An Integrated Workflow for Transforming Infrastructure Projects Data into the Metaverse

Mohammed Amer Younus Al-Shaheen
GIS Senior Engineer, Public Works Authority (Ashghal), Doha, Qatar
malshaheen@ashghal.gov.qa

Raj Mukta Sundaram
GIS Engineering Expert, Public Works Authority (Ashghal), Doha, Qatar
rmukta@ashghal.gov.qa

Thirunavukkarsu Ramalingam
GIS Senior Engineer, Public Works Authority (Ashghal), Doha, Qatar
tramalingam@ashghal.gov.qa

Abstract

The infrastructure construction industry is typically characterized by large-scale, complex technologies, long completion times, and challenging collaborations. The provisioning of digital representations in 3D by combining physical properties with geospatial data would assist in addressing some of these challenging issues. These technologies would also provide a fundamental basis for the creation of Metaverse to support sustainable, innovative infrastructure design and construction. Hitherto most studies were focused primarily on integration techniques rather than providing comprehensive workflow for exploiting projects data to support engineers. This study aims to help engineers and decision makers better understand the opportunities and implications of the virtual 3D environment or Metaverse by examining the key emerging trends driving and enabling the development of data workflows for a selected infrastructure project. To build possible levels of workflow, the methodology involved incorporating 3D geometric data acquired from Building Information Models (BIM) and processed with geospatial location. The optimum data workflow and associated advantages for the construction industry have been determined. This paper also describes the concept and workflow approach, including specific data structures, data conversion, and a prototype solution. The results demonstrate the feasibility of the concept's robustness and both in terms of technical implementation and adoption for expediting business processes.

Keywords: Geographical Information System (GIS); Sustainability; Building Information Modelling (BIM); Metaverse; 3D

1 Introduction

The importance of collaboration in the construction industry has led to the development of its information and communication technologies in recent years. In the last few years, digital technology has gained a lot of intangible ground in many parts of the world. This is because COVID-19 sparked a flood of strategies for making workplaces and markets more resilient (Allam et al., 2022). Collaboration between parties and processes, assisted by digital technologies, is frequently cited as a crucial requirement for the effective completion of infrastructure projects.

In spite of the fact that the definition of the Metaverse remains unclear, everyone agrees that users will be immersed in virtual worlds–sometimes in VR, sometimes not, which implies that spatial data will be crucial to the experience (Collins, 2022). As a word, Metaverse also comes up with a meaning like “Metaverse” by combining the words “meta” meaning “after, beyond” in Greek and “universe” meaning “universe” in English (Teknosa, 2022). There is no complete implementation of the Metaverse, however certain platforms incorporate Metaverse-like components. Video games offer the closest experience to the Metaverse at this time (Türk, 2022).

1.1 Virtual Reality (VR)

Due to technical advancements, digital technologies such as VR has acquired prominence and popularity in recent years (Shen et al., 2022). The term virtual reality (VR) refers to an experience that resembles or is completely different from reality based on the combination of hardware and software. It enables people to interact within a computer-generated simulated environment (Lo & Tsai, 2022). VR head-mounted displays (HMDs) provide the most immersive VR experiences to date due to their sophisticated technical capabilities, including high-quality image rendering and a variety of accessories that allow freedom of movement within the virtual environment (Parong et al., 2020).

Today, HMD-based Virtual reality (VR) produces virtual settings that can influence how users think, conduct, and feel in ways that no other technology can (Hershfield et al., 2011; Neguţ et al., 2016; Spence et al., 2017). By delivering functions such as immersive vision, hearing, feeling, and experiencing, virtual reality (VR) technology can build a region that resembles the actual world (Mandal, 2013; Zhou & Deng, 2009).

1.2 BIM and GIS

Increasingly sophisticated systems are being created for buildings, cities, and infrastructure (Najeh et al., 2019). Building Information Modelling (BIM) and Geographical Information System (GIS) are two inter-disciplinary scientific fields that use computers to integrate and visualize diverse project data and provide an objective source of project information to aid project managers in making project-related decisions (Wei et al., 2021).

As a result, a number of studies have examined new approaches and technologies to address these issues in the construction industry, such as Building Information Modelling (BIM) and Geographic Information Systems (GIS) (Celeste et al., 2022). The Building Information Model (BIM) is used to share and transmit all types of building information throughout the entire project planning, construction, operation, and maintenance life cycle (Xu, 2021). BIM can streamline the construction process for all MEP utilities, civil, architectural, and landscaping works by adopting a new process across the various phases of the design and construction process (Abotaleb et al., 2020).

In addition to the 3D model and the 3D Geographic Information System (GIS), there are also many opportunities for growth in many other areas. Examples include urban planning and management, planning and design, local government construction, housing industry development, land management, and environmental evaluation (Xu, 2021).

GIS technology enables access to infrastructures in the actual world based on their coordinates. Therefore, it can model infrastructures based on the actual locations of their components (Carneiro et al., 2018). Implementation of GIS reduced costs and improved the timeliness and accuracy of project and program planning for large transportation infrastructure developments (Ford et al., 2012; Wei et al., 2021).

Interoperability of data between BIM and GIS technologies is a formidable obstacle. Existing solutions emphasize integrating BIM and GIS based on their respective schemas (Zhao et al., 2019).

Yet, BIM and GIS derive from distinct sources with varied levels of detail, it is possible that certain data will never be correctly transferred (Karan & Irizarry, 2015). Compared to BIM, GIS is more advanced and well-developed, and it is mostly used to analyse spatial linkages and patterns (Wang et al., 2016).

To properly manage infrastructure projects, the data must be accurately represented geometrically and semantically. BIM has limitations on these types of projects in several respects, including precision in finding objects over large regions, information about the surrounding area, and spatial analytics. Considering the vast quantity of spatial data utilized in infrastructure project planning, GIS can be quite useful for managing the project's surroundings(Zhao et al., 2019). As BIM can give extensive project information, the integration of BIM and GIS is becoming a prominent topic under these circumstances.

Despite some attempts to integrate BIM and GIS systems, BIM and GIS are two very different systems, as they have different standards, data types, and levels of detail. As part of this study, BIM data was processed using a GIS application, which minimized information loss and linked the model interactively with the retrieval of domain data (architecture, structure, and mechanical engineering).

To this end, the integration of BIM and GIS can help to create a broader perspective in the assets management and its training by incorporating, via GIS, all the additional spatial information that falls within the territory and relates to infrastructures, subservices, and all the existing surroundings. The combination of BIM data and spatial data pertaining to the context in which the 360 VR is placed, enables spatial analysis and observation with scenarios to be performed on a large number of projects and assets. All of this makes intervention planning more informed and hence more effective and robust.

2 Methods and Workflow

As a case study, this paper focuses solely on infrastructure works. The selected project is Pumping Station Project PS16 North/PS16. The project is one of the projects submitted in BIM format by the contractor. A goal of this paper is to specify, formulate, and develop a workflow utilizing BIM and GIS technologies that will aid engineers in the entire data process and conversion, from start to finish, so that it becomes an essential workflow to resolve all issues that may arise along the way to produce web-based 360 VR experiences.

The value of reaching this goal is to develop a comprehensive procedure for using BIM to its maximum 3D modelling details that merge different 3D modelling disciplines to visualize and identify all the engineering domains (architectural, structural, mechanical, and electrical) during the data processing phase and extends to the 360 VR phase to assist in visualization and resolve any issues that may arise, formulating a coordination platform that could not have been conceived without this workflow and technology. The methodology for this paper is a case study done by exploring the data of a pumping station project, project code: PS16 North/PS16, of the infrastructure projects at the Public Works Authority (PWA/ASHGHAL). The first step was to collect the BIM files from the contractor. Four files collected which are as follows:

1. Architectural Model.
2. Structural Model.
3. Mechanical Model.
4. Electrical Model.

The federated project model was shared as well in Autodesk Navisworks format, due to the limitations highlighted in several literature including the software application in exporting the information of the model (Grosso et al., 2017; Shaw et al., 2007; Wetzel & Thabet, 2018).

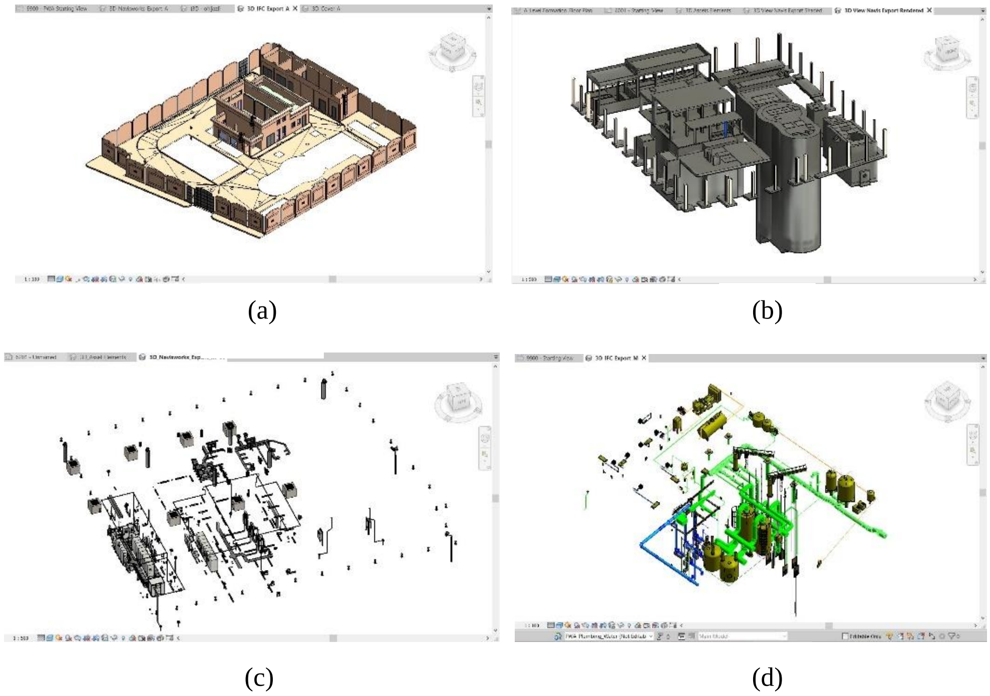


Fig. 1 BIM Model Files: (a) Architecture Model (b) Structural Model (c) Mechanical Model (D) Electrical Model

This study uses BIM and GIS as the foundation for a collaborative process environment. Modelling indoor spaces is the strength of BIM, whereas outdoor mapping spaces are the strength of GIS (Amirebrahimi et al., 2015). This study is divided into three stages: First Stage: Processing the model into 3D GIS, Second Stage: Export geometries (Discipline based) and import into ESRI CityEngine, Third Stage: Publishing 360 VR Experience, Figure 2.

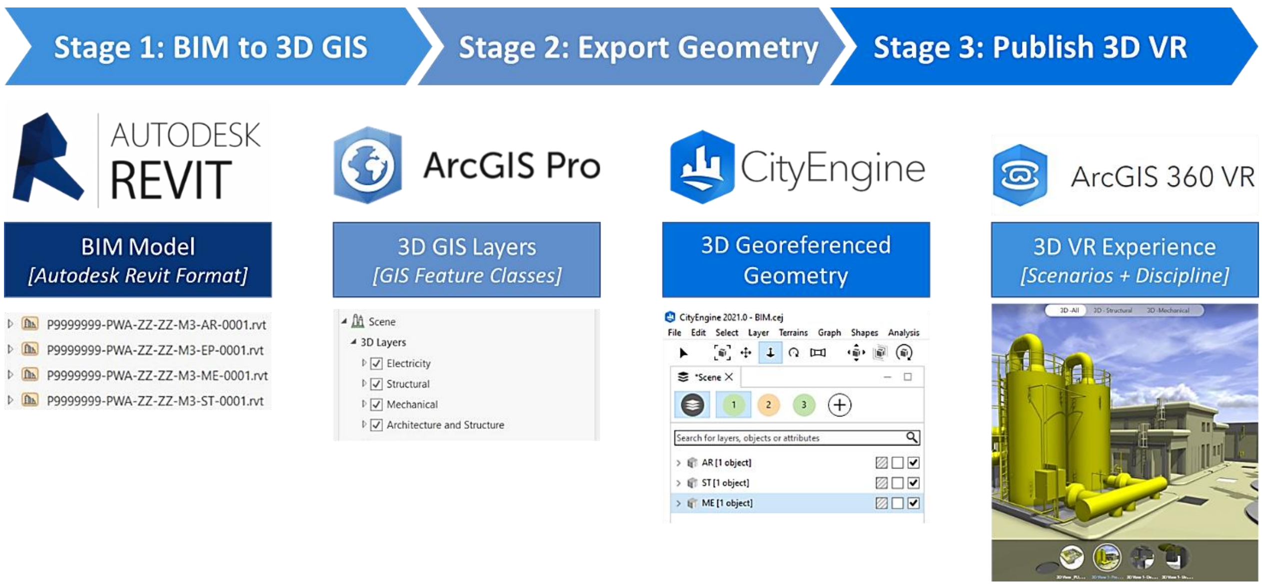


Fig. 2: The Study Workflow

3 Results and Processed Data

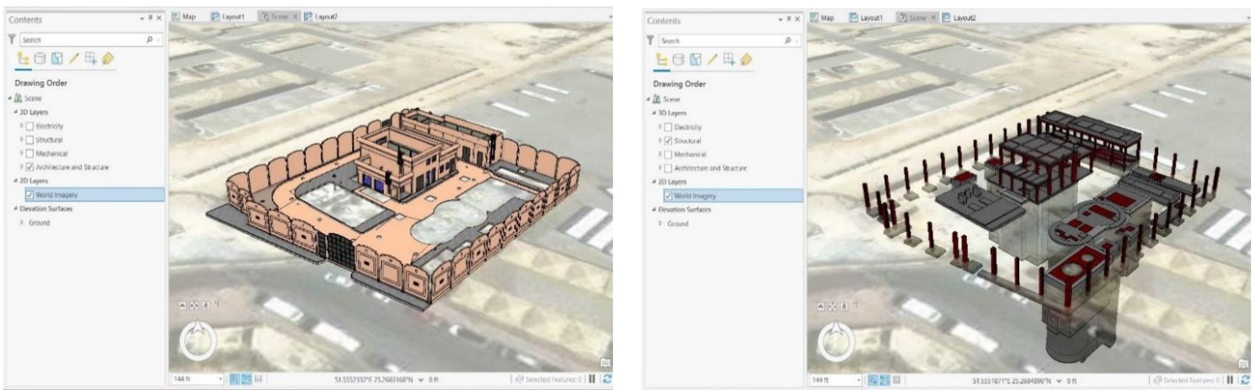
Due to the final outcomes of the data being rendered via ESRI 360 VR Experience, it is critical to use the native format, Revit, as a data source. As a 3D-based VR application, ESRI 360 VR Experience uses only 3D models. (Ioannis Pispidikis & Athanasiou, 2020). Starting with the. rvt format and reading by ArcGIS Pro application of these files. Subsequently, the Revit files will be investigated and extract the data needed for each discipline. The second step and in order to avoid the complexity a selected feature layer is reflected in ArcGIS Pro.

The import of BIM data into 3D GIS was accomplished through a simple workflow that integrated several steps at first stage. ArcGIS Pro 2.8 and a higher version can read natively the Autodesk Revit format. Only selected layers for the purpose of demo have been transferred and imported into .gdb file via ArcGIS Pro and viewed in a local scene tab. This method enabled the REVIT 3D virtual model to be transferred into the 3D GIS completely and without loss of data. Next, the model is georeferenced and navigable within the context of the urban environment in which it is placed as illustrated in Figure 3.

(a) (b)

Fig. 3: Pumping Station Project PS16 North/PS16: (a) Processed 3D GIS Data (b) Processed Top View Data

3D GIS data is arranged according to engineering disciplines as part of the processing of 3D GIS data. As a result, three sets of feature layers have been created to facilitate visual filtering of the 3D GIS data elements as shown in Figure 4.



(a) (b)

Fig. 4: Pumping Station Project PS16 North/PS16: (a) 3D GIS Architecture Model (b) 3D GIS Structure Model

At stage two, all required layers and data was exported to ESRI CityEngine. Since the aim is to maintain geometrical data for the model and avoid loss of the project information, all 3D GIS layers were converted and exported to fbx format and results rendered in Figure 5.

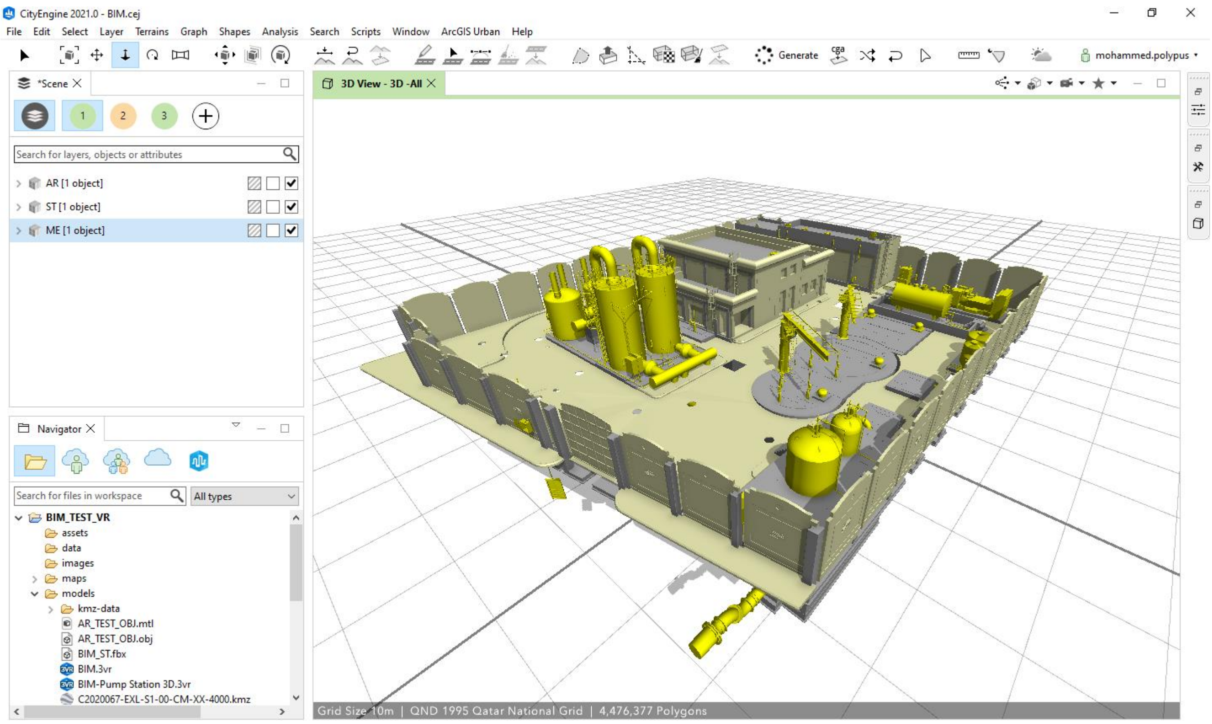


Fig. 5: Pumping Station Project PS16 North/PS16 - 3D Render in ESRI City Engine

The CityEngine Modelling application from ESRI allows users to create accurate 3D models of urban environments that can be used for simulations. This software is primarily known for its ability to create 3D content using rule-based modelling to generate detailed 3D objects from 2D data. In addition, rules can use attributes stored in GIS data, such as building heights and information specific to cadastral systems (Ribeiro et al., 2014).

After successfully importing the model in CityEngine and based on the methods followed, scenarios are created for the purpose of VR experience. These scenarios are created to render the capability of filtering the geometry based on the engineering discipline. As for the last stage of processing the 3D georeferenced model to VR experience, scenarios should be created. As a result of the exporter, CityEngine scenarios or layer compositions are converted into 360 VR Experience scenarios; turning CityEngine camera bookmarks into 360 VR Experience viewpoints (ESRI, 2022) , Figure 6.

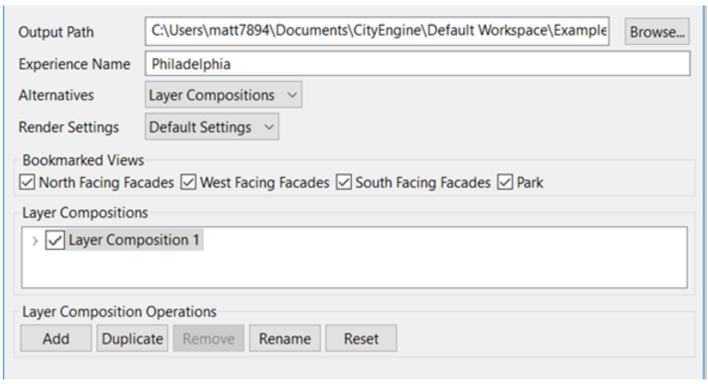


Fig. 5: 360 VR Experience Export Window

Despite the fact that CityEngine can export generated content to ArcGIS Online, it is not a web client or contains any web-enabled functionality (Ribeiro et al., 2014). At its core, the CityEngine 360 VR Experience exporter is an automated method of taking a series of viewport snapshots based on camera bookmarks. This collection of snapshots is combined into panoramic images (one for each bookmark). After uploading the exported 360 VR Experience, the experience may be consumed either locally or through the cloud (ESRI, 2022). The output format is .3vr file which can be uploaded to ESRI cloud account and viewed in the ArcGIS 360 VR environment. Figure 7 illustrates the results examined using Oculus (Quest 2) VR headset after publishing the results.

Fig. 6: 360 VR Experience Public on ArcGIS Online Cloud

With the 360 Virtual Reality Model built into the project, participants will be able to see it in three dimensions, which will help them understand the details and surroundings of the project better. Also, a 3D visualization makes it easier for users to talk to each other and share information, which reduces the chance of mistakes and misunderstandings.

4 Conclusion

Combining GIS (Geographic Information System) with BIM (Building Information Modeling) to create a spatial database that describes the built environment could be effective in supporting more informed and effective decision-making in the design scenarios and infrastructure asset management (Cecchini, 2019). Organizations can benefit from the affordances of immersive VR to provide richer and personalized user experiences. The implementation of VR capturing the lifecycle of the infrastructure projects at the Public Works Authority ‘Ashghal’ will have multi-faceted benefits. As compared to traditional collaboration platforms, immersive VR would provide richer and more effective collaboration platforms. A combination of VR’s affordances makes it distinguishable from other collaboration technologies in its ability to foster a sense of community among engineers (Dincelli & Yayla, 2022; Nunamaker, 1997; Kane, 2017).

Additionally, studies have demonstrated that VR training is superior to traditional training methods. By focusing on the create-ability aspect of VR training, organizations can increase employee efficiency at the workplace (Dincelli & Yayla, 2022). The Public Works Authority ‘Ashghal’ will have a greater opportunity to implement the VR in assets management and operation training particularly for complex infrastructure facilities and projects.

Thus, Ashghal can tailor the training material for each trainee to create more personalized learning experiences in a simulated environment. Next, this technology provides many opportunities for the Public Works Authority to reduce operational costs, such as the ability to create, embody, and interact with it (Stone et al., 2021). Also, it will be possible to provide safer and more accessible services by focusing on the create-ability, navigation, and sense-ability affordances (Dincelli & Yayla, 2022).

Even though VR offers businesses a lot of great opportunities, it also has a number of problems that could make it harder for businesses to use it and keep using it. One of the greatest obstacles is the availability of VR content that organizations can utilize for their purposes (Mattila et al., 2020). In other words, the data and source of the data is essential to create a meaningful content to be consumed as VR contents. The delivery of high performance and visual fidelity has been a challenge for virtual reality since its founding. For the successful adoption of immersive VR, potent computers and seamless connections to other peripherals are essential. In fact, low-quality graphics was one of the primary reasons why early VR technologies were not widely adopted. Infrastructure should be considered as key item to provide the robust VR adaptation.

Due to the vast number of design criteria and their complex interrelation, which are unique across businesses and industries, successful VR applications would create a sustainable competitive advantage and value for the Ashghal over the coming years. The study emphasizes the simplicity of contemporary technologies to produce data and contents for VR consumption comprising of complex infrastructure project details. Ashghal is embarking on gaining and exploiting the advantages by considering these as strategic opportunities in order to increase operational efficiency, improve corporate social responsibility, create new markets, and, overall, increase operational efficiency with this emerging technology.

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