# FEEDBACK-DRIVEN DESIGN FRAMEWORK TO BRIDGE THE GAP BETWEEN BUILDING DESIGN AND OPERATIONS

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Despite the significance of building design in influencing subsequent lifecycle stages, the disconnect between building design and Operation & Maintenance (O&M) stages remains a persistent challenge in today's building industry. This disconnection creates a critical knowledge gap in the decision-making process, leading to the loss of valuable operational insights for new building designs and limiting the potential to address O&M challenges within modern complexities. While past researchers have examined various building design aspects, a key limitation is the absence of structured frameworks for systematically incorporating building performance feedback into new design decisions. Therefore, this study develops a feedback-driven design framework that ensures the connection between design and O&M, fostering long-term efficiency, adaptability, and continuous learning and improvement. A critical literature review (CLR) was conducted to synthesise existing building design perspectives and identify their limitations. The proposed framework emphasises a key mechanism for integrating operational insights into future design decision-making through interdisciplinary stakeholder collaboration, knowledge integration, and the use of advanced methods and techniques. It positions building design as a dynamic, iterative process shaped by ongoing performance feedback and continuous improvements.

Keywords: building design; design decision-making; design framework; operational feedback

## INTRODUCTION

The architecture, engineering, construction and facilities management (AEC/ FM) industry has experienced declining productivity, particularly in building performance. Poor design decisions have become a major contributor to this situation, leading to multiple problems such as difficulty accessing areas for maintenance, safety hazards, budget overruns and inefficient energy usage (Akanmu *et al.,* 2020; Astarini *et al.,* 2024; Guo *et al.,* 2013; Knotten *et al.,* 2015). For example, buildings with poorly coordinated mechanical and architectural designs often face recurring access issues for maintenance, resulting in increased maintenance costs (Akanmu *et al.,* 2020). These

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issues not only hinder efficient building operations but also compromise long-term functionality and maintainability. Therefore, the influence of design decisions extends far beyond the early project stages, ensuring enhanced building performance and sustainability (Akanmu *et al.,* 2020; Astarini *et al.,* 2024).

Building design is a complex, multidisciplinary process (Gray and Hughes, 2000; Hegazy *et al.,* 2001) that has been viewed and conceptualised differently by researchers over time, emphasising various key aspects. However, an essential yet often overlooked aspect of improving building design process is incorporating building performance feedback into new design decisions (Criado-Perez *et al.,* 2019; Hay *et al.,* 2017; Petrova *et al.,* 2018; Wang and Leite, 2016). Building performance data are vital for new design decisions to ensure continuous building performance improvement with modern complexities and demands over time (Goçer *et al.,* 2015; Petrova *et al.,* 2018). Consideration of building performance insights during architectural design has been explored in recent studies through different approaches like Performance-Based Design (PBD), Building Performance Modelling (BPM), Building Information Modelling (BIM), Artificial Intelligence (AI), computational tools (Akanmu *et al.,* 2020; Astarini *et al.,* 2022; Petrova *et al.,* 2018; Tian *et al.,* 2021). However, they are often grounded in data-based assumptions and conceptual ideas rather than real-time operational insights (Breadsell *et al.,* 2020; Yu *et al.,* 2022). While they are valuable for estimating building performance, they rarely reflect actual building operation, leading to discrepancies between predicted and real-world performance. Also, they cannot fully understand the complexity, variability and evolving nature of actual building use. Therefore, a more dynamic and continuous connection between building design and O&M is essential to incorporate real-time building performance data into new building designs to make design decisions more informed and evidence based. However, such connection has not been well-established between building design and O&M, leading to a performance gap, where buildings may be excellent in architecture but underperform in usability, adaptability and operational efficiency (Breadsell *et al.,* 2020; Davoodi *et al.,* 2021).

To address this issue, a systematic feedback-driven approach is crucial to complement conventional design activities across the building value chain, enabling continuous learning and improvement. Since existing literature has not explicitly framed the design process through this lens, and research in building design management is evolving with significant opportunities for further development (Agegn *et al.,* 2024), this study develops a feedback-driven design framework that emphasizes a key mechanism for integrating operational feedback into the design process.

## METHOD

This study employs a critical literature review (CLR) following the typologies identified by Grant and Booth (2009) given that it entails to critically assess and synthesize the prevalent literature regarding the research area to produce a 'conceptual contribution' to the field (Snyder, 2019). Although CLR does not follow strict, systematic literature selection like systematic literature reviews (SLR), it allows for the inclusion of a wide range of perspectives and theoretical underpinnings from different sources, which is often limited in SLRs (Greenhalgh *et al.,* 2018; Snyder, 2019). As such, adopting CLR is favoured in this study to understand different aspects of building design investigated by various researchers over the past years and develop a new design framework that assists in addressing the limitations in the existing design theories.

The relevant sources were identified through a snowballing search approach, which refers to article identification based on reference lists or citations of a key article/s (Wohlin *et al.,* 2022). This approach enabled the identification of the most appropriate and influential sources in the subject area. This study employed insights from different sources such as journal articles, conference papers, industry reports and documents, books and book chapters. The academic literature search was conducted using Google Scholar, Scopus and Web of Science, which are recognised as main reputable databases that facilitate access to high-quality publications (Ali *et al.,* 2017). To identify the most influential sources, appropriate keywords within the research area were used, such as design process, building design management, design methodology, design strategy, design approach, building performance feedback, and feedback loop. Key seed articles that initiated the snowballing process included (Gero, 1998), (Koskela *et al.,* 2002) and (Bølviken *et al.,* 2010) on different design models, which provided foundational insights into understanding the design process. Ideas generated from reading the resulting sources were then used to develop the new design framework.

## Theoretical Background

By the late 19th century, the division between the "hard" (scientific, quantifiable) and "soft" (aesthetic, qualitative) aspects of culture was increasingly questioned, leading to the modern concept of "design" as a bridge between art and science (Flusse, 1995). With that, two dominant viewpoints emerged regarding the value of design as "hard" and "soft". This perspective is deeply embedded in building design where both conceptual thinking and technical implementation need to be effectively reconciled (Bølviken *et al.,* 2010; Knotten *et al.,* 2015). The conceptual aspect involves generating innovative ideas, concepts and assumptions, while the technical aspect focuses on the streamlined and structured execution of those ideas into tangible, meaningful and actionable outputs. Accordingly, Gero (1998) categorised design activities into conceptual and detail designing, further highlighting the interplay between conceptual and structured aspects of design. Conceptual design is often exploratory and problem-defining, where knowledge is incomplete and innovative solutions are required. In contrast, detail designing relies more on structured knowledge to refine established concepts. However, these aspects are not mutually exclusive; conceptual design may also adhere to established patterns, and detail design may require innovative ideas (Gero, 1998). Expanding on this perspective, (Bølviken *et al.,* 2010) defined three main phases of the building design process. Phase one is design creation process which primarily includes conceptual thinking. Phase two is design production process which mainly operates with more defined and structured parameters to execute the concepts. Phase three; the decision-making process connects and guides both phase one and two allowing for iterations. These phases emphasize the dynamic interaction and evolving nature of building design where iteration and feedback play critical roles.

### Different perspectives of building design

Over the years, conceptualisations of building design have evolved from structured and linear models to more dynamic, context-sensitive understandings. Early views, such as those by Lawson (1990) described the building design process as a reciprocal process involving analysis, synthesis, and evaluation, suggesting a logical sequence designers follow towards a defined goal. Expanding on this, Knotten *et al. (*2015) highlighted that design problems cannot be documented or stated comprehensively and the design solutions for these problems are unlimited. Therefore, building design requires a continuous process of analysis, synthesis and evaluation to find the most optimal design solutions. This perspective highlights the iterative nature of the building design process that requires continuous refinement within the design process itself to produce design solutions. Each iteration during this process contributes to adding value to the end product (Aasrum, 2016). While these views acknowledges that design involves iterations and refinements, it still identifies the design process as logical and structured where each step follows from the previous one in a planned way.

Contrasting this viewpoint, Gero (1998)'s different models of design provided a turning point, emphasising that design is not always a problem-solving process with a known goal. The "design as exploration" model embraces the open-endedness of the design process, where neither the problem nor the solution is fully understood at the outset. The possible solutions and pathways to resolve the design problem need to be discovered and defined. More reflective and emergent models like "design as reflection in action" and "design as emergence" started to challenge linear notions of design, emphasising it as an adaptive process where unintended patterns, relationships and opportunities were seen in a design that can lead to new insights or creative solutions. These latter models recognise the importance of intuition, reinterpretation, and continuous learning, aligning more closely with real-world practices where ambiguity and complexity are the norm. However, Gero (1998) argued that these traditional models still do not fully capture the complex, evolving and context-dependent nature of real-world designs. To address this, two new concepts were proposed: situatedness and constructive memory. Situatedness highlights that design decisions are influenced by where and when they are made, while constructive memory identifies that interpreting insights from past experiences shapes future design decisions. This divergence between structured and emergent views of design also surfaces in the three different perspectives: process-driven, flow-driven and value-driven, proposed by Koskela *et al. (*2002). While the process-driven view aligns with older, more deterministic notions of design as a linear transformation of inputs into outputs, the flow-driven view introduces a needed recognition of temporal and collaborative complexity, where the movement and integration of materials, information, and people are central. The value-driven perspective, which is about ensuring that the final design outcomes meet end-user requirements and expectations, is especially critical and aligns with a broader shift towards user-centred and performance-based design.

The managerial lens offered by Emmitt and Ruikar (2013), Knotten *et al. (*2017) and Sinclair (2011) further contributes to the framing of building design as a discipline of management, focusing on planning, organising and controlling the process. People in this context are stakeholders involved in a building project, and information is deliverables among the stakeholders. These different stakeholders possess specific knowledge (which can be explicit or tacit), that they can transform into meaningful data/ information needed by the project.

Together, these perspectives highlight two broad paradigms of the design process.

- Design as a sequential and predictable process that can be planned and managed step by step.
- Design as a dynamic and evolving process, shaped by experience, judgment, and changing situations.

While both paradigms offer valuable perspectives into how building design is approached, it is important to critically examine how they are reflected in current practices and where key limitations persist.

Limitations in the existing building design perspectives

Among the two main paradigms, it is the first paradigm - design as a sequential and predictable process - that has predominantly shaped current building design practices. Jiang (2015) highlighted that since building design practices are based on different design philosophies, assumptions, and theoretical underpinnings at large, often there are buildings with excellent architectural designs but problematic situations in satisfying user experience. In contrast, the second paradigm, which views design as a dynamic and evolving process driven by experience and judgment, remains underexplored in the existing literature and practical applications. Incorporating building performance and Post-Occupancy Evaluation (POE) insights such as energy efficiency, indoor air quality, occupancy comfort and user experience into building design is crucial to ensure continuous building performance improvement within modern complexities and demands (Goçer *et al.,* 2015; Petrova *et al.,* 2018). In the study by (Gero, 1998), the idea of making design process adaptive, flexible and aligned with real-world challenges was emphasized. Similarly, Koskela *et al. (*2002) argued that improvements in building design require a combination of a solid theoretical understanding of the complexities and nuances of the building process and insights from real-world contexts. While existing perspectives acknowledge the iterative nature of design (Gero, 1998; Knotten *et al.,* 2017; Knotten *et al.,* 2015), they primarily emphasize refinement within the design phase itself rather than incorporating insights from the actual building performance or post-construction, leaving a crucial knowledge gap unaddressed.

This gap underscores the missing element in the building process - a structured, long-term feedback loop; a mechanism to integrate building performance data from O&M into future designs. As a result, real-world building performance data are not systematically fed back to inform and drive new designs. While existing viewpoints like process-driven, flow-driven and value-driven perspectives focus on structured information flow, stakeholder engagement, and value-creation (Koskela *et al.,* 2002), they tend to treat O&M as a downstream phase rather than a continuous knowledge source that can continuously inform future design decisions. At the same time, they do not explicitly define how interdisciplinary knowledge from O&M professionals should be structured and how the collaboration of stakeholders should be ensured, although they identified building design as managing people and information (Emmitt and Ruikar, 2013; Knotten *et al.,* 2017). Therefore, the building design process requires a balanced approach that ensures that design decisions are not largely based on initial assumptions, predefined design principles and theoretical models but are continuously refined through real-world building performance feedback. This acknowledges the design process as a dynamic and evolving process rather than a sequential and predictable process, and shaped by past evidence, experience and changing situations.

**Towards an Adaptive and Intelligent Building Design Process**

Despite the breadth of theoretical perspectives and techniques explored in the literature on understanding building design process, the absence of a structured and continuous feedback mechanism from building operation to design has resulted in a persistent performance gap where design excellence does not necessarily translate into operational success. The current approaches remain largely predictive and assumption-based with limited grounding in the realities of actual building performance (Petrova *et al.,* 2018; Wang and Leite, 2016; Yu *et al.,* 2022). Also, although a large amount of building performance data is captured through various techniques, the systematic application of these data for future building designs remains incomplete and underutilised due to different challenges (Brown and Arens, 2012; Criado-Perez *et al.,* 2019; Hu *et al.,* 2018; Ostergård *et al.,* 2016; Riley, 2013; Tian *et al.,* 2021). Some of the significant examples of these challenges include limited integration of multi-source data into a centralised, well-designed data models, limited access to the building performance data, lack of building performance data disclosure laws, limited availability of high-quality datasets, financial limitations, interoperability issues between different data management platforms, complexity of analysing a large datasets (Astarini *et al.,* 2022; Fang and Cho, 2019; Tian *et al.,* 2021). Consequently, valuable operational insights are often overlooked, leaving the design process disconnected from real-world outcomes. This disconnection between building design and O&M results a valuable knowledge loss from actual building performance, limited design adaptation based on real-world conditions and siloed decision-making that leads to disjointed workflows and fragmented data utilisation. To address this gap, there is a pressing need to understand the building design process not merely as a sequential process but as a dynamic, feedback driven process that evolves through continuous learning from post-construction performance. This calls for an adaptive and informed design framework (as presented in Figure 1) that actively incorporates operational data in design, facilitates interdisciplinary knowledge exchange, and transforms how design decisions are made in the face of increasing complexity, uncertainty, and performance expectations in the built environment. To that, a structured mechanism that systematically captures, integrates and applies real-world building performance data into new designs is crucial.

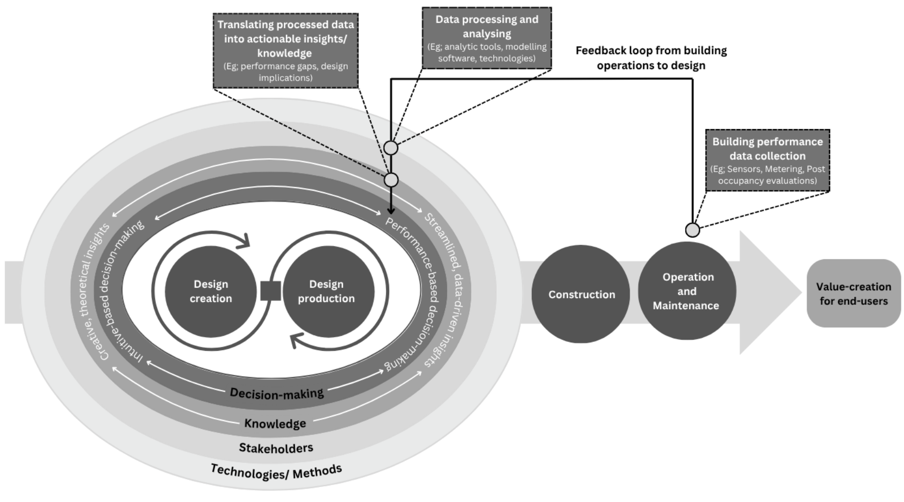


*Figure 1: Feedback-driven design framework*

The framework operationalises how building performance insights from existing buildings are fed back into the early design process, creating a continuous cycle of learning and improvement in the decision-making process. It positions building design as an iterative and feedback-driven process, rather than a purely sequential.

At its core, the design process comprises design creation and design production, corresponding to conceptual design and detailed design aspects. While the design creation process is primarily driven by innovative, conceptual insights and the design production process is mostly driven by streamlined, data-driven insights, each phase can inform the other. Surrounding the core design process, multiple layers can be identified that support a structured feedback mechanism.

The decision-making layer constitutes both intuitive-based decision-making (driven by assumptions and conceptual understanding) and performance-based decision-making (informed by building performance data). The framework enables these two modes to co-exist and influence one another. Building performance data are first collected (e.g., sensors, POEs), then processed and analysed (using technologies, modelling tools, analytics), and finally translated into actionable insights (e.g., performance gaps, design implications) that inform early-stage decisions. Early conceptual design ideas can be refined by these analysed building performance insights to make more accurate and informed ideas for execution. The knowledge layer represents the key insights or knowledge areas, either from initial assumptions/ intuition (creative/ theoretical insights) or building performance data like energy use data, temperature data, indoor air quality data, maintenance data etc. (streamlined/ data-driven insights), that lead to actionable decisions. By analysing building performance data, key knowledge aspects like building performance gaps, design implications can be extracted, where these knowledge areas need to be mapped across different design phases to ensure their timely application. The stakeholder layer represents the collaboration between multidisciplinary stakeholders throughout the building value chain who possess multidisciplinary knowledge for decision-making. Building professionals across the entire building lifecycle including architects, engineers, facilities managers, and sustainability consultants contribute different types of knowledge, and the framework promotes structured knowledge transfer among them, especially from operations to design teams. The technologies/ methods layer presents different techniques like BIM, AI, Internet of Things (IoT), digital twins, building performance monitoring, data analytics tools, software etc., that facilitate the transformation of raw building performance data into actionable design decisions in new building projects. These advanced methods enable more effective data-driven decision-making in building design through real-time tracking. Accordingly, this framework presents how to systematically complete the missing link between design and O&M in terms of knowledge management, ensuring that future projects benefit from knowledge accumulated in existing building stock without any knowledge loss. Such feedback-driven design framework transforms more conventional building design process into an adaptive and evolving system, ensuring long-term sustainability and efficiency in building projects within the increased industry demands, changing conditions and complexities.

## CONCLUSION

This study proposed a feedback-driven design framework to address the missing link between building design and O&M, ensuring a continuous cycle of learning and improvement. While existing perspectives acknowledge the building design as an iterative process, they have not fully understood the building performance feedback-driven approach in building design that is more adaptable, practical and high performing. In today's industry, building projects often repeat inefficiencies and miss opportunities for continuous improvement due to not having a structured mechanism to incorporate building performance data into the design process. The proposed design framework provides a structured mechanism, making the building process more adaptable and integrated through a continuous cycle of learning and improvement. Further, it highlighted that how multidisciplinary knowledge, stakeholders, and different methods/ systems can facilitate this feedback-driven approach. Accordingly, the findings of this study offer a novel conceptual perspective that contributes to ongoing efforts to bridge the gap between design and O&M. While preliminary, it lays the groundwork for further research in feedback-driven building design process to make new designs more informed and evidence-based.

Future research could explore the applicability of this approach within the contemporary building industry by exploring how industry practitioners perceive it within the modern world's demands and complexities. This may include investigating its level of acceptance, potential implementation challenges, and the practical implications of such a feedback-driven design process in existing workflows. Further, the role of advanced technologies like AI, BIM and digital twins in automating and optimising this approach can be investigated in future to strengthen its applicability in the real-world context. Accordingly, the proposed framework lays the baseline for a more resilient and data-informed design culture. Also, this will be a crucial step towards proposing a systematic approach for data-driven design decision-making as the main outcome of the first author's Doctoral research.

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