BIM-based Data Visualization: Exploratory Evaluation of Existing Methods

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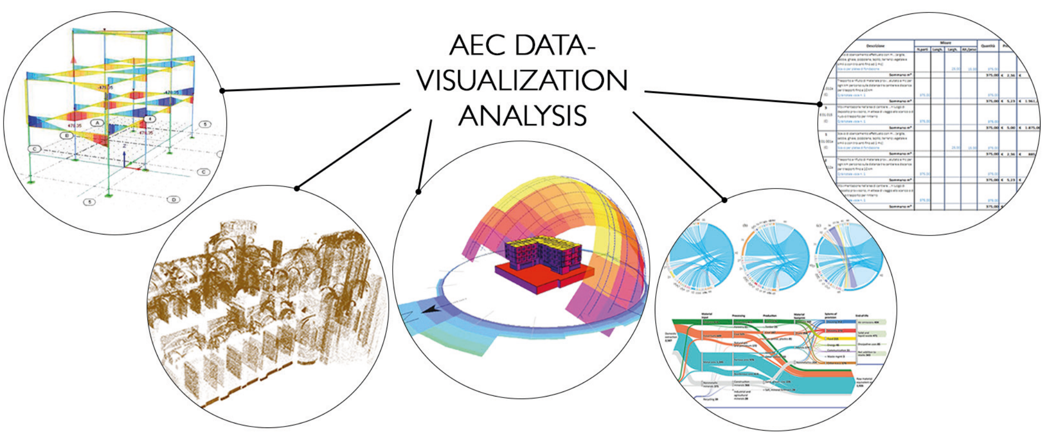
Abstract

The Architecture, Engineering, and Construction (AEC) sector is a major consumer of global resources and a significant contributor to carbon dioxide emissions, highlighting the need for digital solutions like Building Information Modeling (BIM) to enhance sustainability and efficiency. BIM integrates geometric models with relevant data, enabling advanced analysis throughout a building's life cycle. Data visualization plays a crucial role in extracting actionable insights from the large amount of data available in this sector. This study conducts a scientometric analysis of recent research trends in BIM-based data visualization literature, revealing the increasing significance and diffusion of data visualization within the BIM environment. The paper categorizes the most diffused visualization techniques according to the use cases where they are used, such as, for example, structural analysis, cost estimation, environmental assessment and others. Additionally, it examines the current visualization methods focusing on their relationship with BIM's core functionalities. Finally, the study proposes main criteria for optimizing BIM-specific visualizations, including geometrical representation, data structure considerations, model interactivity, domain specificity, and visual grammar consistency. The findings emphasize the need for tailored visualization strategies to improve data comprehensibility, bridging the gap between theoretical advancements and professionals' applications for more effective and integrated BIM-based data visualizations, to support the construction sector's digital transformation.

Keywords
Data visualization, BIM, spatiality, advanced visualizations, scientometric analysis.



Conceptual overview of the most diffused data visualization types in BIM-uses [Succar, Saleeb, Sher 2016] (elaboration by the authors).

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Introduction

The Architecture, Engineering, and Construction (AEC) sector's digitalization has accelerated significantly over the past decade and has been driven by the increasing adoption of Building Information Modeling (BIM). BIM enables the creation of three-dimensional geometric models, allowing objects to be directly associated with relevant information, such as material properties, construction costs, and various other attributes. In this regard, BIM facilitates data analysis and interpretation that would otherwise be unfeasible using traditional CAD (Computer Aided Design) methodologies [Castronovo *et al.* 2014]. The implementation of BIM has led to an exponential increase in the analytical capabilities applied to buildings across all phases of their life cycle. This process results in the generation of large volumes of data that must be effectively interpreted and understood to optimize their utilization, particularly in an era where data-driven decision-making is becoming increasingly prevalent within companies. Recognizing BIM as an innovative technology that enhances the AEC sector's efficiency [Akinlolu, Haupt 2021; Gerrish *et al.* 2017], it is essential to examine its relationship with data visualization to fully exploit the combined potential of these two technologies. This integration can address sector-specific challenges and provide reliable and efficient support to professionals [Golparvar-Fard *et al.* 2013], while maximizing data clarity and comprehension [Cairo 2013]. The objective of this research is to analyze the state of the art of data visualization in BIM, emphasizing its significance, identifying its potential and limitations, and establishing a set of fundamental criteria for developing specialized and domain-specific visualizations in the construction industry. Within this sector, data visualization plays a crucial role in bridging the gap between theory and practice, making theoretical analyses more accessible to professionals. To narrow this divide, it is essential to adopt a hybrid approach that considers both academic advancements and industry requirements, integrating insights from various sources [Leite *et al.* 2016] [1].

Scientometric analysis of visualization in BIM

To understand the significance of data visualization in the AEC sector, and particularly within the BIM methodology, a state-of-the-art review was conducted. Specifically, a scientometric analysis was performed on publications from the last decade to identify current research trends and to examine how data visualization is currently addressed and utilized in this field.

This type of analysis provides a quantitative approach to systematically explore and map the scientific literature, highlighting influential works, emerging topics, and the structure of knowledge in a given domain. In 2017, Zhao [Zhao 2017] conducted a state-of-the-art review focusing on global research related to BIM, revealing that visualization has experienced a significant increase in citations in recent years. In line with this trend, Wu et al. [Wu *et al.* 2019] carried out the first literature review in 2019, specifically examining the concept of visualization applied to BIM. The analysis was conducted using the Scopus database, which includes the world's most relevant and influential scientific journals. The following query was used to retrieve documents:

TITLE-ABS-KEY ((bim OR building AND information AND modeling) AND (visualization OR data AND visualization)) AND PUBYEAR > 2014 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA , "ENGI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

A total of 484 documents were identified, with more than one-third published in the last two years alone. Through the scientometric analysis, both the number of published documents and the recurrence of keywords in them is examined, enabling a visual representation of scientific developments and interconnections in this specific research domain [Bornmann 2015]. A consistent increase in the number of total publications by year can be observed (fig. 1), but, most importantly, a relative growth in the occurrence of the keywords 'BIM' and 'visualization' compared to others. This confirms that data visualization applied to BIM is an emerging research area receiving increasing attention and resources. Furthermore, as expected, the dominant clusters are those related to BIM (blue) and visualization (yellow); however, in this context, clusters associated with virtual reality (red), openBIM and collaboration (green) and information management (magenta) also emerges (fig. 2). This provides a clear picture of how broad the digitalization of construction sector is: it encompasses many different topics making difficult to discern one from the others, highlighting the importance of considering their interconnections when analyzing a single one.

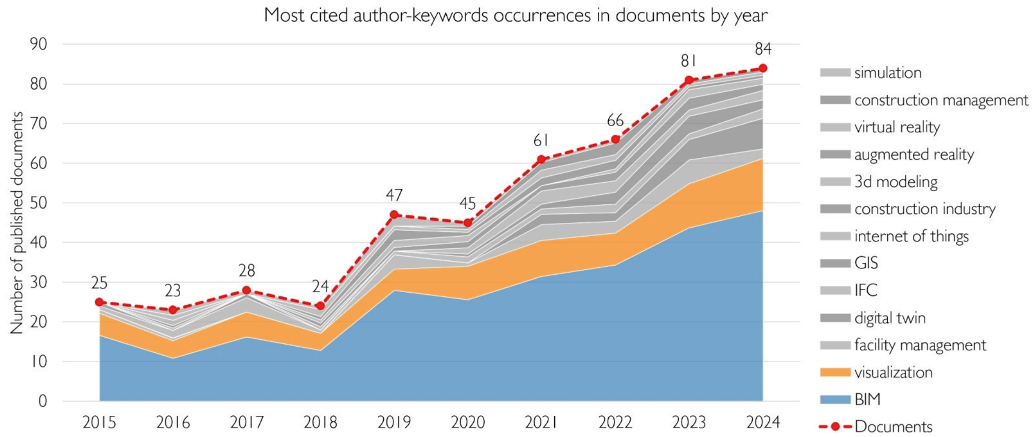

Fig. 1. Line chart shows the number of documents published by year, area chart shows the relative occurrences of author keywords in documents by year (only keywords with at least a total of 10 occurrences from 2015 to 2024 are shown; elaboration by the authors).

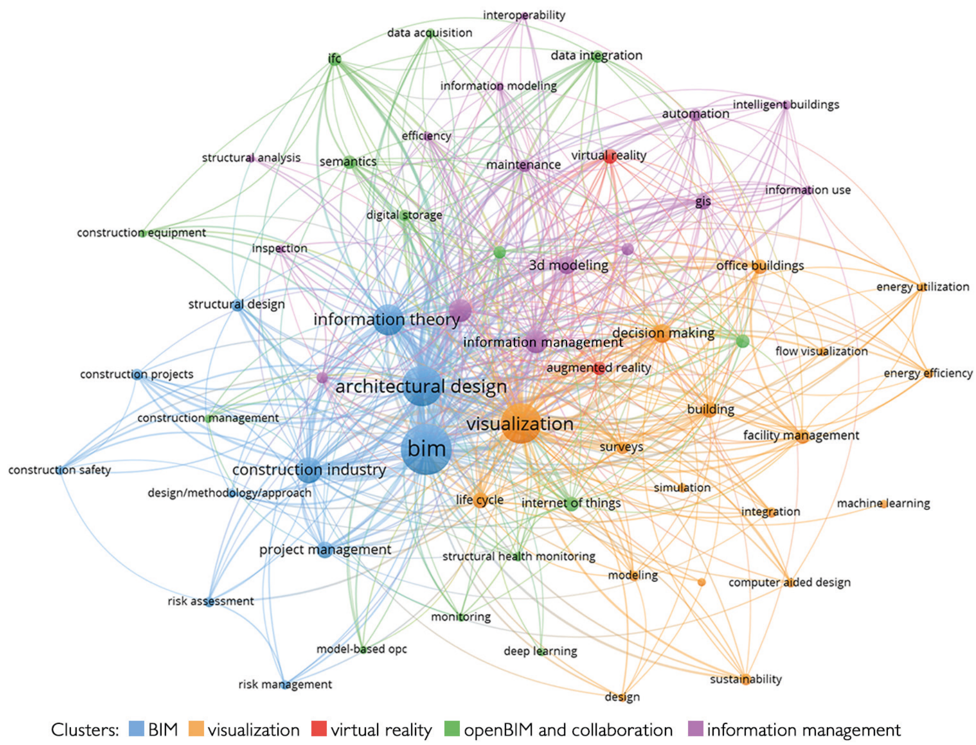

Fig. 2. Network map of keywords in published documents from *Scopus* (elaboration by the authors).

Most diffused BIM-based visualizations

Traditionally, two-dimensional architectural drawings have been the foundation of any project, from design to construction. These, encoded as a set of plans, elevations, sections, and curve and surface developments, are already forms of data visualization for the construction industry [Koutamanis 2000]. However, BIM has revolutionized this concept, brought substantial innovations, particularly in visualization support, by providing a three-dimensional base for any representation. Given the broad scope of the two core topics addressed in this paper, a coherent analysis of the most common visualization techniques in BIM requires structuring the discussion into macro-areas, based on the purpose of the visualizations and the types of data represented. Succar [Succar, Saleeb, Sher 2016] studied the uses of BIM models, categorizing them into a well-known list according to specific industry domains. He classified the information that must be contained in BIM models based on their intended application–first identifying a list of BIM uses and then grouping them into seven macro-categories. This paper selects a limited number of BIM uses from certain macro-categories, focusing on those that already have incapsulated data visualization techniques and that currently feature the highest density of visualizations to analyze, specifically those where the digital environment plays a crucial role. BIM-uses which respond to these characteristics belong to following macro-categories: *capturing and representing, planning and designing, simulating and quantifying, construction and fabricating*. A preliminary review was conducted to identify and understand the most widespread types of data visualization in general, independently of the BIM context. This involved analyzing existing visualization catalogues and typologies –such as those developed in the *DataViz Project* [Ferdio 2025] and *Data Visualization Catalogue* [Ribecca 2025]– which classify visual formats based on structure, purpose, and data type. These general typologies were then examined and cross-referenced with BIM applications to determine which types are already present in the construction sector. In doing so, the selected visualization types were not considered as mere 2D charts or diagrams, but were analyzed with particular attention to the integration of 3D components and spatial representation capabilities enabled by BIM environments. A schematic summary of the most widespread visualization types used in the construction sector –organized according to their corresponding BIM use– is provided in figure 3. To support understanding, figure 4 presents illustrative examples of these visualization types taken from the *DataViz Project* catalogue [Ferdio 2025]. The following paragraphs describe some significant examples identified in both academic literature and professional practice. In traditional professional practice, with the advent of CAD (Computer-Aided Design)

	Photogrammetry/Laser scanning	Construction planning	Space programming	Acoustic analysis	Clash detection	Cost estimation	LCA/Sustainability analysis	Lighting/Solar/Thermal analysis	Structural/Finite element analysis	Quantity take-off	Wind studies	Real-time utilization
Table chart		•	•		•	•				•		
Line graph		•		•	•	•	•	•			•	•
Area graph/Histograms		•		•	•	•	•	•	•			•
Pie/Donut chart		•			•	•	•	•				
Heat map	•		•	•			•	•	•	•	•	•
Dot/Scatter map	•			•	•							•
Flow map (vector)				•				•	•		•	
Gantt/Timetable/Timeline		•		•								•
Sankey/Chord diagram		•					•	•				
Treemap			•									
Radar chart							•	•				•
Network diagram					•							•

Fig. 3. AECOO-specific data visualization matrix (elaboration by the authors).

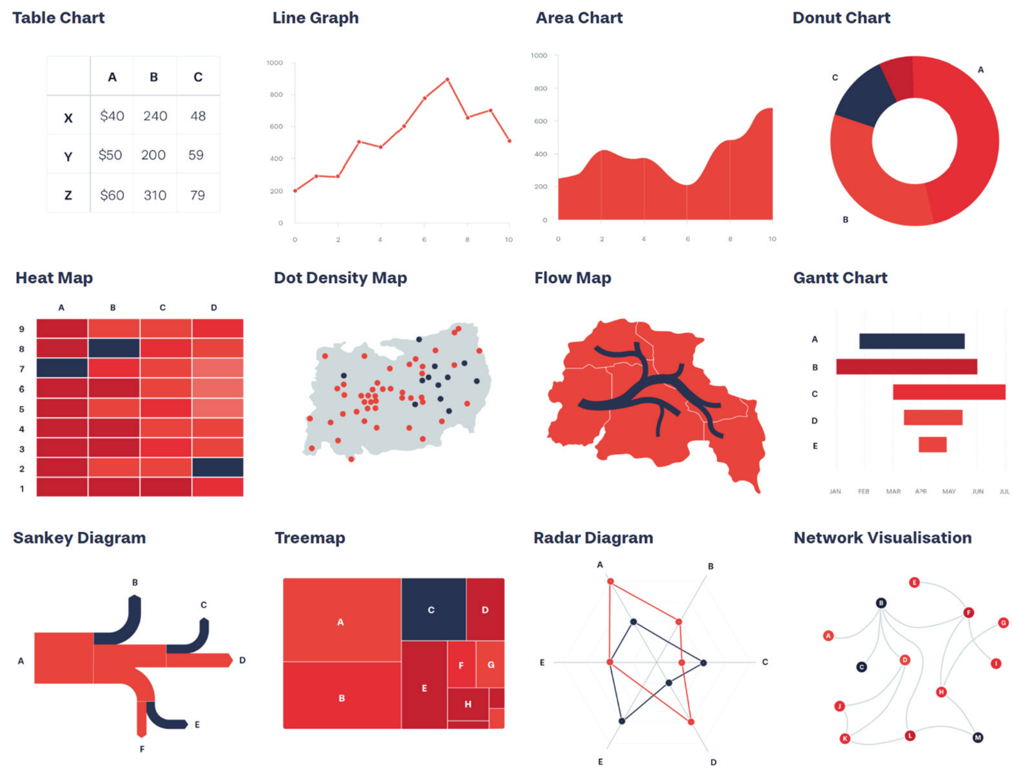

Fig. 4. Most diffused visualization types in AECOO industry. Illustrations from [Ferdio 2025] (edit by the authors).

and FEM (Finite Element Model) analyses, the results of energy, solar, and thermal analyses are supported by visualizations that provide fundamental support in data comprehension (figs. 5, 6). [Brehmer *et al.* 2016], for example, analyzes visualization techniques for monitoring the energy performance of large building portfolios, highlighting the limitations of traditional graphs such as line charts for derived and aggregated data due to a combination of data semantics and domain conventions. Through a design study, they evaluate scalable alternatives, identifying

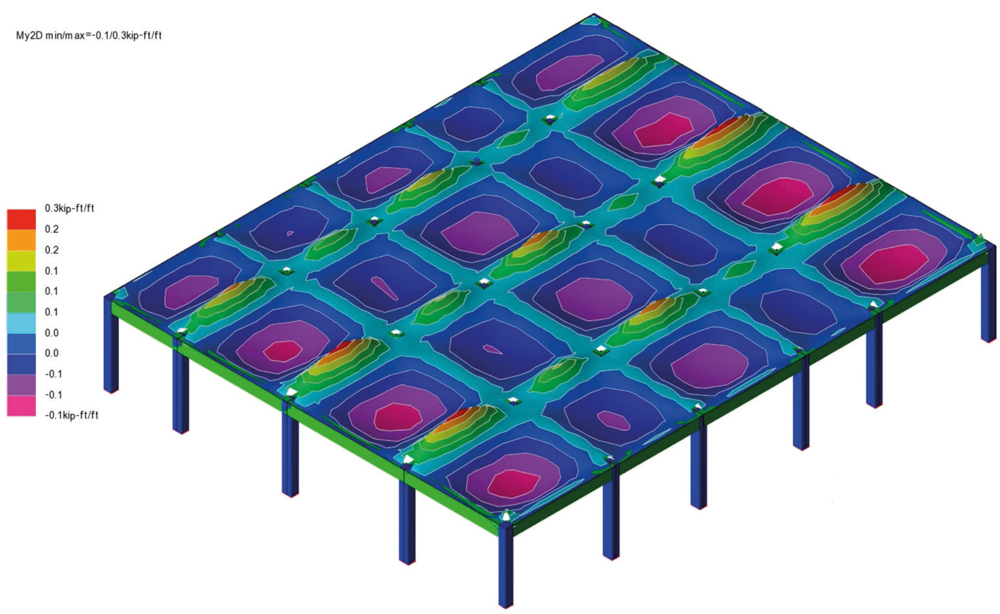

Fig. 5. Example of structural analysis heatmap visualization on three-dimensional geometrical model. [Decode BD 2017].

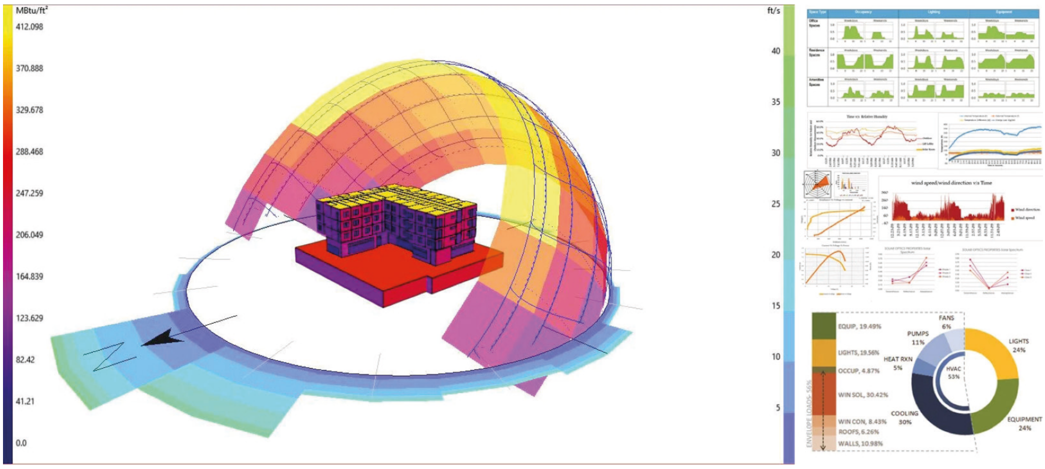

Fig. 6. Example of solar and energy analysis results visualization combining BIM model and traditional charts [Hnin 2022].

stacked area charts, matrices of data, and faceted visualizations as more effective solutions that enhance the understanding of energy analyses. Another visualization type widely used in the study of building energy performance and material flows is Sankey diagrams (fig. 7) [Abdelalim, O'Brien, Shi 2017; Miatto *et al.* 2024]. However, the mere representation of a flow is not sufficient in complex and highly detailed data contexts where more articulated visualizations are required [Lupton, Allwood 2017]. In the field of digital surveying tools such as photogrammetry and laser scanning allow for the digital visualization of existing structures, offering a highly accurate replica of reality. This technology enables reliable building modeling but also the monitoring of construction progress [Wang *et al.* 2022].In the field of environmental sustainability, the combination of BIM and data visualization is essential, particularly in the domain of Life Cycle Assessment (LCA). Interactive visualization based on LCA data, such as the relationship between material intensity and building geometry [Miatto *et al.* 2023], is fundamental for supporting design decisions already in the early design phases. The method proposed by [Forth, Hollberg, Borrmann 2023] aims to improve the understanding of environmental impacts by non-experts. The results obtained show that color coding and the use of heatmaps in BIM models help identify building elements or areas that significantly contribute to greenhouse gas emissions and support the selection of design alternatives by comparing the different effects of each. Extracting quantitative data from models and linking objects with indirect information from other sources, such as costs and construction timelines, requires advanced and detailed visualizations that go beyond simple two-dimensional

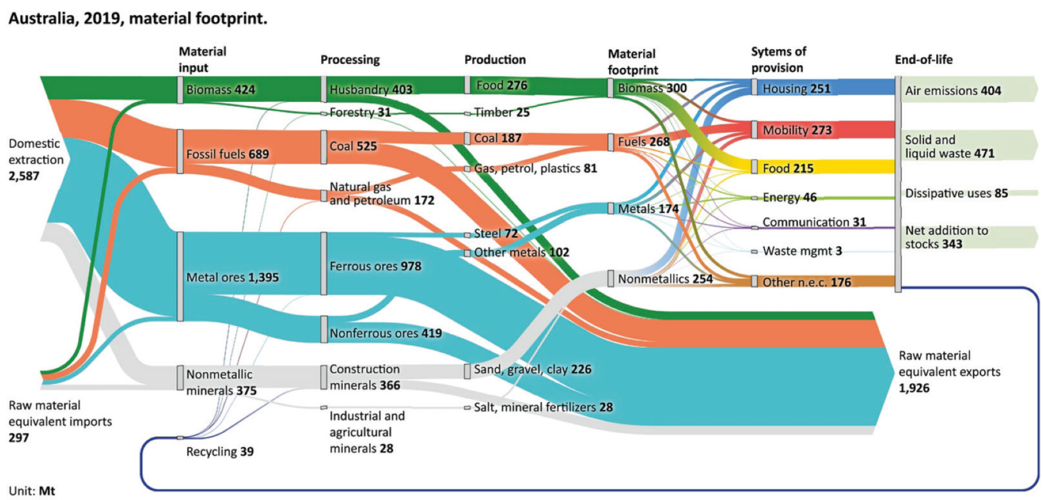

Fig. 7. Example of typical Sankey diagram to show LCA analysis results [Miatto *et al.* 2024].

graphs. In this sense, dashboard visualization is widely adopted today: they are defined as a tool that displays data concisely and actionably, providing crucial information briefly [Wexler, Shaffer, Cotgreave 2017]. The use of dashboards in the AEC sector is considered fundamental for information exchange among the different stakeholders of a project, especially in large-scale projects [Hughes *et al.* 2013]. The most comprehensive configurations aim to directly relate data to model objects through the combined use of classic two-dimensional graphical representations and the three-dimensional geometries of the building model under construction. Typically, the interface is dominated by an area where the BIM model is displayed, while the remaining space is occupied by charts and tables that present the analyzed data (fig. 8). Dashboards are particularly widespread for reporting purposes in the fields of quantity takeoff, scheduling analysis (4D), and cost estimation (5D). Their creation is often supported by Business Intelligence tools [Rodrigues, Alves, Mato 2022; Wefki, Elnahla, Elbeltagi 2024] which offers interesting insights for taking data analysis to the next level in the construction sector. Islam and Jin [Islam, Jin 2019] examine the crucial role of data visualization in Business Intelligence (BI). They highlight how this science has transformed BI itself, making data analysis accessible even to non-technical users, supporting advanced analytics projects, and facilitating informed and rapid decision-making within organizations.

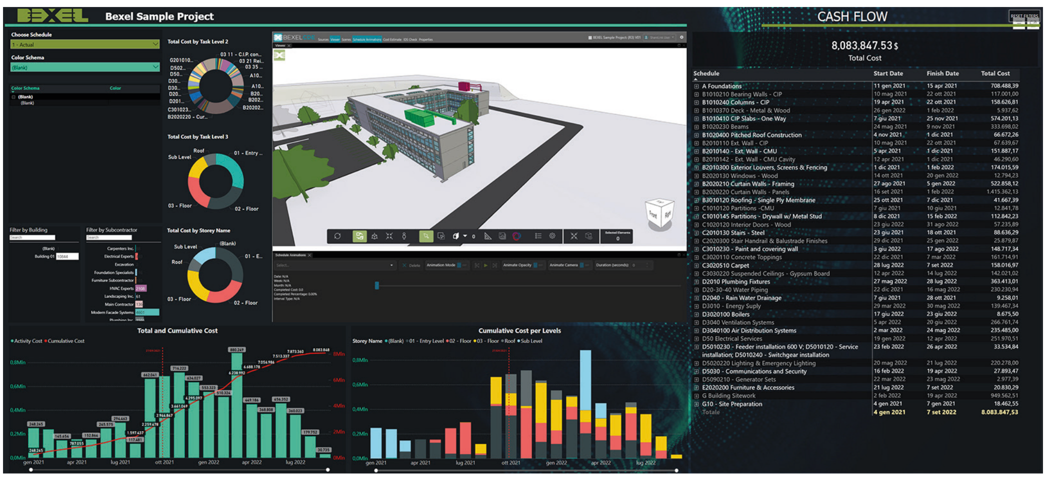

Fig. 8. Example of dashboard composed of traditional visualization techniques paired with BIM model [Bexel 2024].

Criteria for advanced visualization in BIM

In the context of creating advanced visualizations for the AEC industry, some criteria are proposed here that should always be followed to ensure that visualizations optimally support professionals in the decision-making process. These criteria are the result of the analysis conducted in the previous sections. By examining the most common types of data visualization in general, mapping them to BIM-specific applications, and identifying their current usage across different BIM uses, it was possible to extract the key strengths and limitations of each. The proposed criteria thus reflect recurring patterns, best practices, and functional elements observed across the visualizations studied, and are specifically tailored to leverage the unique capabilities of the BIM methodology. They also take into particular consideration the potential offered by BIM compared to other sectors, where data visualization is more advanced and specialized but, for this very reason, difficult to transpose without a process of integration and adaptation.

Geometric and Spatial-Data Integration: the main feature that BIM models offer is undoubtedly the ability to use three-dimensional geometries. Spatiality, also understood as spatial thinking [Taylor, Burte, Renshaw 2023], has always played a fundamental role in the AEC industry. In this sense, it is possible to establish relationships between data and geometries, opening up new possibilities for interaction, navigation, and data querying that are not possible in other sectors. Thanks to this, approaches are being developed for integration with webXR-based technologies [Balin, Bolognesi, Borin 2023], moving towards the frontier of total immersion in visualizations.

Identity of Data and Relation with the Model: to adopt the most appropriate visualization, it is first necessary to study the typology of data available, i.e., identify whether the data to be represented is simple or aggregated. The first case refers to information extracted directly from models and uniquely associated with geometries (e.g., the volume of a wall, the position of a window). The second case, instead, refers to data derived from a series of analyses or queries on external sources and therefore indirectly linked to model objects without a primary connection to geometries. Examples of the latter type include the results of energy or performance analyses based on numerous calculations or cost reports that consider multiple interconnected factors such as object volume, materials used, labor hours required for construction, transportation to the site, etc.

Model interactivity: the availability of a three-dimensional BIM model also means being able to navigate, rotate, select, and group objects and, consequently, the information linked to them. Therefore, it is essential that two-dimensional representations are also interactive and dynamically respond to user inputs. For example, selecting a data point in a table or chart should trigger a cycle of visual modifications in the model objects to highlight their mutual relationship, and the same process should occur in reverse.

Open and Collaborative Accessibility: collaboration is crucial in the AEC industry; therefore, access to visualizations and their associated data must be ensured through openBIM and web-based workflows, leveraging open standards such as IFC (Industry Foundation Classes) and BCF (BIM Collaboration Format). Additionally, accessibility to visualizations also encompasses the simplicity and usability of the tools' user interfaces [Kubicki, Halin, Guerriero 2007].

BIM-use Specificity: the construction sector is so vast and varied in its disciplines that it is difficult to create visualization archetypes that are replicable across all of them. For this reason, representations must be tailored to the specific BIM-use in which they are applied so that they can effectively and clearly convey meaning without being used in circumstantial ways. However, the integration of visualizations from multiple domains serves as a pathway to achieving the necessary depth for understanding and making complex design choices in an informed and reasoned manner.

Visual Grammar and Design Integrity: finally, the graphical aspect should not be underestimated. Stylistic choices remain fundamental for the immediate and correct understanding of data and must always coherently and specifically accompany the previous criteria. Colors, transparency, graphic symbols, their size, density, and position are of primary importance to help users focus on the data, not only on the design itself [Cairo 2013].

Conclusion

Scientometric analysis has confirmed the growing importance of data visualization in BIM research. However, common visualizations in BIM reveal both potential and critical issues. The connection between BIM and data visualization is often reduced to mere graphics, neglecting the crucial link between data and its representation. The use of tables and 2D graphs is sometimes redundant, failing to leverage BIM's full potential. BI and dashboards offer a step forward by integrating data and models, but their immaturity leads to ineffective visual representations. Moreover, literature lacks guidelines linking model uses to visualizations. Finally, this research proposes BIM-based criteria to improve AEC-specific visualizations respecting both graphic consistency and BIM methodologies principles for helping decision-making processes.

Note

[1] Ygor Fasanella wrote chapters *Scientometric analysis of visualization in BIM, Criteria for advanced visualization in BIM* and *Conclusion*; Paolo Borin wrote chapters *Introduction* and *Most diffused BIM-based visualizations*.

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