdf
[5] B. Flyvbjerg, "What You Should Know about Megaprojects and Why: An Overview," *Project Management Journal*, vol. 45, no. 2, pp. pp 6-19, 2014, doi: 10.1002/pmj.21409.
[6] OGP, "Government Strategy to Increase use of Digital Technology in Key Public Works Contracts," ed. https://ogp.gov.ie/government-strategy-to-increase-use-of-digital-technology-in-key-public-works-projects-launched/: Office of Government Procurement, 2017.
[7] H. J. Miller and S.-L. Shaw, *Geographic Information Systems for Transportation: Principles and Applications*. New York: Oxford University Press, 2001, p. 458.
[8] M. H. Ismail, S. S. M. Ishak, and M. Osman, "Role of BIM+GIS checker for improvement of technology deployment in infrastructure projects," presented at the 10th Malaysian Road Conference & Exhibition, Malaysia, 2018.
[9] R. Fosu, K. Suprabhas, Z. Rathore, and C. Clark, "Integration of Building Information Modelling (BIM) and Geographic Information Systems (GIS) - a literature review and future needs," presented at the CIB W78 Conference, Eindhoven, The Netherlands, 2015.
[10] J. Zhu, G. Wright, J. Wang, and A. Wang, "A Critical Review of the Integration of Geographic Information Systems and Building Information Modelling at the Data Level," *International Journal of Geo-Information*, vol. 7, 66, 2018, doi: 10.3390/ijgi7020066.
[11] H. Wang, Y. Pan, and X. Luo, "Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis," *Automation in Costruction*, vol. 103, pp. 41-52, 2019.
[12] M. Ismail, S. M. I. Siti, and M. Osman, "Role of BIM+GIS checker for improvement of technology deployment in infrastructure projects," presented at the IOP Conference Series : Materials Science and Engineering, 2019.
[13] *Organisation and digitization of information about buildings and civil engineering works, including building information management (BIM) - Information management using building information modelling - Part 1 Concepts and principles (ISO19650-1:2018)*, I. S. Organisation, EU, 2018.
[14] *Organisation and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information*

management using building information modelling - Part 2: Delivery phase of assets (ISO 19650-2:2018), I. S. Organisation, Brussels, 2018.

[15] X. Zhu, *GIS for Environmental Applications - A Practical Approach*, First Edition ed. London and New York: Routledge, 2016, p. 471.

[16] G. Vacca, E. Quaquero, D. Pili, and M. Brandolini, "Integrating BIM and GIS Data to Support the Management of Large Building Stocks," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Informations Sciences*, vol. XLII-4, 2018, doi: https://doi.org/10.5194/isprs-archives-XLII-4-647-2018.

[17] M. Wang, Y. Deng, J. Won, and J. C. P. Cheng, "An integrated underground utilitiy management and decision support based on BIM and GIS," *Automation in Construction*, vol. 107, 2019.

[18] K. A. Ohori, A. Diakité, T. Krijnen, H. Ledoux, and J. Stoter, "Processing BIM and GIS Models in Practice:Experiences and Recommendations from a GeoBIM Project in the Netherlands," *International Journal of Geo-Information*, vol. 7, 2018.

[19] P. Gray and H. Lawerence, "Future Technologies Review: How new technologoes will shape the future of the UK's GeoSpatial Sector," Geospatial Commission, https://www.gov.uk/government/publications/future-technologies-review, 2019. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/827507/Final_Version_-_Future_Technologies_Review.pdf

[20] C. Ellul, J. Stoter, I. Harrie, M. Shariat, A. Behan, and M. Pla, "Investigating the State of Play of GeoBIM across Europe," in *13th 3D GeoInfo Conference*, Delft, The Netherlands, 2018, vol. XLII-4/W10: The International Archives of the Photogrammetry, Remote Sesning and Spatial Information Sciences, pp. 19-26.

[21] ESRI. "ESRI announces new indoor mapping product." ESRI. (accessed 10/01/2020, 2020).

[22] Z. Ma and R. Yuan, "Integrated Application of BIM and GIS: An Overview," in *Creative Construction Conference*, Croatia, P. Engineering, Ed., 2017, vol. 196: Elsevier, pp. 1072-1079, doi: doi 10.1016/j.proeng.2017.08.064.

[23] I. Petri, S. Kubicki, Y. Rezgui, A. Guerriero, and H. Li, "Optimizing Energy Efficiency in Operating Built Environment Assets through Building Information Modeling: A Case Study," *Energies*, vol. 10, 8, p. 1167, 2017, doi: 10.3390/en10081167.

[24] K. Ohori Arroyo, A. Diakité, H. Ledoux, J. Stoter, and T. Krijnen, "GeoBIM Project: Final Report," TU Delft, Netherlands, 2018.

[25] J. M. Sani and A. A. Rahman, "GIS and BIM Integration at Data Level: A Review," *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLII-4, W9, pp. 299-306, 2018, doi: 10.5194/isprs-archives-XLII-4-W9-299-2018.

[26] S. Amirebrahimi, A. Rajabifard, P. Mendis, and T. Ngo, "A BIM-GIS integration in support of the assessment and 3D visualisation of flood damage to a building," *Journal of Spatial Science*, vol. 61, No 2, pp. 317-350, 2016, doi: http://dx.doi.org/10.1080/14498596.2016.1189365.

[27] X. Liu, X. Wang, G. Wright, J. C. P. Cheng, X. Li, and L. Rui, "A State-of-the-Art Review on the

Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS)," *International Journal of Geo-Information*, vol. 6, 53, p. 21, 2017, doi: 10.3390/ijgi6020053.

[28] L. Zhao, Z. Liu, and J. Mbachu, "Highway alignment optimisation: An integrated BIM and GIS approach," *International Journal of GeoInformation*, vol. 8(4):172, p. 28, 2019, doi: https://doi.org/10.3390/ijgi8040172 .

[29] S. Vilgertshofer, J. Amann, B. Willenborg, and A. Borrmann, "Linking BIM and GIS Models in Infrastructure by Example of IFC and CityGML," presented at the ASCE International Workshop on Computing in Civil Engineering, Seattle, Washington, 2017.

[30] T. Kang, "Development of Conceptual Mapping Standard to Link Building and GeoSpatial Information," *International Journal of Geo-Information*, vol. 7, 162, 2018, doi: 10.3390/ijgi7050162.

[31] Y. Song *et al.*, "Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective," *International Journal of Geo-Information*, vol. 6, 2017.

[32] Safe Software. "Safe Software." Safe Software. (accessed 20/01/2020, 2020).

[33] S. Paul, "BIM Vs GIS or BIM and GIS: Why are we still in doubt?," vol. 2019, ed. https://www.geospatialworld.net/blogs/bim-vs-gis-or-bim-and-gis/: GeoSpatial World, 2018, p. GeoSpatial World Blog on BIM and GIS.

[34] P. Shimonti, "BIM Vs GIS or BIM and GIS: Why are we still in doubt?," vol. 2019, ed. https://www.geospatialworld.net/blogs/bim-vs-gis-or-bim-and-gis/: GeoSpatial World, 2018, p. GeoSpatial World Blog on BIM and GIS.

[35] B. del Rosario. "BIM and GIS Integration:Smart Designs, Better Outcomes." (accessed 10/10/2019, 2019).

[36] P. Shimonti. "GIS and BIM - A must have for transformational infrastructure design." GeoSpatial World. (accessed 2019).

[37] G. Floros. "HS2 advances BIM and GIS Integration." www.railwayage.com. https://www.railwayage.com/analytics/hs-2-advances-bim-and-gis-integration/ (accessed 5/12/2019, 2019).

[38] PRNewsWire. "AutoDesk and ESRI partnering to Advance Infrastructure Planning and Design." PR NewsWire. https://www.prnewswire.com/news-releases/autodesk-and-esri-partnering-to-advance-infrastructure-planning-and-design-300557130.html (accessed 11/01/2020, 2020).

[39] K. Weiss. "Integrating GIS and BIM Technology:Construction Technology of the Future." AutoDesk. https://connect.bim360.autodesk.com/gis-bim-construction-technology (accessed 11/01/2020, 2020).

[40] M. H. Ismail, S. S. M. Ishak, and M. Osman, "Role of BIM+GIS checker for improvement of technology deployment in infrastructure projects," presented at the 10th Malaysian Road Conference & Exhibition, Malaysia, 2018.

[41] F. Biljecki and H. Tauscher, "Quality of BIM-GIS Conversion," in *14th 3D Geoinfo Conference 2019*, Singapore, ISPRS, Ed.,

2019, vol. IV-4/W8: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

[42] K. A. Ohori, F. Biljecki, A. Diakite, T. Krijnen, H. Ledoux, and J. Stoter, "Towards an integration of GIS and BIM Data: What are the Geometric and Topological issues?," in *12th 3D Geoinfo Conference 2017*, Melbourne, Australia, 2017, vol. IV-4/W5: ISPRS, in Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

[43] A. Costin, A. Adibfar, H. Hu, and S. S. Chen, "Building Information Modelling (BIM) for transportation infrastructure - Literature review, applications, challenges and recommendations," *Automation in Construction*, vol. 94, pp. 257-281, 2018, doi: 10.1016/j.autcon.2018.07.001.

[44] G. A. Boyes, C. Ellul, and D. Irwin, "Exploring BIM for operational integrated Asset Management - A Preliminary study utilising real-world infrastructure data.," in *12th 3D GeoInfo Conference*, Melbourne, Australia, 2017, vol. IV-4/W5: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 49-56, doi: https://doi.org/10.5194/isprs-annals-IV-W5-49-2017.

[45] S. Kurwi, P. Demian, and T. M. Hassan, "Integrating BIM and GIS in railway projects: A critical review," presented at the 33rd Annual ARCOM Conference, Cambridge, UK., 4-6 September, 2017, 2017.

[46] V. S. Government. "Victoria Digital Asset Strategy." Victoria State Government. (accessed 8th December 2019, 2019).

[47] (2020). *Digital Engineering*.

[48] A. f. C. a. Engineering, "HS2-making digital transformation a reality," 4th March 2019 ed. Infrastructure Intelligence, 2019.

[49] ESRI. "ESRI announces new indoor mapping product." ESRI. https://www.esri.com/about/newsroom/announcements/esri-announces-new-indoor-mapping-product/ (accessed 10/01/2020, 2020).