UNIVERZA V LJUBLJANI | FGG Fakulteta za gradbeništvo in geodezijo

IGOR SILVA GUILHERME

VISUALIZATION OF DATA ANALYTICS USING BIM MODELS FOR ENHANCED DECISION-MAKING

VIZUALIZACIJA REZULTATOV PODATKOVNE ANALITIKE Z UPORABO MODELOV BIM ZA IZBOLJŠANO SPREJEMANJE ODLOČITEV

BIM A+ European Master in Building Information Modelling

Master thesis No.: 004:69(043.2)

Supervisor:
Assist. Prof. Tomo Cerovšek, Ph.D.

Co-Supervisor:
Andraž Starc, MSc Str. Eng., MSc BIM

President of the Committee
Prof. Goran Turk, Ph.D.

Co-Supervisor:
Miha Bečan, Eng. (Tutor in company)

Ljubljana, 2025

ERRATA

Page	Line	Error	Correction

BIBLIOGRAFSKO – DOKUMENTACIJSKA STRAN IN IZVLEČEK

UDK:	**004:69(043.2)**
Avtor:	**Igor Silva Guilherme**
Mentor:	**Doc. dr. Tomo Cerovšek**
Somentor:	**Andraž Starc, mag. inž. grad., Miha Bečan, Inž. (tutor v podjetju)**
Naslov:	**Vizualizacija rezultatov podatkovne analitike z uporabo modelov BIM za izboljšano sprejemanje odločitev**
Tip dokumenta:	**Magistrsko delo**
Obseg in oprema:	**62 str, 47 sl, 8 pregl.**
Ključne besede:	**Informacijsko modeliranje stavb (BIM), analiza podatkov (DA), integracija podatkov v realnem času, Power BI, BIM in Power BI, nadzorna plošča BIM**

Izvleček:

Strateški potencial informacijskega modeliranja gradenj (BIM) v analitičnih delotokih ostaja večinoma neizkoriščen, zlasti v sektorju prenosa in distribucije energije. Kljub široki uporabi orodij poslovne inteligence (BI) primanjkuje učinkovite povezave med prostorskimi podatki iz modelov BIM in poslovnimi podatki.

To magistrsko delo obravnava to vrzel z zasnovo in predlaga nov analitični sistem za podjetje ELES, operater prenosnega sistema v Sloveniji. Jedro rešitve je vzpostavitev robustne povezave med obstoječimi modeli BIM in platformo Microsoft Power BI. Povezava temelji na stabilnih identifikatorjih – primarno na internih alfanumeričnih oznakah, vnesenih v modele, in sekundarno na globalnih identifikatorjih (IfcGUID).

V okviru raziskave so bile implementirane in kritično ovrednotene štiri tehnične poti za integracijo: VCAD, Autodesk Data Connector, Speckle in Flinker Connectors. Glavni prispevki dela so: (1) ponovljiv načrt za integracijo podatkov BIM s Power BI v realnem operativnem okolju, (2) transparentna strategija za preslikavo identifikatorjev in (3) praktični vpogledi, ki podjetju ELES in podobnim organizacijam omogočajo prehod od reaktivnega nadzora k proaktivnemu, podatkovno podprtemu odločanju..

BIBLIOGRAPHIC– DOKUMENTALISTIC INFORMATION AND ABSTRACT

UDC:	**004:69(043.2)**
Author:	**Igor Silva Guilherme**
Supervisor:	**Assist. Prof. Tomo Cerovsek, Ph. D.**
Cosupervisor:	**Andraž Starc, MSc Str. Eng., MSc BIM, Miha Bečan, Eng. (Tutor in company)**
Title:	**Visualization of Data Analytics using BIM Models for Enhanced Decision-Making**
Document type:	**Master Thesis**
Scope and tools:	**62p, 47 fig, 8 tab.**
Keywords:	**Building Information Modelling (BIM), Data Analytics (DA), Real-time Data Integration, Power BI, BIM & Power BI, BIM Dashboard**

Abstract:

While analytics are now fundamental for guiding investment and operations in modern infrastructure, a significant disconnect persists. Despite the widespread adoption of Business Intelligence (BI) tools, the strategic potential of Building Information Modelling (BIM) remains largely untapped within analytic workflows, particularly in the energy transmission and distribution sector.

The present work focuses on tackling this implementation gap. It details the design and deployment of an original, BIM-connected analytics pipeline developed for ELES, Slovenia's transmission system operator. The core of this work establishes a robust link between existing BIM models and enterprise data within Microsoft Power BI. This connection is forged through stable identifiers, primarily the organization's own alphanumerical tags filled into the models, supplemented where possible by the universal IfcGUID. The research operationalizes and critically compares four distinct technical pathways for this integration: VCAD, the Autodesk Data Connector, Speckle and Flinker Connectors.

The main contributions of this work are many. It provides a reproducible blueprint for integrating BIM with Power BI in a live operational environment. It establishes a transparent, organization-specific mapping strategy for identifiers. The findings equip ELES and similar entities with actionable insights for embedding rich spatial context into their analytics, ultimately enabling a shift from reactive oversight to earlier, data-informed decision-making.

ACKNOWLEDGEMENTS

I would like to express my most sincere gratitude to all of those who have supported me to pursue the dream of becoming an international Master of Science in the field I'm passioned about, BIM. Also, specifically during the dissertation I asked and needed comprehension of many people due to the harsh reality of such deep-layered situation I've put myself into, so to all of them, I'm profoundly grateful.

At first perspective, I am deeply grateful to my supervisor, Assist. Prof. Tomo Cerovšek, for his steady guidance, incisive advice, and generous support throughout this dissertation process, during which the difficulty really challenged the completion. Not a bit less important, I also thank my co-supervisor, Andraž Starc, with his careful reviews and targeted suggestions helped refine the ideas, align the outcomes and adjust everything that created the final work.

I would also like to acknowledge the great support and participation from Miha Bečan, Senior Data Analyst at Diagnostics and Analytics Centre of ELES d.o.o. and his whole team. The acceptance of ideas and active participation of all involved in the development of this significant piece of work.

I begin by thanking my parents, Maria José and Cirineu, who have embraced me from the start to the end of every new endeavour in my life; I still remember my departure to Belo Horizonte and, of course, to Europe and know I could not have faced it without their support. Through many battles, sleepless nights, pressures, and days of fear, I always knew I could rest in the arms and company of my father and mother. I also honour my brother Clayton, who has always been my greatest adviser, example, and supporter, with deep gratitude for his patience and readiness to help whenever I needed it. Finally, my heartfelt thanks to Júlia, who shared this dream since the very first day we ever talked and stands present in this achievement; my eternal gratitude for our shared care, every help given, and the companionship and unity that sustain us, our future is bright ahead, wherever we may be, always together (and Guto).

Whether from Barbacena, Belo Horizonte, Guimarães or Ljubljana, I had very important people I could count on at all times. Thank you very much to Igor, Felipe, Jonathan, Viegas, Bárbara, Marquito, Amanda, Leandro, Ana Teresa, Ramon, Gabriel, Matheus, Paiva, Júlia, Tereza, Victor, Phelipe, Fabrício, Samara, Veloso, Afonso, Amanda, Juliana, Daniel, Ashik, Sangeen, Ahtism, Mujahed, Manzur and so many other friends, colleagues, and partners who overcame countless obstacles with me for so long.

Gratitude will always frame the story of my achievements. As this BIM A+ Master's Program comes to a close, it will be remembered with joy and pride. The end of this chapter marks the beginning of many others, and I carry with me the incredible people who made this journey possible. Onward together, always.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

3D	Tridimensional.
ACC	Autodesk Construction Cloud.
AEC	Architecture, Engineering, Construction.
API	Application Programming Interface.
APS	Autodesk Platform Services.
BEM	Building Energy Model.
BI	Business Intelligence.
BIM	Building Information Modelling.
CAD	Computer Aided Design.
CDE	Common Data Environment.
DAC	Diagnostics and Analytics Centre.
DAX	Data Analysis Expressions.
DT	Digital Twin.
ELES	Slovenian Transmission System Operator.
HV	High-Voltage.
IFC	Industry Foundation Classes.
ISO	International Organization for Standardization.
QTO	Quantity Take-Off.

INDEX OF FIGURES

INDEX OF TABLES

»This page is intentionally blank«

1 INTRODUCTION

The integration of Building Information Modelling (BIM) with data analytics has become a pivotal approach in modern infrastructure management, as it offers advanced capabilities for real-time decision-making and enhanced asset visualization. In the context of energy transmission and distribution, efficient data utilization is essential for optimizing operations and maintaining infrastructure capacities. However, while data analytics tools such as Microsoft Power BI are widely used for asset management, the integration of BIM models into these analytic environments remains underexplored, as it will be thoroughly analysed during literature review. This gap represents a significant opportunity to improve decision-making by incorporating spatial and contextual information from BIM, especially within organizations managing critical infrastructure, such as the Slovenian combined transmission and distribution system operator (ELES).

ELES currently employs advanced data analytics through its data analytics department to support high-level decision-making. Nevertheless, their current practices do not yet leverage the potential of BIM integration to provide spatial context and interactive visualization. Connecting ELES' existing data workflows with BIM models' metadata could significantly enhance the interpretation of analytical insights, strengthen more efficient infrastructure management and asset monitoring practices.

This research will seek to bridge this gap by proposing practical integration methods that leverage existing models and databases, also to be followed by the development of case study solutions with real datasets. ELES exemplifies this modern challenge; it possesses a sophisticated data analytics department that supports strategic decision-making yet has not fully integrated its valuable BIM assets into these analytical workflows. The central premise of this dissertation is that connecting ELES's existing data pipelines with the metadata from its BIM models will bridge this contextual divide, leading to significantly enhanced interpretation of analytical insights, stronger asset monitoring practices, and more robust infrastructure management.

By tackling a complex and practical challenge with a rigorous academic approach, the present research aim to contribute a valuable model for asset-intensive organizations worldwide, demonstrating a tangible path towards fully contextualized, data-driven decision-making workflow.

2 METHODOLOGY AND FRAMEWORK

This dissertation will be developed considering two main stages:

- Deep literature research and review: With a well-defined scope and guide questions, this step will seek to provide great overall understanding of scientific research on the matter and newly developed solutions on the BIM market.
- ELES Case study: A case study will be executed partnered with ELES (Slovenian Transmission System Operator) leveraging their data analytics sector and their current BIM implementation project.

2.1 Research Scope

This study focuses on the integration of BIM models with data analytics platforms, particularly in the context of ELES' (Slovenian Transmission System Operator) asset management. The research will investigate how BIM data can be connected with existing Microsoft Power BI dashboards through multiple technological pathways. It will specifically examine the use of VCAD, among other similar solutions, Autodesk Data Connector, and Autodesk Platform Services (APS) as potential solutions for achieving this integration. The study aims to deliver interactive data visualizations that enrich decision-making processes by combining spatial and analytical insights.

This dissertation explores the integration of Building Information Modelling (BIM) with data analytics platforms to enhance decision-making in infrastructure management, using a real-world case study from ELES, the Slovenian Transmission System Operator.

The project will not aim to develop new BIM standards or modelling strategies, nor will it involve the creation of new datasets from scratch, it will rely on existing BIM models and operational data.

2.2 Research Questions

To guide this research, literature review and practical study cases, a few questions will be kept on the frame, as they follow:

- How can BIM models be effectively integrated into data analytics environments to enhance infrastructure decision-making?
- What are the comparative benefits and challenges of using VCAD, Autodesk Data Connector, and APS for linking BIM data with Power BI?
- How does the spatial visualization of analytical data improve stakeholder understanding and operational efficiency at ELES?

- To what extent can interactive dashboards contribute to proactive asset management in energy infrastructure?

2.3 ELES Study Case Framework

ELES, the partner company to this dissertation, plays a crucial role in maintaining the Slovenia's energy infrastructure. Its data analytics department utilizes data-driven approaches for asset management, primarily using Power BI for visualization and analysis. Leveraging the moment of BIM implementation for the company's assets, integrating BIM models into the existing analytics framework could positively impact the decision-making process. This study proposes to link ELES' existing database systems with their recently created BIM models through three distinct visualization pathways, those are:

- VCAD Power BI Connection: VCAD offers a bridge between BIM models and business intelligence platforms, enabling the embedding of interactive BIM models within Power BI dashboards (VCAD., n.d.). This solution allows stakeholders to interact with 3D models directly while analysing data, enhancing spatial understanding and decision accuracy.
- Autodesk Data Connector Power BI Connection: The Autodesk Data Connector facilitates the direct transfer of data from Autodesk Construction Cloud (ACC) to Power BI, allowing for automated data extraction and visualization.
- Autodesk Platform Services (APS) Connection: APS, formerly known as Forge, provides APIs for creating custom applications that embed BIM data into web-based analytical tools

For developing such these tools a few ground rules will be defined, to avoid putting effort wastage and focus on solution-driven work. Focus rules to be followed are:

- A single substation, already modelled in BIM standards and enriched with metadata, serving as the central case study.
- Model linking: Connecting BIM metadata with ELES' existing database systems to establish relational connections.
- Interactive dashboards: Creating intuitive, dynamic dashboards where stakeholders can interact with both data and BIM models during decision-making workflows.

2.4 Research and Work Objectives

Although the general objective of the work of this paper revolves around providing a practical BIM visualization solution for the data analytics department of the partner company, a few specific objectives can be traced for scientific research purposes, such as:

- To explore methods for integrating BIM data with analytical tools to enhance decision-making in infrastructure management.

- To assess the feasibility and efficiency of linking BIM models with ELES' data systems using distinct approaches
- To develop interactive visualizations that leverages spatial data from BIM to improve asset monitoring and operational planning.
- To evaluate the practical impact of these visual solutions on ELES' decision-making workflows.

3 LITERATURE REVIEW

Processes, methodologies, technologies, teams, and workflows, in the field of construction, have traditionally followed a standardized and incremental path of evolution. Differently than what is seen in industries like automotive, electronics, and aerospace manufacturing, which embraced rapid transformations and flexible production methods, the construction sector has historically progressed by gradually adding complementary elements to an already intricate network of practices (Bühler et al., 2025). This step-by-step approach has often led to fragmented processes, possibly limiting gains in productivity.

On the other hand, manufacturing industries have managed to achieve productivity improvements by systematically managing data and information, and the use of digital tools, and gained efficiency with it, what is called Industry 4.0 as deeply discussed by Bolpagni et al. (2021). This contrast highlights a fundamental difference in how these sectors approach evolution and innovation. The present review will deepen in how digitalisation of construction processes can affect decision-making in practice, with a keen focus to the use of BIM and Data Analytics together.

3.1 Overview

A comparative study by Mansoori et al. (2024) further underscores the above-cited disparity, emphasizing the importance for construction companies to clearly define their services and standardize data management practices. Such steps are essential to promote industrialization and improve overall efficiency within the construction sector.

Among the various emerging technologies, Building Information Modelling (BIM) stands out as not only the most recent major shift in workflows and structures within a key economic sector but also one of the most promising advancements within the Architecture, Engineering, and Construction (AEC) industry (Kadcha et al., 2022).

A BIM paradigm can be observed not only during on-site construction activities but also throughout the entire project lifecycle, beginning with early-stage investment planning and extending to the eventual operation, maintenance, and even demolition of built assets. This includes all intermediary phases such as planning, design development, performance analysis, production coordination, execution, renovation, and refurbishment. The digitalisation of construction, of which BIM represents the most globally recognized and consolidated set of methodologies and collaborative frameworks, has introduced a series of transformational challenges to an industry traditionally characterized by fragmented practices and a resistance to rapid technological change, as explored by Samuelson & Stehn (2023).

CAD (Computer Aided Design), 3D modelling, radar topography work, scan-to-BIM technologies and Data Analysis processes can be affected by what the implementation of BIM can offer to achieve better quality and results. Such a broad movement can be resumed, in a very simple manner, as:

> BIM (Building Information Modelling) is a model-based process that provides methods and tools for creating and managing building projects faster and more economically (Sacks, et al., 2018). It allows sharing information efficiently among several stakeholders, so reducing errors and optimizing project management (Shi, et al., 2020). It stores all relevant information in one integrated model that can be leveraged for many applications during the building life cycle (Kim, et al., 2013), such as clash detection, cost analysis, and energy analysis. BIM models are highly structured and contain large amounts of geometric and semantic data. (Kadcha, et al., 2022)

Building Information Modelling (BIM) has evolved to serve as a digital backbone for information management throughout the entire AEC lifecycle. While it initially focused on 3D modelling and clash detection, BIM has gradually developed into a critical tool for decision-making, cost management, and facility operations, as Morin & Romero-Torres (2024) successfully understood.

This evolution has introduced a shift from traditional CAD systems to integrated digital platforms that allow interdisciplinary coordination, data centralization, and semantic richness. With standardized practices becoming widespread (e.g., ISO 19650), Abanda et al. (2025) explored that BIM now supports full-lifecycle data integration for design, construction, and operations.

As Kadcha et al. (2022) point out, “BIM stores all relevant information in one integrated model that can be leveraged for many applications during the building life cycle.” However, even when developed within a standardized BIM practice environment, a well-structured and information-rich BIM model may not always be efficient for quickly extracting specific data. This issue becomes particularly evident when addressing targeted queries, as noted by Kadcha (2022).

As understood by Harode et al. (2022), most studies involving BIM application in the workflow of construction and management have highlighted the positive impact of BIM on productivity, but their main goal of their work was to shed light on how facility life-cycle data, production status and information captured in BI models during design and construction can be critical for facility management and decision-making process during the period the data associated to the model still relevant.

Maranchello (2023) also highlights the growing trend within the AEC industry to leverage data for more informed decision-making and improved outcomes. As the AEC industry becomes increasingly data-driven, it’s essential to transform complex and abundant information into clear, actionable visuals. To support this, tools like Microsoft Power BI, Tableau, and other Business Intelligence (BI) platforms play a crucial role. They simplify data aggregation and make information more accessible, which is key for integrating major processes.

3.2 BIM as a Data-Rich Environment

As the AEC industry becomes increasingly data-driven, it's essential to transform complex and abundant information into clear, actionable visuals, as explained by Rodrigues et al. (2022). To support this, tools like Microsoft Power BI, Tableau, and other Business Intelligence (BI) platforms play a crucial role. They simplify data aggregation and make information more accessible, which is key for integrating major processes.

The digital evolution of the AEC sector has been significantly shaped by the adoption of BIM, but its potential goes far beyond geometric modelling and design coordination. As BIM practices mature, the focus is gradually shifting from simply creating models to effectively managing and utilizing the data embedded throughout the project lifecycle. According to Das et al. (2025), while BIM is widely recognized for reducing design errors and improving scheduling, its real strength lies in supporting data-driven decision-making across design, construction, and operational stages. This shift is transforming BIM from a visualization and coordination tool into a centralized information system that holds extensive semantic, geometric, and operational data (Morin & Romero-Torres, 2024).

However, to truly leverage this potential, we need more advanced methods to extract, organize, and interpret BIM data. This allows decision-makers to move away from intuition-based approaches and adopt strategies grounded in real evidence. In this sense, BIM presents itself as more than just a modelling tool, but as a data-rich ecosystem that needs to be integrated with analytics platforms and innovative ways of interacting with its information, as perceived by Revolti et al. (2024).

3.3 Integration of BIM with Data Analytics Tools

At its core, BIM represents the physical and functional characteristics of a facility in a digital format. In this context, it could act as a shared database, providing reliable information throughout a facility's lifecycle. Data analytics, on the other hand, involves using qualitative and quantitative methods to increase productivity and business outcomes. Zabala-Vargas et al. (2023) deepened onto how integrating data analytics with BIM not only seeks to enhance decision-making processes in construction and facility management but also to ensure that data becomes a central asset rather than just a byproduct of the modelling process.

Data analytics is considered as a transformative force in the construction industry, enabling stakeholders to leverage vast amounts of information for enhanced decision-making. This approach can be categorized into three main types: descriptive, predictive, and prescriptive analytics. Descriptive analytics focuses on historical data to identify trends and patterns, providing insights about past project performances. Predictive analytics is the one that uses statistical models and machine learning to forecast future outcomes, helping project teams anticipate challenges and make informed decisions proactively. Finally, prescriptive analytics goes a step further by recommending specific actions based on data analysis, optimizing project outcomes through calculated strategies (Cote, 2021).

Retrieving information from a BIM model is difficult to achieve when it comes to selecting and extracting information that requires in-depth processing of the raw data and representing it according to the user's needs. For instance, clash detection requires mathematical evaluation of geometric interferences between elements in the BIM model (Andrich, et al., 2022).

As Harode et al. (2022) explicit, the lack of knowledge and skills of most facility managers regarding interaction with BIM authoring and analysis platforms represents a major barrier to a broader use BIM Integrated Solutions by facility staff and hinders their ability to access critical life-cycle information embedded in models.

3.4 Advancements in Data Visualization Techniques

Visualization is a critical component of data analytics, enabling stakeholders to interpret complex datasets intuitively as effective visualization can reveal patterns, trends, and insights that might not be apparent from raw data alone. By providing interactive 3D models, stakeholders can better understand project dynamics and make more informed choices. Immersive visualization techniques, such as virtual reality (VR), further improve stakeholder engagement and facilitate better communication among project teams. A systematic literature review by Yigitbas et al. (2023) highlighted the integration of BIM with VR and augmented reality (AR) technologies, allowing users to immerse themselves in a virtual environment generated from the BIM model.

In the context of BIM, advanced visualization techniques enhance the accuracy and traceability of data conversions, facilitating better decision-making. For instance, the BEMTrace framework integrates 3D data wrangling with visualization methodologies to improve the conversion of BIM data into Building Energy Models (BEM), aiding in error detection and user comprehension (Walch et al., 2024).

Some other solutions along this concept are already available on the market, for instance there is Autodesk Data Connector, which is a plugin for Microsoft Power BI internally created by Autodesk to connect models between their conception, modelling and coordination, preferably done in Autodesk software solutions, to a data analytics approach. As defined by the company itself, this connector provides robust data visualization, analysis, and connectivity to various data sources (Autodesk, 2025).

VCAD and Speckle are other well-known software products as they provide multiformat solutions for BIM interconnections with Data-Analytics, AI empowered controlling features, and tailored BIM uses for each client. VCAD enables seamless integration of BIM data with business intelligence tools like Power BI, allowing users to create interactive dashboards and perform advanced analyses without extensive technical knowledge (VCAD, n.d.). Speckle, on the other hand, provides an open-source platform that supports real-time collaboration, data interoperability across various AEC tools, and automation capabilities, affecting primarily decision-making processes (Speckle Systems, n.d.).

As a digital concept like BIM became increasingly widespread and organisations like BuildingSMART and ISO took place for standardisation practices (e.g., IFC format as an interoperability guarantee) (buildingSMART International, 2024), it did not take long for developers and programmers to start exploring and proposing new approaches for BIM advances and uses. A recent example is a company called That Open Company, that advocates in the online BIM environment for an entirely open-source BIM environment. This company recently launched an IFC alternative format that promises to reduce computer processing power demands to operate equally detailed models (That Open Company, n.d.). At the same time, giant BIM solution companies like Autodesk are promoting its programming platform to bring innovations to their private BIM formats. APS (Autodesk Platform Services) relies on the company's software APIs (Application Programming Interface) to create new software components and other software solutions within Autodesk family tools (Autodesk Platform Services, n.d.).

3.5 Asset Management with BIM

Traditional asset management approaches often struggle with challenges such as fragmented information, decentralized data and only reactive maintenance strategies. These limitations slow down effective decision-making and can lead to inflated operational costs. The integration of BIM with Digital Twin (DT) technologies offers a transformative solution. As Nguyen and Adhikari (2023) explored, a Digital Twin is a dynamic digital representation of a physical asset, facilitating real-time monitoring, predictive maintenance.

3.5.1 Infrastructure and Database Specific Needs

Effective asset management through digital twins requires robust infrastructure and database systems capable of handling complex queries and real-time data updates as observed by Nguyen and Adhikari (2023).

Moreover, the capacity to update data in real-time within a dashboard is crucial for maintaining the accuracy and reliability of the Digital Twin. This continuous data synchronization between the physical asset and its digital version allows for seamless tracking of changes and updates.

Implementing BIM for asset management can present some infrastructure and database challenges. For instance, the real-time updating of asset information requires robust IT infrastructure and advanced data management systems, which may not be readily available in all organizations (Brazauskas et al., 2021). These challenges requires tailored strategies to ensure effective BIM and DT integration (Gordo-Gregorio et al., 2025).

3.6 Enhanced Decision-Making through BIM Visualization

One notable example of the several case studies, that have demonstrated the practical benefits of integrating BIM and data analytics in real-world construction projects, is the study by Das et al. (2025), which found that implementing BIM can lead to an average reduction of 15% in project costs. The gain of efficiency, in this occasion, was largely attributed to better design coordination, fewer errors, and more effective resource allocation. Such findings highlight the tangible advantages of these technologies in pushing operational efficiency forward.

By integrating BIM and data analytics tools project teams could better predict project outcomes and identify potential issues before they would escalate, what can significantly improve the ability to make real-time data-based decisions, as it was perceived by Harode et al. (2022). This proactive approach can not only reduce time and costs but also to promote improved communication among participants of the processes, enhancing collaboration and alignment on project goals. As a result, planning becomes more strategic and better controlled, resources are utilized more efficiently, and schedules are better maintained.

In addition, when BIM data is paired with advanced analytics techniques, it becomes possible to perform predictive modelling, which can allow the early detection of delays or cost overruns based on initial indicators. Rane (2023) in their research explored the role of Artificial Intelligence (AI) in enhancing this integration by automating processes like schedule and risk analysis, predicting occurrences and further amplifying the value of BIM-based data environments.

For instance, real-time monitoring systems based on BIM can generate early warnings and performance insights, helping stakeholders track progress and respond promptly to emerging challenges (Halder et al., 2024). Additionally, using BIM to visualize data fosters better communication across different disciplines, promoting a collective understanding of project status and performance metrics, which ultimately enhances coordination and client satisfaction.

4 CASE STUDY – BIM VISUALISATION WITHIN ELES DATABASE

As part of a recent strategic acquisition, ELES is incorporating a series of substations into its infrastructure portfolio, also ELES is implementing BIM into their business processes. One useful aspect is during the due-diligence process, during which, a digital audit of these assets was initiated. In this context, BIM is being adopted as a foundational strategy to digitally capture and structure relevant asset information from the outset. The substation selected for this study is one of the first assets undergoing such a process, serving as a pilot for a broader digital transformation roadmap within the company.

ELES contracted IBE d.d., design and consulting company that also specializes in BIM services, to model the physical and functional characteristics of the substation and enrich it with structured metadata. This effort is not isolated, it directly supports the work of ELES' data analytics department, which is already leveraging data-driven tools such as Power BI for maintenance forecasting and asset performance analysis. The integration of BIM data with ELES's analytics workflows aims to streamline information accessibility and bring spatial intelligence to operational dashboards.

4.1 Models and Databases

The package of data made available to execute this case study included four IFC models, the EIR table and a sample of ELES' internal database.

ENTRY NO.	ELES_SREDSTVO							
	LOKACIJA	SREDSTVO	SREDSTVO_TIP	SREDSTVO_VRSTA	PROIZVAJALEC	TIP	TOVARNISKA	LETNICA
1	MXL129666	R8136074	VNO	NIT	RITZ	OTEF 123	580601	1995
2	MXL129667	R8136075	VNO	NIT	RITZ	OTEF 123	580602	1995
3	MXL129668	R8136076	VNO	NIT	RITZ	OTEF 123	580603	1995
4	MXL129695	MXA133811	VNO	NIT	KONCAR	VPU-123	23103174	2022
5	MXL129696	MXA133812	VNO	NIT	KONCAR	VPU-123	23103175	2022
6	MXL129697	MXA133813	VNO	NIT	KONCAR	VPU-123	23103176	2022
7	MXL129408	R8136143	VNO	NIT	RITZ	OTEF 123	580625	1995
8	MXL129409	R8136144	VNO	NIT	RITZ	OTEF 123	580626	1995

POST INSULATORS | BUSHINGS | WALL BUSHINGS | VOLTAGE TRANSFO

Figure 1 - Example of available data from ELES' database

Although all the data has been developed in local language (Slovenian), as seen in Figure 1, the EIR document was delivered fully translated to English and guided the process to integrate models and the database. In the following table, Resource (Sredstvo), Location (Lokacija) and Documentation (Dokumentacija) property sets are displayed as they were presented, developed and filled to the model.

Table 1 - Identification datasets

ATTRIBUTE SET	ATTRIBUTE	ATTRIBUTE DESCRIPTION
ELES_DOKUMENTACIJA	DOKUMENTACIJA	Documentation folder relative link
ELES_SREDSTVO	LOKACIJA	Location number
ELES_SREDSTVO	SREDSTVO	IBM MAXIMO asset number
ELES_SREDSTVO	SREDSTVO_TIP	IBM MAXIMO asset type
ELES_SREDSTVO	SREDSTVO_VRSTA	IBM MAXIMO asset class
ELES_SREDSTVO	PROIZVAJALEC	Manufacturer
ELES_SREDSTVO	TIP	Type
ELES_SREDSTVO	TOVARNISKA	Serial number
ELES_SREDSTVO	LETNICA	Manufacturing year
ELES_LOKACIJA	CIPO	Regional control centre name
ELES_LOKACIJA	POSTAJA	Substation
ELES_LOKACIJA	NAP_STIKALISCA	Substation rated voltage
ELES_LOKACIJA	POLJE	Bay naming
ELES_LOKACIJA	LOKACIJA_VRSTA	Location type
ELES_LOKACIJA	NAP_NIVO	Rated system voltage level
ELES_LOKACIJA	OZNAKA	Device identification as in a single pole diagram.
ELES_LOKACIJA	FAZA	Phase
ELES_LOKACIJA	EAM	EAM identification code of the location
ELES_LOKACIJA	POLJE_ID	Bay ID

In the Table 1, it is possible to find the properties and property sets that are important to reference and correlate BIM models and alphanumerical data in the company's database, for example, to correlate BIM model elements and data 'SREDSTVO' is used, which is the unique MX ID. TOVARNISKA is a factory serial number, and it is linked to equipment (if the equipment is changed there is a new serial number but asset id remains).

Another property set called "ELES_TEHNICNI_PODATKI", which translates to Technical Data, will be displayed in the dashboard leveraged by the relationship created through identifier data.

4.2 Integration between Models and Databases

To connect the BIM model with ELES's asset database, we use shared parameters that help keep the data organized and easy to track. This connection is made in Power BI, using a clear structure that matches elements in the model with information from the database.

To make the dashboard easier to use, it is also used filters. One filter is for the type of equipment, using the "SREDSTVO_VRSTA" parameter, also in the "ELES_SREDSTVO" set. Another filter helps group elements by the BAY they are in, using the "POLJE" parameter from the "ELES_LOKACIJA" set. This helps users understand where each element is in the substation.

A last filter checks if an element is managed by ELES. This is based on the "SREDSTVO" parameter: if the value has a dash ("-"), it means ELES does not manage that element.

By using these connections, it is possible to create dashboards that are easy to explore and full of useful information. The BIM model and the database work together, helping ELES make better decisions with clear and connected data.

5 DEVELOPMENT OF SOLUTIONS – MODEL VISUALIZATION AND DATA ANALYTICS INTERFACE

The solutions to be developed will focus on finding a variety of solutions that solves the research questions, and the problem defined at the previous chapter. As explained as the methodology of this paper, five different options of integration between BIM and Data Analytics will be developed for the case study alongside the partner company, ELES.

While the adoption of BIM is still in its initial stages within the organization, ELES has been progressively integrating digital technologies to enhance its infrastructure management and there is a growing recognition of BIM's potential to streamline asset management and maintenance processes. The company's commitment to innovation is exemplified by its Diagnostics and Analytics Centre (DAC), which functions as a hub for mass data collection, advanced analytics, and technical expertise.

The DAC has implemented predictive models, such as the work created partnered with the Institute "Jožef Stefan", developed to forecast maintenance needs for critical components like on-load tap changers, utilizing historical data to optimize operational efficiency (Institute Jozef Stefan, 2023). By connecting the existent, and very advanced, data analysis assets of the company to a model of the substation through a single relationship, it becomes possible to interact and filter data using the 3D visual input and vice versa.

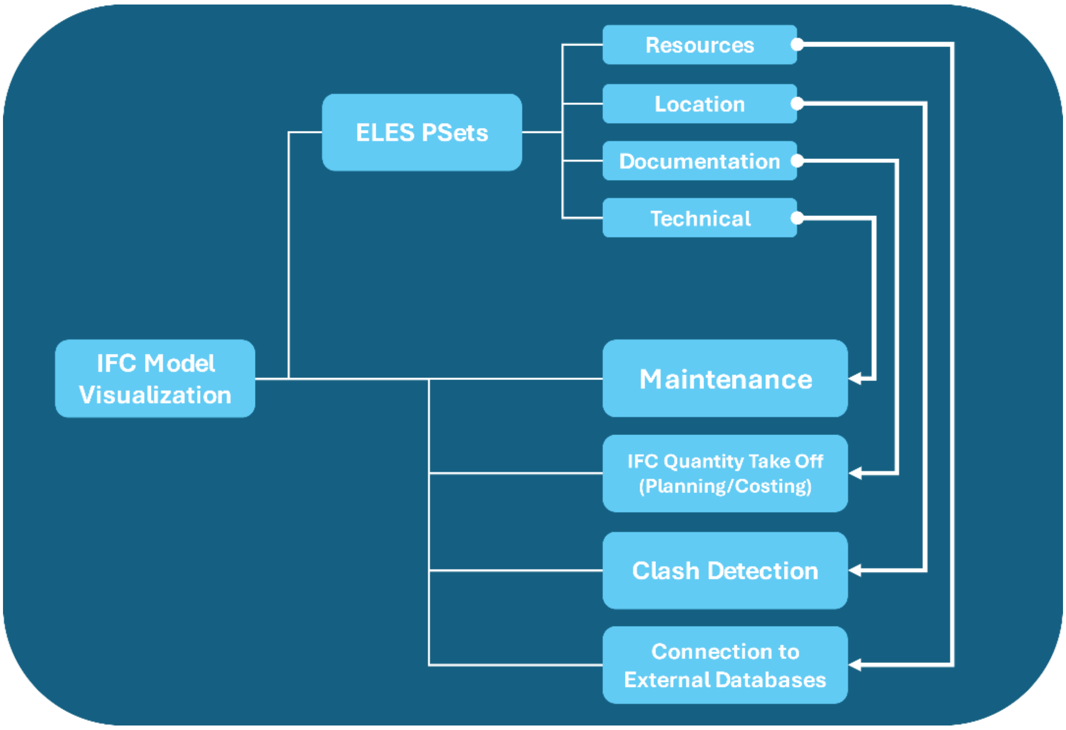


Figure 2 – Framework of interface between types of data and BIM Uses

As for the data made available to work with in the present report, the framework in Figure 2 shows the maximum use from the model to the Case Study referred. The upper cluster defines the Property Sets that ELES had created with their business partner IBE during the development of the models. Resources, Location, Documentation and Technical information are the summaries of interest to the company, among other property sets, each of them, although created following the concept of LOIN (Level of Information Need) (ISO 7817-1, 2024) purposes and not BIM uses specifically, can mainly be linked to at least one specific BIM Use (PennState, n.d.) (e.g. Maintenance, Quantity Take Off, Clash Detection). The connection between BIM model information and external datasets opens a big perspective of possibilities for exploration of all different sets of data that ELES' DAC has acquired over the years linked to their facilities, also further BIM Uses.

5.1 Strategic Use of Data, Graphics and filters

Ther main objective of the collaboration with ELES is to utilize visual insights which in a long-term case, can also better their ability to provide the management and maintenance of stations and equipment. It was strategically defined, in agreement with ELES representatives, as important data and data visualization options for those goals the following:

- Page for Asset Health Index:
    - External dataset aligning the unique code 'SREDSTVO' to age of equipment and its period of validity.
    - View of historic evolution graph of maintenance, with the 'Grades' given by the responsible inspectors. Those grades must vary by criticality, from 1 (one) to 5 (five), 1 being least urgent of replacing and 5, the most urgent.
- Graph for costing of replacing equipment, to be provided in the same dataset as the maintenance history.
- Page for technical information and Failure events:
    - Graph of listing the events of failure logs.
    - 3D View with colouring filter by criticality of error. Varying between Maintenance Needed, Maintenance Planned and No Problem.
- Page for identifying if each equipment is managed by ELES or not.
    - In the dataset primarily sent as external and filled in the model as metadata, this could be identified in the filling of the parameter 'SREDSTVO', if it is correctly filled, the equipment is managed by ELES, if it is blank or filled with a "-" (hyphen), it is not managed by ELES.
    - 3D viewer graph filtered by colour, 'green for managed by ELES', red for 'not managed by ELES'.

    - Toggle button to activate/deactivate the colouring of the filters.
- Page for IFC quality evaluation:
    - Graph showing types of models.
    - Graph defining information provided by models.
    - Filter identifying lack of 'SREDSTVO' identifier parameter.

Alongside the agreement with the Data Analytics Center from ELES, the strategy for this BIM-based Power BI dashboard was complemented by theory grounded in Chaomei Chen's (2006) Information Visualization principles, ensuring each view maximizes cognitive support, knowledge amplification, pattern recognition, and decision-making utility. In line with Chen's framework, the dashboard follows the classic "overview first, zoom and filter, then details-on-demand" paradigm described by Shneiderman (1997). This approach off-loads mental work to the visual system, reducing the "manual labour" of searching through raw data, so users can focus on insight rather than data retrieval. Each dashboard page will correspond to a specific BIM model and the information the model can offer, a first overall page with a federated model will also be a part of the report.

- Dashboard First Page: Federated Model Overview (All BIM models displayed together)

The federated overview provides a high-level 3D visualization of the entire substation model, functioning as the dashboard's cognitive "big picture". This reflects Chen's concept of shifting the unit of analysis from individual items to an integrated knowledge domain view. By presenting all disciplines together, the overview reveals emergent structural patterns and interdependencies across the project. With this visualization of the project users can immediately detect spatial relationships, clusterings of components, or potential conflicts that would remain hidden in siloed data. The design aligns with empirical evidence that a clear overview boosts higher-level understanding and primes effective navigation through the digital construction. In Chen's (2006) terms, this overview mitigates the "information access fault" by allowing users to retrieve needed information at a glance instead of "shovelling" through thousands of data points. This broad contextual awareness enhances decision-making, as stakeholders can rapidly recognize global patterns and focus their attention where anomalies or critical areas appear.

- Dashboard Second Page: High-voltage Equipment (Technical equipment BIM model displayed)

The HV Equipment page dives into the most data-rich model, containing detailed alphanumeric attributes for high-voltage components. This corresponds to a "zoom and filter" stage of the visual analytic process, where the user examines a specific subset of the domain in detail. Following Chen's (2006) knowledge domain visualization logic, HV equipment is treated as a specialty within the broader project domain, essentially focusing on one "cluster" of the information space for deeper insight, as part of a due diligence process during the buyout of the substation. The dashboard couples an interactive 3D view of the equipment with linked data tables and charts, an embodiment of multiple coordinated perspectives.

Chen's (2006) empirical survey underscores the importance of such multi-faceted views: different users leverage spatial visual memory versus symbolic data in varying ways. By providing both a spatial model and abstract data charts, the visualization supports individual cognitive differences – for instance, a user with high spatial ability might spot a pattern in the 3D layout, while another relies on tabular details. Crucially, the combination enables pattern recognition across modalities: one can identify clusters of equipment by type or voltage level in the model and see their specifications or quantities in the data charts simultaneously.

This design echoes Chen's point that insights often emerge from connecting lower-level perceptual cues to higher-level tasks. In summary, Page 2's strategy is justified by Chen's principles of focus + context interaction and empirical findings on visual memory: it maximizes information retrieval and understanding for complex equipment data by blending immersive visualization with analytic detail. This yields a decision-making advantage – users can pinpoint specific equipment issues or outliers in context, with the visual and numeric evidence reinforcing each other.

- Dashboard Third Page: Foundations and Infrastructure (Structural BIM model displayed)

The Foundations page presents the substation's foundation elements via a 3D model and QTO data, despite minimal alphanumeric attributes. Here the visualization leans on spatial cognition and basic perceptual cues to convey information. Chen's (2006) empirical review emphasizes that even "lower-level" perceptual tasks – such as recognizing spatial alignment, shapes, or counts – are crucial for insight. By visualizing foundation locations and dimensions in 3D, the dashboard allows users to immediately perceive patterns like the grid layout, relative depths, or any irregular spacing of footings.

Human vision excels at detecting such spatial patterns, providing cognitive support that a raw list of coordinates or volumes would not. In Chen's (2006) terms, the spatial–visual interface is "more likely to make a lot of difference" in user understanding than text alone, for instance. The page design avoids unnecessary complexity or photorealistic detail, instead favouring an abstracted view that aligns with human perceptual abilitiespage-one.springer.com – for example, using simple shapes or consistent colours for all foundations so that outliers pop out to the viewer.

This follows the guideline of designing visualization to relate to the user's perceptual strengths rather than overwhelming with realism. Coupled with a basic data table summarizing counts or volumes, the page supports decision-making by enabling quick cross-checks, like if number of modelled foundations and their positions are correct according to the plan. By grounding the view in spatial context, the dashboard amplifies the user's ability to verify and reason about the foundations efficiently. This is an outcome that echoes Chen's (2006) observation that well-crafted visualizations reduce cognitive load and "provide valuable insights into the complex relationship between tasks and visual cues".

- Dashboard Fourth Page: Superstructure (Above-ground built objects BIM model displayed)

The Superstructure page focuses on the large structural portal frames, concrete slabs, or any other built structures above ground in the area in study, again using a 3D model with minimal attached data. The theoretical backing for this page is similar to Page 3, emphasizing immersive spatial understanding and pattern detection. In this case, the portal frames are visualized in context, which provides immediate cognitive cues about their arrangement and their relationship to other elements.

The task here is structural verification and pattern recognition (e.g. checking alignments, clearances, repetition of standard portal units), which is best served by a clear 3D overview rather than dense data fields. By reducing extraneous detail and highlighting each portal's geometry, the visualization taps into the viewer's associative memory – seeing the portal frames in situ allows recalling design intent and spotting discrepancies naturally. This resonates with Chen's (2006) summary that visualizations should be evaluated in terms of how they support the user's perceptual and cognitive processes, not just how much data they display.

- Dashboard Fifth Page: Terrain, Exterior Appliances and Urbanization (Earthworks and urbanistic BIM models displayed)

The Terrain and Exterior Design page provides the geographical and site context via the terrain surface in a 3D view as Chen's (2006) insights on spatial metaphors and immersive environments strongly underpin this page's design. By visualizing the substation in its terrain, the dashboard leverages humans' innate spatial orientation abilities. By recognizing slopes, distances, and the substation surroundings, users end up building a mental map that aids in navigation and planning. This addresses known challenges of wayfinding in virtual worlds.

Additionally, aligning the visualization with real-world perceptual cues (e.g. consistent scale, recognizable terrain features) rather than abstract graphs means the information is immediately intuitive, reflecting Chen's (2006) guidance to design for perceptual realism only insofar as it benefits user cognition. In summary, Page 5 provides cognitive support by grounding the substation model in a familiar spatial context, allowing users to seamlessly integrate project data with real-world geography to inform their decisions.

Across all five pages, the dashboard's design exemplifies Chen's (2006) vision of information visualization as a tool for knowledge crystallization and insight. By combining an overview, detail structure with interactive 3D spatial displays and data charts, the dashboard aligns with empirically supported principles to reduce cognitive load and enhance pattern recognition. Each page is tailored to the nature of its data (or model) and the expected user tasks, reflecting the "interdependence between task features and interface design" that Chen emphasizes. This theoretical framework ensures the BIM dashboard is not just a collection of visuals, but a coherent environment for cognitive work – one that amplifies human intelligence by visually synthesizing complex BIM information into actionable knowledge.

Finally, the structure of the Power BI dashboard will by defined as:

- Dashboard Page 1: Federated Model Overview (All BIM models displayed together)
- Dashboard Page 2: High-voltage Equipment (Technical equipment BIM model displayed)
    - Combined with ELES' Page for Asset Health Index and ELES' Page for technical information and Failure events.
- Dashboard Page 3: Foundations and Infrastructure (Structural BIM model displayed)
    - Combined with ELES' graph for costing of non-HV equipment (e.g. building structure and other elements).
- Dashboard Page 4: Superstructure (Above-ground built objects BIM model displayed)
    - Combined with ELES' graph for costing of non-HV equipment (e.g. building structure and other elements).
- Dashboard Page 5: Terrain, Exterior Appliances and Urbanization (Earthworks and urbanistic BIM models displayed)
    - Combined with ELES' graph for costing of non-HV equipment (e.g. building structure and other elements).
- Dashboard Page 6: Federated IFC quality evaluation (All BIM models displayed together)
    - Combined with ELES' suggestion of graphs for identifications if each model is managed by ELES or not.

5.1.1 ELES Internal Sample Data ETL to Power BI

The ETL (Extraction, Transformation and Loading) stage of the work for this scope were considered quite simple, as the documentation of the real data delivered were already well-structured.

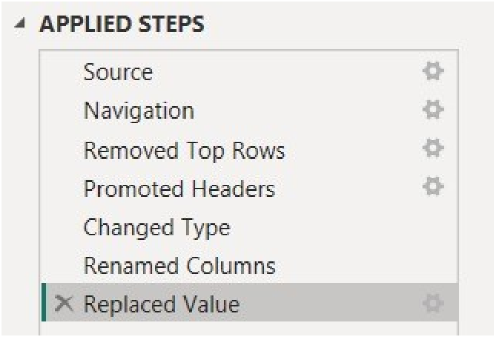


Figure 3 - ETL Steps

As Figure 3 shows, only 7 (seven) total steps, or 5 (five) of customization of the tables were necessary to guarantee a ready-to-use column structured set of tables. The written code of the five steps are as follows:

- = Table.Skip(#"CURRENT TRANSFORMERS_Sheet",1)
- = Table.PromoteHeaders(#"Removed Top Rows", [PromoteAllScalars=true])
- = Table.TransformColumnTypes(#"Promoted Headers",{{"Column1", type any}, {"LOKACIJA", type text}... **[Iteration for specific columns of each table]**
- = Table.RenameColumns(#"Changed Type",{{"Column1", "Entry No."}})
- = Table.ReplaceValue(#"Renamed Columns","NOTES:","",Replacer.ReplaceValue,{"Entry No."}) **[Iteration to other notes in this column]**

To be able to filter data to specific needs all in one page of the dashboard, all the sheets need to be identified and later combined in one master dataset. To combine equipment data from different sources into a unified visualization table in Power BI, it's necessary to follow a structured transformation process using Power Query Editor. This was done as follows:

- Adding a Custom Column for Classification

Each equipment table must be enriched with a custom column to identify its source or type. This is typically done by adding a column called "Consult Type" using the M code function Table.AddColumn. For example:

= Table.AddColumn(PreviousStepName, "Consult", each "SURGE ARRESTERS")
This step ensures that when multiple tables are combined, it's still possible to identify the origin of each row based on the equipment type.

- Append Queries

Once all source tables are structurally aligned, they can be appended into a single table using Power BI's 'Append Queries as New' feature under the Home tab. This consolidates all equipment types into one centralized dataset. The final M code function looked something like this:

= Table.Combine({BUSBARS, BUSHINGS, #"CABLE TERMINATIONS", #"CIRCUIT BREAKERS", CONDUCTORS, #"CURRENT TRANSFORMERS", DISCONNECTORS, #"POST INSULATORS", #"POWER TRANSFORMERS", #"SURGE ARRESTERS", #"VOLTAGE TRANSFORMERS", #"WALL BUSHINGS"})

- Rename 'Consult' column to filters

In order to filter the combined data in the visuals, the 'Consult' term was substituted by 'Type of Equipment' in the column name:

= Table.RenameColumns(Source,{{"Consult", "Type of Equipment"}})

These steps allow a fair use of the data to display scenarios in the dashboard interface.

5.1.2 Standardized Graphics and Filters of Alphanumerical Data in Power BI

Once all metadata is complete and combined in one consult, the data can be saved and loaded into the dashboard interface of Power BI. Before relating the data to 3D viewers in visuals, one last cleaning step needs to be done, to avoid empty rows, that was not cleaned in the ETL process in the 'Power Query Editor' of Power BI to avoid losing important data.

A table visual is instanced and all identification properties, as seen in Table 1, are inserted into the visual.

Type of Equipment	SREDSTVO	SREDSTVO_TIP	SREDSTVO_VRSTA	POLJE	POLJE_ID	DOKUMENTACIJA	EAM	FAZA	CIPO	TIP
BUSBARS										
BUSHINGS										
BUSHINGS						-				
CABLE TERMINATIONS										
CIRCUIT BREAKERS										
CIRCUIT BREAKERS										
CIRCUIT BREAKERS	[redacted]									
CIRCUIT BREAKERS										
CIRCUIT BREAKERS										
CIRCUIT BREAKERS	MXA129451	VNO	ODKL	Zvezno polje 110kV	AEZ02	Ožbalt065	OZBHSE02Q0	-	CIPO Maribor	3AQ1FG
CIRCUIT BREAKERS	[redacted]									
CIRCUIT BREAKERS										
CIRCUIT BREAKERS										
CONDUCTORS										

Figure 4 - Table visual in Power BI

The table seen in Figure 4 displayed a set of empty data that received 'Type of Equipment' parameter from each consult combined. To avoid this, it was created a filtering solution directly in the visual.

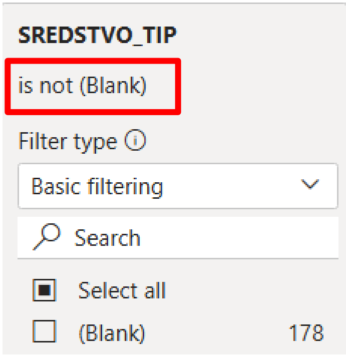


Figure 5 - Power BI filter for not blank

By clicking in the table visual, in the filters panel within 'Filters on this visual' space, the parameter 'SREDSTVO_TIP' is, by the providers standard, always filled in valid rows for valid units of equipment, by selecting 'Select all' and unselecting '(Blank)', just valid rows of the table will show in the visual, as seen in Figure 5.

One of the strategic needs of the company as data provider and dashboard consumers seen in previous chapter is a set of filters by type of equipment, by asset identification and by bay where it is located.

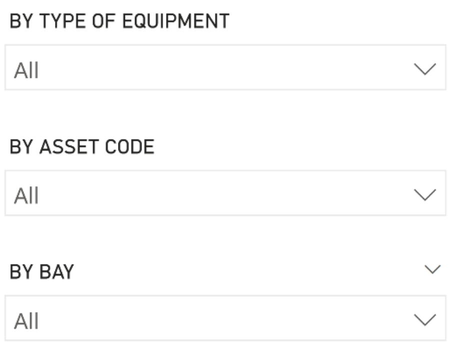


Figure 6 - User friendly filters in Power BI

For each of these filters, parameters associated from the combined dataset are 'Type of Equipment' for Type of equipment, 'SREDSTVO' for asset code and 'POLJE' for bay, as shown in the Figure 6.

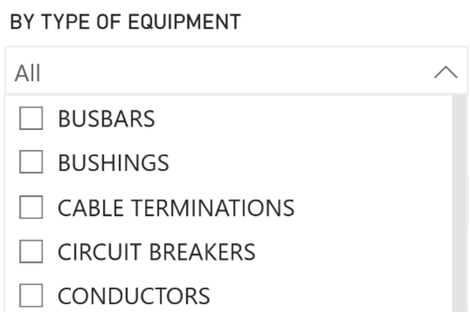


Figure 7 - Dropdown list filtering in Power BI

These filters were created to enhance the user experience when consuming the dashboard, by using the slicer visual and resuming its options to a dropdown menu, as shown in Figure 7.

Another filter defined as a must-have is if the represented object is managed by ELES or another company. To do that, a calculated column was added in Power BI using DAX (Data Analysis Expressions). This was based on the SREDSTVO parameter from the ELES_SREDSTVO property set, which follows a rule: if the value is a hyphen (-), empty, or blank, the asset is not managed by ELES. The process is as follows:

- Create the DAX Column the Data View and locate the table named 'AllEquipment', which contains the unified data for all assets.

Click on "New Column" and insert the following DAX expression:

Managed by = IF (ISBLANK('AllEquipment'[SREDSTVO]) || TRIM('AllEquipment'[SREDSTVO]) = "" || TRIM('AllEquipment'[SREDSTVO]) = "-","Not ELES","ELES")

This expression checks three conditions:

If the SREDSTVO field is blank, if it is an empty string and if it contains only a hyphen (-).

If any of these are true, the equipment is tagged as "Not ELES"; otherwise, it is marked as "ELES". This allows filtering and reporting on which assets fall under ELES's management.

- Repeat the dropdown filter in a Slicer visual as previously explained

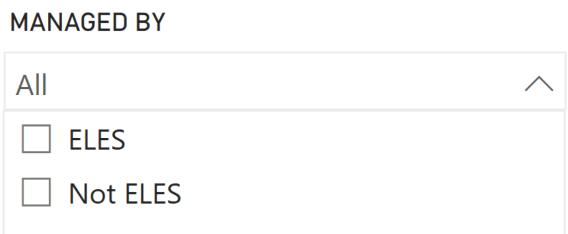


Figure 8 - Managed by filter in Power BI

To create this last filter, it was only necessary to use the column created earlier in values of the visual, as shown in Figure 8.

5.2 Power BI Connectors with Third-party Databases

Some solutions found to develop the present work tend to offer more complex integrated solutions than just to fill the Power BI BIM/3D visualization gap, intending to create a workflow and environment that forms marketable products, subscription services and further a loyal client base.

Those solutions often have a web-based interface connected to a database that will store and process the model data, delivering a dataset that is ready to use into Power BI.

5.2.1 Autodesk Data Connector for Power BI

The Autodesk Data Connector for Power BI is a tool designed to bridge the gap between design data and business intelligence, in which it is made possible to visualize and interact with BIM models, from Autodesk tools, within Microsoft Power BI (citation).

To utilize this connector, it is necessary to export a Data Exchange package within the Autodesk Construction Cloud (ACC), which serves as the database from which Power BI will retrieve the BIM model information. This data exporting process involves selecting specific subsets of project data to share, ensuring that only relevant information is transferred to the dashboard.

Once the project data package is established and saved in the cloud service, the connector allows for the data import into Power BI, where it can be transformed, filtered and visualized according to specific needs. As the query module of BI tools often allows, the dataset related to the model can have its columns associated with other queries and datasets to enable different approaches for visual data analytics.

5.2.2 Autodesk IFC Data Connector for IFC

After introducing the data packages called "Data Exchange", Autodesk allows the use of the Power BI 3D viewer from an IFC file, as the Autodesk Data Exchange for IFC is a recently introduced feature, currently in public beta, designed to enhance interoperability by allowing users to share specific subsets of IFC model data.

To utilize this IFC data packaging feature, it is needed to upload an IFC file to ACC, where an interface will allow the creation of a Data Exchange from the IFC model. This interface will involve selecting the relevant portions of the model to export, which can then be accessed by other applications that are using other Data Exchange connectors, as for the above-mentioned Power BI integration.

5.2.3 Autodesk Data Connector for Power BI Dashboard Creation

To implement this 3D viewer a set of steps had to be followed, as described:

a. Create an IFC Data Exchange (In Beta Stage) from IFC in the ACC account used:

As the IFC Data Exchange is still in beta development stage, two options were used in the present case study, the main Autodesk Data Exchange from Revit will be a safe option to guarantee integral information transfer.

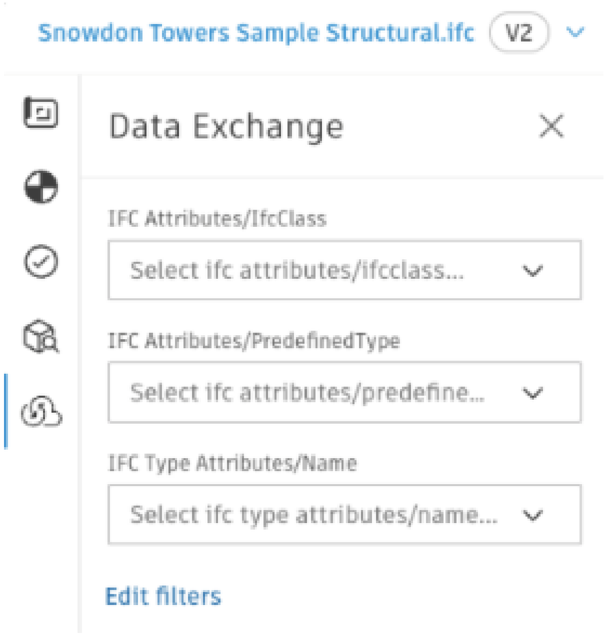


Figure 9 - IFC Data Exchange

In Figure 9, it is possible to check the requisites to export a package of data from IFC in an ACC project. It displays a set of filters to apply to the IFC file before creating the Data Exchange model package.

a.1. Or open the IFC files in Revit and use the Data Exchange Connector for Revit:

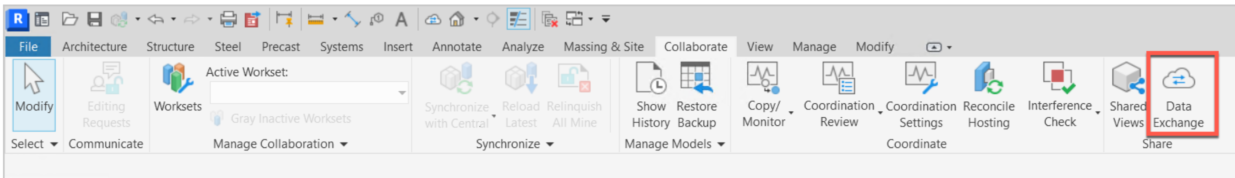


Figure 10 – Data Exchange add-in in Revit

The Data Exchange Connector add-in, shown in Figure 10, can create packages of model views opened in Revit to be uploaded to an ACC active project, which will be connected to the Power BI viewer to load the views onto the dashboard.

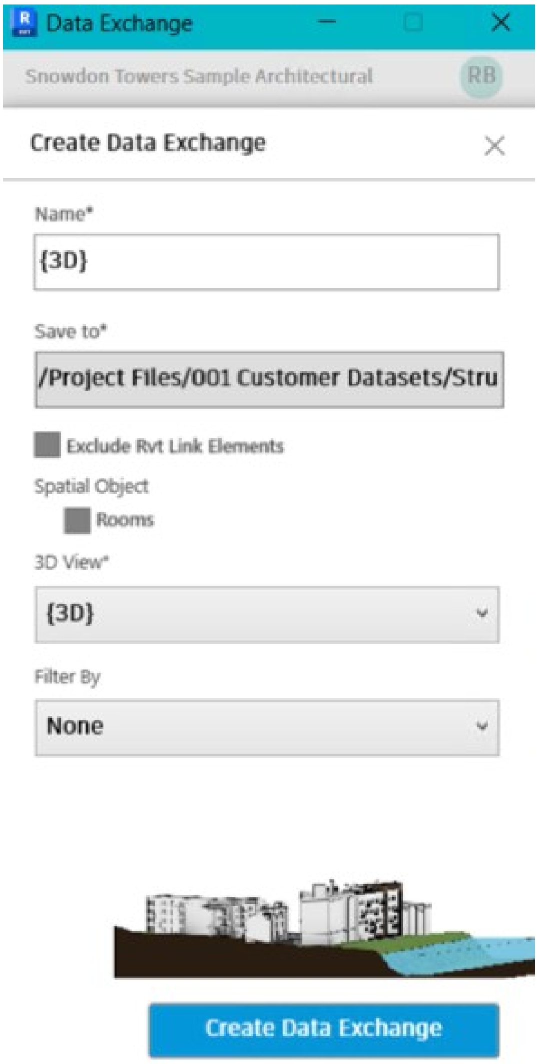


Figure 11 – Inputs to Data Exchange add-in in Revit

The package is defined by a model view and filters, seen in Figure 11, can be applied to it, for the case study in the present work, the export must be a simple 3D view with no filter to avoid losing any data from the models.

b. Loading the visual in an existent dashboard

After downloading and installing the extension, it is simple to start using the 3D viewer, it is necessary to open a Power BI dashboard and select 'Import a visual from a file', as shown in Figure 12:

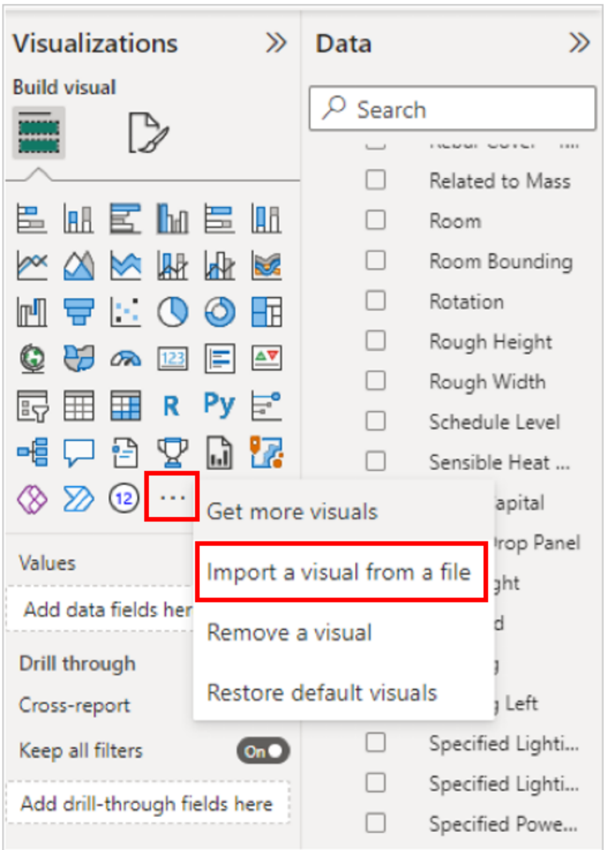


Figure 12 - Import from a file selection

Following the process, it must be selected the custom visual in the correct directory, as displayed in Figure 13:

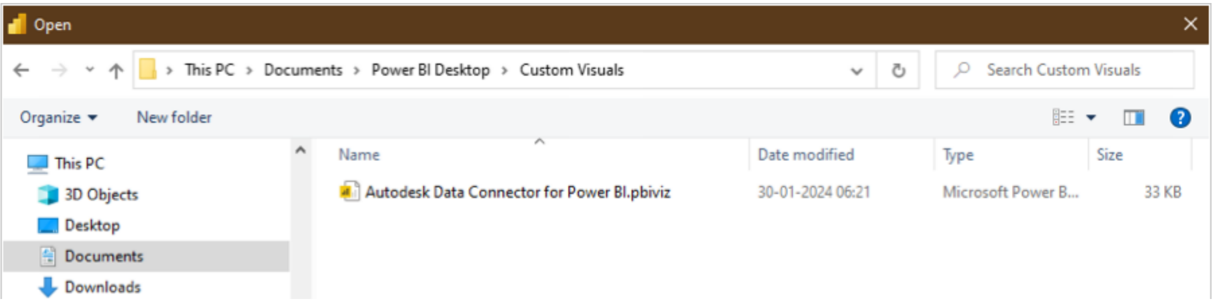


Figure 13 – Selection of custom visual in the directory

This will allow to open the viewer as a new visual in the dashboard.

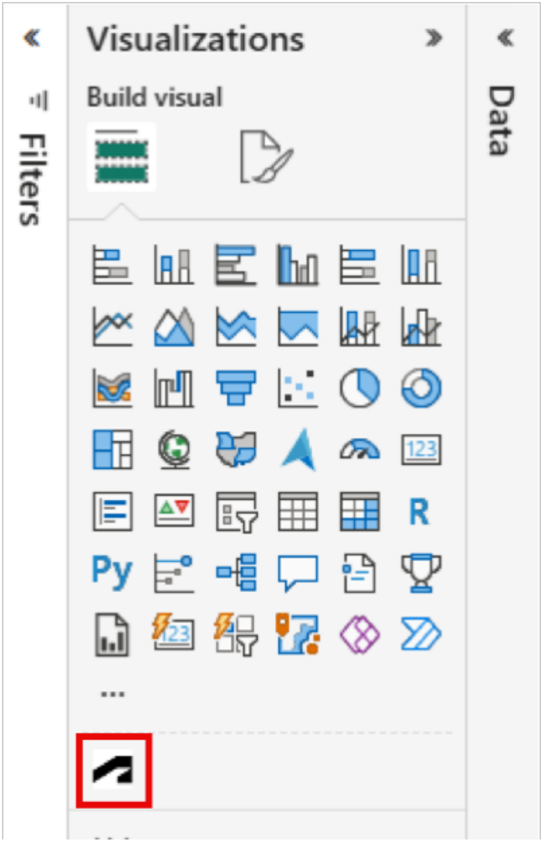


Figure 14 – Display of the Autodesk Data Connector 3D Viewer

The Figure 14 shows how the new visual will be available to use in the dashboard environment.

c. Load Data Exchanges

After having the necessary infrastructure in the Power BI environment, it is possible to bring the Data Exchange packages from the ACC cloud.

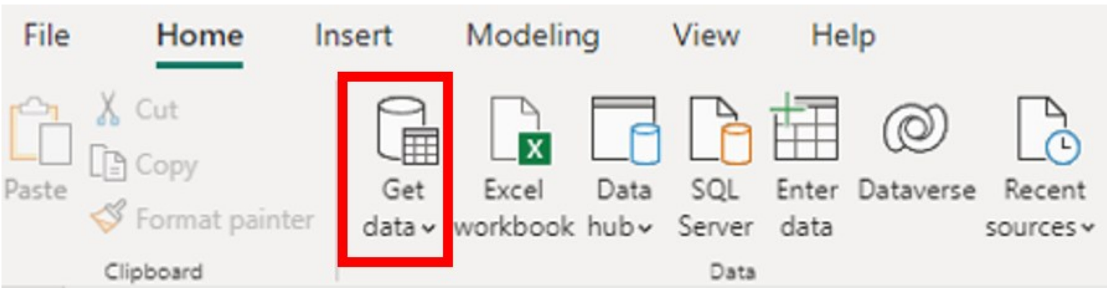


Figure 15 – Load data exchange model views

First step to effectively do that is select ‘Get data’ in the interface of Microsoft Power BI, as shown in Figure 15.

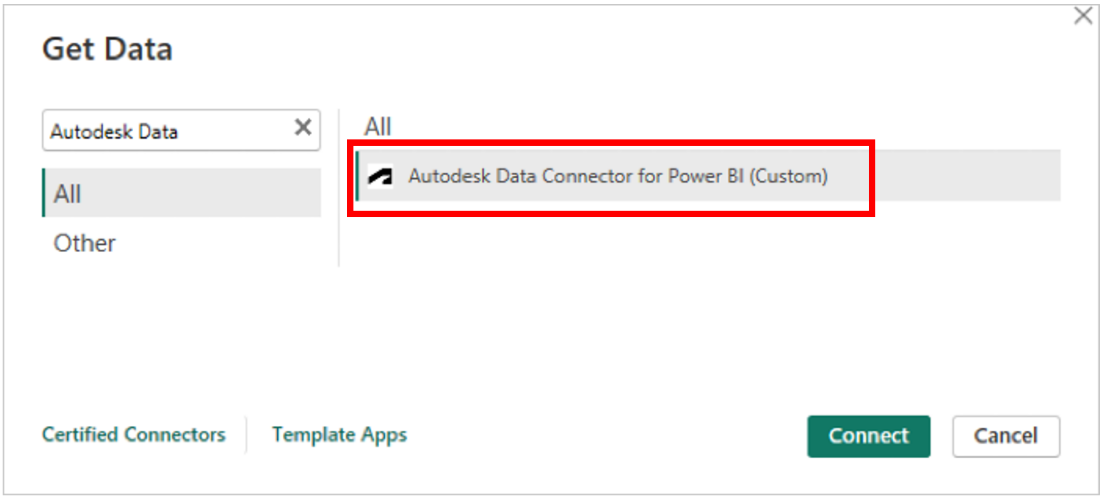


Figure 16 – Selecting Autodesk Data Connector source of data in Power BI

After a pop-up window appears, it is needed to find Autodesk Data Connector source, as shown in the Figure 16.

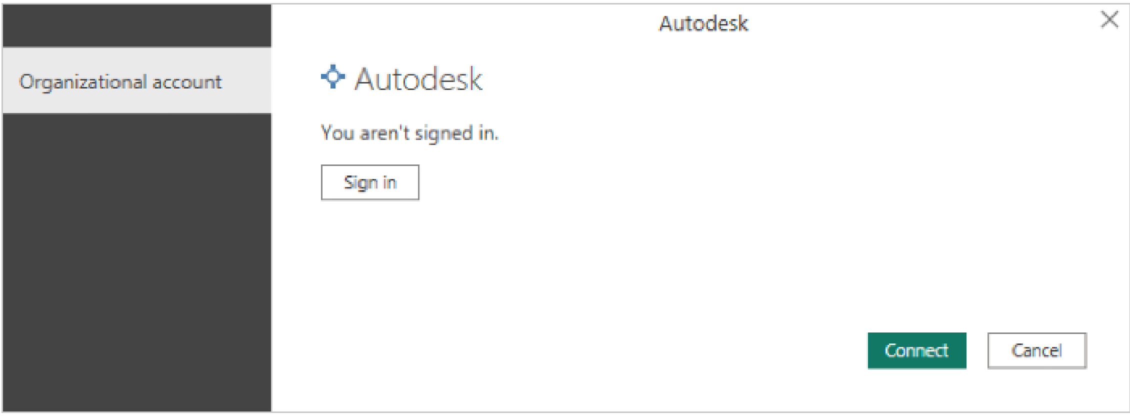


Figure 17 – Login to ACC account

An error might happen, as explained in Autodesk Official website, this should be about the access permissions to the ACC environment. As shown in Figure 17, it is simply needed to login the same account used to load the Data Exchanges packages in previous steps.

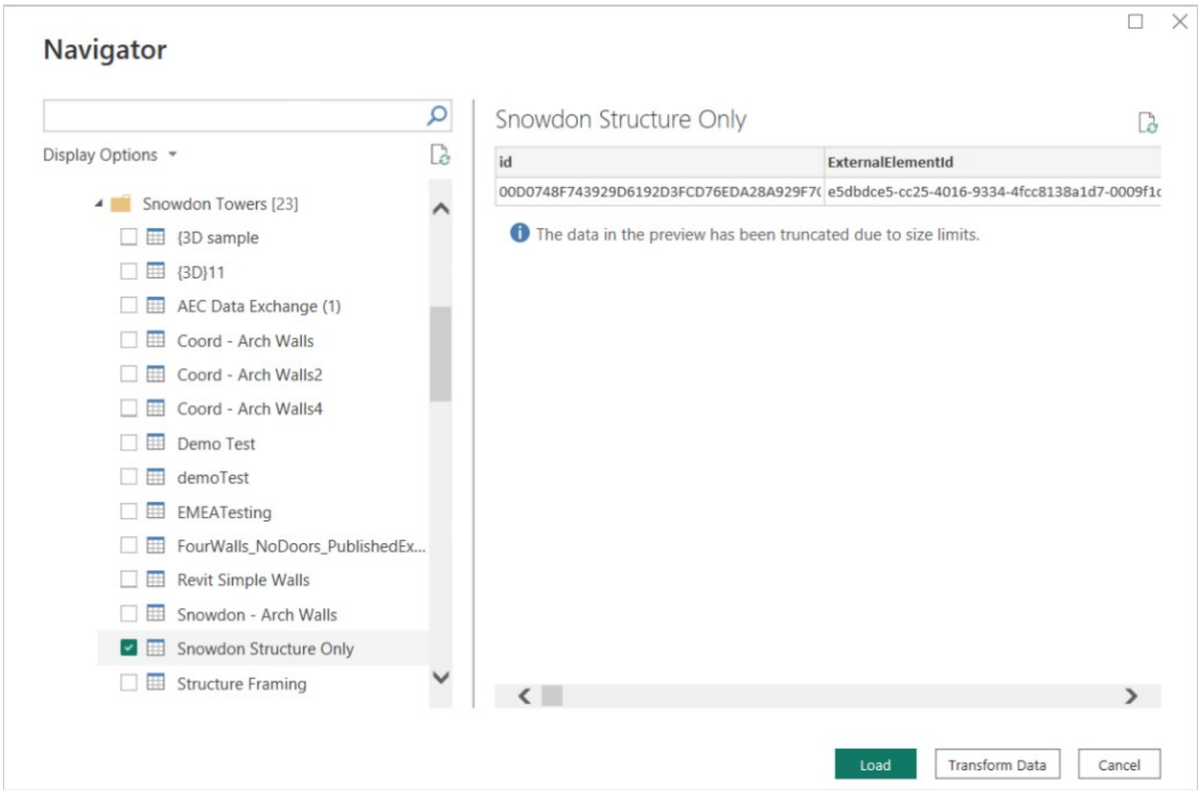


Figure 18 – Data loading from the ACC into Power BI

After solving the access issue, another pop-up window will show up to select the packages exported to the selected project folder, as exposed in Figure 18.

At the end of this step, the dataset of the model will already be available to the dashboard use.

d. Displaying the models in the dashboard

After instancing the visual and loading the models in the dashboard, it follows simply to display the models.

For the 'Viewer' attribute of the visual, it was necessary to find the '.viewer' property of the loaded data of the models. As shown in Figure 19, after this property were assigned to the visual slots, the models automatically appeared in the viewer.

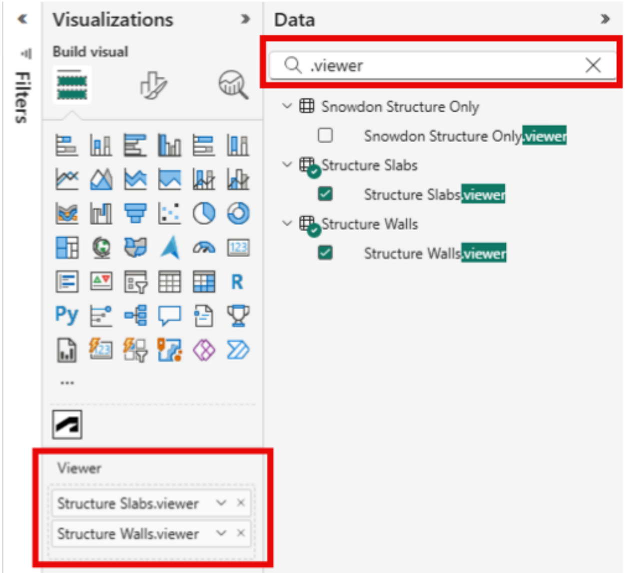


Figure 19 – Displaying the model in the dashboard

e. Creating Data Relationships

Once the BIM model is successfully displayed in the dashboard, it is made necessary to also connect the elements identifiers so the model can interact with a different dataset from a different database.

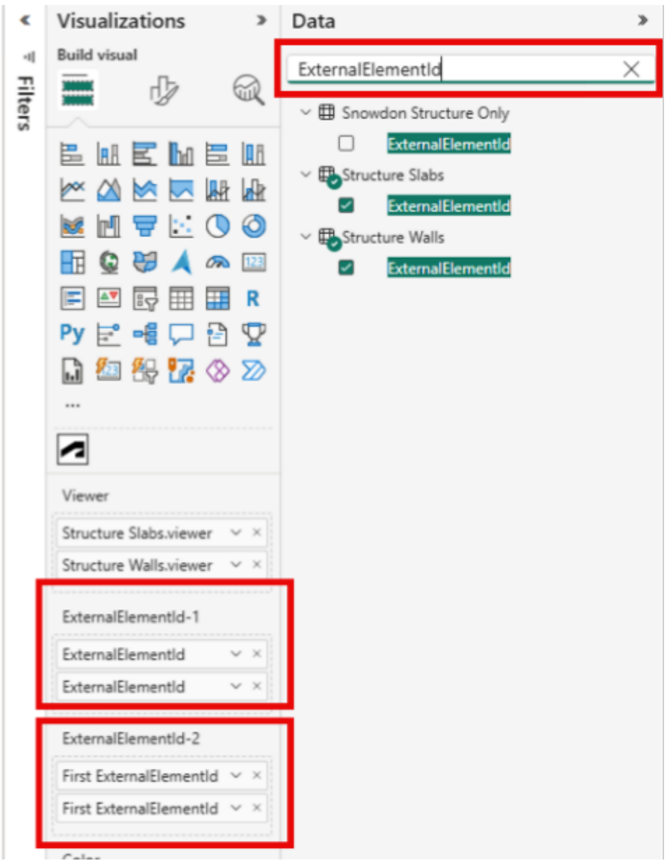


Figure 20 – ExternalElementId property associated to the model viewer

As shown in Figure 20, the property called 'ExternalElementId' should be searched and inputted to the equivalent attribute of the visual. It is assigned twice to avoid errors of filtering elements an assigning textual data to visual data (Autodesk, 2025).

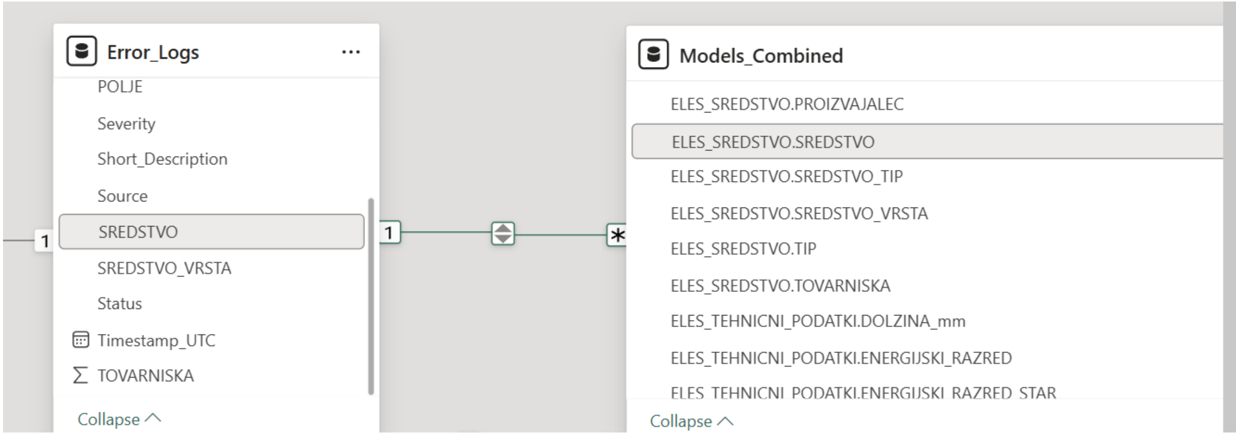


Figure 21 - Relationship using Id parameter

The parameter designated to link unique model elements with the company's alphanumeric database is the SREDSTVO code, as it can be seen in Figure 21, which is a globally unique identifier automatically assigned to each IFC object at creation. This ensures a stable one-to-one relationship between each BIM element and its corresponding database entry, as this identifier remains consistent across exports and imports—providing a reliable bridge for data assignment and synchronization

f. Creating Federated Model Views

Federating models in Autodesk Data Connector for Power BI is quite uncomplicated, as the processing of the models during exporting to ACC already create a specific federation parameter exclusively to the Power BI visual called 'Federated Viewer Mapping'.

By simply relating different model data exchange packages through this parameter, as shown in Figure 22, the models will automatically federate with the specified coordinate system selected when exporting, for this it was used shared coordinates between the models.

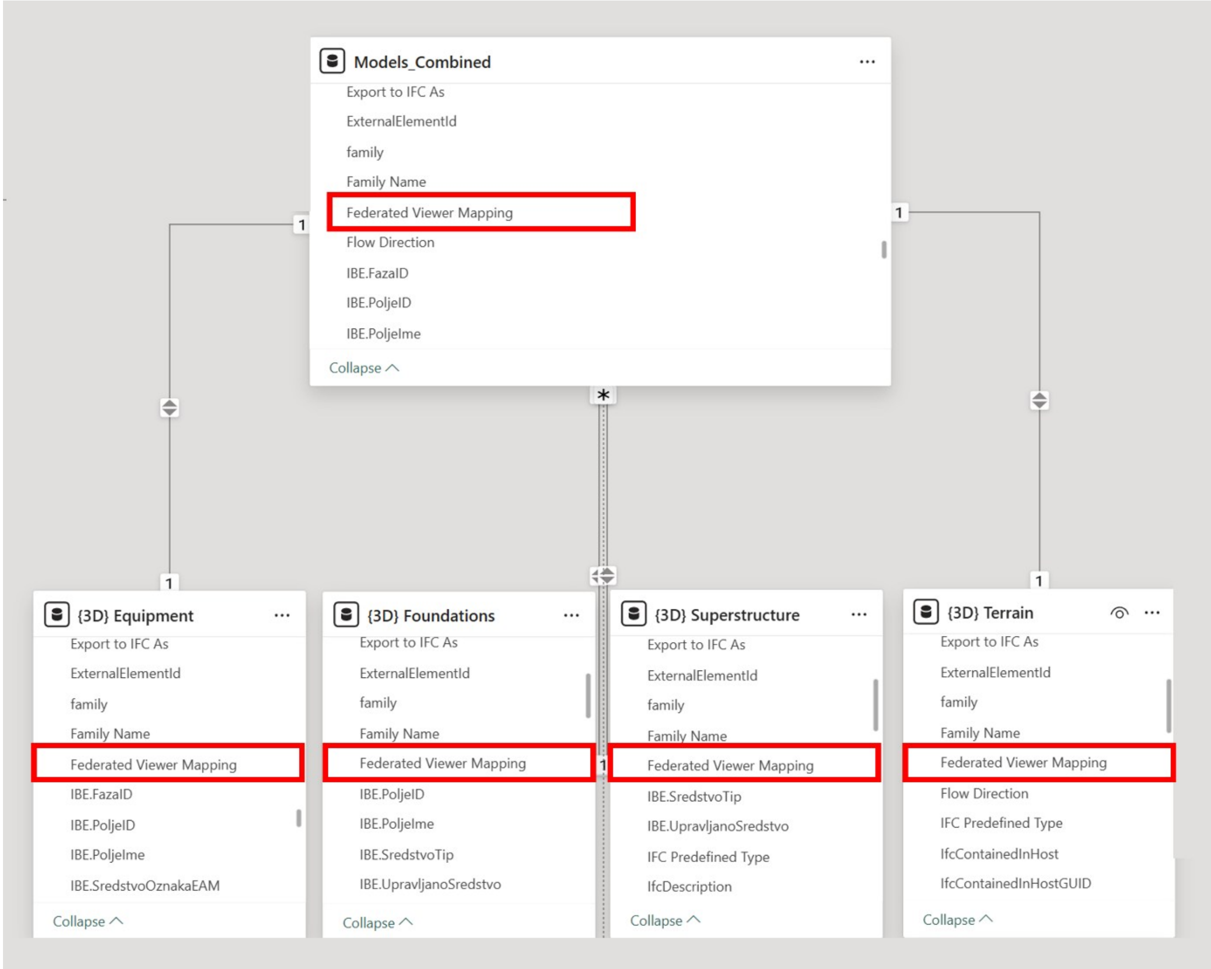


Figure 22 - Federated Viewer Mapping relationship to federate models in Power BI

g. Synchronizing the 3D viewer with the standard dashboard

As a solution that only exists combined with the overall Autodesk environment, all the data submitted to the Autodesk Data Exchange and Connector is processed and is delivered in the best format for the environment itself. After being processed, the IFC models from the present Case Study are presented in Power BI after being retrieved from ACC.

Similarly for every connector tested in the present work, 'SREDSTVO could be used as the identifier to create a relationship between IFC models and external data, but, as displayed in Figure 23 a different approach was addressed, using 'Element ID' to better incorporate all the data to Autodesk environment, to avoid data loss and function loss.

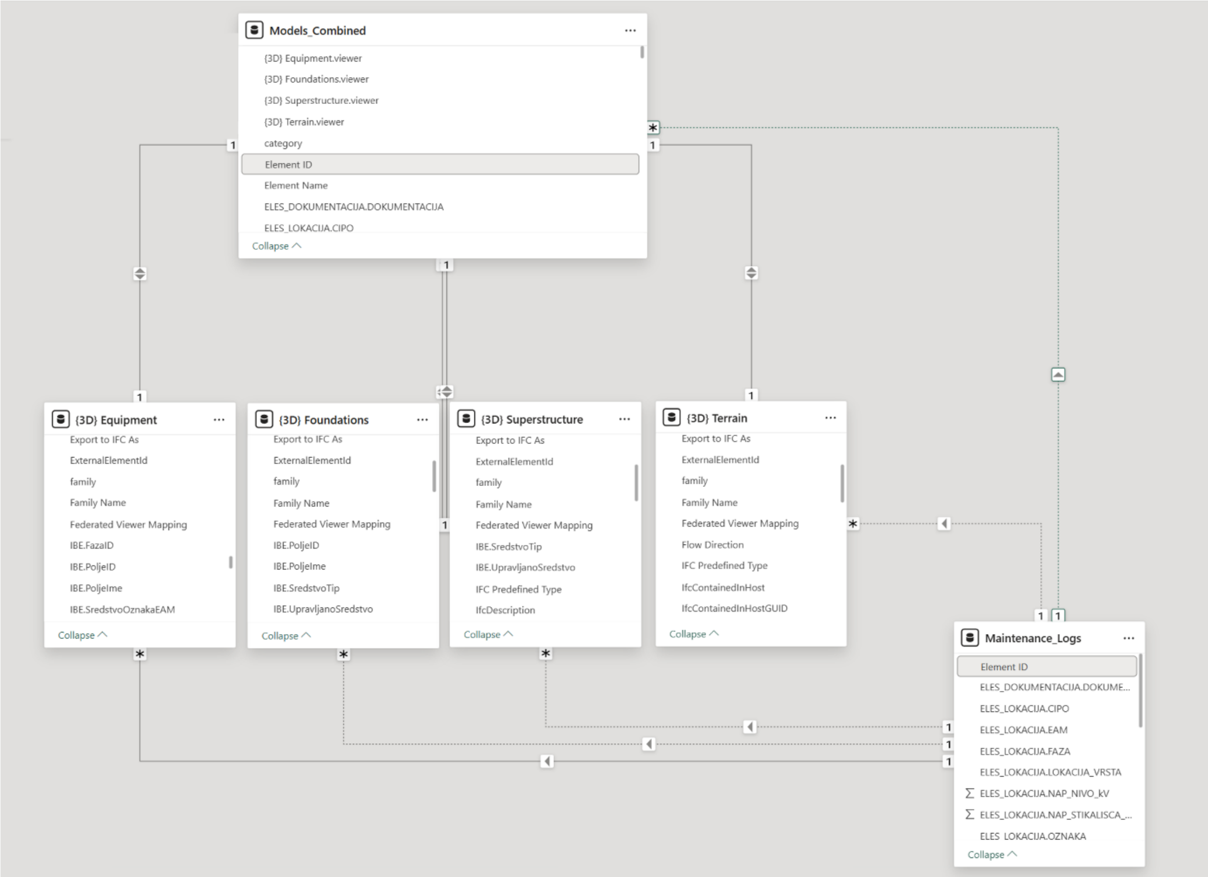


Figure 23 - One to one relationship between 3D model and external data (Autodesk Data Connector)

Using Element ID to connect the data across datasets will avoid data loss due to human error while filling data into BIM models. To connect the Autodesk generated 'Element ID' to data that doesn't have it, a bridge dataset can be built and correlated, again avoiding human transformation of the data.

5.2.4 Speckle Connector for Power BI

Speckle Connector for Power BI offers a similar feature, creating an integration of BIM data BI workflows, as it allows importing structured data from various AEC applications, such as Revit, Rhino, and Grasshopper, into Power BI. Differently than Autodesk connectors, a lot of different formats and software sources can be used within Speckle. Also, the database structure differs from the previously presented solutions as it doesn't rely on Autodesk based CDE, as it uses its own cloud storage with interface for the user.

5.2.5 Speckle Connector for Power BI Dashboard Creation

a. To utilize the Speckle Connector, it is necessary to install it via the Speckle Manager, in their website. Once installed, Power BI will recognize new data sources labelled as "Speckle - Get Model by URL (beta)" and "Speckle - Get Model by URL [Structured] (beta)."

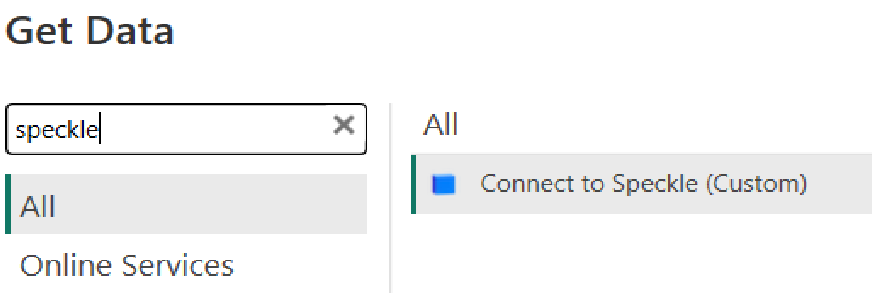
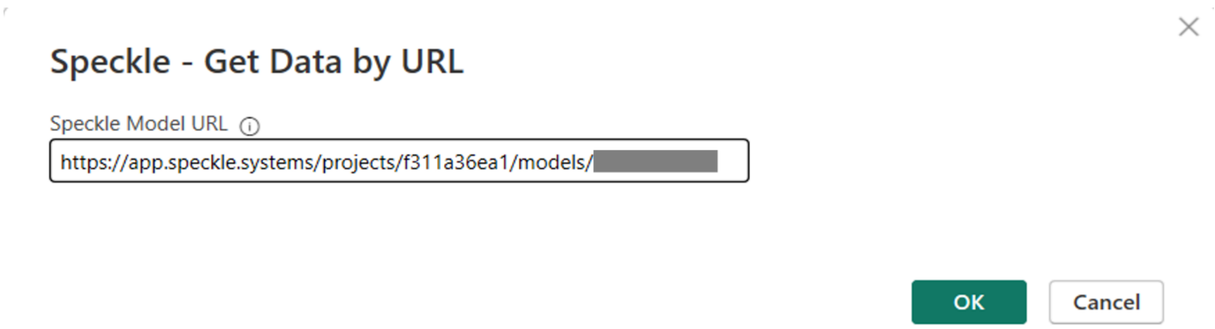


Figure 24 - Getting Speckle connector in Power BI

b. By selecting this option, users can input the URL of a Speckle model, version, or object to retrieve the corresponding data. The connector then imports this data into Power BI, where it can be transformed and visualized according to project needs.



c.

Figure 25 - Inserting IFCs URL to display model in Speckle viewer

Each model has a unique URL, for a federated model, the IDs of the models can be combined from one model’s URL.

d. **Synchronizing the 3D viewer with the standardized dashboard**

As the Speckle connector uses a solution that embodies processing the models and information, which offers similar options of data analytics from the models in the platform, the connection between the model’s dataset and other external datasets is done by following Speckle’s specific tutorials.

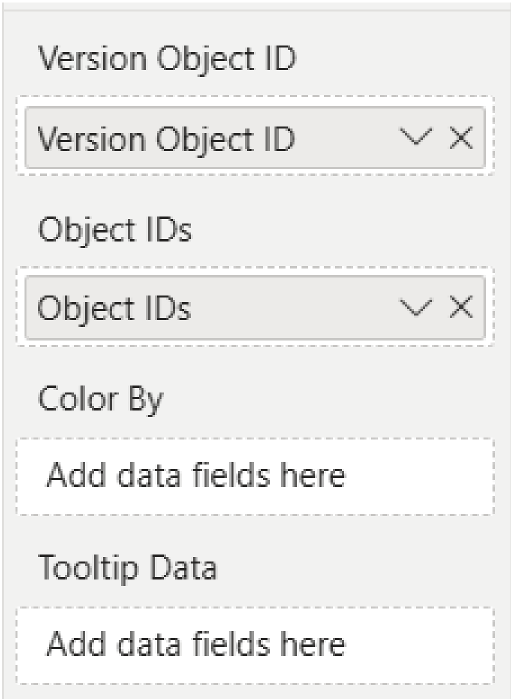


Figure 26 - Synchronizing 3D viewer with external data via object IDs (Speckle)

As Figure 26 shows, Version Object ID and Object ID are mandatory fields to fill in the BI visual with the respective column from the data retrieved by filling the URL of each model, as represented in Figure 24.

From the 3D visual in Power BI, the first two spaces (Version Object ID) are necessary to visualize the model, the other two fields to fill are optional. 'Color by' is a possibility of creating in the model data (or relate to the model data) a parameter to view the models in specific patterns of colours. 'Tooltip Data' is the set of data that will show on the screen as any element from the loaded models gets clicked, this field is also optional but is becomes mandatory to be possible to relate with other datasets.

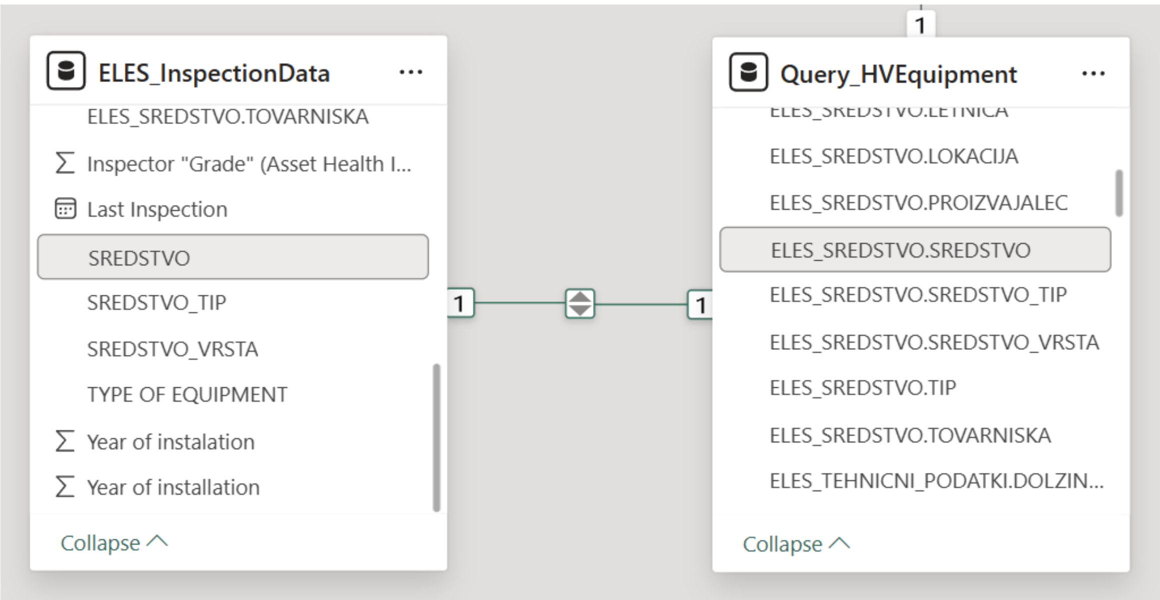


Figure 27 – One to one relationship between 3D model and external data (Speckle)

As seen in Figure 27, the identifier code to link model and external data is the 'Resource Code' or 'SREDSTVO' in the original filling language.

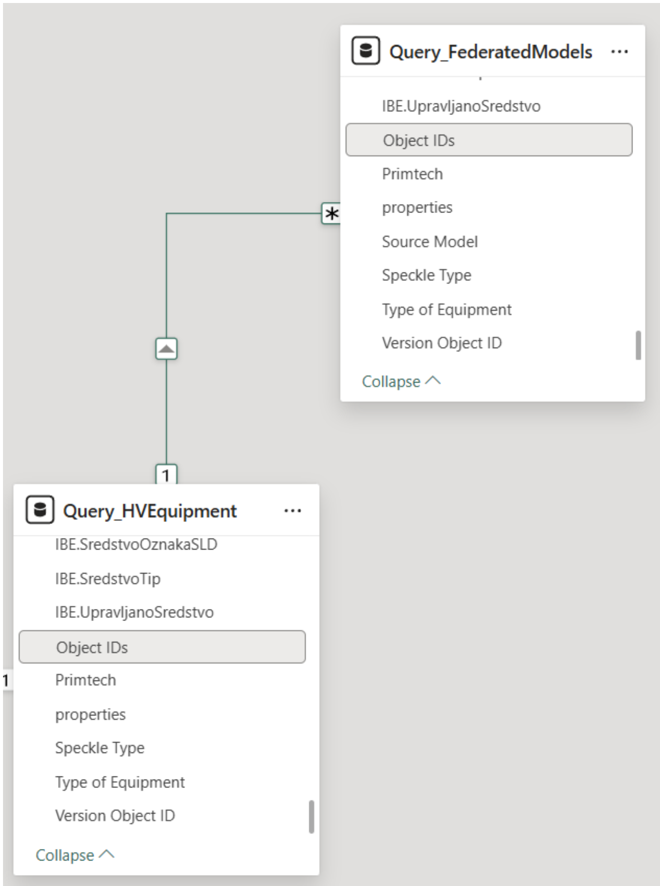


Figure 28 – Relationship between unique and federated models (Speckle)

Although specific models and federated models are queried apart from each other from the speckle database, if necessary to exchange any information between them, a one-to-many relationship from the specific query of the model to the federated one, as shown in Figure 28.

5.2.6 VCAD Standalone for Power BI

A third, very similar, option for importing BIM 3D data into traditional data analytics dashboards is VCAD Connector for Power BI, as it is a specialized tool developed by Blogic.

To utilize the VCAD Connector, it is necessary begin by uploading their BIM files, in this case, IFC files, into the VCAD platform. VCAD then processes these files, extracting relevant data and generating a Power BI template tailored to the specific model. This template includes interactive 3D views, data tables, and filters.

VCAD integration supports features like element highlighting, once selected filters or other singularized model-related data, data-driven colouring, and dynamic tooltips.

To utilize VCAD, an account must be created, and a subscription plan must be contracted, for this case VCAD Standalone version was used to avoid using other product, which would be an Autodesk ACC account.

5.2.7 VCAD Standalone for Power BI Dashboard Creation

To import the visualization for the Power BI, it is necessary to use the webpage of the file manager at BimServices (company holder of VCAD solution) portal and upload the BIM models used for the present case study.

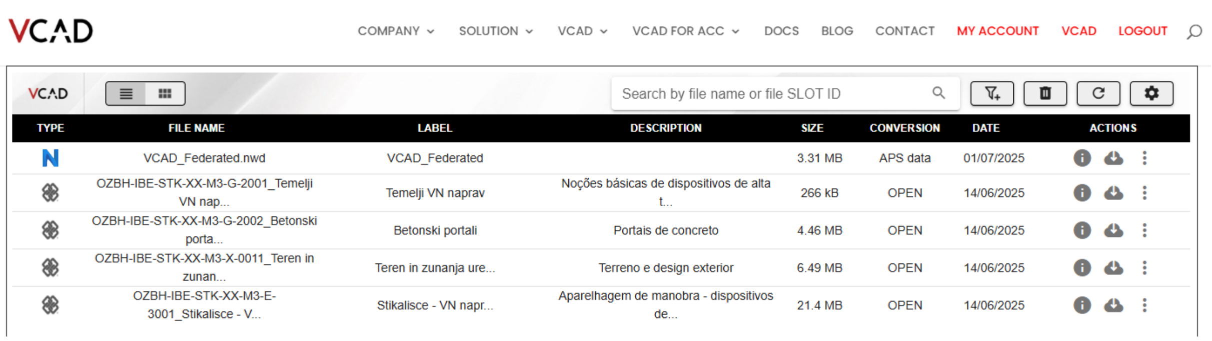


Figure 29 - File manager VCAD webpage

As shown in Figure 29, the interface is quite simple and the four models that are part of the dataset for this work were successfully uploaded, a fifth model is a federated model in NWD format.

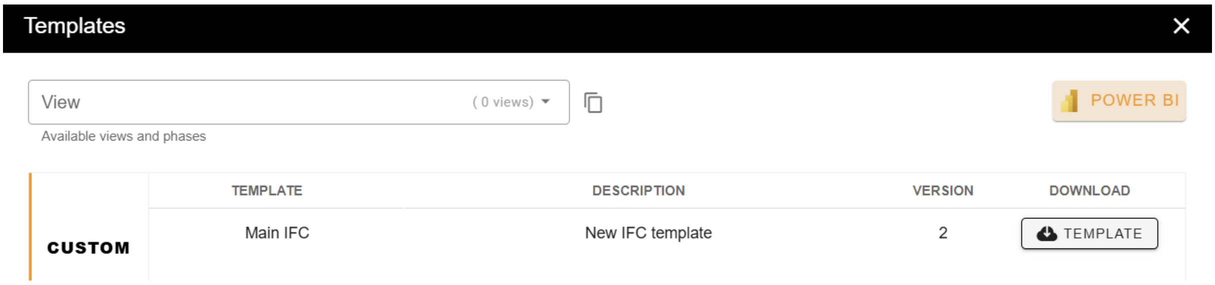


Figure 30 - VCAD Template download

For each model, a template can be downloaded from the file manager webpage, in this case each model will generate a different Power BI dashboard, as shown in Figure 30. Also, in the settings of the main dashboard, it is possible to point to different models and slot IDs for each page of the complete report.

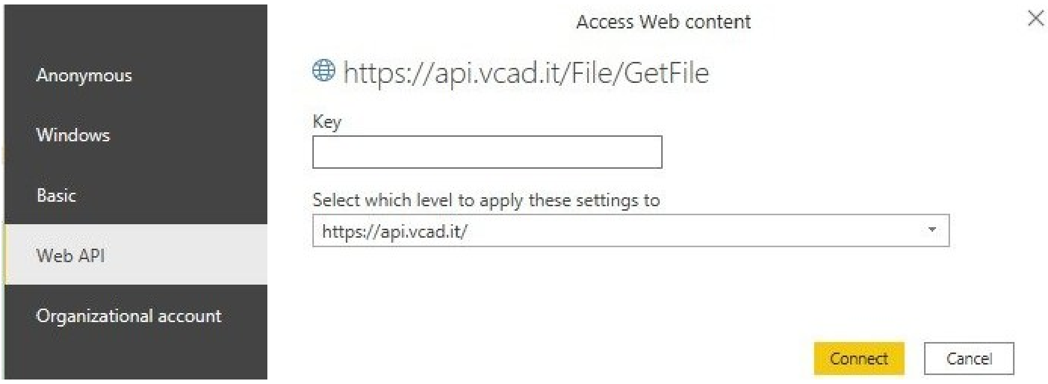


Figure 31 - Web content API access in Power BI

To access the data imported to the online external database, an API key provided by the VCAD platform will be inserted in the 'Web API' access option offered in Power BI, displayed in Figure 31.

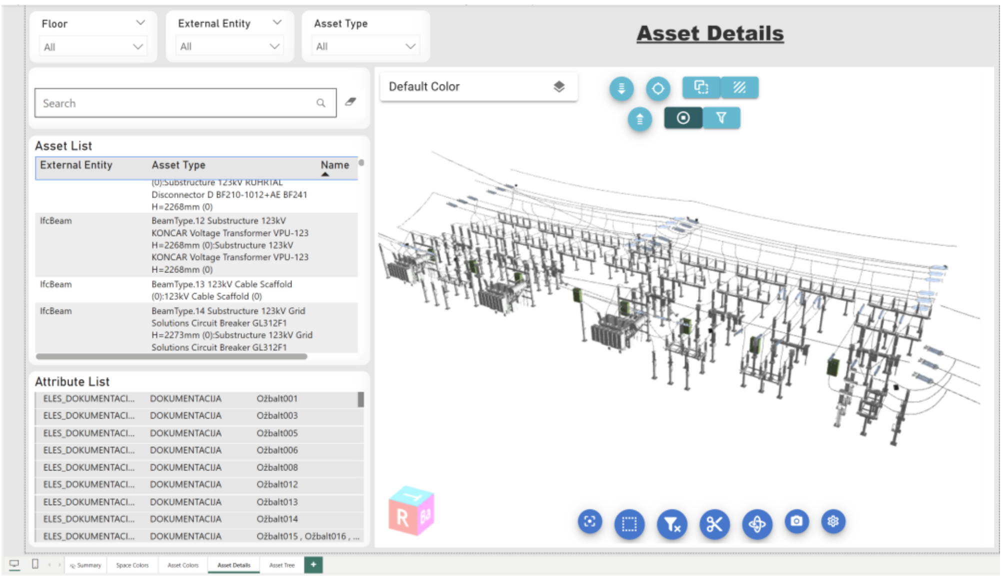


Figure 32 – IFC Sample Dashboard (VCAD)

As Figure 32 shows, a very complete dashboard is delivered as templates available in Figure 29, unfortunately, federated options did not work as expected and the federation of different processed IFCs turned the dashboard heavy option to load, these and other situations contributed for ELES not advancing with VCAD viewer option.

5.3 Power BI Connectors with Local Databases

Some solutions found to fill the Power BI BIM/3D visualization gap rely on a different approach than the previous ones. As previously perceived, options like Autodesk Data Connector, Speckle and VCAD tend to offer more complex integrated solutions, as a way of creating a workflow that includes their tools, to develop marketable products and subscription services and further a loyal client base.

Other found solutions are more directly connected into the main issue, which is enabling a 3D viewer for power BI, not necessarily putting the commercial aspect as a priority. These solutions tend to minimize its costs of operation; therefore, databases are commonly local or locally integrated to other cloud services the user might already have. This type of solution will be considered and tested here.

5.3.1 Flinker Open IFC Viewer for Power BI

As introduced earlier, standalone solutions represent a good opportunity to the company's profile, that already runs a well-developed data analytics department, because it will allow the highest possible level of customization or even help build a tailored option from zero.

Flinker was discovered through LinkedIn, and it consists of a company focused on the development of Microsoft 365 web-apps and add-ins. The Open IFC Viewer for Power BI allow users to embed and interact with a 3D IFC model directly within Power BI Desktop—without needing additional software or credentials. This enhances BIM and business data integration by enabling live element selection, metadata retrieval, and dashboard synchronization (Flinker GmbH, n.d.).

5.3.2 Flinker Open IFC Viewer Dashboard Creation

To set it up, users simply:

a. Install the visual via Microsoft AppSource, making it available in the Power BI Visualizations pane.
b. Create the queries for IFC file for online or local file by copying it from the sample dashboard that can be downloaded from in the same page as the addon, as Figure 32 shows.

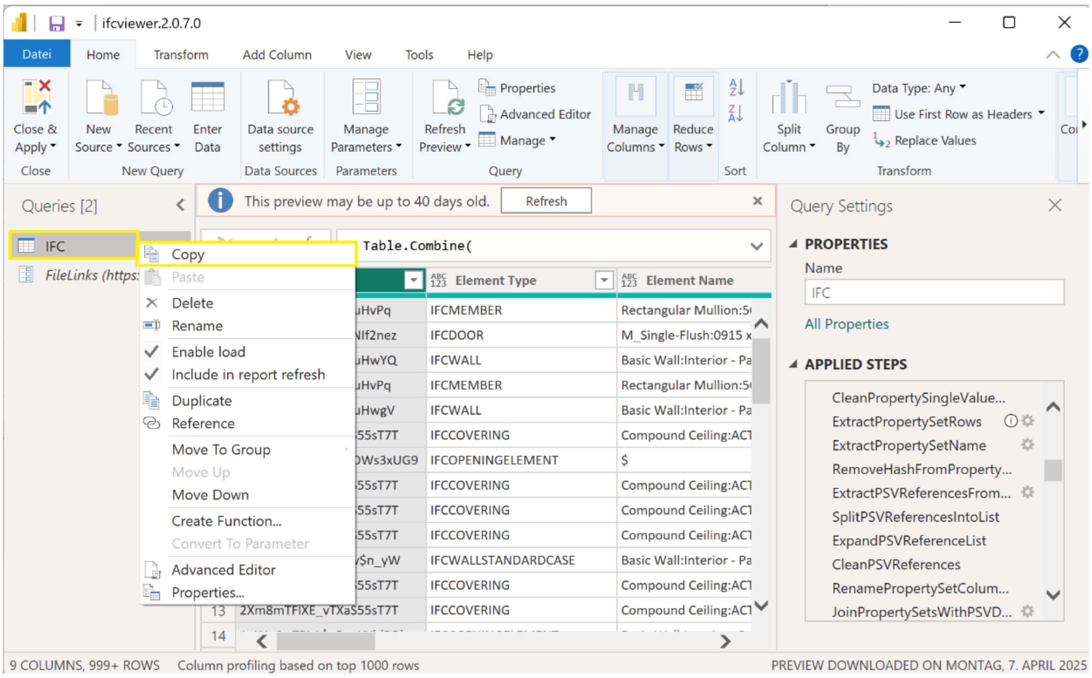


Figure 33 - Copying IFC query from the sample dashboard (Flinker)

c. Load an IFC model by providing a local or cloud URL in the visual's parameter pane.

Figure 34 - Inserting IFCs URL to display model in Flinker viewer

d. Synchronizing the 3D viewer with the standardized dashboard

The sample dashboard query comes already with several steps already applied, which can be understood as the last phase of the processing of the model that all of the providers evaluated in the present work makes.

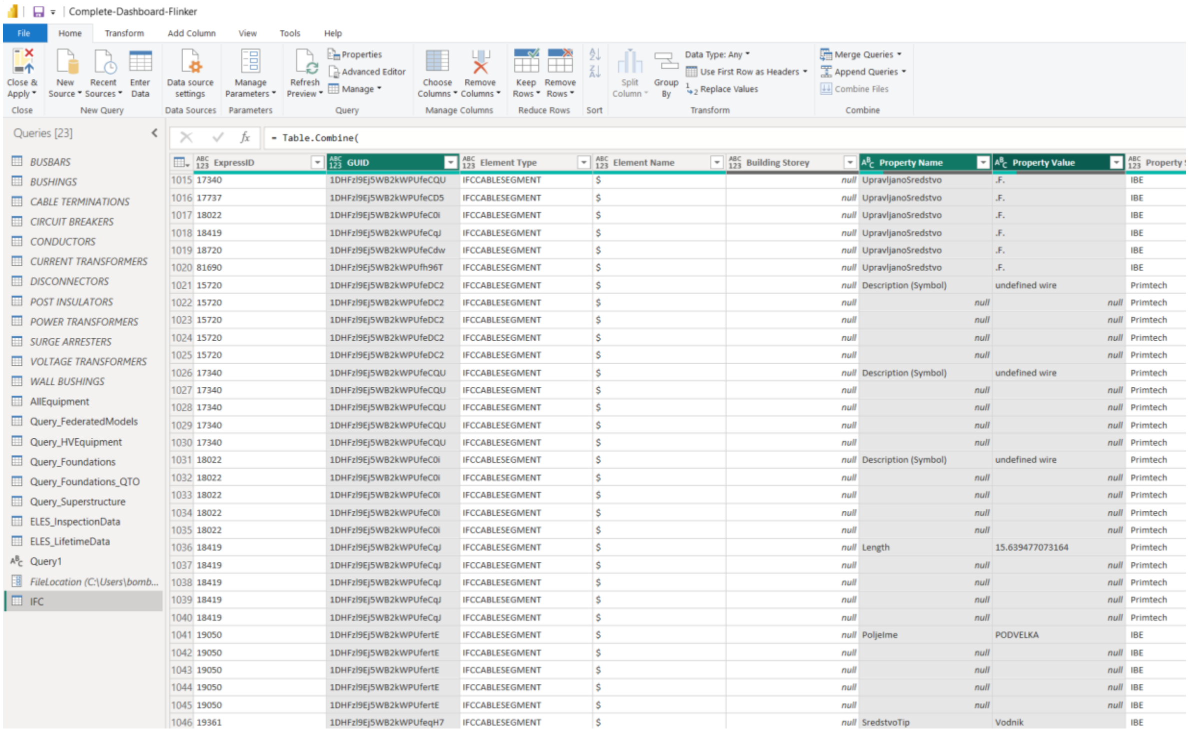


Figure 35 – IFC final table of query from sample dashboard (Flinker)

The final IFC table retrieved from the sample dashboard's query, as showed in Figure 35, draws a very simple connection point between IFC data and external data. Every IFC instance is represented in how many rows is necessary to expand all data related to that instance. This instance is identified in the table by the repetition of its 'IfcGUID' parameter in every row related to it.

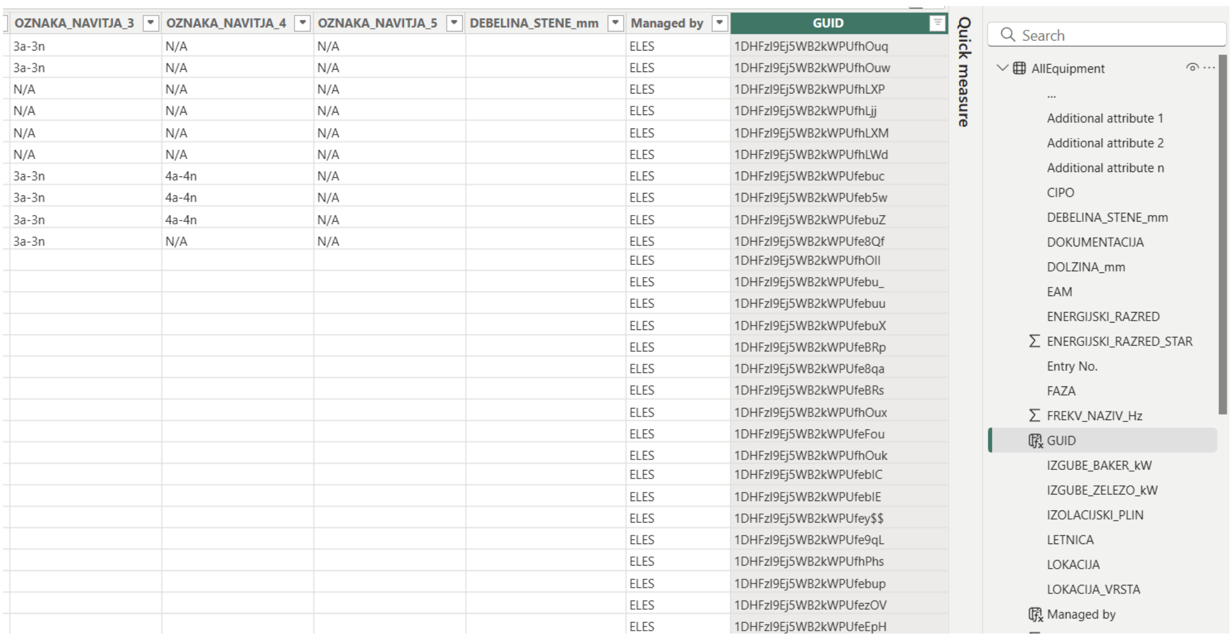


Figure 36 – GUID retrieval from IFC data to external data

The connection by the same ‘SREDSTVO’ attribute used in different viewer options will try to retrieve to the external data the ‘IfcGUID’ attribute of each element mapped by the resource identifier in external datasets.

However, the processing of IFC data through its XML textual data made in the query from the sample dashboard couldn’t explore very well the properties associated to each element in the model. The ‘SREDSTVO’ attribute, then, was not enough to query the model association through ‘GUID’ attribute.

Other unique textual attributes that could work as identifiers were prompted to create the ‘GUID’ column in the external dataset, those attributes are ‘LOKACIJA’, ‘EAM’ and ‘TOVARNISKA’. It is important to highlight that the less attributes needed to create this connection, better, to avoid the reliance on manual work inside the BIM models.

The DAX code with all possible identifiers for the present model’s case study ‘GUID’ retrieval follows the structure:

Table 2 – DAX code block for GUID retrieval (Flinker)

```
GUID =
VAR _sredstvo  = UPPER( TRIM ( AllEquipment[SREDSTVO] & "" ) )
VAR _lokacija  = UPPER( TRIM ( AllEquipment[LOKACIJA] & "" ) )
VAR _eam       = UPPER( TRIM ( AllEquipment[EAM] & "" ) )
VAR _tovarniska= UPPER( TRIM ( AllEquipment[TOVARNISKA] & "" ) )
VAR guidSredstvo =
    CALCULATE (
        SELECTEDVALUE ( IFC[GUID] ),
        FILTER (
            IFC,
            UPPER ( TRIM ( IFC[Property Name] ) ) = "SREDSTVO"
            && UPPER ( TRIM ( IFC[Property Value] & "" ) ) = _sredstvo
        )
    )
VAR guidLokacija =
    CALCULATE (
        SELECTEDVALUE ( IFC[GUID] ),
        FILTER (
            IFC,
            UPPER ( TRIM ( IFC[Property Name] ) ) = "LOKACIJA"
            && UPPER ( TRIM ( IFC[Property Value] & "" ) ) = _lokacija
        )
    )
VAR guidEAM =
    CALCULATE (
        SELECTEDVALUE ( IFC[GUID] ),
        FILTER (
            IFC,
            UPPER ( TRIM ( IFC[Property Name] ) ) = "EAM"
            && UPPER ( TRIM ( IFC[Property Value] & "" ) ) = _eam
        )
    )
VAR guidTovarniska =
    CALCULATE (
        SELECTEDVALUE ( IFC[GUID] ),
        FILTER (
            IFC,
            UPPER ( TRIM ( IFC[Property Name] ) ) = "TOVARNISKA"
            && UPPER ( TRIM ( IFC[Property Value] & "" ) ) = _tovarniska
        )
    )
RETURN
-- Priority: SREDSTVO → LOKACIJA → EAM → TOVARNISKA
COALESCE ( guidSredstvo, guidLokacija, guidEAM, guidTovarniska )
```

Following that a relationship between external data with the IFC data could be drafted. Unfortunately, the different options as unique alphanumerical data identifiers filled to the model were not enough to successfully create a one-to-one relationship with the external data.

To solve this issue, the ‘IfcGUID’ parameter of the model elements should be attached to the database at an early stage of the modelling process to be the connector between databases. This was not the case for ELES in the present work, for that reason, Flinker viewer dashboard had its development stopped.

6 IMPLEMENTATION, INTERNAL INTERVIEW AND RESULTS OF CASE STUDY

Speckle was the option preferred by ELES and IBE representatives and data analytics team to be advanced until the last version to be tested with all pages and graphs proposed and solicited. VCAD, due to its deeper complexity and processing failures, was left as a backup option for a longer and corporative evaluation.

Similarly to the evaluation of Autodesk Data Connector, that revealed itself as an accessible and viable opening for the users that can take advantage of a wider use of the Autodesk environment and licenses. As that is not the case for ELES, which had the BIM work was punctually contracted from IBE.

Flinker unfortunately incurred into several displaying errors and IFC miscalculations and for that reason was taken out of consideration during the testing and validations for the present work.

6.1 Speckle 3D Viewer Final Version Dashboard

Speckle 3D Viewer, by offering a free use of up until 5 models in one same project, presented a cheaper prototyping option, as said by (insert reference of testing cheap), as it is not necessary to have prior licences or specific access to just input information, real or created for that purpose and consider how it is applicable to you intended uses of BIM alongside of Data Analytics. The full dashboard could be created seamlessly by having the correctly exported models and sample data to align it with.

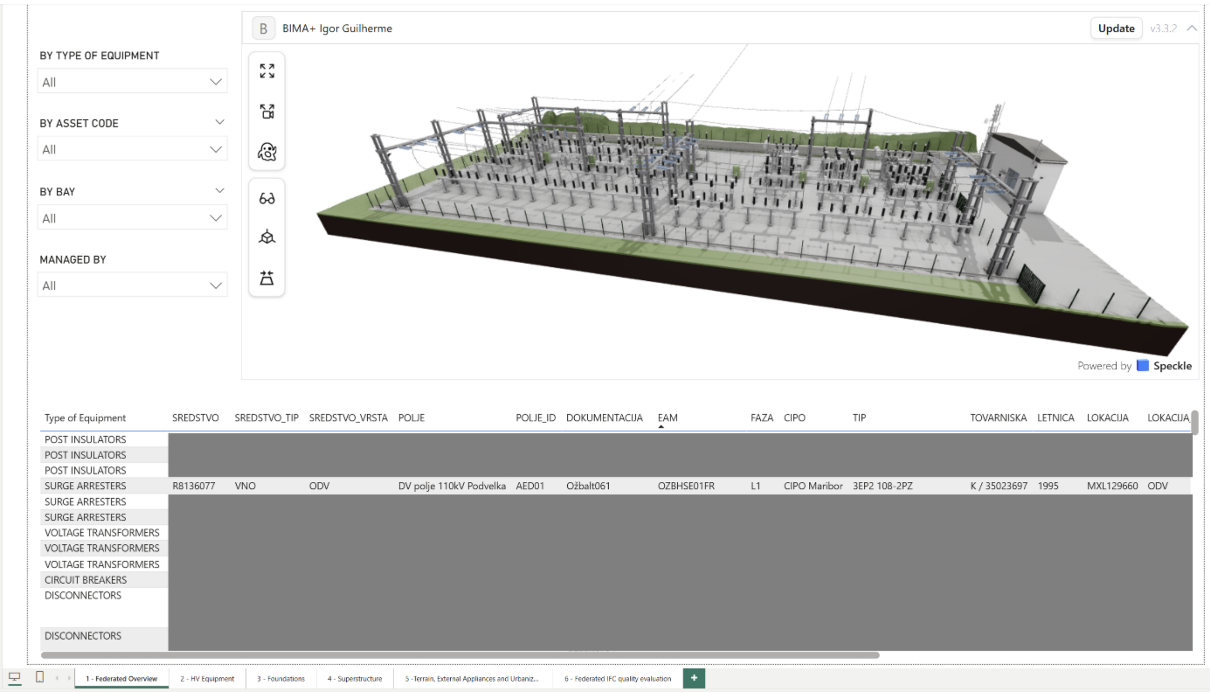


Figure 37 - Federated Overview page in Final version Speckle Dashboard (Update with fail log)

The first page of the dashboard, strategically defined in the session 5.1 had the visuals illustrated in Figure 37. The four, fully connected, visuals in this page are:

- 3D Viewer with loaded federated model.
- Filters panel, by Type of Equipment, Asset Code, Bay and whether it is managed by ELES or not.
- Summary Table of alphanumerical information from the model.
- Equipment Failure log table, external data connected to the model.

All information displayed in this page is interconnected, meaning that the model queries the tables, and vice-versa, the filters change the models, that queries the tables.

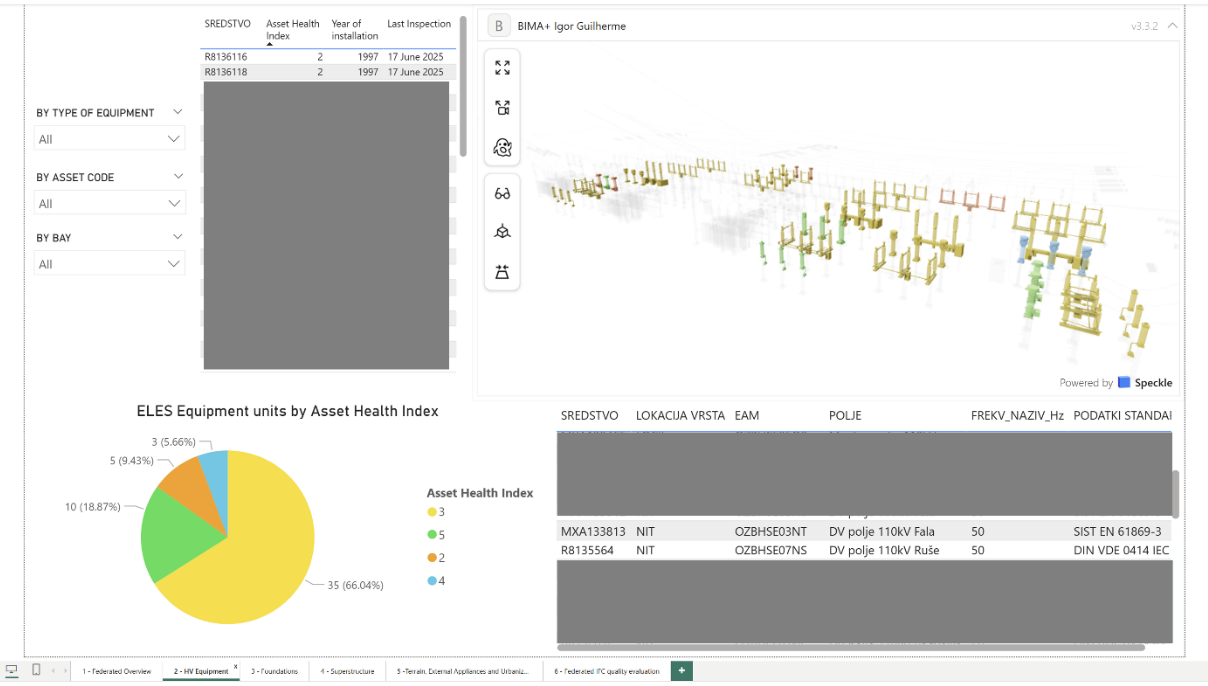


Figure 38 – HV Equipment page in Final version Speckle Dashboard

The second page was considered the most important in the template dashboard that was created for the present case study, because it had most modelled elements which are the main interest to the analytics department of the partner company.

As displayed in Figure 38, five visuals are used to connect the information and those are:

- 3D Viewer with loaded technical equipment model.
- Filters panel, by Type of Equipment, Asset Code and Bay.
- Pie chart for quantity of equipment by the colours related to the health index database.
- Table view of inspection history.
- Table view of model queried alphanumerical information.

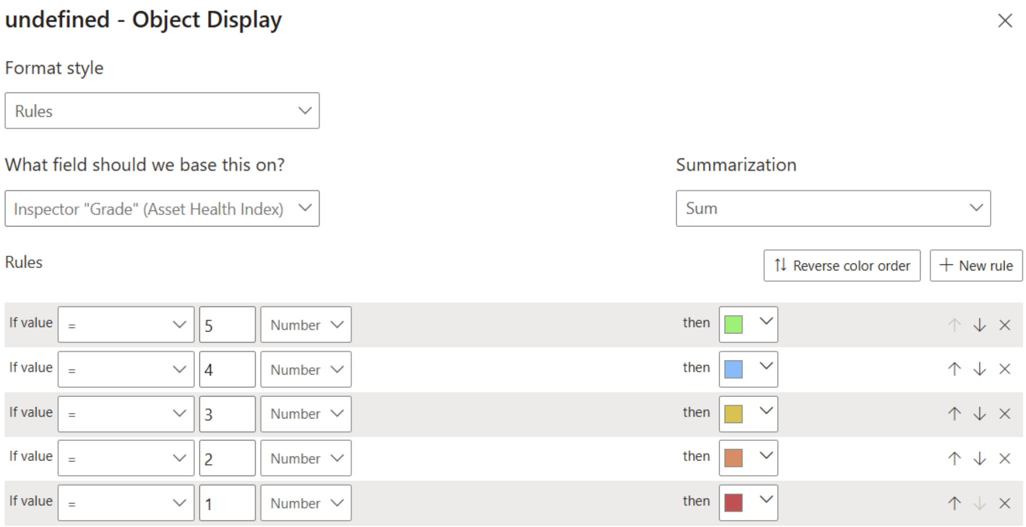


Figure 39 – Colouring conditional rules by property value (Speckle)

In order to create the colour scheme seen in Figure 38, a set of conditional rules need to be created. Those rules are associated with the ‘Inspector “Grade” (Asset Health Index)’ parameter, as seen in Figure 39.

Grades go from 1 to 5 and they have colours associated with each value, to better interpret the urgency of attention of each equipment in real life. Similar functions are seen in Digital Twin applications, which can be the case for the use of Power BI, if associating the database with real-time sensors used in the building.

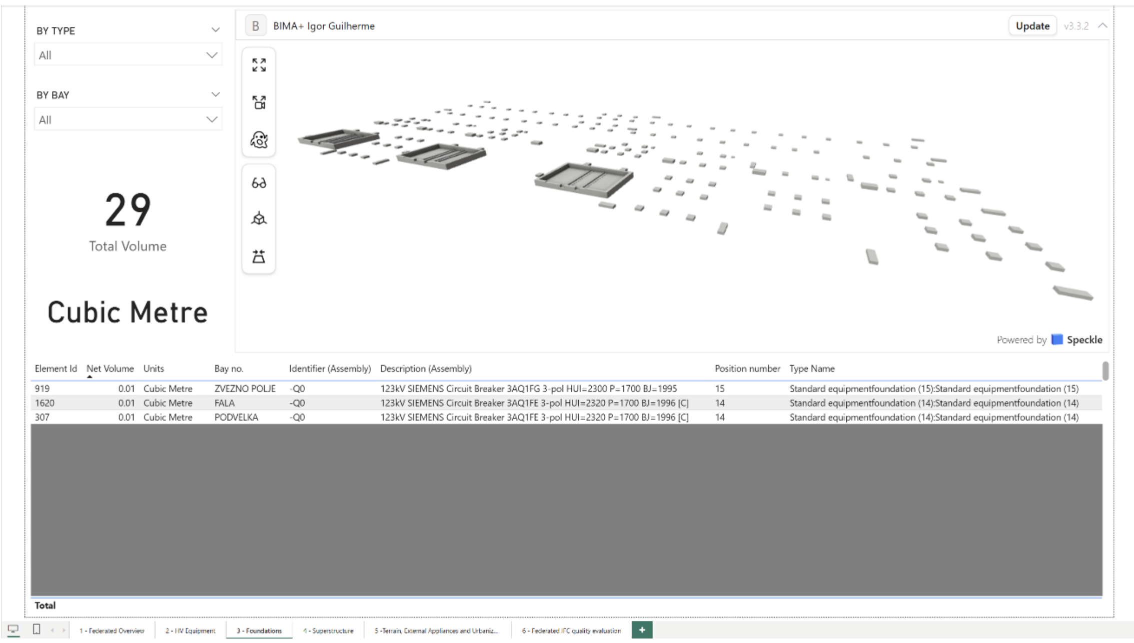


Figure 40 – Foundations page in Final version Speckle Dashboard

For the page relative to the foundations and the Superstructure (pages 3 and 4) a similar display of charts as the federated model (page 1), with the main difference of including quantitative data in the table view. As seen in in Figure 40 for foundation elements.

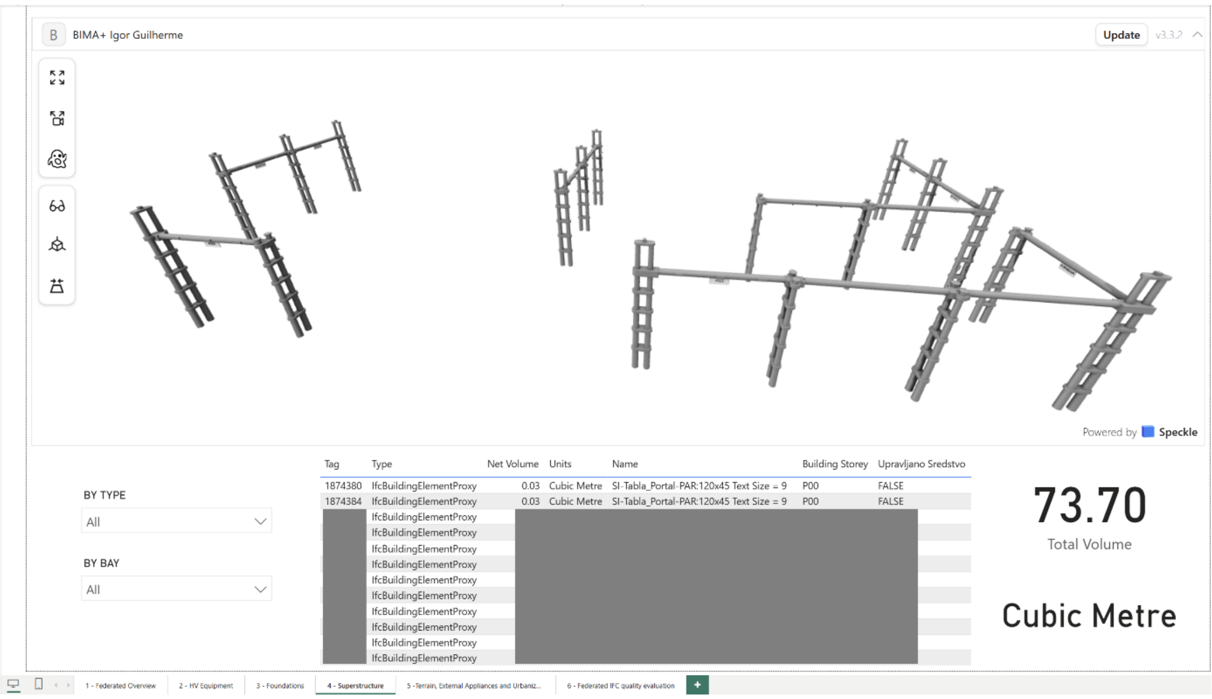


Figure 41 - Superstructure page in Final version Speckle Dashboard

The visuals for pages 3 and 4 are:

- 3D Viewer with loaded specific model.
- Filters panel, by Type of Equipment and Bay.
- Table with alphanumerical data queried from the model, including quantitative data from the model.
- Card view of the sum of the volume of material used.

The fifth page, named Terrain, External Appliances and Urbanization, has general information about a model that for ELES doesn’t really comes in hand, specifically for this study case, as everything of this discipline was generically captured and modelled to be displayed as realistic as possible, but without quantification process or measuring accountability.

For further models and projects yet to be conceived, this view has a great potential for overall understanding of the work site and quantification of earth works.

Figure 42 - Terrain, External Appliances and Urbanization page in Final version Speckle Dashboard

The visuals present in fifth page can be seen in Figure 42 and they are:

- 3D Viewer with loaded specific model.
- Table with alphanumerical data queried from the model.
- Filters panel, by IFC Type, Id and Tag.

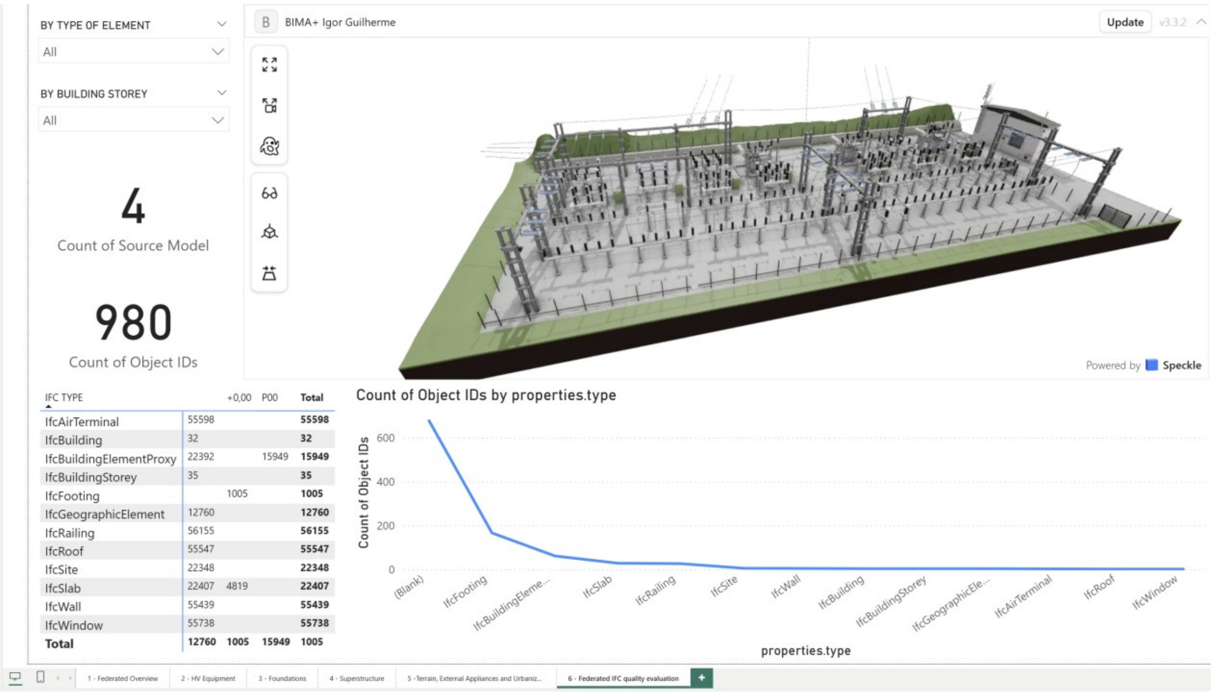


Figure 43 – Federated IFC quality evaluation page in Final version Speckle Dashboard

The final page ("Federated IFC quality evaluation") provides a quick QA/QC view of the federated model before analytics are applied. The visuals are:

- 3D Viewer with loaded federated model.
- Filters panel, by IFC Type and Building Storey.
- Card panel summarizing models combined and objects combined.

6.2 ELES Internal Interview and overall perceptions from solutions developed

To better understand the level of satisfaction with the developed solutions the receiving end (and 'problem-situation' holder) was taken too after thorough evaluation, a quick form interview is needed to be formulated and conducted with ELES data analytics department personnel.

It is, however, very important to highlight that no personal data and/or identification is to be asked inside this interview, which pledges to be totally unbiased and anonymous.

In the beginning of the present report, it was defined several questions to guide all of the resource applications within the research and the case study, now it is necessary to remind those questions and revisit it to better conclude the perceived advancements. The research questions are:

- How can BIM models be effectively integrated into data analytics environments to enhance infrastructure decision-making?
- What are the comparative benefits and challenges of using VCAD, Autodesk Data Connector, and APS for linking BIM data with Power BI?
- How does the spatial visualization of analytical data improve stakeholder understanding and operational efficiency at ELES?
- To what extent can interactive dashboards contribute to proactive asset management in energy infrastructure?

Those questions will serve as start-point to develop the survey that will be passed on to the 'client' of the solutions.

6.2.1 Mapping research questions to develop survey items

To better develop the survey questions that are easily understood by the taker and that are useful for the evaluation of the effectiveness of the goals in the present report, a summary of the questions is needed, and this summary will guide the survey items development.

Table 3 - Research Question Summary

RESEARCH QUESTION	RESEARCH QUESTION SUMMARY
How can BIM models be effectively integrated into data analytics environments to enhance infrastructure decision-making?	RQ1. Effective integration of BIM in analytics
What are the comparative benefits and challenges of using VCAD, Autodesk Data Connector, and APS for linking BIM data with Power BI?	RQ2. Comparative benefits & challenges (VCAD, Data Connector, APS)
How does the spatial visualization of analytical data improve stakeholder understanding and operational efficiency at ELES?	RQ3. Impact of spatial visualization
To what extent can interactive dashboards contribute to proactive asset management in energy infrastructure?	RQ4. Contribution to proactive asset management

Having done the summary of each question, it is possible to expand each into questions to survey ELES team.

6.2.2 Survey items development

From the four summaries of each question, it is possible to define what will be asked in the survey.

A. Usage (contextualization)

A1. Approx. time using the dashboard: (< 30 min, 30–120 min, > 2h)

A2. Prior experience with BIM-linked dashboards: (None, Some, Extensive)

B. Integration Effectiveness (RQ1)

B1. The dashboard reliably links model elements to database records via our identifiers (e.g., SREDSTVO, TOVARNISKA, IfcGUID).

B2. Drill-through/traceability from a metric to the exact model element works as expected. (1–7 / Not used)

B3. Data refresh and update cadence meet our analytical needs. (1–7 / Not used)

B4. Overall, the integration improves decision-making compared with data-only dashboards. (1–7 / Not used)

C. Comparative Connectors (RQ2)

C.1 Depth of model interaction (select/locate, highlight, filter) met needs. (1–7 / Not used)

C.2 Data refresh/automation fit our workflow. (1–7 / Not used)

C.3 Extensibility/customization meets future needs. (1–7 / Not used)

C.4 Governance/security fit (access, lineage) is acceptable. (1–7 / Not used)

D. Spatial Visualization Impact (RQ3)

D1. Seeing analytics in spatial context (model view) improved my understanding. (1–7 / Not used)

D2. I could locate the right equipment faster (e.g., by TOVARNISKA, SREDSTVO or POLJE). (1–7 / Not used)

D3. The model view improved communication across roles/teams. (1–7 / Not used)

D4. Confidence: I feel more confident making decisions with the spatial view. (1–7 / Not used)

E. Proactive Asset Management (RQ4)

E1. The dashboard helped me spot issues earlier than our usual process. (1–7 / Not used)

E2. It triggered concrete actions (e.g., inspection, maintenance order, re-prioritization). (1–7 / Not used)

E3. It reduced time-to-insight for routine questions. (1–7 / Not used)

E4. I expect to use it regularly in my work. (1–7 / Not used)

F. Global Perception and Comments

F1. This system's capabilities meet my needs. (1–7 / Not used)

F2. This system is easy to use. (1–7 / Not used)

F3. I would recommend adopting this dashboard for ELES operations. (1–7 / Not used)

F4. What one improvement would most increase your adoption? (Short Text Answer)

F5. Anything we should remove or simplify? (Short Text Answer)

6.2.3 Analysis Plan (to be done in 7. Conclusions)

A few evaluation laws were drawn to guide the survey results takeouts:

- Using 1–7 Likert for B/C/D/E.
    - Report RQ indexes and IQR.
- Building RQ indices by averaging their items:
    - RQ1_index = average (B1–B4)
    - RQ2_index = average (C1–C4)
    - RQ3_index = average (D1–D4)
    - RQ4_index = average (E1–E4)
- For practical impact, report the proportion answering ≥6/7 on D1–D4 and E1–E4 ("top-box").
- Present one radar chart per RQ (B, D, E indices), and a connector comparison bar chart (C).
- In Discussion, the findings will be tied back to each RQ explicitly, and the progress on them.

Table 4 – Survey items mapped by research question

<table>
<tr><td>RESEARCH QUESTION SUMMARY</td><td colspan="2">Survey Items</td></tr>
<tr><td>RQ1. Effective integration of BIM in analytics</td><td>B1-B4</td><td rowspan="4">F1-F5</td></tr>
<tr><td>RQ2. Comparative benefits & challenges (between each viewer option)</td><td>C1-C4</td></tr>
<tr><td>RQ3. Impact of spatial visualization</td><td>D1-D4</td></tr>
<tr><td>RQ4. Contribution to proactive asset management</td><td>E1-E4</td></tr>
</table>

6.2.4 Answers to survey and adherence and answers to research questions

As revisited in the last chapter, the research questions were made to guide the sole purpose of the present piece of scientific work. Most specific details taken from the questions were approached in a theoretical basis in the Literature Review, but only now it is possible to use an overall approach to tie it all together, having developed a few different solutions, tested it and gathered the perception from third-party stakeholders about the solutions provided.

6.2.5 Survey results analysis

The survey had two responses by the closure of this work and can be biased for this reason, but it present the first and main perception of real stakeholders of the project whilst using the dashboard.

Usage:

- A1: < 30 min – 100%
- A2: None – 100%

RQ1. Effective integration of BIM in analytics (items B1–B4)

Index: RQ1_index = 6.5 (IQR = 2.25).

Top-box (≥6/7): 50%

Table 5 - Answers registered for the B Section

	Answer 1	Answer 2
B1	7	7
B2	7	5
B3	4	3
B4	7	6

Refreshing of data is perceivably a weak point, but decision-making improvement and connection between model and data are the strongest ones. The 2.25 IQR indicate a low variance and outlier presence for the answers, which can implicate to constancy in the responses.

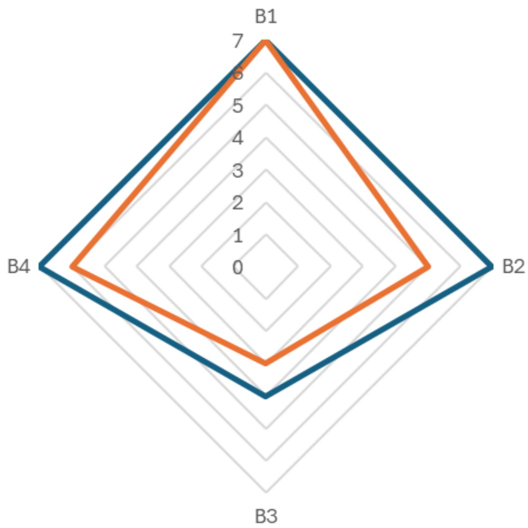


Figure 44 - B Section Radar Chart

RQ2. Comparative benefits & challenges of connectors (items C1–C4)

Index: RQ2_index = 5.5 (IQR = 3.75).

Top-box (≥6/7): 50%

Table 6 – Answers registered for the C Section

	Answer 1	Answer 2
C1	6	6
C2	6	5
C3	0	7
C4	3	0

The perceived weakest point here is the governance and data security, and the strength lies on its scalability of the final product and the depth of the model interactions. The 3.75 of IQR highlights the presence of outliers, as seen in C3 with 0 and 7, between liking the feature and haven't used it, and a 0 and 3, representing not really liking it and also haven't used it, varying the interpretation of the results.

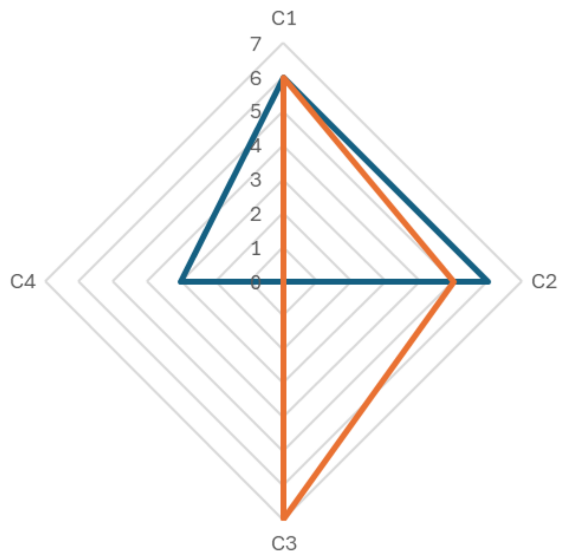


Figure 45 - C Section Radar Chart

RQ3. Impact of spatial visualization (items D1–D4)

Index: RQ3_index = 6.5 (IQR 1.25).

Top-box (≥6/7): 75%

Table 7 - Answers registered for the D Section

	Answer 1	Answer 2
D1	7	7
D2	7	7
D3	6	0
D4	6	5

Here, the main weakness is a 5 out of 7, and it is onto feeling more confident on making decisions using the dashboard. The strengths are improvements in understanding the data, locating the construction easily and communication across roles. The low 1.25 IQR relies one the unique 0 present in the data and the compliance between each response and low variability.

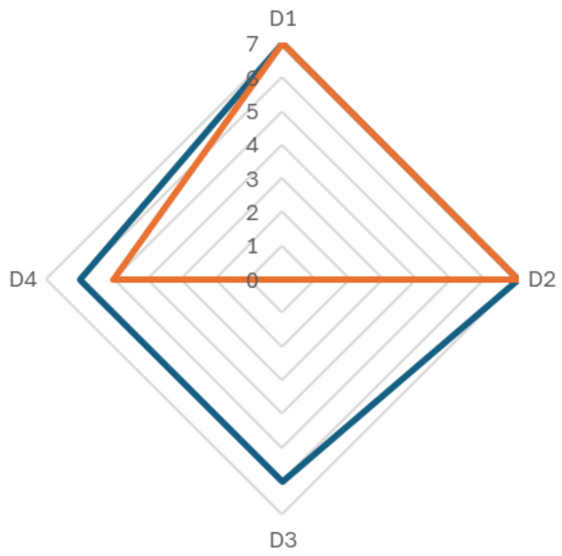


Figure 46 - D Section Radar Chart

RQ4. Contribution to proactive asset management (items E1–E4)

Index: RQ4_index = 5.5 (IQR 3.75).

Table 8 - Answers registered for the E Section

	Answer 1	Answer 2
E1	6	3
E2	0	0
E3	6	5
E4	6	7

The only not used appeared in the E section, related to taking concrete action after using the dashboard for decision-making, what is understandable from the short-used time, another weakness is tied to issue creation in the models. The strength here is the high expectation for future use. No big variances were perceived, even with the IQR of 3.75, which weighed up the quartile calculations.

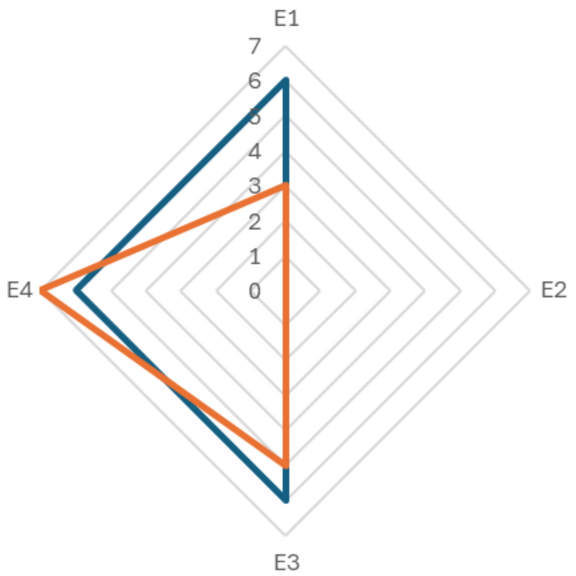


Figure 47 - E Section Radar Chart

RQ1: With an index of 6.5, it is safe to say that the first research question is supported by the study-case development.

RQ2: Speckle connector was the only used and this shows it as the main option comparatively, with a 5.5 index out of 7, its acceptance is considered good and RQ2 is considered supported by the present work.

RQ3: The best index of all evaluation, at a 6.5 out of 7, RQ3 finishes as a highlight of the objectives previously established and supported by the research and case study.

RQ4: The lowest result in this research, with an index of 5.5 out of 7, what reflects the implementation process difficulties when changing processes already stablished

7 CONCLUSIONS

A practical path was designed and tested to integrate BIM information with ELES' analytics department, using stable identifiers to ensure traceability and enabling spatially aware dashboards in Power BI. The deployed solution was evaluated against the four research questions and across alternative integration routes, revealing both clear benefits for understanding, communication, and proactive asset decisions, and practical efforts in setup, performance, extensibility, and governance. Taken together, the results demonstrate feasibility and value while clarifying the conditions required for reliable scale-up. Limitations of scope, data availability, and pilot duration are acknowledged, and directions for improvement and future work are outlined to support sustained adoption in operational environments.

7.1 Limitations of the Study

The present study's findings should be interpreted in light of a few limitations. The first one, the evaluation is determined in a single organisational context (ELES), although the literature review encountered other similar appliances study cases, and a single, recently modelled substation, which constrains generalisability to other asset types, data governance regimes, and maturity levels.

A second one is that the outcomes depend on the completeness and consistency of model metadata and database fields, any omissions, legacy naming, or mapping errors may have biased the dashboards and the measured usability, this also affects the scalability of the developed BI model.

7.2 Suggestions for deeper developments of further research works

The pilot which served as case study for the present work revealed several lines of work that merit deeper investigation to sustain and scale BIM-connected analytics at huge-project companies like ELES. The proposed roadmap groups next steps into: (i) platform diversification for data–model integration, (ii) a lean Digital Twin built on APS, (iii) data governance and identifier policy, (iv) performance engineering of the BI–model pipeline, and (v) user adoption and evaluation at scale.

7.2.1 Development of New Platforms for Data and Model Integration

Another possibility to be exploited in the present work is to deepen in new approaches of integration of Data and 3D Models for data analysis. Although Power BI represents the majority share in the data analytics market, new and lesser-known solutions are available and can be explored with the intent of validate what's preferrable for each use-case and tailor visualisation according to these defined preferences.

Some options will be developed to create a larger scope of possibilities for the data analytics department working in partnership for this report.

New 3D systems are being developed and inserted into the market in a fast pace, for example BonsaiBIM, add-on that can convert Blender into an BIM authoring tool, natively creating and editing IFC files, or the new BIM file format 'Fragments' created by That Open Company, alongside a new 3D open-source environment to replicate and further create tools that uses 3D as main function.

7.2.2 Autodesk Platform Services Digital Twin

With the recent growth of programmers entering the BIM environment and AECO professionals doing the inverse path (Logotheti et al., 2018), APS – Autodesk Platform Services (formerly Autodesk Forge) has become a deep innovation hub for the matter of the creation of new and tailored solutions for companies individually defined interests. This platform offers tutorial pre-made solutions, and the Digital Twin option summarized the expectations for this paper, so a version of it was chosen to be developed.

A minimum viable Digital Twin is proposed to extend the current dashboard with lightweight web components built on Autodesk Platform Services (APS). The design target is operational traceability rather than full simulation:

- Functional backlog (MVP):

  REST endpoints to: (a) get element by single parameter; (b) highlight or isolate by more than three parameters; (c) return selected properties from model and relationships; (d) log user actions for audit processes.

This APS path can consolidate model–table traceability, keeping the identifier policy stable, and creating a foundation to connect future data sources without the need of rework into the dashboard.

7.3 Closing Remarks

To conclude the evaluation and complete path of work, it is perceived that bringing BIM and BI together turned dispersed technical information into a single, navigable decision surface. Spatial views from the model, combined with model-to-table joins, improved traceability, reduced ambiguity, and shortened the path from question to insight. In practice, filters aligned with operations raised situational awareness, supported earlier detection of issues, and helped prioritize actions with consistent auditability.

The overall effect is a shift from reactive checks to proactive, evidence-based management, where the model provides context and BI supplies measurement. With data governance, performance engineering, and focused user onboarding, this approach is scalable beyond the pilot and forms a realistic foundation for model-aware analytics and future digital-twin capabilities across the asset portfolio.

REFERENCES

Abanda, F. H., Balu, B., Emmanuel, S., & Akintola, A. (2025). Decoding ISO 19650 Through Process Modelling for Information Management and Stakeholder Communication in BIM. *Buildings, 15(3), 431*. Fonte: https://doi.org/10.3390/buildings15030431

Andrich, W., Daniotti, B., Pavan, A., & Mirarchi, C. (2022). Check and Validation of Building Information Models in Detailed Design Phase: A Check Flow to Pave the Way for BIM Based Renovation and Construction Processes. *Buildings, 12(2), 154*. Fonte: https://doi.org/10.3390/buildings12020154

Autodesk. (2025). Acesso em 28 de Aug. de 2025, disponível em https://www.autodesk.com/support/technical/article/caas/sfdcarticles/sfdcarticles/Generate-Power-BI-report-of-BIM-360-project-activities.html

Autodesk Platorm Services. (s.d.). Acesso em 28 de Aug. de 2025, disponível em https://aps.autodesk.com

Bolpagni, M., Gavina, R., & Ribeiro, D. (2021). *Industry 4.0 for the Built Environment: Methodologies, Technologies and Skills.* Berlin/Heidelberg, Germany: Springer Nature.

Brazauskas, J., Verma, R., Safronov, V., Danish, M., Merino, J., Xie, X., . . . Mortier, R. (2021). Data Management for Building Information Modelling in a Real-Time Adaptive City Platform. Fonte: https://doi.org/10.48550/arXiv.2103.04924

Bühler, M. M., Nübel, K., Jelinek, T., Köhler, L., & Hollenbach, P. (2025). Bridging the Construction Productivity Gap—A Hierarchical Framework for the Age of Automation, Robotics, and AI. *Buildings, 15(16), 2899*. Fonte: https://doi.org/10.3390/buildings15162899

buildingSMART. (2024). Acesso em 28 de Aug. de 2025, disponível em https://www.buildingsmart.org/ifc-4-3-formally-approved-and-published-as-an-iso-standard/

Chen, C. (2006). *Information Visualization: Beyond the Horizon.* Springer London. Fonte: https://doi.org/10.1007/1-84628-579-8

Cote, C. (19 de October de 2021). *4 Types of Data Analytics to Improve Decision-Making*. Fonte: Harvard Business School: https://online.hbs.edu/blog/post/types-of-data-analysis

Das, K., Khursheed, S., & Paul, V. K. (2025). The impact of BIM on project time and cost: insights from case studies. *Discover Materials, 5, 25*. Fonte: https://doi.org/10.1007/s43939-025-00200-2

Gordo-Gregorio, P., H. A., & Forcada, N. (2025). Decoding BIM Challenges in Facility Management Areas: A Stakeholders' Perspective. *Buildings, 15(5), 811*. Fonte: https://doi.org/10.3390/buildings15050811

Halder, S., Afsari, K., & Akanmu, A. (2024). A Robotic Cyber-Physical System for Automated Reality Capture and Visualization in Construction Progress Monitoring. Fonte: https://doi.org/10.48550/arXiv.2402.07034

Harode, A., Ensafi, M., & Thabet, W. (2022). Linking BIM to Power BI and HoloLens 2 to Support Facility Management: A Case Study Approach. *Buildings, 12(6), 852*. Fonte: https://doi.org/10.3390/buildings12060852

ISO 19650-1. (2018). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling*. ISO. Acesso em 28 de Aug. de 2025, disponível em https://www.iso.org/standard/68078.html

ISO 7817-1. (2024). *Building information modelling - Level of information need - Part 1: Concepts and principles*. Acesso em 17 de September de 2025, disponível em https://www.iso.org/standard/82914.html

Kadcha, Y., Legmouz, D., & Hajji, R. (2022). AN INTEGRATED BIM-POWER BI APPROACH FOR DATA EXTRACTION AND VISUALIZATION. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 62-73. Retrieved from https://doi.org/10.5194/isprs-archives-XLVIII-4-W4-2022-67-2022

Logothetis, S., Karachaliou, E., Valari, E., & Stylianidis, E. (2018). OPEN SOURCE CLOUD-BASED TECHNOLOGIES FOR BIM. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2, 607–614*. Fonte: https://doi.org/10.5194/isprs-archives-XLII-2-607-2018

Mansoori, S., Harkonen, J., Haapasalo, H., & Annunen, P. (2024). Industrialization in Construction Companies—A Benchmark Study on Manufacturing Companies. *Buildings, 14(5), 1407*. Fonte: https://doi.org/10.3390/buildings14051407

Maranchello, F. (8 de June de 2023). Construction Data Analytics: Connecting BIM Data with Power BI. e-verse. Fonte: https://e-verse.com/learn/construction-data-analytics-connecting-bim-data-with-power-bi

Morin, X., & Romero-Torres, A. (2024). How does building information modeling influence decision-making process in the project design? An input, process and output analysis. *Project Leadership and Society, Volume 5*. Fonte: https://doi.org/10.1016/j.plas.2024.100160

Nguyen, T. D., & Adhikari, S. (2023). The Role of BIM in Integrating Digital Twin in Building Construction: A Literature Review. *Sustainability, 15(13), 10462*. Fonte: https://doi.org/10.3390/su151310462

PennState College of Engineering. (s.d.). Acesso em 28 de Aug. de 2025, disponível em BIM Uses: https://bim.psu.edu/uses

Rafael Sacks, C. E. (2018). *BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers.* John Wiley & Sons.

Rane, N. (2023). Integrating Building Information Modelling (BIM) and Artificial Intelligence (AI) for Smart Construction Schedule, Cost, Quality, and Safety Management: Challenges and Opportunities. Fonte: https://dx.doi.org/10.2139/ssrn.4616055

Revolti, A., Gualtieri, L., Pauwels, P., & Dallasega, P. (2024). From building information modeling to construction digital twin: a conceptual framework. *Production & Manufacturing Research, 12(1)*. Fonte: https://doi.org/10.1080/21693277.2024.2387679

Rodrigues, F., Alves, A. D., & & Matos, R. (2022). onstruction Management Supported by BIM and a Business Intelligence Tool. *Energies, 15(9), 3412*. Fonte: https://doi.org/10.3390/en15093412

Samuelson, O., & Stehn, L. (2023). Digital transformation in construction – a review. *Journal of Information Technology in Construction, 28. 385-404*. Fonte: http://dx.doi.org/10.36680/j.itcon.2023.020

Speckle System. (s.d.). Acesso em 28 de Aug. de 2025, disponível em https://www.speckle.systems/

That Open Company. (s.d.). Acesso em 27 de May de 2025, disponível em https://thatopen.com

VCAD. (s.d.). Acesso em 18 de Jun de 2025, disponível em https://www.bimservices.it

Walch, A., Szabo, A., Steinlechner, H., Ortner, T., Gröller, E., & Schmidt, J. (2024). BEMTrace: Visualization-driven approach for deriving Building Energy Models from BIM. *IEEE Transactions on Visualization and Computer Graphics*. Fonte: https://doi.org/10.48550/arXiv.2407.19464

Yigitbas, E., Nowosad, A., & Engels, G. (2023). Supporting Construction and Architectural Visualization through BIM and AR/VR: A Systematic Literature Review. *IFIP Conference on Human-Computer Interaction*, 145-166. Fonte: https://doi.org/10.48550/arXiv.2306.12274

Zabala-Vargas, S., Jaimes-Quintanilla, M., & Jimenez-Barrera, M. H. (2023). Big Data, Data Science, and Artificial Intelligence for Project Management in the Architecture, Engineering, and

Construction Industry: A Systematic Review. *Buildings, 13(12), 2944*. Fonte: https://doi.org/10.3390/buildings13122944