TOWARDS A FRAMEWORK FOR RAILWAY NETWORK ASSETS MANAGEMENT BASED ON BIM/GIS INTEGRATION

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ABSTRACT: *Complex infrastructures such as railway networks face increasing challenges related to resource allocation, external events, constraints, and demands. Therefore, it is crucial to optimize the Asset Management (AM) phase to ensure the value and functionality of the assets. The integration of Building Information Modelling (BIM) and Geographic Information Systems (GIS) can support this phase, but it can only yield benefits with a comprehensive approach that considers and addresses the specific needs and resources of the assets and their AM organization. The main benefits include improved data management, manipulation, information visualization and optimized resource allocation. This study describes an intermediate step towards developing a BIM/GIS integration framework for AM that can guide both researchers and practitioners. The framework aims to bridge theory and practice by incorporating insights from literature reviews and case studies. Its main objectives are to provide a comprehensive multi-stakeholder view and methods for effectively integrating BIM and GIS in this context. To develop the framework, the study employed focus groups, interviews, and practical BIM/GIS tests, which provided insights reported in this article. Furthermore, the study provides research directions for effective BIM/GIS integration in infrastructure AM.*

KEYWORDS: *Building Information Modeling, BIM, Geographic Information Systems, GIS, BIM/GIS integration, Asset Management, Railway*

1. INTRODUCTION

Railway networks, like other complex infrastructures, are affected by manifold challenges. Given their significance for societal improvement, they must provide increasingly high-quality services (Famurewa et al., 2015) while coping with external factors such as extreme weather and resource management (Garmabaki et al., 2021). Moreover, railway networks function as intricate systems, requiring adoption of complexity-based approaches in order to achieve effective management (Oughton et al., 2018). The improvement of the tools, processes and information management during the Asset Management (AM) phase and the Operation & Maintenance (O&M) phase is a key factor to address these issues and to implement an effective management of railway networks. O&M represents one element of the broader concept of (AM), which is defined as "the coordinated activities of an organization aimed at generating value from assets" (ISO, 2014). The O&M phase, being focused on the operational and maintenance aspects of the asset is commonly considered as a part of the whole AM phase, in which also strategical and tactical decisions about the owned assets are addressed (e.g., investments, risk management etc.). In particular, for infrastructure such as railways, a systematic approach is required in order to properly manage the assets and to avoid resource waste which would affect the benefits provided to society (Almeida et al., 2022). According to the National Institute of Standards and Technology (NIST), approximately 60% of the total life costs of built assets are accounted for in the O&M phase due to inadequate interoperability, leading to considerable wasted resources on information retrieval and poor data management (Gallaher et al., 2004).

As a technical solution, the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) has been widely addressed both in literature and in practice. BIM is a widely adopted methodology that encompasses the entire AECO/AM sector (Architecture, Engineering, Construction, Operation, and Asset Management) and the complete life cycle of a built asset. BIM aims to promote collaborative processes and prevent information loss between phases, such as from construction to the AM phase. By means of parametric 3D models and standardized workflows and information exchanges, BIM allows to implement digital built environment asset management (Re Cecconi et al., 2017). BIM aims to address cost reduction and optimize related tools and processes. However, for effective BIM adoption in AM, asset owners and managers (in the role of appointing party as defined by ISO 19650) need to carefully assess which information and BIM uses are required. This process involves the definition of several requirements, as specified in ISO 19650, such as OIR, AIR, EIR, and PIR (Organizational, Asset, Exchange, and Project Information Requirements) (BS EN, 2019). In the context of AM, OIR and AIR serve as the primary sources of requirements for delivering the AIM (Asset Information Model),

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derived from the PIM (Project Information Model). For most AM processes, 3D geometries become less relevant, while non-geometric data related to the asset, e.g., warranties, installation dates, etc. are more important. Furthermore, organizations managing infrastructures deal with diverse assets, including both punctual buildings and horizontal infrastructures like railways, roads, and pipelines. Infrastructural AM can benefit especially from BIM/GIS integration, due to the specific need of multi-scale approaches (Breunig et al., 2017). In fact, while BIM may provide detailed data about the asset itself, GIS complements it by representing data at larger scales. The aim of this research is to investigate and address the needs of railway network management through business-oriented BIM/GIS integration for AM. To link literature with practice, the final goal of the entire research is to provide a framework based both on current theories and the findings from case studies. The construction of the framework was guided by the following research questions:

- Which is the current status of BIM and GIS implementation by organizations in charge of AM of the railway network?
- Which are the main benefits and hindrances of BIM/GIS integration for the AM of complex infrastructures such as railway networks?
- How BIM/GIS integration should be implemented according to the business core of the organization in charge of AM of railway networks?

At the current state of the research, results from an Italian case study are presented. The subject of the case study is RFI (Rete Ferroviaria Italiana), a large public company responsible for managing the railway network in Italy. The case study was conducted through Focus Groups and semi-structured interviews. Subsequently, practical tests of both BIM and GIS software have been performed and discussed in order to highlight theoretical and practical implications of BIM/GIS integration for AM in the railway context.

1.1 Background

1.1.1 BIM/GIS integration

BIM/GIS integration is a topic that has been deeply investigated in recent decades due to its acknowledged multi-purpose potential. A key point of the topic is that methodologies for integration may vary significantly, occurring at different levels and with different tools (X. Liu et al., 2017). Moreover, BIM/GIS integration is affected by several issues and challenges at the geometric and semantic levels. Several methods, frameworks, and software prototypes have been proposed for different applications, such as flood damage assessment (Amirebrahimi et al., 2015), web-based bridge management (J Zhu et al., 2020), infrastructure asset management (Garramone et al., 2020), etc. In terms of semantics, a promising approach found in literature is the adoption of semantic web technologies, ontologies, and Building Linked Data (Pauwels et al., 2017). Liu et al. (X. Liu et al., 2017) proposed a ranking of the several BIM/GIS integration methods classified by EEEF criteria, namely Effectiveness, Extensibility, Effort, and Flexibility. Addressing these criteria is crucial because the choice of a BIM/GIS integration path depends on the needs of the specific case and context. According to these criteria, semantic web technologies have been ranked with a “high” score in Effectiveness and Extensibility, but also a “high” amount of effort required for the implementation. These criteria imply a cost/benefit analysis which is necessary for effective BIM/GIS integration. Linked to this matter, another recurrent trend found in literature is the almost forced adoption of commercial software for effective BIM/GIS integration. In fact, the adoption of ArcGIS PRO is recurrent, along with the one-directional approach “BIM to GIS” for data integration (Ma & Ren, 2017). Regarding the complex conversion of BIM to GIS files, FME software is also a solution frequently found in the literature (Junxiang Zhu et al., 2019). However, important efforts found in literature foster open-source approaches and tools (Jiang et al., 2019), because they may provide support to address the increasing complexity of projects, the need for better interoperability and the need to mitigate costs. Among relevant open-source tools, Cesium is an open platform for 3D geospatial data that may implement a 3D BIM/GIS environment (F. Liu et al., 2020), as long as BIM models are converted to other formats such as .gltf or .obj. The literature shows that BIM/GIS integration is a complex and multifaceted topic, which requires an in-depth contextual analysis. For this reason, this research attempts to contribute by providing a framework based on knowledge obtained not only from literature but also from specific case studies. Besides the technical challenges, BIM/GIS integration is also an organizational cultural and competence shift, thus it should be addressed according to the specific needs of companies and involved stakeholders.

1.1.2 Asset Management and BIM/GIS integration for infrastructures

When compared to previous phases such as design and construction, AM and the O&M phase are affected by peculiar theoretical and practical gaps when related to BIM. One of the reasons is that the object-oriented paradigm and the parametric approach provided by BIM authoring software tools are less straightforward to utilize in the context of AM. On the other hand, given that AM is facilitated by IT systems, leveraging BIM for automated information exchanges holds considerable promise and potential benefits. Furthermore, the primary standard for AM, namely the ISO 5500x collection (ISO, 2014), does not directly address BIM methodology. Instead, it relies on ISO 19650-3 (BS EN, 2019) as the main reference source. In comparison to GIS, BIM is relatively recent and lacks shared and well-standardized paths for AM. Several factors contribute to this situation. Firstly, AM suffers a lack of a structured framework of BIM standards and tools (Munir et al., 2019). Secondly, the IFC (Industry Foundation Classes) data model has only recently been updated to consistently represent railways with the IFC 4.3 schema release (buildingSMART, 2022). Lastly, the specification of OIR and AIR poses challenges for asset management companies due to unclear role of BIM in supporting their core activities (Hadjidemetriou et al., 2023). The conjunction of these factors hinders BIM or BIM/GIS adoption, with the risk to implement an ineffective change management from traditional to BIM-based AM (Jupp & Awad, 2017) thus nullifying the benefits of BIM adoption and resources invested (Dixit et al., 2019).

Despite the challenges of BIM/GIS integration, the literature still agrees on its need and expected benefits. For instance, BIM-based information exchange and storage standards may ease information retrieval and management, meanwhile GIS may provide analysis tool for the whole asset portfolio and its relation with environment and surroundings (Wang et al., 2019). However, fully unlocking the potential of integrating BIM/GIS for infrastructure AM requires a more in-depth investigation across strategic, tactical, and operational levels. The entire potential of BIM/GIS integration for infrastructure AM needs to be further explored at these levels (Garramone et al., 2020). Existing literature and available tools illustrate a promising scenario for achieving and effectively implementing BIM/GIS integration. To the best knowledge of the authors, in the current literature, organizations' awareness of possible benefits given by BIM-based AM approaches and solutions is not sufficiently considered, especially in the specific context of railway networks. To address this gap, this research aims to offer insights from an organizational perspective while conducting technical evaluations of both commercial and open-source alternatives.

2. MATERIAL AND METHODS

To answer the aforementioned research questions, a broader research has been undertaken as a multi-step process, of which a brief overview is provided in Figure 1.

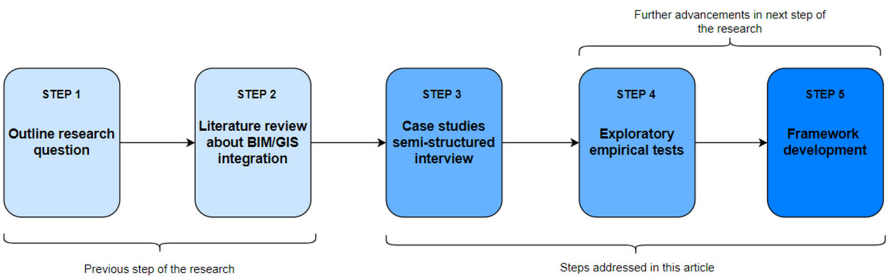

Figure 1 Overview of the multi-step research.

The work presented in this article follows a systematic literature review (SLR) concerning BIM/GIS integration (Mangia et al., 2022). Building upon the findings from this initial step, the focus was subsequently narrowed down to a specific life-cycle phase and asset class, namely the AM phase and transport infrastructures. Following this, two case studies (involving RFI and Trafikverket, respectively) have been conducted to answer the research questions. In this work the RFI case study is presented, and case study methodology is defined as an in-depth investigation of a particular subject, such as a group, organization or phenomenon in a real-life context (Crowe et al., 2011). The case studies have been addressed by means of four main activities:

1. Data collection by means of semi-structured interviews (SSIs) and focus-group;

2. Data processing;

3. Tests and experiments with several BIM and GIS-based software;

4. Evaluations of the key elements of a framework for business-oriented BIM/GIS integration.

Data collected in activity 1 are mainly related to the following two topics:

- Existing AM, GIS and/or BIM systems employed by the company;
- Awareness of benefits obtainable from BIM and BIM/GIS integration for the business core of the company.

Activity 1 was carried out across multiple sessions. The Focus Group method was selected as it facilitated the involvement of RFI departments interested in BIM/GIS integration and allowed confirmation of the authors' hypothesis: "BIM is not yet a well-established tool adopted in the core business and it lacks a standardized integration approach with existing systems." The focus groups engaged personnel from various RFI departments that could potentially be impacted by BIM/GIS integration, such as AM/ERP system users and administrators, GIS users, and others (Table 1). The researchers, acting as focus group facilitators, were able to provide a common and shared understanding of BIM/GIS integration opportunities and limitations and to receive feedbacks from different perspectives.

Table 1 List of participants of focus groups and interviews.

Department	Executive Manager	Maintenance management	InRete.2000 system support	MUIF support	Asset Management
Interviewees	N°1	N°2, N°3, N°4	N°5, N°6	N°8, N°9	N°10, N°11

In addition to this, semi-structured interviews were conducted with each business unit to delve deeper into the investigation and to pose specific technical and organizational inquiries to each interviewee. The “Data processing” activity involved the analysis of the information retrieved from the Focus Groups, interviews and related documentation provided. Knowledge about company-level standards, demonstrations of existing systems and datasets were provided for processing. This led the authors to the “Tests and experiments” activity, in which a series of exploratory experiments with several BIM and GIS software and tools were performed. The objective of these tests was to identify and assess a list of “key-elements” which the framework should address (i.e., the fourth activity of this research). For the tests and experiments, QGIS was employed for inspecting and extracting data from the geodatabase provided by RFI. Autodesk Revit and Bentley OpenRail Designer were used as BIM authoring tools to create simple 3D models of different types of assets (such as buildings, railway tracks, and sidewalks). Autodesk InfraWorks was utilized to present a 3D BIM/GIS environment for Proof of Concept (POC) purposes. The IFCjs and ifcopenshell software libraries are currently under test in order to extract data from IFC BIM models and evaluate web-based BIM/GIS viewers. Taking into consideration the outcomes of focus groups, interviews, and software tests, the final step of the broader research will concentrate on developing the framework for BIM/GIS integration for AM.

3. RESULTS

In this section the results obtained in the scope of the Step 3 and 4 reported in Figure 1 are reported. These results provided the conceptual and practical foundations which drive the ongoing development of the framework (i.e., Step 5) discussed in Section 4.

3.1 BIM potential for existing systems

One of the pivotal results for the development of the framework is the identification and analysis of existing systems. This information is one of the two main results retrieved from the Data Collection and the Data Processing activities. The second main result is addressed ins sub-section 3.2. RFI adopts two primary information systems for AM that have potential for integration with BIM. The authors were presented with comprehensive demonstrations of these systems during the interviews. The examination of the systems currently utilized by RFI supplied essential insights for assessing BIM/GIS integration options and addressing the initial research question.

A schematic overview of the two main systems is provided in Table 2.

Table 2 Overview of the two RFI system investigated.

System	Type	Data involved	Tasks performed
InRete.2000	ERP	SeTe's data model, master data sheets	- Translation of infrastructure projets into a railway network model composed of locations and routes. - Censorship the railway network assets by means of a compiled master data sheet (e.g., train stations, railways). - Management and maintenance tasks of every asset of RFI (e.g., asset is in function or surpressed, failure management etc.).
MUIF	WebGIS	Geodatabase consisting of 2D GIS layers, DTMs photospheres and 3D pointclouds.	- Context and asset visualization at the macro-, meso- and micro-scale. - GIS spatial analysis (e.g., buffer zones). - Bi-directional linkage with other RFI systems for AM and O&M (e.g., route interruption).

The first system is InRete.2000, a customized version of SAP AM software. It is an Enterprise Resource Planning (ERP) software which supports the management and maintenance of the railway network infrastructure. Based on RFI data model, assets managed with InRete.2000 are represented by means of two entities, namely called "Sede Tecnica" (SeTe) and "Equipments". SeTe entities serve to represent spatial structures or components that require maintenance, such as train stations and tracks. "Equipments" refer to physical objects installed within SeTes. Each SeTe and Equipment is assigned an ID within InRete.2000, referred to as the "Code of Sede Tecnica," which establishes semantics and hierarchy among the assets. Information within a SeTe is populated through on-site surveys, manual checks, and operator input. A SeTe is composed of sets of data and metadata, such as its location, working status, maintenance activities etc. In InRete.2000, a SeTe's record acts as a master data sheet for the respective entity. The hierarchical decomposition of SeTes mirrors the network model adopted by RFI. In particular, the railway network (which is a SeTe of first level) is characterized by two main elements: "Località" (Locations, code LO0000) which constitutes the nodes and "Tratte" (Routes TR0000) as the edges of the network.

Presently, InRete.2000 lacks geometrical and geographical visualization for SeTes, which is instead provided by MUIF (Modello Unico dell'Infrastruttura – Unified Infrastructural Model) in the form of a web-GIS application. MUIF is a long-term project initiated to establish a common information system supporting the business logic of each department of RFI. MUIF encompasses information about all assets within the rail network managed by RFI, facilitating the tracking of related data, visual representation of asset physical aspects, and verification of their geographic locations. The geodatabase predominantly comprises shapefiles, Digital Terrain Models (DTM), photogrammetric data sources like point clouds and orthophotos. Both InRete.2000 and MUIF are firmly established as essential tools for RFI, supporting their core business functions. These systems enable activities such as failure management, maintenance orders, route interruptions, and more. The former is employed for the management and maintenance of the railway network, and at the current state it is bi-directionally linked with MUIF by means of the hierarchical ID named "Code of Sede Tecnica". In addition, MUIF users may inspect a part of the railway network by means of photo-spheres and point clouds as shown in Figure 2. However, the 2D maps and the 3D point clouds are displayed in two distinct frames within a browser page, thus a unified 3D web GIS environment is not implemented yet. According to the interviewees, BIM holds potential for integration with existing systems, since it could significantly improve several processes such as context inspection and information retrieval. With BIM, detailed asset-level 3D models and information could be readily accessible, both for large entities as SeTes and for small ones like Equipments, which can be challenging to represent in MUIF despite their presence in InRete.2000. Moreover, the hierarchical data model of assets managed can be reflected in BIM components with dedicated attributes, which needs to be specified by RFI in its AIR. Working as an ID, these attributes may also partly overcome the needs of semantic which will be provided by the release of the new IFC 4.3 version.

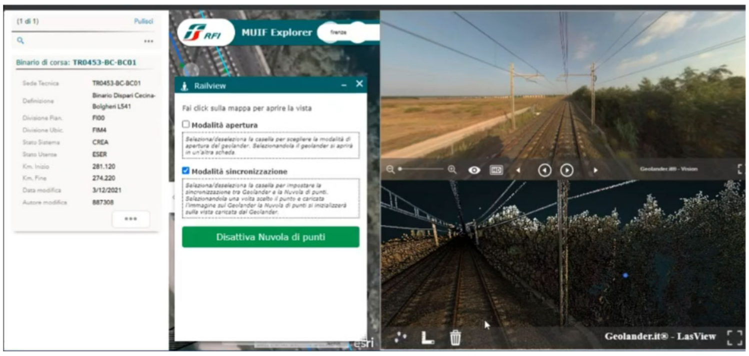

Figure 2 Screenshot of MUIF point clouds and photospheres to integrate the 2D GIS environment.

3.2 BIM and GIS state of the art in the organisation

The interviewees provided a comprehensive and multi-perspective overview of the current status of BIM and GIS within the organization. From the analysis of the Italian case study, as the second main result of the Data Collection and Data Processing activities, the researchers identified key concepts that need to be considered for the development of the framework:

- BIM: While existing systems have not yet fully integrated BIM, the organization actively participates in various BIM pilot case studies and work groups to test and implement BIM led by buildingSMART initiatives;
- The existing systems are undergoing continuous strategic development, making disruptive software changes impractical. Therefore, BIM should be integrated into the existing systems without severe changes to the system architecture;
- Several commercial vendors of AM systems already offer BIM-plugins in the AM environment, including SAP;
- Asset management personnel currently lack autonomous access to relevant data and technical drawings of assets (e.g., plants, sections), where AIM CDE linkage could provide support;
- BIM data and models can enhance several manual processes, such as InRete.2000 datasheet filling and on-site inspections;
- Organizations involved in AM of infrastructures are typically large, and implementing changes and processes can be costly and time-consuming;
- Vendor-agnostic approaches for information exchange, like OpenBIM, are vital since these organizations will mainly receive BIM-based data in open formats such as .ifc or COBie-compliant datasets. It also supports BIM/GIS integration thanks to IFC model conversion to 3D GIS formats;
- The prevailing notion regarding BIM models is that they become static data sources stored in the AIM CDE after project handover. However, there is potential for dynamic BIM utilization in the AM context, involving data management and manipulation tasks.

To support these conceptual foundations, the authors conducted experiments and tests to gather insights on how BIM and GIS data can be effectively managed according to business needs, current system limitations, resources, and requirements.

3.3 Test and experiments on software applications and tools.

Throughout the design and handover phases, specialized tools are employed to facilitate iterative and extensive data manipulation activities for generating BIM models. The authors sought to explore the applicability of these tools for Asset Management (AM) purposes and conducted tests on two software solutions: Autodesk Revit's Dynamo plug-in and the "Asset Manager" tool in Bentley OpenRail Designer CE Edition. Both tools enable users to carry out batch operations, including property set and properties creation, parameter updates, and more. Dynamo adopts a Visual Programming Language (VPL) with a graphical user interface (GUI) to facilitate script development, although some level of programming familiarity is still necessary. Conversely, the "Asset Manager" tool follows an approach more aligned with traditional AM systems and user experience. It employs pre-structured Excel files, allowing users to batch assign property sets and properties to the necessary entities. This tool expedites the rapid incorporation of especially pertinent data for integration with InRete.2000, such as the "Sede Tecnica" ID and the class code. The tests began with the creation of a BIM model of an actual location using data and documentation provided by RFI, which included a geodatabase (.gbd) containing point clouds, 2D shapefiles of the asset, digital terrain models (DTM), and orthophotos. Furthermore, RFI guidelines and the class database of the "Sede Tecnica" classes were made available. These tasks were conducted in the "BIM model creation" step shown in the overall workflow is summarized in Figure 3. Once the BIM models have been developed, the authors wanted to employ them both with commercial software (i.e., Autodesk Infraworks) and open-source tools (ifcopenshell, IfcJS). In this article, we acknowledge that only the workflow "BIM/GIS viewer POC" is introduced and discussed; however, a comprehensive discussion of the "BIM web-based viewer and AM module" workflow is intentionally omitted because it is still in development and to avoid an excessive length of the article.

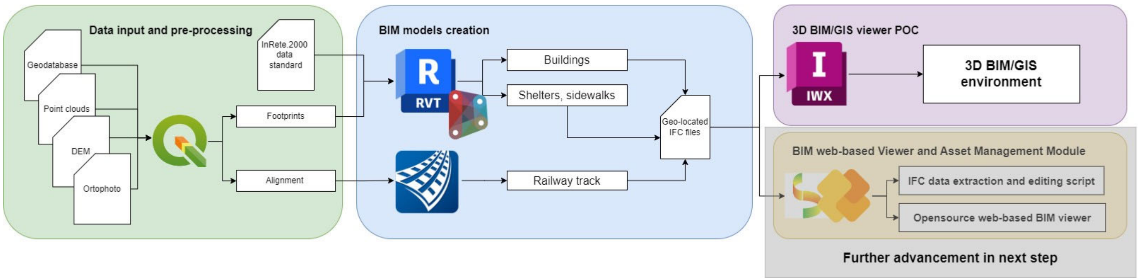

Figure 3 Workflow of the different software and tools tests performed in this study.

Shapefiles provided the asset footprint and alignment, along with coordinates and InRete.2000 data. These data were used to develop the BIM models. Buildings were modeled with Autodesk Revit (2022-2023 version), with simple architectural models linked together to provide an overview idea of a set of contiguous assets. From QGIS, as shown in Figure 4, the "Info Project" pop-up window is shown with the two most important data, namely the ID of the "Sede Tecnica" and the class code of the InRete.2000 data model. To replicate the attributes and values of the data from the shapefile attribute table to the BIM models, several paths can be undertaken after the export of the table in a spreadsheet.

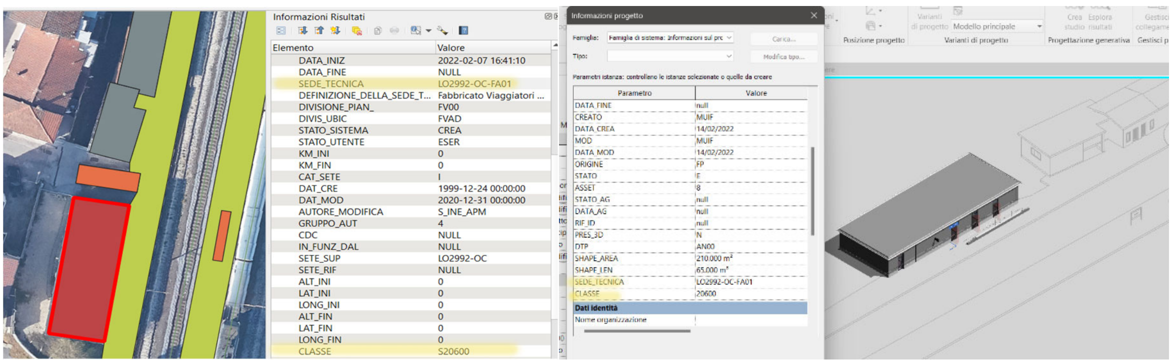

Figure 4 Shapefiles in QGIS (left picture) and derived BIM models (right picture.)

In Figure 4 is also reported a 3D view of the model, with the other developed models attached to check the correctness of geolocation data. Data at "asset-level" has been assigned to the "Info Project" entity in Revit. During the export to IFC files, information about the main SeTes representing the nodes and the edges of the railway network can be associated to the IfcProject or IfcBuilding entity. To handle the large amount of data that should be added to or extracted by BIM elements, batch parameters procedures are an opportunity to save time and reduce errors. Shifting to Bentley OpenrailDesign CE, the same process has been performed for railway tracks using the Asset Manager pre-structured excel files. These two workflows were shown to the interviewees, for feedback collection. Both the aforementioned processes require commercial software, even if an IFC file is used. These kinds of tasks are typically performed by designers (usually not an RFI employee). However, the authors are confident in the idea that companies like RFI may adopt similar tools for the management of data inside their AIM BIM models. In fact, these tools provide semi- or automated procedures for data extraction and manipulation which can ease the link of BIM models with InRete.2000 and MUIF. For this reason, the IfcOpenShell and IfcJS library are also under test to implement sample scripts for extracting, validate and store data in JSON or CSV format for information exchanges with InRete.2000 and MUIF, based on REST API protocols. Compared to commercial software, these libraries allow to develop bespoke script for the extraction and manipulation of data from IFC models. However, this improved flexibility and interoperability requires dedicated team of developers compared to “out of the box” commercial software, and thus companies such as RFI needs to evaluate which alternative best suit their needs and capabilities.

In addition to the criticalities regarding information management and exchanges, interviewees raised an issue regarding the limitations of MUIF for precise measurements and inspections despite its ability to visualize 2D GIS layers, point clouds, and 360° photos. They expressed the need for a more reliable tool, such as BIM models, to facilitate indoor inspections, object data retrieval, and accurate measurements. For this reason, two alternative integration pathways were discussed. The "basic" integration involves BIM models being integrated into MUIF similar to point clouds and 360° photos, connected to the 2D GIS environment via a URL inserted in an attribute field of 2D GIS shapefiles entities. The "basic" integration, therefore, involves a process-level integration where BIM and GIS data are not manipulated or converted into each other's formats. However, according to the interviewees, this integration can already enhance the aforementioned tasks. Conversely, an "advanced" integration would establish a unified environment where 3D BIM and GIS geometries are visualized together. This advanced integration could be achieved through open-source tools like CesiumJS or QGIS, as well as commercial software options like ArcGIS PRO and Autodesk ESRI GEOBIM. For the purpose of this research, Autodesk InfraWorks, as depicted in Figure 5 was selected because it readily provided a proof of concept for a 3D BIM/GIS environment. The interviewees conveyed that such an environment would yield significant benefits to their core business tasks, providing enhanced context visualization, multi-scale dimensioning and data aggregation at larger scales. However, despite recognizing the advantages of the "advanced" approach, the interviewees exhibited a stronger interest in the "basic" integration due to its easier implementation. While the "advanced" approach was seen as a desirable future goal, the interviewees identified complex change management efforts as the main hindrance to its company-wide implementation.

Figure 5 Infraworks 3D BIM/GIS environment for proof of concept.

4. DISCUSSION

Upon the findings of the Focus Group, interviews and experiments, two relevant points of discussion were identified. The first one focuses on the technical aspects of the BIM/GIS integration for infrastructure AM, discussing two alternatives which could be implemented in the short- or mid-term. The second point is about the organizational aspects, which according to the authors should require a deeper investigation in future works.

4.1 Pathways of BIM/GIS integration for AM

For the “Test and experiments” of this study (sub-section 3.3), a limitation is that Semantic Web Technologies have not been tested. This is due to the fact that RFI currently relies on relational databases, and transitioning to more advanced tools like graph databases and ontologies may present a challenging change management effort while a full BIM adoption is still in progress. According to the outcomes of the “Test and experiment” activity, the development of custom scripts and software to link the BIM AIM CDE with existing systems could prove advantageous for AM activities by reducing error-prone manual data management. The interviewees expressed positive feedback regarding several functionalities available within BIM authoring tools, particularly the Visual Programming Language (VPL) features of Dynamo. As a result, the authors suggest that a potential AM-specific BIM solution could incorporate VPL or similar tools as one of the possible modules to enable guided scripting for AM purposes.

Regarding the second research question, it was found out that the answer hinges on the chosen approach and thus it is strongly correlated to the third research questions (i.e., how to integrate BIM and GIS). For these reasons, in this work two approaches are considered, named “basic” and “advanced”, yielding distinct outputs in terms of benefits and hindrances. The "basic" integration primarily involves linking BIM models and shapefile attributes with tailored scripts for data management. This integration allows for converting simple data and geometries from BIM models into the GIS system, such as footprints and project-level information. In the MUIF web-environment, BIM models can be accessed as a separate frame by clicking on the GIS 2D representation. Despite its simplicity, this level of integration already provides benefits for maintenance tasks such as census activities and on-site inspections. For asset management and maintenance tasks, non-geometric data are commonly related to the asset itself and does not require an intensive integration with territorial data. However, efforts and resources must be dedicated to developing solutions for managing non-geometric data and handling sets of properties across multiple systems, using the "SeTe ID" as the matching key. Following an OpenBIM approach, a BIM-viewer inside MUIF web application can be implemented by means of IFCjs or ifcopenshell libraries avoiding intensive rework inside the existing system.

Conversely, the "advanced" integration unlocks the potential for converting conventional 2D spatial analysis into a dynamic 3D realm, seamlessly incorporating attributes like elevations, building stories, BIM components, and more within a comprehensive 3D BIM/GIS environment. The primary advantage of this approach lies in the amalgamation of asset-specific and territorial data within a single interactive environment, enabling querying and management capabilities across diverse assets, such as multiple BIM models of railway bridges. In contrast to the "basic" integration, where each BIM model resides within its individual window frame, the "advanced" approach facilitates asset-specific data analysis on multiple models coherently. Moreover, 3D BIM/GIS visualization contributes to increased awareness of the impact of the asset in the environment compared to its footprint on a 2D GIS map. Thus, the “advanced” approach allows for a comprehensive 3D model of the railway network assets alongside other assets (e.g., from third party sources) and digital terrains. However, its implementation is more complex and costly, especially with open-source approaches, due to the technical pipelines and workflows required to utilize BIM data in a 3D GIS environment. There exists a clear trade-off in benefits between the "basic" and "advanced" integration. While 3D BIM/GIS models enable 3D spatial and data analysis, achieving it demands intensive efforts with open-source solutions or the adoption of commercial software. In perspective of the development of the framework, a “integration layer” should be conceptualized to highlight that the choice of a BIM/GIS integration approach directly influence the “business layer”.

It is also important to consider the recent advancements of the latest version of the IFC schema, i.e., IFC 4.3. Even if crucial for semantic interoperability between BIM-based software, it is worth noting that in the AM context the link with other systems may be driven by specifying an attribute which allows companies to implement its company-level data model or classification systems. In the case study performed with RFI, the “Code of Sede Tecnica” attribute implemented in the BIM model act as a global ID of the asset throughout the other systems such as MUIF and InRete.2000. This approach can ease both the implementation of the “basic” and “advanced” integration, since it enables a certain degree of interoperability even if several elements in the BIM modeles needs to be exported in IFC files as IfcBuildingElementProxy entities.

4.2 BIM/GIS integration insights for framework development

Given the expansive nature of BIM/GIS integration for AM, it is essential to approach it at the organizational level as a systematic, step-by-step process, delineated into "modules" or "key functions". This segmentation allows for the assessment of enabling technologies, prioritization, benefits, challenges, and other pertinent aspects for each module. For instance, one module could pertain to the "BIM/GIS viewer," evaluating its necessity and applications. In this context, the aforementioned "basic" integration would enable swift asset location on GIS, while inspections would be conducted using a BIM-only viewer. On the other hand, assessing how a BIM model of a railway route interacts with train stations necessitates a 3D BIM/GIS viewer, as envisaged in the "advanced" integration. Another illustrative module could be "AM data analysis," aiming to empower BIM/GIS-based business intelligence and data analysis tools. The adoption of this modular approach mandates the formulation of a well-considered change management strategy that aligns with existing information systems, processes, and staff competencies. Without such a strategy, companies might choose counterproductive BIM/GIS integration solutions. While advanced solutions may seem preferable, adopting a modular mindset enables companies to opt for a cost-effective "BIM/GIS viewer" module while concentrating greater resources on other modules. Therefore, concerning the third research question, organizations should strive to associate the benefits of modules with particular tasks, such as utilizing a 3D BIM viewer for asset-wise measurements or employing a 3D BIM/GIS viewer for context-wise measurements. The framework currently in development not only aims to provide a module-based view of the problem, but it is also linked to the primary concerns and needs emerged from the semi-structured interviews and Focus Group outlined in the sub-section 3.2. It's worth noting that both the "basic" and "advanced" does not serve as substitutes for MUIF or InRete.2000. Furthermore, modularity enables changes to be implemented incrementally. For example, if only a BIM-based data exchange for InRete.2000 is required, it can be developed without the need for investment in a BIM/GIS viewer. However, it is important to emphasize that these assumptions hold true if there is a comprehensive understanding of the existing systems employed, as they will inevitably impact the effectiveness and significance of BIM/GIS-based modules and tools in relation to business activities and objectives.

As a future work, the authors aim to embed this concept in the development of the framework, highlighting this "modularity by design" approach for the specific case of RFI as a novel contribution to the current body of knowledge. This approach is intended to provide the framework with a certain degree of generalization, since it is also meant to be a replicable tool for asset owners responsible for other kinds of infrastructures. In the AM phase, BIM is addressed by means of AIM. Since they are considered the backbone of Digital Twins (DT) (Lu et al., 2021), the framework is also intended to be extendable with modules regarding other technologies and tools such as Internet of Things (IoT), Machine Learning (ML) and Virtual/Augmented Reality (VR/AR) (Johansson & Roupé, 2022) which could uplift AM activities. However, these strides necessitate preliminary steps, and BIM/GIS integration is among the most intricate. Compared to previous researches, the ongoing work presented in this article aims to provide a connection point between the advanced proposals found in literature (e.g., semantic web technologies, brand new BIM/GIS systems) and the short- and mid-term needs of organizations involved with AM. Hence, this work addresses the second research question by offering guidance and assessment on implementing changes within existing systems. As a theoretical implication, this research aims to contribute providing two research directions. First, a BIM/GIS integration approach specific for AM should take in consideration the feasibility and the concept of "modularity" and to "innovate with the lowest degree of changes required to the overall existing system architecture". The second research direction is related to the analysis of specific BIM requirements for AM software features and the definition of core skills and needs of a "AM-BIM specialist". Unlike prior phases, the escalating significance of non-geometric data, the pivotal role of open non-proprietary formats, and the dynamic nature of working with AIMs highlight the need for a professional role currently undefined. Furthermore, while BIM authoring tools in earlier phases evolved naturally from preceding tools (e.g., AutoCAD), BIM/GIS-based AIM software poses challenges as it requires integration into existing AM systems. In light of this, the authors recommend investigations into change management for AM-specific BIM/GIS integration, spanning tool prerequisites and professional roles encompassing competencies, core skills, and training.

5. CONCLUSION

The work presented in this paper marks an intermediate stage within an ongoing research endeavour focused on the development of a BIM/GIS integration framework for efficient assets management in the railway context. Starting from this, the framework will be enriched by insights derived from literature, two case studies, and experiments with both open-source and commercial software. Tests involved the creation of simple 3D BIM models from existing data sources, batch data manipulation and BIM/GIS representation alternatives. As a future work, the authors plan to extend the applicability of the framework to complex infrastructures beyond railways. One limitation of this current work is its reliance on the perspective of an Italian case study; thus, a future Swedish case study is being developed to enable a comparison and generalize the framework's applicability. Another limitation lies in the exclusion of widely discussed software like ArcGIS PRO and FME. Instead, Autodesk

Infraworks was selected for the purpose of the proof of concept. Additionally, the company's unfamiliarity with semantic web technologies restricted the inclusion of this technology in the study.

The results of this work are geared towards contributing to two distinct research directions. Firstly, pertaining to the technical facets of BIM/GIS integration for infrastructure asset management, the suggestion is to explore alternatives that can be readily comprehended and implemented by companies. This implies that BIM-based solutions should be approached more as adaptive tools designed to seamlessly integrate with existing GIS and AM systems. This is preferable to introducing disruptive, entirely new systems that would necessitate significant investments and comprehensive system overhauls. The second research direction focuses on organizational aspects. Change management emerges as a pivotal factor in BIM/GIS integration and should be closely aligned with the operational, tactical, and strategic levels of asset management. Several tools and procedures can be tailored from BIM software employed in earlier phases to benefit asset management. However, this adaptation necessitates a profound comprehension of the organization and may warrant the establishment of novel professional roles, such as AM BIM specialists. The final goal of this work is to contribute to the body of knowledge by addressing this multidimensional problem suggesting "modularity" as a key concept for BIM/GIS integration-based AM frameworks. Regarding this, future works in this research will address the complexity of the technical alternatives declined with the capabilities (i.e., resources, staff training, tools etc) of organizations. It is important to note that, without effective change management, companies might encounter counterproductive BIM/GIS integration efforts, which could substantially impede investments intended to enhance the quality and functionality of critical and complex infrastructures, such as railway networks.

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