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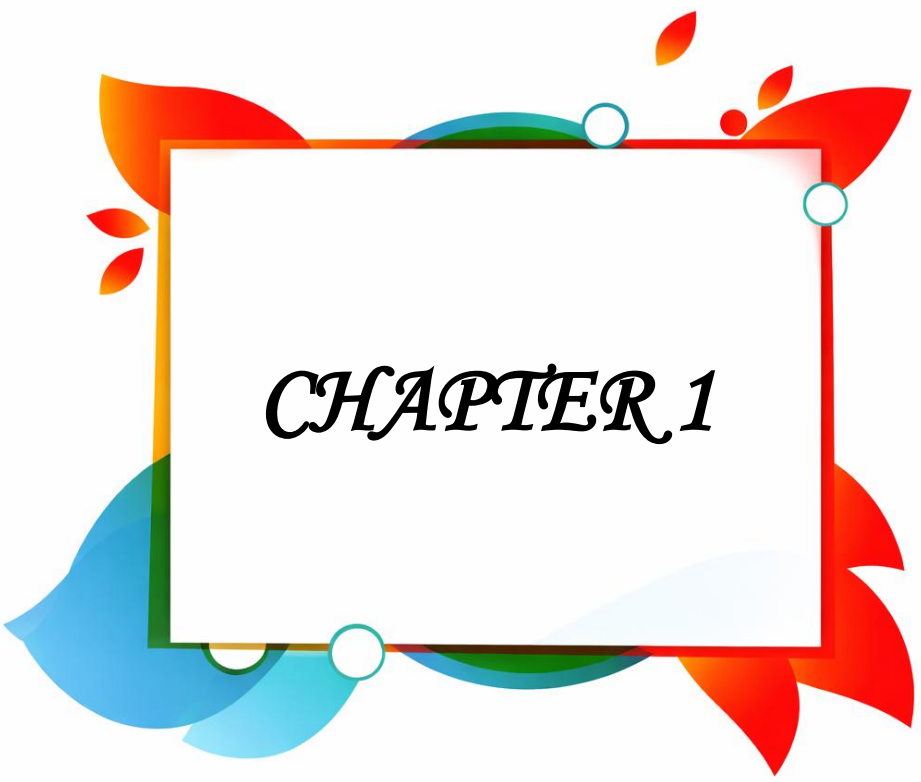
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CHAPTER 1

An Integrated Project Management Framework for Contemporary Interior Architecture Practice

Ali Kemer¹

INTRODUCTION

The scope of contemporary interior architecture has expanded significantly over the last decade. Interior architects are no longer responsible solely for developing spatial concepts and aesthetic solutions; they are increasingly involved in coordinating project stakeholders, managing procurement processes, selecting materials and furniture systems, supervising fit-out activities, and ensuring that project objectives are achieved within predefined constraints. As a result, project management has become an essential component of professional interior architecture practice.

The increasing complexity of interior architecture projects has been influenced by several factors, including technological innovation, sustainability requirements, changing user expectations, and the growing demand for interdisciplinary collaboration. Contemporary projects often require the integration of architects, interior architects, engineers, contractors, suppliers, facility managers, and clients throughout the project lifecycle. Managing these interactions effectively has become critical for achieving successful project outcomes.

Unlike traditional design-oriented approaches, contemporary interior architecture projects involve a wide range of managerial activities extending beyond the design phase. These activities include project planning, budgeting, scheduling, stakeholder communication, procurement coordination, risk management, quality control, and post-occupancy evaluation. Consequently, interior architects increasingly operate within complex project environments where managerial capabilities are as important as design expertise.

At the same time, digital technologies have transformed the way projects are developed, coordinated, and monitored. Building Information Modeling (BIM), cloud-based collaboration platforms, digital project management systems, artificial intelligence-assisted planning tools, and immersive visualization technologies have improved information exchange and project coordination across multidisciplinary teams. These developments have encouraged

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organizations to adopt more integrated management approaches capable of responding to both technical and organizational challenges.

In practice, many interior architecture projects continue to experience difficulties related to stakeholder coordination, design revisions, procurement delays, budget control, and communication management. Such challenges demonstrate that project success depends not only on creative design solutions but also on the effective integration of planning, communication, leadership, and performance management processes. Therefore, understanding project management within the specific context of interior architecture has become increasingly important for both researchers and practitioners.

Although project management has been extensively studied within construction and architectural management literature, relatively limited attention has been devoted to the unique requirements of interior architecture projects. Issues such as FF&E coordination, interior fit-out management, material specification, user experience considerations, and client-driven design changes introduce managerial challenges that differ from those encountered in broader construction projects. This gap highlights the need for a more focused discussion of project management frameworks tailored to contemporary interior architecture practice.

Accordingly, this chapter examines the theoretical foundations and practical dimensions of project management in interior architecture. Particular attention is given to stakeholder collaboration, digital transformation, risk management, performance evaluation, and sustainability considerations. In addition, the chapter proposes an Integrated Interior Architecture Project Management Framework (IIAPMF), which aims to support strategic planning, stakeholder engagement, digital integration, performance monitoring, and continuous organizational learning throughout the project lifecycle.

The chapter is structured into six sections. Following this introduction, the theoretical foundations of project management are discussed. Subsequent sections examine stakeholder collaboration, digital transformation, and the management of risk, cost, time, and quality. The proposed Integrated Interior Architecture Project Management Framework is then presented and discussed. Finally, the chapter concludes by outlining practical implications and future research directions for project management in interior architecture.

1. THEORETICAL AND CONCEPTUAL FOUNDATIONS

The increasing complexity of contemporary interior architecture projects has transformed project management from an administrative support function into a strategic component of project success. Contemporary projects involve multidisciplinary teams, advanced digital technologies, sustainability requirements, and diverse stakeholder expectations. Under such conditions, project management extends beyond traditional planning and control activities and increasingly focuses on integrating people, processes, information, and technologies throughout the project lifecycle (PMI, 2021; Kerzner, 2022).

Historically, project management theory was primarily associated with the efficient management of time, cost, and quality. This perspective, often referred to as the “iron triangle,” has long served as the foundation of project performance evaluation. However, recent research suggests that project success should also incorporate stakeholder satisfaction, organizational learning, sustainability performance, value creation, and long-term operational outcomes (Kerzner, 2022; Motalebi et al., 2025). This broader understanding is particularly relevant for interior architecture projects, where user experience and functional performance frequently determine the perceived success of project outcomes.

1.1. Systems Theory and Project Integration

One of the most influential theoretical foundations of project management is systems theory. From a systems perspective, projects are viewed as interconnected networks of activities, stakeholders, resources, and processes rather than isolated tasks. Decisions made during one project phase often generate consequences that affect subsequent phases and project outcomes (Kerzner, 2022).

Within interior architecture practice, systems thinking is particularly valuable because design decisions directly influence procurement strategies, construction activities, project budgets, operational performance, and user satisfaction. Material selection, spatial planning, lighting systems, furniture specification, and sustainability considerations frequently interact throughout project development. Consequently, project managers must understand the relationships among project components and coordinate them within an integrated management structure.

The systems approach also supports holistic decision-making by encouraging project managers to evaluate the broader implications of project interventions. Rather than focusing exclusively on individual project activities, systems thinking promotes a comprehensive understanding of project performance and organizational effectiveness (PMI, 2021).

Stakeholder theory has become increasingly influential within contemporary project management literature. According to this perspective, project success is strongly influenced by the ability to identify, engage, and manage stakeholders throughout the project lifecycle. Stakeholders include all individuals and organizations capable of affecting or being affected by project outcomes (Singh, 2021).

Interior architecture projects are characterized by extensive stakeholder involvement. Clients, designers, consultants, contractors, suppliers, facility managers, regulatory authorities, and end-users often possess different expectations and priorities. Managing these relationships requires continuous communication, negotiation, and collaborative decision-making. Failure to align stakeholder expectations may result in conflicts, project delays, budget overruns, and reduced user satisfaction.

Recent studies indicate that stakeholder engagement contributes significantly to project performance by strengthening trust, improving communication quality,

and facilitating knowledge exchange among project participants (Hosseini et al., 2022). As a result, stakeholder management is increasingly recognized as a strategic project management function rather than a supplementary administrative activity.

1.2. Sociotechnical Perspectives and Digital Integration

The rapid adoption of digital technologies has contributed to the emergence of sociotechnical approaches in project management. Sociotechnical theory argues that project performance depends on the interaction between technological systems and human factors, including organizational culture, communication practices, leadership, and professional competencies (Hosseini et al., 2022).

Within interior architecture projects, technologies such as Building Information Modeling (BIM), cloud-based collaboration platforms, virtual reality applications, and digital procurement systems have transformed traditional project workflows. However, technological adoption alone does not guarantee project success. Organizations must simultaneously address training requirements, stakeholder engagement, communication structures, and change management processes to maximize the benefits of digital transformation.

This perspective is particularly relevant for interior architecture practice because project delivery increasingly depends on both technical innovation and effective collaboration among project participants. Contemporary project management therefore requires an integrated understanding of technological and human dimensions of project performance.

The growing complexity of design and construction projects has encouraged the development of collaborative project delivery approaches. Traditional project delivery methods often rely on fragmented communication structures in which project information is transferred sequentially between participants. Such approaches frequently result in coordination problems, delays, and information loss (RIBA, 2020).

Collaborative project delivery frameworks seek to overcome these limitations by promoting early stakeholder involvement, shared decision-making, and continuous information exchange throughout the project lifecycle. Building Information Modeling and cloud-based collaboration systems have further strengthened collaborative management by enabling stakeholders to work within shared information environments (Yigitbas et al., 2023).

For interior architecture projects, collaborative delivery is particularly important because design revisions, procurement decisions, and construction activities are highly interconnected. Improved collaboration can reduce project risks, minimize design conflicts, and enhance overall project efficiency.

1.3. Sustainability-Oriented Project Management

Sustainability has emerged as a major consideration within contemporary project management theory. Project managers are increasingly expected to balance economic objectives with environmental and social responsibilities.

Consequently, project performance is no longer evaluated solely through traditional metrics such as time and cost but also through sustainability outcomes and long-term value creation (Motalebi et al., 2025).

Interior architecture projects frequently incorporate sustainable materials, energy-efficient systems, circular economy principles, and occupant well-being considerations. Integrating these objectives into project planning and implementation processes requires a more comprehensive management approach capable of addressing multiple performance dimensions simultaneously.

Recent research suggests that sustainability objectives are most effectively achieved when incorporated into project planning from the earliest stages of project development. Early stakeholder engagement, integrated decision-making, and digital coordination tools play important roles in supporting sustainability-oriented project delivery.

1.4. Toward an Integrated Theoretical Perspective

The theoretical foundations discussed in this chapter demonstrate that contemporary project management extends beyond traditional planning and control functions. Systems theory, stakeholder theory, sociotechnical perspectives, collaborative project delivery approaches, and sustainability-oriented management collectively contribute to a more comprehensive understanding of project performance.

For interior architecture projects, these theoretical perspectives provide a foundation for developing integrated management frameworks capable of addressing increasingly complex project environments. The following chapter builds upon these concepts by examining stakeholder collaboration and digital transformation processes that influence project delivery in contemporary interior architecture practice.

2. STAKEHOLDER COLLABORATION AND DIGITAL TRANSFORMATION

The successful delivery of contemporary interior architecture projects increasingly depends on the ability to coordinate multiple stakeholders within dynamic and technology-driven project environments. Unlike traditional project settings, contemporary projects involve a wide range of participants whose expectations, responsibilities, and decision-making authority may differ significantly throughout the project lifecycle. Consequently, stakeholder collaboration has become a critical determinant of project performance and organizational effectiveness (Singh, 2021).

Interior architecture projects involve a complex network of stakeholders, including clients, designers, consultants, contractors, suppliers, manufacturers, facility managers, and end-users. Each stakeholder contributes unique expertise and expectations that influence project outcomes. As project complexity increases, effective collaboration becomes essential for aligning stakeholder

objectives, reducing conflicts, and improving project performance (Hosseini et al., 2022).

Stakeholder management begins with the identification and analysis of individuals and organizations capable of influencing project outcomes. Early stakeholder engagement enables project teams to recognize potential challenges, establish communication protocols, and improve decision-making processes before project implementation begins (Singh, 2021).

In interior architecture projects, stakeholder influence frequently changes throughout project development. During conceptual design stages, clients and designers typically exert significant influence over project direction. During procurement and construction phases, contractors, suppliers, and technical consultants become increasingly important. Effective project management therefore requires continuous stakeholder assessment rather than one-time stakeholder analysis.

Research suggests that proactive stakeholder engagement contributes to higher levels of trust, transparency, and project satisfaction. When stakeholders are actively involved in project discussions and decision-making activities, they are more likely to support project objectives and contribute positively to project implementation (Hosseini et al., 2022).

Communication represents one of the most important components of stakeholder collaboration. Interior architecture projects generate substantial amounts of technical, financial, managerial, and design-related information that must be exchanged among project participants. Communication failures frequently contribute to design inconsistencies, project delays, cost overruns, and stakeholder dissatisfaction (PMI, 2021).

Traditional project delivery methods often rely on fragmented communication structures where project information is transferred sequentially between stakeholders. Such approaches may create information gaps and reduce project responsiveness. Contemporary project management frameworks increasingly emphasize collaborative communication models that promote transparency, continuous feedback, and shared understanding among project participants (RIBA, 2020).

Collaborative decision-making is particularly important within interior architecture because project solutions often require balancing aesthetic, technical, financial, and operational considerations simultaneously. Through collaborative processes, project teams can evaluate alternatives collectively, identify risks at an earlier stage, and improve overall project quality.

2.1. Digital Transformation and BIM-Based Collaboration

Digital transformation has fundamentally changed the way project teams collaborate within the architecture, engineering, and construction sector. Building Information Modeling (BIM) has emerged as one of the most influential

technologies supporting integrated project delivery and stakeholder coordination (Yigitbas et al., 2023).

Unlike conventional documentation systems, BIM provides a shared digital environment where stakeholders can access, update, and coordinate project information in real time. This capability improves communication quality, reduces information fragmentation, and enhances interdisciplinary collaboration throughout project development (Hosseini et al., 2022).

Within interior architecture projects, BIM supports coordination between spatial planning, furniture integration, material specifications, lighting systems, mechanical services, and construction activities. The visualization capabilities offered by BIM also improve communication with non-technical stakeholders by enabling clients and end-users to better understand proposed design solutions before implementation begins.

The emergence of cloud-based collaboration systems has further accelerated digital transformation within project management. These technologies allow geographically dispersed project teams to access project information, participate in decision-making activities, and monitor project progress regardless of physical location (Qadir et al., 2025).

Cloud-based platforms contribute to project transparency by maintaining centralized information repositories that document communications, approvals, revisions, and project decisions. Such systems reduce information loss, improve accountability, and support organizational learning through systematic knowledge management.

For contemporary interior architecture practice, cloud-based collaboration has become increasingly important due to the growing prevalence of multidisciplinary project teams and international project delivery environments.

2.2. Artificial Intelligence and Emerging Technologies

Recent developments in artificial intelligence (AI) have introduced new opportunities for improving project management performance. AI applications increasingly support project scheduling, risk assessment, cost estimation, resource allocation, and decision-making processes through advanced data analysis capabilities (Salimi moghadam et al., 2025).

Predictive analytics enables project teams to identify potential delays, procurement risks, and budget deviations before they significantly affect project performance. Similarly, machine learning algorithms can improve forecasting accuracy by utilizing data generated from previous projects and continuously refining prediction models.

Although AI adoption within interior architecture remains at an early stage, emerging technologies are expected to play an increasingly important role in supporting project coordination, performance monitoring, and strategic decision-making.

Despite its advantages, digital transformation introduces several organizational challenges. Resistance to change, insufficient digital competencies, limited training opportunities, and technological integration difficulties frequently affect implementation success (Alnajjar et al., 2025).

Furthermore, the increasing reliance on digital systems raises concerns related to cybersecurity, data governance, and information reliability. Project organizations must therefore develop effective management strategies that balance technological innovation with organizational readiness and stakeholder capabilities.

The growing integration of BIM, cloud computing, artificial intelligence, and collaborative management approaches suggests that future project success will increasingly depend on the ability to combine technological capabilities with effective stakeholder engagement and organizational leadership.

3. RISK, COST, TIME, AND QUALITY MANAGEMENT

Risk, cost, time, and quality management remain the fundamental dimensions of project performance within interior architecture practice. Although these dimensions are often discussed independently, contemporary project management theory emphasizes their interconnected nature. Decisions affecting one dimension frequently influence the others, creating complex management challenges that require integrated and adaptive approaches (PMI, 2021).

Interior architecture projects are particularly susceptible to uncertainty because of extensive client involvement, evolving design requirements, customized material specifications, and complex procurement processes. Consequently, project managers must continuously balance project constraints while maintaining alignment with stakeholder expectations and organizational objectives.

Risk management has become an essential component of contemporary project management practice. Project risks may arise from design changes, procurement challenges, regulatory requirements, technological integration, market fluctuations, and stakeholder interactions (Kerzner, 2022).

One of the most significant sources of risk within interior architecture projects is design-related uncertainty. Frequent revisions resulting from client requests, functional modifications, or technical requirements may affect project schedules, budgets, and quality outcomes. Such changes often generate cascading effects that influence multiple project activities simultaneously.

Procurement-related risks represent another important challenge. Interior architecture projects frequently rely on customized materials, imported products, and specialized furniture systems. Supply chain disruptions, manufacturing delays, transportation issues, and material shortages may significantly affect project performance.

Effective risk management therefore requires continuous risk identification, assessment, monitoring, and mitigation activities throughout the project lifecycle.

Time management remains a critical determinant of project success. Interior architecture projects are frequently subject to strict deadlines associated with commercial operations, residential occupancy, or institutional opening schedules. Delays may result in financial losses, contractual disputes, and reduced stakeholder satisfaction (PMI, 2021).

Traditional scheduling techniques such as Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and Gantt charts continue to provide valuable planning tools. However, contemporary project environments increasingly require adaptive scheduling approaches capable of responding to changing project conditions.

Digital scheduling systems integrated with BIM environments further enhance project monitoring capabilities by enabling real-time progress tracking and performance evaluation.

Cost management is particularly important in interior architecture projects because design ambitions, material selections, and customized solutions frequently create budgetary pressures. Clients often expect high-quality design outcomes while maintaining financial predictability and cost efficiency.

Project costs generally include direct expenditures such as materials, labor, furniture, and equipment, as well as indirect expenditures associated with administration, logistics, and professional services. Effective budget management requires continuous monitoring throughout project implementation (Kerzner, 2022).

One of the most common causes of budget overruns involves uncontrolled scope changes. Design modifications, specification upgrades, and unforeseen site conditions frequently increase project costs beyond original estimates. Consequently, change management procedures play a critical role in maintaining financial control.

Quality management extends beyond compliance with technical standards and construction specifications. Within interior architecture, quality encompasses functionality, aesthetics, durability, user experience, sustainability, and overall project value (RIBA, 2020).

Achieving quality objectives requires systematic planning and monitoring throughout project development. Material selection, procurement activities, construction supervision, and post-occupancy evaluation all contribute to project quality outcomes.

Recent technological developments have strengthened quality management processes through automated clash detection, digital inspections, simulation tools, and performance monitoring systems. These technologies improve information accuracy while reducing errors and rework activities.

The relationship among risk, cost, time, and quality represents one of the most important considerations in contemporary project management. Accelerating project schedules may increase project costs and reduce opportunities for quality

control. Similarly, aggressive cost reduction strategies may introduce quality risks if not carefully managed.

Risk management plays a central role in balancing these competing objectives. Effective project managers recognize that project performance should be evaluated holistically rather than through isolated performance indicators. Consequently, integrated management approaches have become increasingly important within contemporary interior architecture practice (PMI, 2021; Kerzner, 2022).

The following chapter builds upon these findings by proposing an Integrated Interior Architecture Project Management Framework (IIAPMF) designed specifically for contemporary interior architecture projects.

4. AN INTEGRATED PROJECT MANAGEMENT FRAMEWORK FOR CONTEMPORARY INTERIOR ARCHITECTURE PRACTICE

The preceding sections have demonstrated that contemporary interior architecture projects operate within increasingly complex professional environments characterized by multidisciplinary collaboration, digital transformation, stakeholder diversity, sustainability requirements, and heightened performance expectations. While traditional project management methodologies continue to provide valuable planning and control mechanisms, contemporary project environments require more comprehensive approaches capable of integrating technological, organizational, and strategic dimensions simultaneously.

Current project management frameworks often address specific aspects of project delivery, including scheduling, budgeting, risk management, stakeholder communication, or quality control. However, interior architecture projects frequently involve complex interactions among these dimensions. Design modifications may influence procurement activities, procurement delays may affect construction schedules, and stakeholder decisions may impact both project costs and quality outcomes. Consequently, fragmented management approaches may be insufficient for addressing the interconnected nature of contemporary project environments.

In response to these challenges, this chapter proposes an Integrated Interior Architecture Project Management Framework (IIAPMF). The framework aims to establish a holistic management structure that integrates stakeholder collaboration, digital technologies, performance monitoring, risk management, and continuous organizational learning within a unified project delivery model.

The proposed framework is grounded in five complementary theoretical perspectives discussed in previous sections: systems theory, stakeholder theory, sociotechnical theory, collaborative project delivery, and sustainability-oriented project management (Kerzner, 2022; Hosseini et al., 2022; Motalebi et al., 2025).

First, systems theory emphasizes the interconnected nature of project activities and highlights the importance of managing relationships among project

components rather than focusing exclusively on individual tasks. Second, stakeholder theory recognizes that project success depends heavily on stakeholder engagement and collaborative decision-making processes. Third, sociotechnical perspectives underline the interaction between digital technologies and human factors within project environments. Fourth, collaborative delivery approaches promote transparency, coordination, and shared responsibility among project participants. Finally, sustainability-oriented management expands project objectives beyond traditional performance metrics by incorporating environmental and social considerations into decision-making processes.

Together, these theoretical perspectives provide the foundation for an integrated project management model specifically tailored to the requirements of contemporary interior architecture practice.

4.1. Structure of the Integrated Framework

The Integrated Interior Architecture Project Management Framework consists of five interconnected management layers. Each layer contributes to project performance while simultaneously interacting with other framework components.

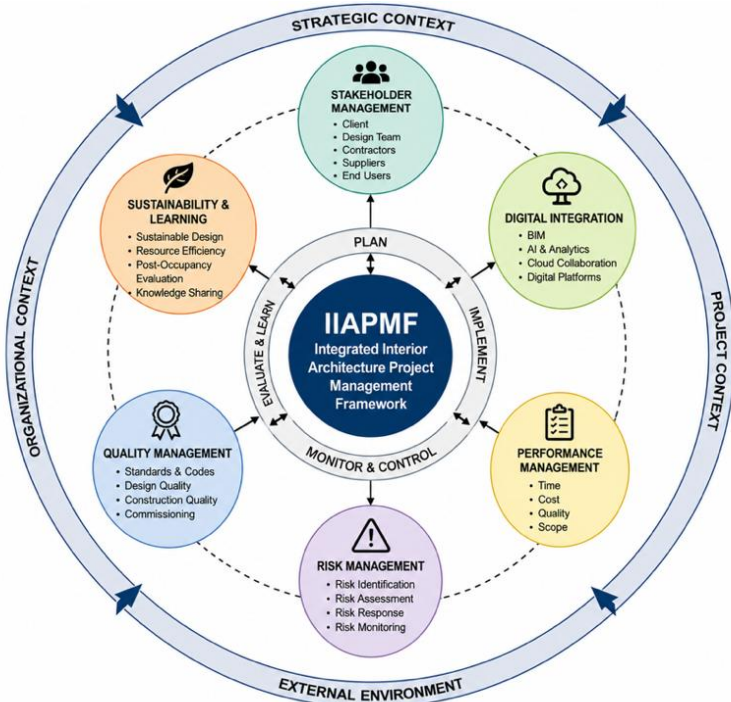


Figure 1. Integrated Interior Architecture Project Management Framework (IIAPMF)

The first layer, Strategic Planning, establishes project objectives, governance structures, sustainability targets, and performance expectations. At this stage, project scope, stakeholder requirements, and success criteria are defined.

The second layer, Stakeholder Management, focuses on stakeholder identification, engagement, communication planning, and conflict resolution. Effective stakeholder management ensures alignment between project objectives and stakeholder expectations throughout project implementation.

The third layer, Digital Integration, provides the technological infrastructure required to support information management and project coordination. Technologies such as Building Information Modeling (BIM), artificial intelligence-assisted planning systems, cloud-based collaboration platforms, and digital project management tools facilitate information sharing and improve decision-making processes (Qadir et al., 2025; Alnajjar et al., 2025).

The fourth layer, Performance Management, continuously monitors project performance through indicators associated with schedule, cost, quality, risk, and stakeholder satisfaction. This layer enables project managers to identify performance deviations and implement corrective actions before significant project disruptions occur.

The fifth layer, Continuous Improvement and Sustainability Learning, focuses on knowledge management, lessons learned, organizational learning, and sustainability performance evaluation. This component supports long-term organizational development and contributes to future project success.

4.2. Framework Application Throughout the Project Lifecycle

The proposed framework is designed to support all phases of interior architecture project delivery.

During project initiation, strategic planning activities establish project objectives and define stakeholder expectations. Early stakeholder involvement contributes to improved communication and facilitates the identification of potential project risks.

During design development, digital integration mechanisms become increasingly important. BIM environments and collaborative information platforms support interdisciplinary coordination while improving design quality and reducing information fragmentation. During procurement and construction phases, performance management activities become more prominent. Project teams continuously monitor schedule performance, budget utilization, quality outcomes, and procurement activities while implementing risk mitigation strategies when necessary.

Finally, during project completion and post-occupancy evaluation, continuous learning mechanisms support organizational knowledge development and sustainability assessment. Lessons learned from completed projects can subsequently inform future project planning and decision-making processes.

4.3. Comparative Evaluation of Traditional and Integrated Approaches

The proposed framework differs substantially from conventional project management approaches. While traditional methodologies often focus on

controlling individual project variables, integrated management approaches emphasize the relationships among project systems, stakeholders, and technologies.

DIMENSION	TRADITIONAL APPROACH	INTEGRATED APPROACH
 Communication	Sequential	Collaborative
 Information Management	Fragmented	Centralized
 Technology Use	Limited	BIM-Based and Data-Driven
 Decision-Making	Reactive	Proactive
 Risk Management	Periodic	Continuous
 Stakeholder Involvement	Limited	Integrated
 Performance Evaluation	Time-Cost-Quality	Multi-Dimensional
 Sustainability Focus	Secondary	Embedded

Table 1. Comparison Between Traditional and Integrated Project Management Approaches

The comparison illustrates how integrated management approaches respond more effectively to the complexity and uncertainty associated with contemporary interior architecture projects.

4.4. Implications for Professional Practice

The proposed framework has several implications for professional practice. First, it highlights the growing importance of interdisciplinary collaboration and stakeholder engagement within project delivery processes. Interior architecture professionals increasingly operate within complex project networks that require strong communication and leadership capabilities.

Second, the framework emphasizes the strategic role of digital technologies. BIM platforms, artificial intelligence applications, and cloud-based collaboration systems are no longer supplementary tools but integral components of project management practice.

Third, the framework encourages organizations to adopt proactive rather than reactive management strategies. Continuous performance monitoring and integrated risk management enable project teams to respond more effectively to project uncertainties.

Finally, the framework promotes a broader understanding of project success by incorporating sustainability objectives, stakeholder satisfaction, and

organizational learning alongside traditional performance indicators. Such an approach reflects the evolving priorities of contemporary interior architecture practice and supports more resilient and adaptive project delivery systems.

The proposed Integrated Interior Architecture Project Management Framework should therefore be considered a conceptual model that contributes to both project management theory and professional practice. Future empirical studies may further evaluate its effectiveness through case studies and project-based applications across different interior architecture contexts.

5. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

Project management has become an increasingly important aspect of contemporary interior architecture practice. While design quality remains a fundamental concern, many project-related challenges emerge outside the design process itself. Delays in procurement, changes in client requirements, coordination problems among consultants, budget constraints, and communication failures frequently influence project outcomes. For this reason, the successful delivery of interior architecture projects depends not only on creative design solutions but also on effective project management practices.

The discussions presented in this chapter suggest that interior architects are now expected to assume responsibilities that extend beyond traditional design activities. In many projects, professionals participate in stakeholder coordination, material and FF&E selection, procurement planning, fit-out supervision, scheduling, and quality control processes. As projects become more complex and multidisciplinary, these responsibilities are likely to become even more significant.

Another important observation is the growing role of digital technologies in project delivery. BIM environments, cloud-based collaboration platforms, and data-driven management tools have improved information sharing and coordination among project participants. However, technology should be viewed as an enabling tool rather than a complete solution. The effectiveness of digital systems ultimately depends on how they are integrated into project workflows and how project teams utilize them throughout the design and implementation process.

Based on the issues identified throughout this chapter, the Integrated Interior Architecture Project Management Framework (IIAPMF) was proposed as a conceptual model for supporting project delivery. The framework brings together strategic planning, stakeholder management, digital integration, performance monitoring, and continuous learning within a single structure. Rather than treating project activities as separate tasks, it emphasizes the relationships among people, processes, information, and project objectives.

From a professional perspective, one of the main challenges facing the interior architecture discipline is the need to balance design aspirations with managerial realities. Interior architecture projects are often expected to achieve high levels of design quality while operating under strict budget, time, and procurement

constraints. This situation requires professionals who can combine design thinking with communication, coordination, and management skills.

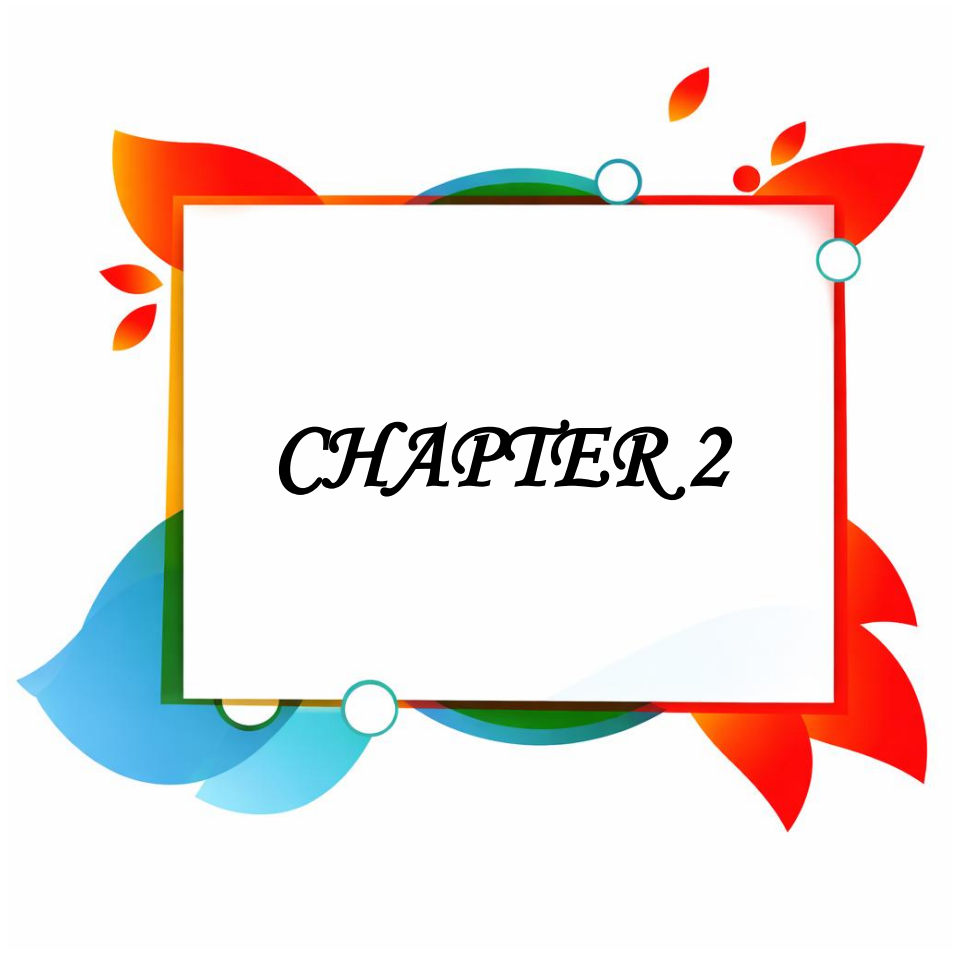
The framework presented in this chapter should be considered a starting point rather than a final solution. Future studies may evaluate its applicability through real project cases involving residential, hospitality, workplace, healthcare, or mixed-use interior environments. Additional research may also investigate the influence of emerging technologies, including artificial intelligence, digital twins, and predictive analytics, on project performance and decision-making processes.

In conclusion, the future of interior architecture will depend not only on the ability to create innovative spaces but also on the capacity to manage increasingly complex project environments. As stakeholder expectations, sustainability requirements, and technological demands continue to evolve, integrated project management approaches are likely to play a more central role in professional practice. The proposed IIAPMF framework represents one possible approach to addressing these challenges and supporting more coordinated, efficient, and adaptable interior architecture projects.

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- Figure 1. Integrated Interior Architecture Project Management Framework (IIAPMF), Source: Developed by the author.
- Table 1. Comparison Between Traditional and Integrated Project Management Approaches, Source: Author's own elaboration based on PMI (2021), Kerzner (2022), and RIBA (2020).



Typology-Based Interpretation of Deterioration in A Rural Historic Fountain: The Case of The Bozkır Hisarlık Fountain

Hatice Sevde Demir¹

1. INTRODUCTION

Historic fountains constitute one of the most widespread building types in Turkish water architecture due to their function of distributing and facilitating the use of water in public space. Since antiquity, the relationship between water and public space has acquired both physical and social dimensions through fountains; these structures have become significant focal points in the spatial organization of both urban and rural settlements (Eyice, 1993; Ödekan, 1992; Önge, 1997). In the Anatolian context, fountains should be regarded not merely as infrastructural elements but as architectural components that regulate social life and shape collective memory (Kara Pilehvarian, 2002; Sözen & Tanyeli, 1996).

From an architectural perspective, historic fountains, despite their small scale, embody dense layers of meaning reflecting construction techniques, material knowledge, and the aesthetic understanding of their period. Although they generally display a more modest architectural language compared to monumental buildings, they generate distinctive spatial configurations through elements such as arches, niches, troughs, and cup holders (Arseven, 1988; Aytöre, 1959). In this respect, fountains represent a building type that renders the direct relationship between architecture and everyday life legible.

From the standpoint of conservation, historic fountains require a particular mode of evaluation, as they are hydraulic structures continuously exposed to water. Moisture, evaporation, salt crystallization, and biological growth associated with water accelerate material deterioration processes in these structures (Denktaş, 2000; Önge, 1997). This condition necessitates conservation approaches that address not only formal integrity but also functional continuity and environmental conditions. Nevertheless, historic fountains are often considered of secondary priority in conservation practice or subjected to standardized interventions, as they tend to be less visible than large-scale

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monumental structures. Although principles such as authenticity, context, and continuity of use emphasized in conservation literature are equally applicable to fountains, their small scale frequently results in the neglect of qualified documentation and informed conservation decisions (ICOMOS, 2004; Jokilehto, 1999).

Despite this significance, studies that systematically examine the relationship between typological characteristics and deterioration processes remain limited in the literature. Typology is often treated primarily as a formal classification tool, while the ways in which typological features influence deterioration patterns have not been sufficiently discussed. In this context, this study investigates how the typological characteristics of a rural historic fountain shape the deterioration processes observed in the structure, taking the Hisarlık Fountain located in the Bozkır district of Konya Province, Türkiye, as a case study. The research is based on fieldwork-derived documentation, including measured drawings, point cloud data, orthophotos, and on-site observations. Deterioration types were identified through analytical drawings and evaluated together with the architectural and typological features of the structure. This approach demonstrates that measured drawings should be considered not only as technical records of the existing condition but also as analytical tools that interpret deterioration processes and guide conservation decisions.

2. TYPOLOGICAL CLASSIFICATION AND DETERIORATION IN HISTORIC FOUNTAINS

Fountains, as one of the most widespread building types in Turkish water architecture, are regarded both as functional structures ensuring the continuity of public life and as architectural components reflecting the spatial and cultural identity of the settlements in which they are located (Eyice, 1993; Önge, 1997). In the Anatolian context, particularly in rural settlements, fountains exhibit more modest solutions in terms of scale, material, and construction techniques; nevertheless, they establish a strong relationship with their surroundings and patterns of use. This condition elevates the concept of typology beyond a merely formal classification tool and positions it as a central parameter in understanding the functioning of the structure and its deterioration dynamics.

In the literature, fountains have been addressed under various typological classifications based on criteria such as location, number of façades, water supply systems, plan and façade organization, function, and architectural character (Figure 1) (Arseven, 1988; Eyice, 1993; Ödekan, 1992; Önge, 1997).

Classification Criterion	Fountain Type		Features of the Fountain
According to Location	Square Fountain		Monumental, free-standing fountains built in city squares; usually multi-façaded, ornamented, and inscribed.
	Wall (Street) Fountain		Fountains attached to a building or garden wall; the most common fountain type.
	Road / Caravan Route Fountain		Fountains built outside cities along roads and caravan routes for travelers.

Figure 1: Classification of Fountains According to Location

Source: Visuals prepared by the authors with the assistance of AI-based visual generation tools

Karpuz & Dülgerler (2006), as well as Denктаş (2000), through detailed studies of Anatolian and Konya-based examples, have identified subtypes such as free-standing fountains, wall fountains, square fountains, and trough-equipped fountains in a comprehensive manner (Figure 2).

Classification Criterion	Fountain Type		Features of the Fountain
According to Plan / Façade	Single-Façade Fountain		Fountains with only one active façade, typically wall fountains.
	Corner (Bifurcated) Fountain		Two- or three-façaded fountains located at corners or intersections.
	Multi-Façade Fountain		Four-façaded or fully accessible fountains, commonly seen in square fountains.

Figure 2: Classification of Fountains According to Plan/Façade

Source: Visuals prepared by the authors with the assistance of AI-based visual generation tools

However, in the majority of these typological studies, typology has primarily been treated as a formal and functional classification tool, and the relationship between typological characteristics and deterioration patterns has been discussed

only to a limited extent. Particularly in rural settlements, trough-equipped and free-standing fountains were designed not only for human use but also for watering animals (Figure 3) (Önge, 1997). This multi-functional use results in continuous exposure of architectural elements such as troughs, benches, and lower wall surfaces to water and moisture. Moreover, the direct relationship of the structure with the ground renders it more vulnerable to surface water, soil moisture, and environmental impacts.

Classification Criterion	Fountain Type		Features of the Fountain
According to Function	Drinking Water Fountain		Fountains built to directly meet human drinking water needs.
	Animal Watering Fountain		Trough-equipped fountains with large basins, commonly located along roads.

Figure 3: Classification of Fountains According to Function

Source: Visuals prepared by the authors with the assistance of AI-based visual generation tools

In conservation literature, deterioration processes are commonly explained through material properties, climatic conditions, and environmental factors (ICOMOS, 2004; Jokilehto, 1999). However, it is increasingly emphasized that building typology constitutes a significant parameter shaping deterioration patterns. The location of the structure, façade organization, degree of exposure to water, continuity of function, and relationship with the ground directly influence where and to what extent deterioration occurs within the building (Figure 4).

Classification Criterion	Fountain Type		Features of the Fountain
According to Elevation	Sunken Fountain		Fountains located below the surrounding road level, accessed by steps.
	Ground-Level Fountain		Fountains arranged at the same level as the road or courtyard.

Figure 4: Classification of Fountains According to Elevation

Source: Visuals prepared by the authors with the assistance of AI-based visual generation tools

Within this framework, deterioration phenomena frequently observed in rural trough-equipped fountains - such as joint opening, surface texture loss in stone elements, surface soiling, salt crystallization, and biological growth - should not be interpreted solely as consequences of material aging. Rather, these forms of deterioration should be evaluated in conjunction with the typological characteristics and patterns of use of the structure. Accordingly, typology should be considered not merely as a classification tool but also as an evaluative parameter that enables the identification and interpretation of deterioration risks (Figure 5 and 6).

Classification Criterion	Fountain Type		Features of the Fountain
According to Purpose	Waqf Fountain		Fountains commissioned for charitable purposes within the waqf system.
	Palace / Külliye Fountain		Fountains located within palace, mosque, or külliye complexes.

Figure 5: Classification of Fountains According to Purpose

Source: Visuals prepared by the authors with the assistance of AI-based visual generation tools

Classification Criterion	Fountain Type		Features of the Fountain
According to Architectural Character	Plain Fountain		Small-scale, function-oriented fountains with limited ornamentation.
	Monumental Fountain		Fountains with monumental character defined by architecture, ornamentation, and inscriptions.

Figure 6: Classification of Fountains According to Architectural Character

Source: Visuals prepared by the authors with the assistance of AI-based visual generation tools

Based on the case of the Bozkır Hisarlık Fountain, this study examines how the rural, trough-equipped fountain typology shapes deterioration processes and aims to demonstrate that a typology-based evaluation approach provides an analytical framework for interpreting deterioration patterns and developing informed conservation decisions.

3. MATERIALS AND METHODS

The primary material of this study is the Bozkır Hisarlık Fountain located in the Hisarlık Neighborhood of the Bozkır district in Konya Province, Türkiye. Data regarding the current condition of the structure were obtained through fieldwork-based measured drawings, photographic documentation, and on-site observational records. In addition, typological classifications and comparative examples of rural and Late Ottoman fountains presented in the literature were used as secondary data sources within the analytical evaluation process. The research was conducted within an integrated three-stage methodological framework extending from documentation to decision-making:

1. Fieldwork-based documentation
2. Analytical deterioration assessment
3. Typology-based interpretation and development of conservation decisions

These stages were not treated as independent technical procedures but as an interconnected and continuous system progressing from data production to analytical interpretation and decision-making.

3. 1. Fieldwork-Based Documentation

In the first stage, on-site fieldwork was carried out at the Bozkır Hisarlık Fountain, and measured drawings were prepared to document the current condition of the structure. Based on the measurement data, a point cloud representing the geometric configuration of the structure was generated. Orthophoto images were derived from this point cloud, and measured drawings of plans, sections, and elevations were subsequently produced (Figure 7).



Figure 7: Point Cloud Visualizations of the Bozkır Hisarlık Fountain
Source: Architectural drawings were prepared by the responsible author

The aim of this stage was to document the architectural characteristics and current physical condition of the structure through measurable, verifiable, and reproducible data. Accordingly, the documentation process was not considered merely as graphic production but as the primary stage of analytical data generation forming the basis of subsequent evaluation.

3. 2. Analytical Deterioration Assessment

In the second stage, the produced measured drawings were evaluated through an analytical approach. At this stage, the drawings were treated not only as technical representations of the existing condition but as analytical documents rendering the spatial configuration, architectural components, and changes resulting from environmental effects legible.

Based on the measured drawing data:

- traces related to the original condition were distinguished from later interventions,
- ambiguous or incomplete areas were explicitly identified,
- the transformation process of the structure was made readable.

Measured drawings and on-site observations were evaluated together to identify existing deterioration types within the structure. Damage patterns such as joint opening, loss of surface texture in stone elements, cement- and concrete-based interventions, surface soiling, salt crystallization, and biological growth were assessed through on-site observation, photographic documentation, and

analytical drawings. Identified deteriorations were classified and analyzed according to: type, spatial distribution and degree of prevalence. This stage aimed not only to define deterioration phenomena but also to map them spatially and relate them to the typological characteristics of the structure.

3. 3. Typology-Based Interpretation Framework

In the third stage, the manner in which findings derived from measured drawings and deterioration analyses informed restitution and restoration decisions was evaluated. Restitution proposals were developed based on measured drawing data and comparative examples in the literature, while restoration decisions were discussed in relation to the specific documentation data on which they were grounded.

Accordingly, the processes of survey, restitution, and restoration were not treated as isolated technical stages but as an integrated and mutually reinforcing continuum extending from documentation to decision-making.

3.4 Documentation Constraints and the Necessity of a Typology-Based Framework

Investigations conducted during the restitution process revealed that written and visual documentation related to the Bozkır Hisarlık Fountain is extremely limited. The absence of an inscription and the inability to access archival documents such as a waqf deed made it impossible to establish a precise construction date based on direct documentary evidence.

This limitation significantly affected the epistemological basis of the study. In the absence of archival verification, restitution decisions could not rely on primary written sources and therefore required an alternative analytical framework. Consequently, the evaluation of the structure was grounded in its architectural characteristics, plan configuration, material properties, and comparative typological analysis with similar examples in the region.

As emphasized in the literature, the lack of inscriptions and archival records is a frequent condition in rural Ottoman fountains, and their dating is often achieved through typological and architectural readings (Denktaş, 2000; Eyice, 1993; Önge, 1997). However, in the present study, typology was not employed merely as a classificatory tool. Rather, it functioned as a methodological framework enabling the interpretation of incomplete data and the formulation of restitution and conservation decisions in the absence of documentary sources.

In this respect, the documentation constraints did not merely constitute a limitation; they revealed the necessity of a typology-based analytical approach. The methodological position adopted in this study thus demonstrates that, particularly in small-scale rural water structures where archival documentation is

scarce, typology can serve as a primary interpretive and decision-making framework.

3.5 Methodological Positioning

The methodological framework adopted in this study is based on the integration of documentation, typological reading, and deterioration analysis within a single interpretive system. Rather than treating survey, restitution, and restoration as isolated technical stages, the study conceptualizes them as interconnected processes structured around typological interpretation.

In contexts where archival documentation is limited or absent—particularly in small-scale rural heritage structures—typology is positioned not merely as a classificatory instrument but as a primary analytical framework. Within this framework, architectural configuration, hydraulic function, and spatial organization operate as interpretive parameters guiding both deterioration assessment and conservation decision-making.

Accordingly, this study advances a systematic typology-based conservation evaluation model that may be applicable to similar rural water structures characterized by limited documentary evidence and continuous environmental exposure.

In addition to field documentation, the typological diagrams presented in the classification tables were produced by the authors with the assistance of artificial intelligence-based visual generation tools. These visuals were developed as schematic representations to support the analytical interpretation of typological categories and do not constitute documentary evidence. The conceptual framework, classification criteria, and interpretative assessments remain entirely the responsibility and intellectual contribution of the authors.

4. DETERIORATION ANALYSIS (RESULTS)

This section presents the architectural and typological characteristics of the Bozkır Hisarlık Fountain and analyzes the deterioration types identified through field documentation. The findings are evaluated in relation to the typological configuration of the structure.

4.1. Architectural Characteristics and Typology of the Bozkır Hisarlık Fountain

The Bozkır Hisarlık Fountain is an independent water structure located in the Hisarlık Neighborhood of the Bozkır district in Konya Province (Figure 8). The fountain is situated to the northwest of the Hisarlık Mosque and positioned below the level of the existing road. The structure is located on parcel 1 of block 180 and was officially registered as a cultural property by the Konya Regional Council for the Conservation of Cultural Heritage with Decision No. 5206 dated 06.04.2018.

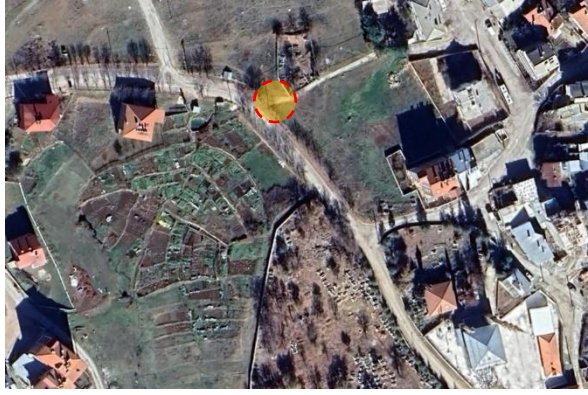


Figure 8: Location of the Bozkır Hisarlık Fountain
Source: Google Earth (Google, 2023)

As the fountain lacks both an inscription and a waqf deed, neither its patron nor its exact construction date can be determined. However, based on its plan scheme, architectural components, and the arrangement of the trough and cup holder, the structure can be evaluated within the context of Late Ottoman rural fountain architecture. This proposed dating is further supported by typological similarities observed in comparable village fountains in Konya and its surrounding region (Karpuz & Dülgerler, 2006; Önge, 1997).

In terms of plan configuration, the Bozkır Hisarlık Fountain exhibits a single-façade and free-standing layout. The structure measures approximately 306 cm in height, 352 cm in width, and 141 cm in depth. The pointed-arched niche on the front façade constitutes the dominant architectural element of the fountain, with the arch resting on profiled piers on either side. The two-tiered plain mouldings located on the upper sections of the piers provide a limited degree of plastic articulation to the façade. This architectural approach reflects the restrained and function-oriented design character commonly observed in rural Ottoman water structures (Figure 9) (Eyice, 1993; Önge, 1997).

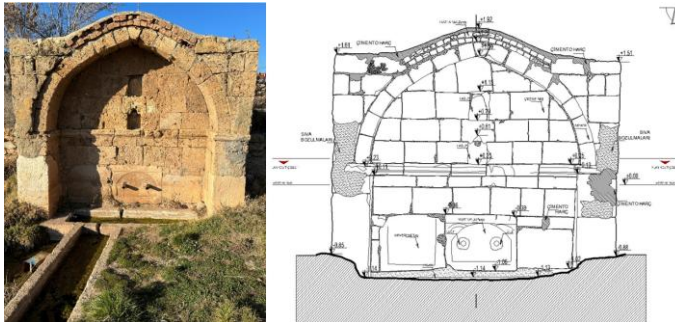


Figure 9: Facade of the Fountain
Source: Architectural drawings were prepared by the responsible author

View and Drawing of the South (Front) Facade of the Fountain

Source: Architectural drawings were prepared by the responsible author

The niche of the fountain has a rectangular plan and measures approximately 288 cm in height. Its surface is clad with finely dressed stone blocks, with mortar joints ranging between 1 and 1.5 cm in thickness. Beneath the spouts, a two-tiered trough arrangement is present, articulated both horizontally and vertically. This trough–cup holder system indicates that the structure was designed not only for human use but also to accommodate rural life practices associated with animal husbandry (Figure 10)(Aytöre, 1959; Denктаş, 2000).

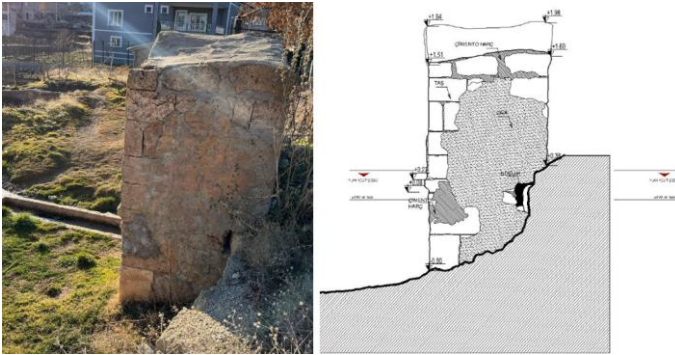


Figure 10: View and Drawing of the East Facade of the Fountain

Source: Architectural drawings were prepared by the responsible author

The primary construction material of the structure is dressed stone. While finely cut stone masonry is observed on the front façade, plastered surfaces are present on the side façades. The limited use of brick on the front façade may indicate either characteristics of the original construction process or interventions associated with subsequent repair phases (Figure 11) (Arseven, 1988; Karpuz, 2009).

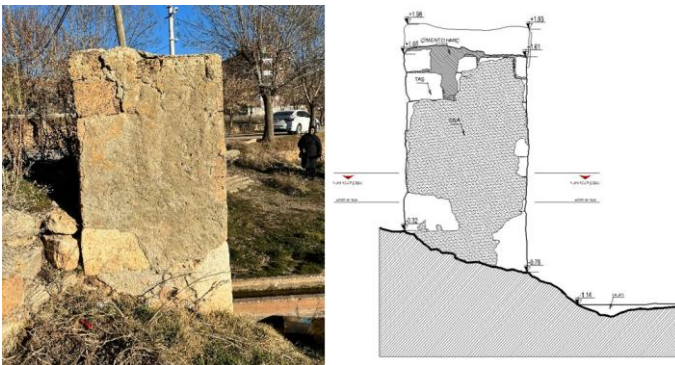


Figure 11: View and Drawing of the West Facade of the Fountain

Source: Architectural drawings were prepared by the responsible author

In terms of ornamentation, the Bozkır Hisarlık Fountain exhibits a highly restrained character. Decorative elements are limited, and the aesthetic effect is achieved primarily through architectural proportions and the organization of the arch–niche composition. The absence of inscriptive ornamentation suggests that the fountain was conceived as a functional village fountain rather than as a monumental charitable structure (Figure 12) (Eyice, 1993; Ödekan, 1992). Within the corpus of Anatolian Turkish fountain architecture, the Bozkır Hisarlık Fountain can be classified among source-fed, single-façade, and free-standing rural fountains.

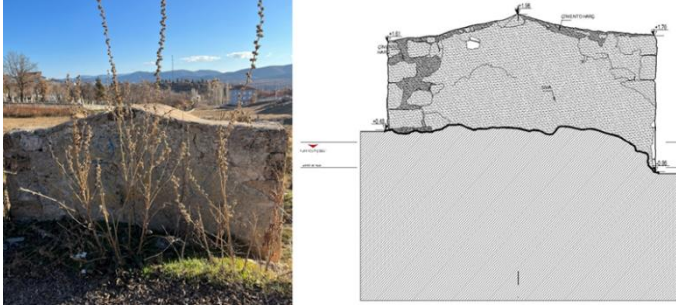


Figure 12: View and Drawing of the North Facade of the Fountain
Source: Architectural drawings were prepared by the responsible author

According to the classification proposed by Önge (1997) based on modes of water supply, structures of this type fall within the group of fountains in which water conveyed through pipes or terracotta conduits is directly discharged through spouts. In terms of location, the structure is classified as a free-standing fountain, as it is not attached to any other building (Table 1) (Karpuz & Dülgerler, 2006).

Table 1: Typological Evaluation of the Bozkır Hisarlık Fountain

Typological Criterion	Typology Defined in the Literature	Corresponding Feature in the Hisarlık Fountain
Building Type	Public water structure (fountain) (Arseven, 1988; Eyice, 1993)	Village fountain open to public use
Location	Free-standing / attached fountain (Karpuz & Dülgerler, 2006)	Free-standing fountain
Settlement Type	Urban / rural fountain (Denktaş, 2000; Önge, 1997)	Rural settlement fountain
Number of Facades	Single-facade / multi-facade (Ödekan, 1992)	Single facade
Facade Composition	Niche-type / non-niche fountain (Eyice, 1993)	Pointed-arched niche fountain
Arch Form	Pointed arch, round arch, etc. (Önge, 1997)	Pointed arch
Water Supply System	Reservoir-fed / directly source-fed (Önge, 1997)	Directly source-fed
Plan Type	Single volume / with reservoir (Arseven, 1988)	Single volume, without reservoir
Trough Arrangement	With trough / without trough (Denktaş, 2000)	Two-tiered trough
Cup Holder Arrangement	With cup holder / without cup holder (Eyice, 1993)	Two cup-holder niches
Ornamentation Approach	Plain / decorated fountain (Ödekan, 1992)	Plain, limited to architectural elements
Inscription	With inscription / without inscription (Karpuz, 2009)	Without inscription
Period	Early / Classical / Late Ottoman (Önge, 1997)	Late Ottoman Period
Functional Character	Human use / mixed use (Denktaş, 2000)	Human + animal use

In terms of façade composition and arch form, the Bozkır Hisarlık Fountain can be classified within the group of single-arched fountains featuring pointed arches. This characteristic establishes a shared typological language with numerous village fountains in Konya and its surrounding region, particularly emphasizing rural, livestock-based use through the arrangement of the trough and bench elements (Denktaş, 2000; Önge, 1997). In this respect, the structure represents a typical example of the restrained, functional, and locally grounded character of rural Ottoman fountains constructed in Anatolia during the nineteenth century.

4.2. Deterioration Observed in the Bozkır Hisarlık Fountain

Joint opening, loss of surface texture, salt crystallization, surface soiling, and biological growth were identified in the Bozkır Hisarlık Fountain. These deterioration phenomena are associated with the fountain's typological characteristics, including continuous contact with water, open-air exposure, and a hydraulic function. Unlike dry-functioning structures such as mosques or residential buildings, fountains are structures in which the building fabric is constantly exposed to moisture, evaporation, and wet-dry cycles. The observed deterioration patterns correspond to these operational and environmental conditions.

The joint openings observed in the structure are associated with continuous water movement within the fountain walls and the freeze-thaw cycles prevalent in the Bozkır region. In hydraulic structures such as fountains, the infiltration of water into the wall fabric and its expansion and contraction due to seasonal temperature fluctuations cause the gradual opening of mortar joints, which constitute the weakest binding elements. This condition reflects physical processes inherent to fountain typology.

Loss of surface texture develops as a consequence of continuous wetting of stone surfaces, evaporation, and salt crystallization processes. In water structures, dissolved salts transported into the stone pores crystallize during evaporation, leading to scaling and material loss on stone surfaces. In the Bozkır Hisarlık Fountain, the concentration of surface loss particularly in areas where water flows and splashes corresponds with the continuation of the structure's hydraulic function.

Surface soiling and moss formation identified in the structure are related to the fountain's open-air location and persistently moist surfaces. Moist stone surfaces trap soil and airborne particles carried by wind, creating a favorable environment for biological growth. Mosses and microorganisms appear as secondary agents emerging under continuous moisture conditions.

Salt crystallization observed in the fountain represents one of the most critical indicators of the deterioration process. Salt crystallization leads to internal disintegration of stone through the crystallization of dissolved salts carried by water and cannot be eliminated through superficial interventions. The presence of salt crystallization in the Bozkır Hisarlık Fountain reflects the ongoing hydraulic character of the structure (Figure 13).

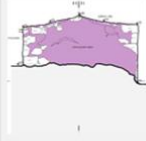
Types of Deterioration	South Façade (Front Facade)	East Facade	North Facade	West Facade
Cement and Concrete Application				
Opening of Mortar Joints				
Loss of Surface Texture				
Salt Crystallization Deterioration				
Surface Soiling				

Figure 13: Deterioration Observed in the Bozkır Hisarlık Fountain

Source: Bozkır Hisarlık Fountain Survey Project, Doku Architecture, Architect Kübra Söğütü, 2023

5. Evaluation

In studies addressing the conservation of historic fountains, typology is generally treated as a formal classification tool, while deterioration processes are primarily evaluated through material properties and environmental factors. However, the findings of this study indicate that, particularly in rural contexts, typological characteristics function as a structural parameter that conditions both the type and spatial distribution of deterioration.

The Bozkır Hisarlık Fountain belongs to the group of single-façade, free-standing, and trough-equipped rural fountains and exhibits deterioration patterns specific to this configuration. Its free-standing position exposes all façades to direct environmental effects, while its hydraulic function creates continuous moisture exposure. Ground-level alterations, surface water accumulation, insufficient maintenance, and climatic conditions collectively intensify deterioration processes. The higher-quality workmanship observed on the front façade compared to the side and rear façades has resulted in differentiated deterioration patterns, demonstrating how material hierarchy within a single structure influences vulnerability.

Joint openings and surface texture loss are directly associated with continuous water exposure and seasonal freeze–thaw cycles. Repeated expansion and contraction in stone and mortar joints weaken binding materials over time, leading to material disintegration. Surface soiling, salt crystallization, and biological growth are linked to the humid microclimate created by the trough system and the fountain’s open-air setting.

Cement and concrete-based repairs, frequently applied as short-term solutions in rural contexts, further intensify deterioration by preventing moisture evaporation and disrupting the material compatibility of the structure. These findings indicate that conservation strategies must address not only visible damage but also the typology-related mechanisms that structure deterioration processes.

Another critical factor is the alteration of the fountain’s environmental context due to roadway elevation changes. The structure’s current position below road level has altered its original ground relationship, increasing surface water accumulation and accelerating moisture-related deterioration. This case demonstrates that typology operates in interaction with environmental transformations and that conservation decisions must consider both structural configuration and contextual change.

The Bozkır Hisarlık Fountain thus illustrates that typology should be regarded not merely as a classificatory instrument but as an analytical framework that enables a more comprehensive understanding of deterioration risks in rural water structures.

6. Conclusion

The results of this study demonstrate that deterioration observed in the Bozkır Hisarlık Fountain cannot be reduced solely to material aging or environmental exposure. The rural, free-standing, and trough-equipped typology of the structure operates as a structural framework shaping the distribution and intensity of deterioration processes. Typology does not replace environmental or material parameters; rather, it conditions and structures their impact on the building fabric.

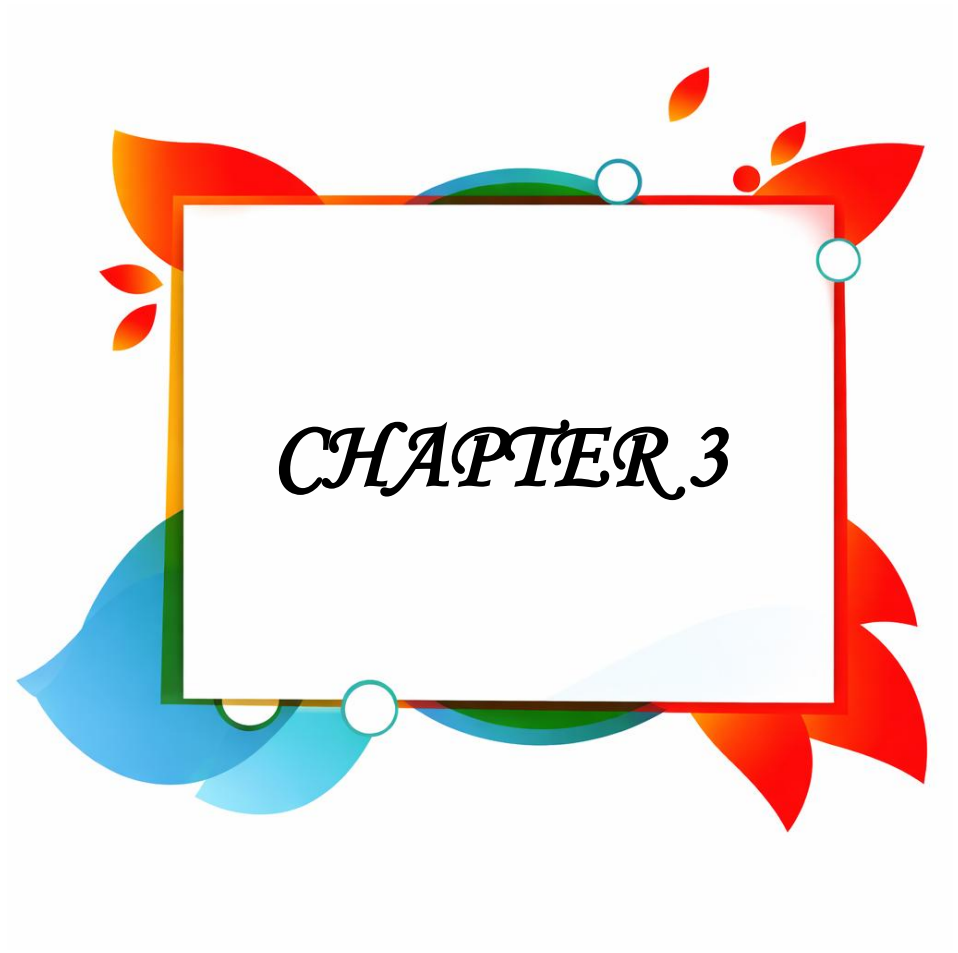
The findings confirm that conservation approaches limited to localized material repair are insufficient for rural fountains. Effective conservation strategies must integrate typological characteristics, hydraulic function, environmental context, and ground-level conditions. In particular, free-standing rural fountains require compatible repair materials, appropriate drainage solutions, and interventions that preserve functional continuity.

The study also highlights the marginal position of small-scale rural water structures within conservation practice. Despite their modest architectural expression, such fountains embody local water culture, everyday life practices, and rural spatial organization. Their conservation should therefore be addressed with the same level of methodological rigor applied to monumental urban examples.

Finally, the research underscores the importance of digital field documentation in contexts where archival data are limited. Point clouds, orthophotos, and digital measured drawings provide reliable and reproducible data that support restitution, restoration, and long-term monitoring processes. In rural heritage contexts, digital documentation should be regarded as an essential component of sustainable conservation practice.

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Evaluating the Impact of Sustainable Flame-Retardant Building Materials on Fire Safety of Buildings Using Artificial Intelligence-Aided Models

Ahmet Cihat Arı¹

1. Introduction

The increasing urban population in recent years has boosted the demand for housing. To meet this housing need, composite building materials have been developed. High-rise buildings have been constructed using composite building materials. However, natural disasters pose a significant threat to the safety of high-rise buildings. Natural disasters, particularly fires, cause damage to structural integrity, environmental sustainability, and building elements (Figure 1) (Martin et al., 2016; Zhang, 2023). Additionally fires in buildings increase the cost of repairing the structure and pose a serious threat to the lives of many people. To prevent this situation, efforts are being made to ensure the fire safety of buildings. Efforts to ensure fire safety in buildings involve both materials science and architecture. Therefore, ensuring fire safety in buildings has become one of the important issues in research (Maluk et al., 2017).

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Figure 1. Fires in high-rise buildings caused by various reasons; (a) Wooshin Golden Suite office, (b) Grenfell Tower, (c) Daebong Green Apartment, (d) Torch Tower (Choi et al., 2023)

Advances in materials science and technology have led to changes in fire protection measures in buildings. Traditional fire protection systems rely on alarm systems that sound during a fire. However, in modern fire protection systems, beyond the classic fire alarm bell, toxic smoke can now be controlled by preventing ignition rate and heat release with flame-retardant building materials (Li, 2023). Although flame-retardant building materials are beneficial for the fire safety of buildings, some flame-retardant building materials can cause environmental pollution (Sharma et al., 2015). For example, halogen-based flame retardant materials negatively affect human health and increase air pollution due to the toxic gases they release during combustion (Sabet, 2024). Therefore, research has begun into flame-retardant building materials to ensure they do not harm the environment or nature. Furthermore, the fact that these materials are recyclable, bio-based, and have minimal toxic effects has been included as important performance criteria in the research (Yang et al., 2022).

Nowadays, sustainable flame-retardant materials are increasingly prominent in research due to their superior performance in protecting structures against fire and their environmentally friendly properties (Andrew et al., 2024; Bhadauria et al., 2025; Kolya & Kang, 2024). Moreover, additives such as inorganic fillers, nanocomposites, phosphorus-based compounds, and biopolymers are added to

these materials to reduce their toxic effects and increase their fire resistance (Mbamalu et al., 2025). The use of these additives in the production of flame-retardant building materials also contributes to achieving energy efficiency (Morsy et al., 2025). Although significant progress has been made in the development of scientifically sustainable flame-retardant materials, there appears to be a lack of sufficient research to ensure their optimum performance under real-world fire conditions.

Advances in technology and materials science have made it possible to offer effective solutions for ensuring fire safety in buildings. For instance, artificial intelligence technologies enable the early detection of fires in buildings, the prediction of fire risk situations, smoke analysis, and the simulation of emergency evacuation plans for buildings with high accuracy according to real environmental conditions. Methods derived from artificial intelligence technologies such as machine learning, deep learning, computerized image processing, and Internet of Things (IoT) based smart monitoring systems are used in conducting fire safety analyses of buildings (Gaur et al., 2023). Unlike traditional fire safety systems, these methods make buildings safer against fire by providing highly accurate predictive decisions based on different types of fires (Yıldız, 2025).

Sustainable flame-retardant building materials and artificial intelligence technologies are among the emerging new approaches in designing fire-resistant buildings (Fu & Wang, 2025). Artificial intelligence technologies provide significant benefits in determining both the thermal degradation behavior and combustion properties of newly developed materials, as well as in analyzing the fire performance of structures (Nguyen et al., 2021). Additionally, digital twin models created with artificial intelligence technologies help in the development of innovative strategies for fire safety systems by performing fire simulations of buildings (Jiang et al., 2023). Different disciplines are coming together in artificial intelligence technology and the production of innovative materials (Patel et al., 2025). This makes it possible to construct sustainable and high-safety building designs. However, due to the diversity of chemical materials used in sustainable flame retardant materials, it needs to be analyzed to ensure sufficient performance in terms of fire safety (Morgan & Gilman, 2013). Therefore, the literature contains many studies on the fire safety of sustainable flame-retardant materials. For example, in the study by Attia (2022), it was stated that phosphorus and mineral-reinforced polystyrene composites have high potential for ensuring fire safety by limiting heat and mass transfer. By using sustainable and halogen-free flame retardants in these composites, it has been determined that they reduce the harm caused by environmental impacts. In a study conducted by Fan et al.

(2023), it was determined that wood densified with ammonium dihydrogen phosphate had 22.6 times and 17.8 times higher tensile and flexural strength against fire, respectively, compared to natural wood. In another study by Zhu et al. (2025), they showed that a biological-based flame retardant prepared using chitosan, phytic acid, and quercetin resulted in a 29.3% reduction in heat release rate, and the composite material also acquired antibacterial properties. Despite all the studies in the literature, there appears to be a limited number of review studies that examine sustainable flame-retardant materials and artificial intelligence-based fire safety systems together. Furthermore, studies show that artificial intelligence technologies are used to a limited extent in assessing the fire resistance properties of building materials. The integration of sustainable flame-retardant materials and artificial intelligence technology systems into fire safety has not been sufficiently studied. In this context, the aim of this study is to examine sustainable flame-retardant building materials and artificial intelligence-supported fire safety systems together. For this purpose, the fire resistance performance of sustainable flame-retardant building materials in the literature was analyzed, and artificial intelligence technology systems and applications were examined. Moreover, the study evaluated future areas of development in the use of artificial intelligence technology systems in material performance and fire safety analysis.

2. Studies on the Development of Sustainable Flame Retardant Building Materials in the Construction Sector

This study examines the developments in sustainable flame-retardant building materials in the construction industry under three main headings. These;

- Biopolymer-based flame retardant materials
- Wood-based flame retardant materials
- Plant-derived flame retardant materials (Yang et al., 2022).

2.1. Biopolymer-Based Flame Retardant Materials

Biopolymers are described as sustainable macromolecular materials that are synthesized by living organisms or obtained from renewable biological sources, and which are biocompatible and mostly biodegradable (Baranwal et al., 2022). These biopolymers offer significant potential for the development of building materials for the construction industry, as they provide advantages in terms of performance and cost compared to synthetic polymers (Plank, 2005). Among the most commonly used polymer matrices currently employed as biopolymers are polylactic acid (PLA), cellulose derivatives, polyhydroxyalkanoates (PHA), and starch-based bioplastics (Teles & Antunes, 2023). For example, in the study conducted by Li et al. (2021), they determined that adding an appropriate amount

of bamboo charcoal powder to the PLA polymer matrix improved its flame retardant and mechanical properties (Figure 2).

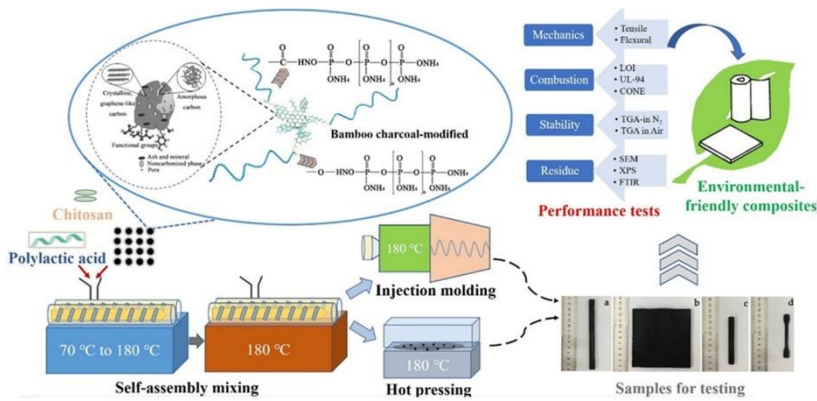


Figure 2. Schematic diagram showing the improvement in flame retardant and mechanical properties of PLA polymer matrix by adding an appropriate amount of bamboo charcoal powder (Li et al., 2021)

In the study conducted by Yu et al. (2022), it was determined that the addition of hexa (ethylene oxide)-cyclotriphosphazene (HCCP-EP) improved the flame retardant properties of PLA. Furthermore, it was determined that the sample did not ignite in combustion tests at a 5% additive concentration (Figure 3).

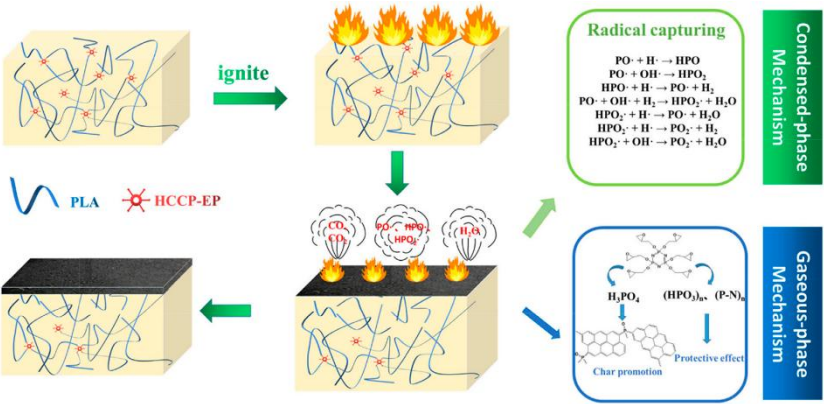


Figure 3. Schematic diagram showing the improvement of PLA's flame-retardant properties with the addition of HCCP-EP (Yu et al., 2022)

2.2. Wood-Based Flame Retardant Materials

Wood has been a widely preferred building material in construction from the past to the present due to its aesthetic, acoustic, thermal, and mechanical properties. However, due to high temperatures, this material undergoes thermal degradation processes, breaking down into its constituent components: hemicellulose, cellulose, and lignin. This deterioration in wood reduces both its

mass and mechanical strength. Problems arising from the thermal deterioration of wood constitute a significant disadvantage in terms of fire safety in buildings. Therefore, different flame retardant materials such as inorganic mineral additives, boron-phosphorus-nitrogen based compounds, and nanocomposite applications are being developed to solve the problems caused by thermal deterioration in wood (Yang et al., 2022). For instance, a study by Chen et al. (2021) showed that modified woods containing phytic acid and silica are fire-resistant. Furthermore, the same study determined that the modified wood exhibited a homogeneous distribution within its cell walls, resulting in a charring efficiency of 32.1% and a limiting oxygen index (LOI) of 47.3%. Due to the dense, cross-linked protective carbon layer of the modified wood, significant reductions in heat release and smoke formation have been observed. However, the fact that the modification does not have any negative effect on the mechanical properties of the wood provides a significant advantage in terms of application (Figure 4).

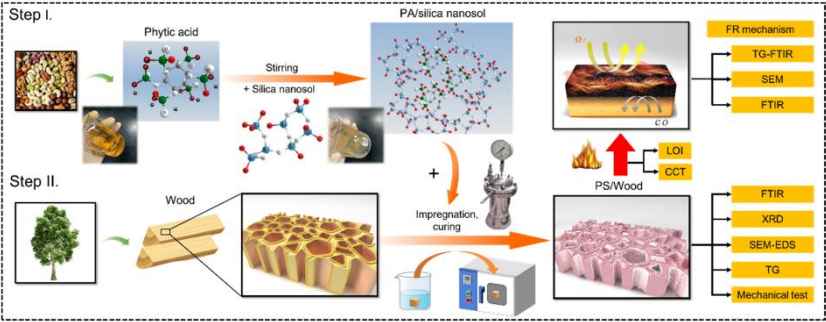


Figure 4. Schematic diagram showing how to increase the fire resistance of modified woods composed of phytic acid and silica (Chen et al., 2021)

In another study by Fan et al. (2023), a treatment containing ammonium dihydrogen phosphate (ADP) was applied to increase the fire resistance of wood. Furthermore, it was determined that as a result of these processes, ADP incorporated into the cell walls of the wood, forming bonds between cellulose fibers. Compared to untreated wood, a structure with high mechanical strength and fire resistance has been created (Figure 5).

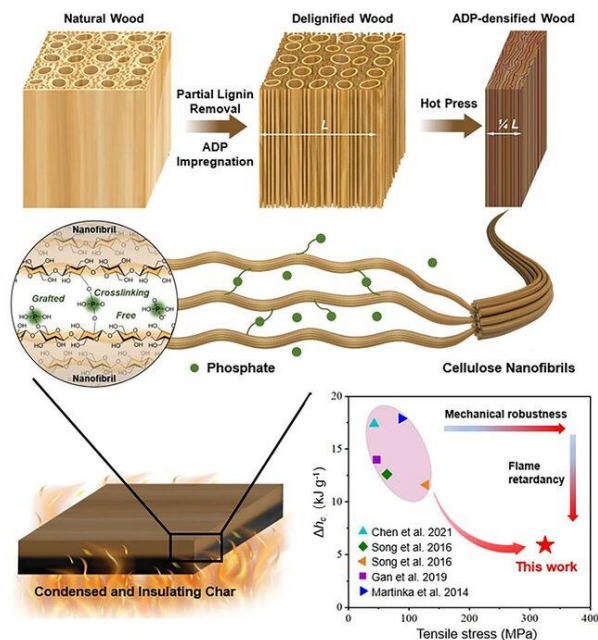


Figure 5. Schematic diagram of a treatment using ADP to increase the fire resistance of wood (Fan et al., 2023)

2.3. Plant-Derived Flame Retardant Materials

In line with the goals of developing sustainable building materials, agricultural waste is being utilized in the construction sector as alternative insulation and composite materials. In this context, lignocellulosic wastes such as wheat straw, rice husk, corn stalk, and sugarcane bagasse, which are produced as a result of agricultural activities, stand out in the construction sector as alternative building materials due to their low density, suitable thermal properties, and widespread availability (Asdrubali et al., 2015). However, insulation materials produced from agricultural waste contain high levels of cellulose and hemicellulose, which reduces their fire resistance due to thermal degradation at low temperatures during a fire (Palumbo et al., 2015; Yang et al., 2007). To address this issue, research is being conducted to improve the fire performance of plant-based building materials. For example, in the study by Zou et al. (2021), they determined that the carbonization process and the use of inorganic binders to increase fire resistance in wheat straw-based composite insulation materials increased the ignition resistance of the material. Thanks to the treatment applied to wheat straw, the structural integrity of composite insulation materials could be preserved during a fire (Figure 6).

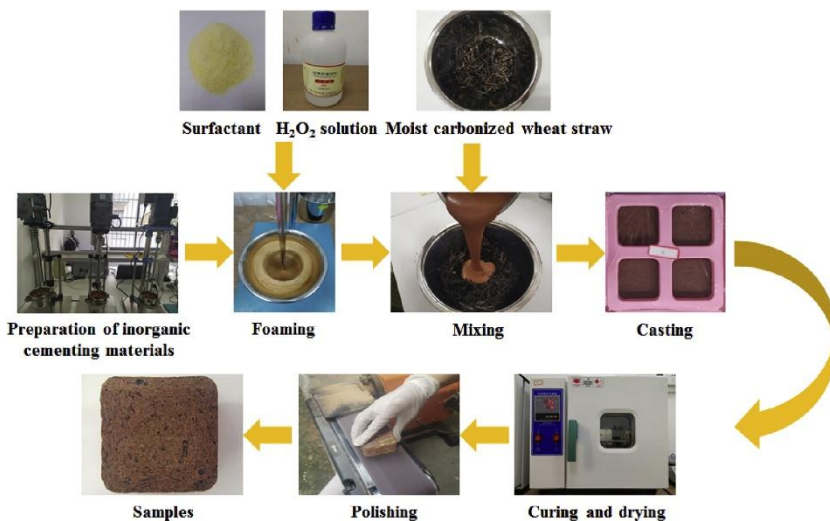


Figure 6. Schematic diagram of the process for increasing fire resistance in wheat straw-based composite insulation materials (Zou et al., 2021)

In the study conducted by Zhang et al. (2023), the fire resistance of bricks produced using calcium hydroxide from corn stalks, an agricultural waste material, was investigated. The same study showed that the brick is fire-resistant because its calcium carbonate layer delays heat transfer (Figure 7).

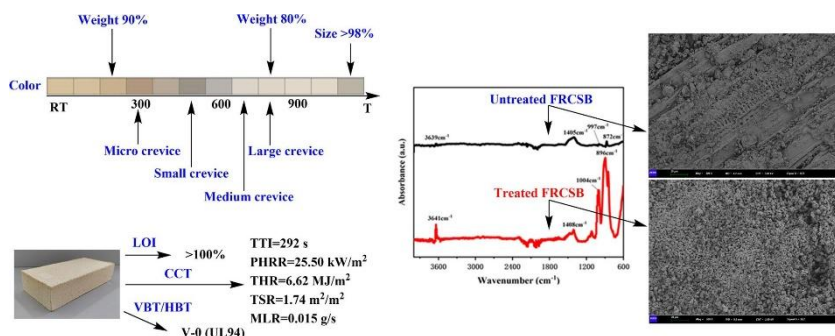


Figure 7. Schematic diagram of the process for increasing the fire resistance of corn stalk and calcium hydroxide-based composite bricks (Zhang et al., 2023)

3. Artificial Intelligence Powered Fire Safety Models

In the architectural design of buildings, ensuring the safe evacuation of users during a fire is of critical importance. Today, thanks to artificial intelligence powered technological systems, it is possible to predict fire risks in advance and provide early warning against potential dangers. Furthermore, artificial intelligence methods such as machine learning and deep learning can detect the onset of fire with higher accuracy than traditional systems by evaluating parameters such as temperature, humidity, gas concentration, and smoke density. Thanks to these methods, the fire response time is shortened, and the structural

integrity of the building is preserved. Additionally, recent scientific studies on artificial intelligence technological systems have contributed to increasing the fire safety of buildings and reducing loss of life and property. For example, in the study by Arun et al. (2025), they stated that the deep learning method has an important place in the development of fire early warning systems and fire risk prediction models for buildings (Figure 8).

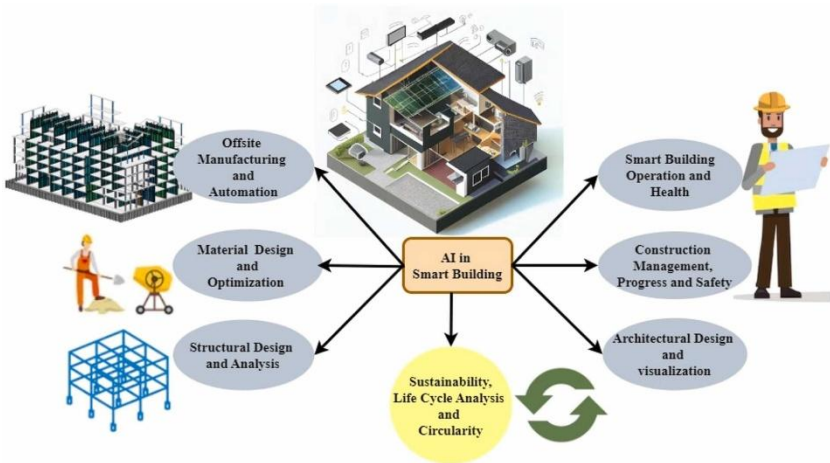


Figure 8. Schematic diagram illustrating the application of artificial intelligence powered technologies in ensuring fire safety in buildings (Arun et al., 2025)

Artificial intelligence powered evacuation systems make a significant contribution to the safe and rapid evacuation of building occupants during a fire. In their research, Lu et al. (2026) evaluated evacuation safety in large-scale structures using artificial intelligence-supported systems. In the same study, the evacuation performance of structures was predicted with high accuracy using real-time data analysis and deep learning algorithms (Figure 9).

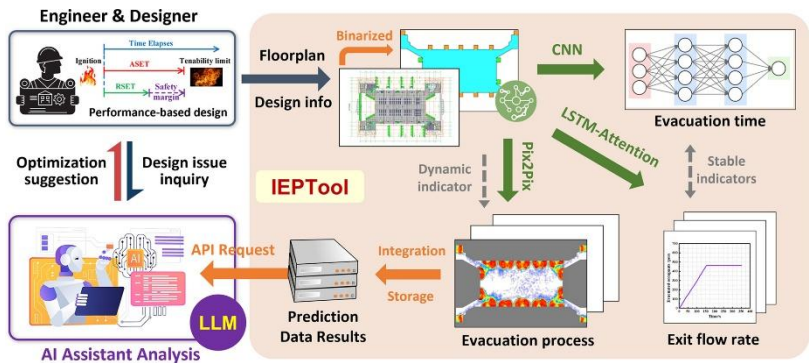


Figure 9. Schematic diagram showing the assessment of evacuation safety in large-scale structures using artificial intelligence assisted systems (Lu et al., 2026)

IoT sensor networks are considered one of the key elements that increase the effectiveness of fire safety applications in buildings. In the study conducted by Shaharuddin et al. (2023), it was stated that early detection of fires in buildings using IoT sensors provides a significant advantage in ensuring the safe evacuation of building occupants (Figure 10). As seen in these studies in the literature, artificial intelligence technological systems have significant potential in fire safety, particularly in the early detection of fires, risk management, and the development of safe evacuation processes.

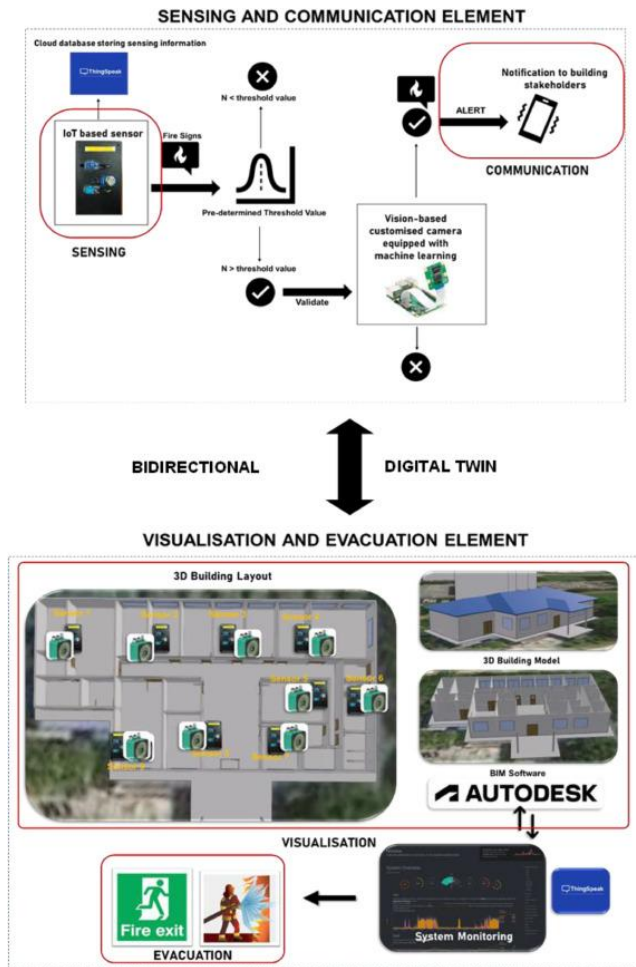


Figure 10. Schematic diagram showing the assessment of early-stage fires and safe evacuation of building occupants using IoT sensors in buildings (Shaharuddin et al., 2023)

4. Integration of Sustainable Flame Retardant Materials with Artificial Intelligence Technologies

Artificial intelligence technologies play a significant role in transforming sustainable building materials into structural components. For instance, the study by Wang et al. (2023) revealed that artificial intelligence systems make a significant contribution to the development of building materials and their use in the construction industry. The same study indicated that machine learning methods can be effectively used in the production of building materials, the analysis of material properties, and the optimization of material production processes (Figure 11).

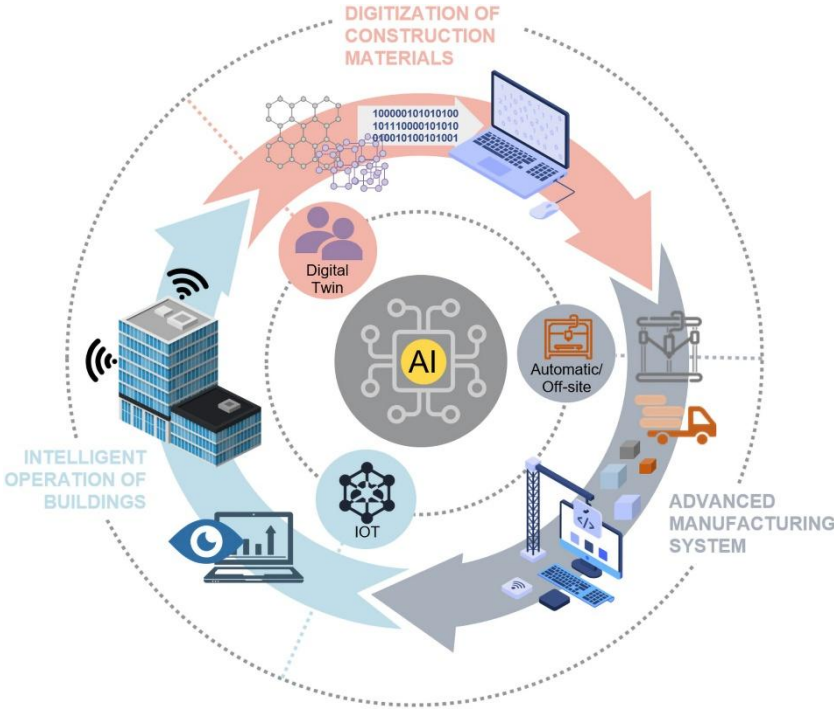


Figure 11. Schematic diagram showing the development and use of artificial intelligence technological systems in building materials and the construction industry (Wang et al., 2023)

Artificial intelligence technology systems make significant contributions to optimizing the fire performance characteristics and fire safety of waste materials. In their research, Xu et al. (2026) evaluated the fire resistance properties of waste wood-based sustainable biocomposites using hybrid deep learning models. The same study determined that tannic acid and phytic acid significantly increased the fire resistance of the modified wood. Furthermore, in this study, the fire performance of the biocomposite material was predicted with high accuracy (R^2

$\approx 0.98\text{--}0.99$) within the framework of analyses carried out with artificial intelligence technological systems (Figure 12).

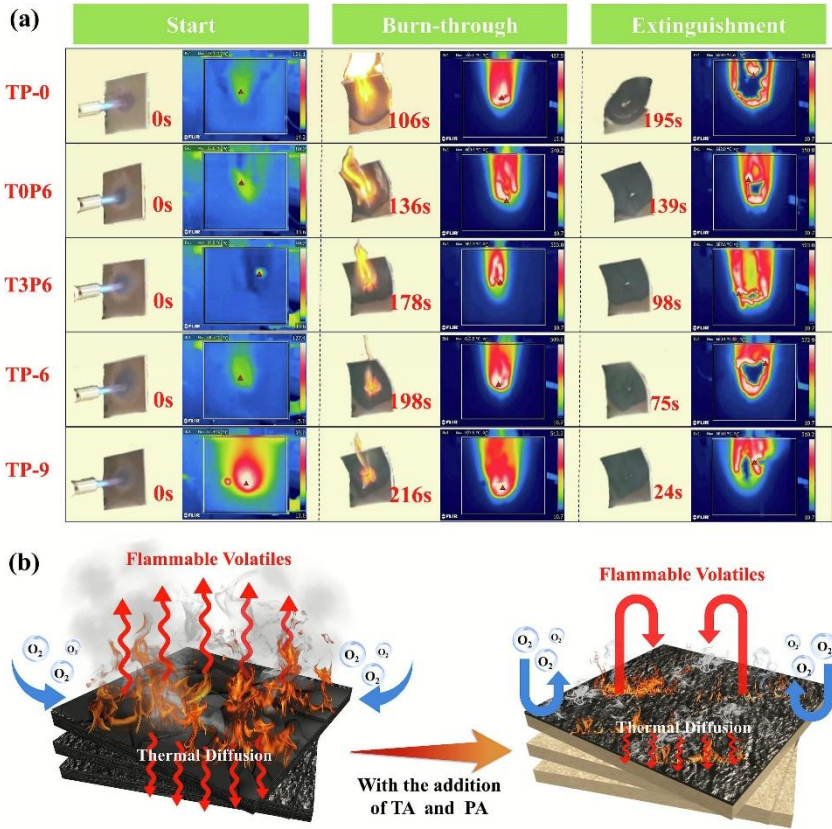


Figure 12. Optimizing the fire performance characteristics and fire safety of waste materials using artificial intelligence technology systems; (a) Photograph of a fire test of biocomposite wood, (b) Schematic diagram showing the fire resistance of biocomposite wood (Xu et al., 2026)

Artificial intelligence technological systems are being used to both develop sustainable and fire-resistant building materials and to evaluate their environmental impacts. In a study conducted by Hua et al. (2025), they stated that artificial intelligence provided approximately 20% higher accuracy in predicting the carbon emissions of a building compared to traditional methods. The study also highlighted that real-time monitoring and adaptive management strategies using artificial intelligence technological systems can reduce carbon emissions by up to 15% and increase energy efficiency by up to 25% (Figure 13).

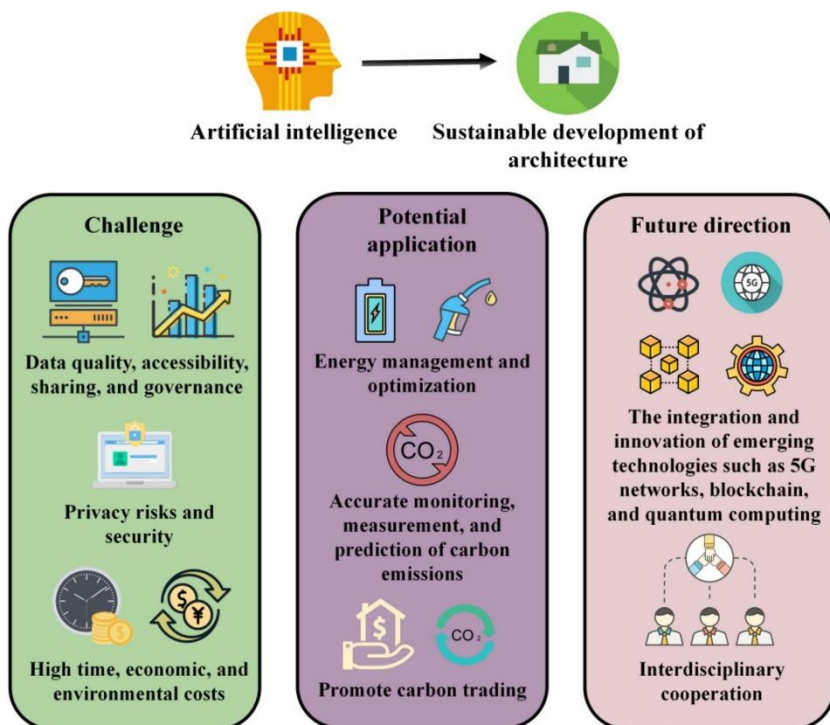


Figure 13. Utilizing artificial intelligence technological systems in assessing carbon emissions from buildings (Hua et al., 2025)

5. Conclusion and Recommendations

This study focuses on the development of sustainable flame-retardant building materials and the evaluation of their fire resistance performance using artificial intelligence technological systems. According to the literature review, artificial intelligence and machine learning techniques can enable the rapid and highly reliable determination of the type and optimum ratios of flame retardants. Artificial intelligence and machine learning techniques contribute to sustainable material production by reducing the number of experiments used in material development, lowering production costs, and shortening production time. Sustainable flame-retardant materials have been identified as potential alternatives to traditional flame-retardant materials through digital design strategies. Artificial intelligence powered analyses contribute to the development, performance, environmental, and economic aspects of next-generation materials.

Based on the results of this study, the following recommendations are made to more effectively utilize artificial intelligence applications in the development of sustainable flame-retardant building materials:

- Development of different bio-based and nano-reinforced composite structural materials for use in the construction industry. It is recommended that

these materials be evaluated in terms of fire safety using artificial intelligence technological methods.

- It is recommended that fire test results for sustainable flame-retardant building materials be integrated with artificial intelligence technological systems to increase the reliability of the models.

- It is proposed that different artificial intelligence models be developed to conduct a holistic assessment of the fire safety and environmental impact of sustainable flame-retardant building materials.

- It is recommended to develop new hybrid models that will contribute to more accurate modeling of the fire behavior of sustainable flame-retardant building materials.

- It is suggested that increasing research in different fields such as architecture, materials science, and artificial intelligence will lead to an increase in sustainable building materials.

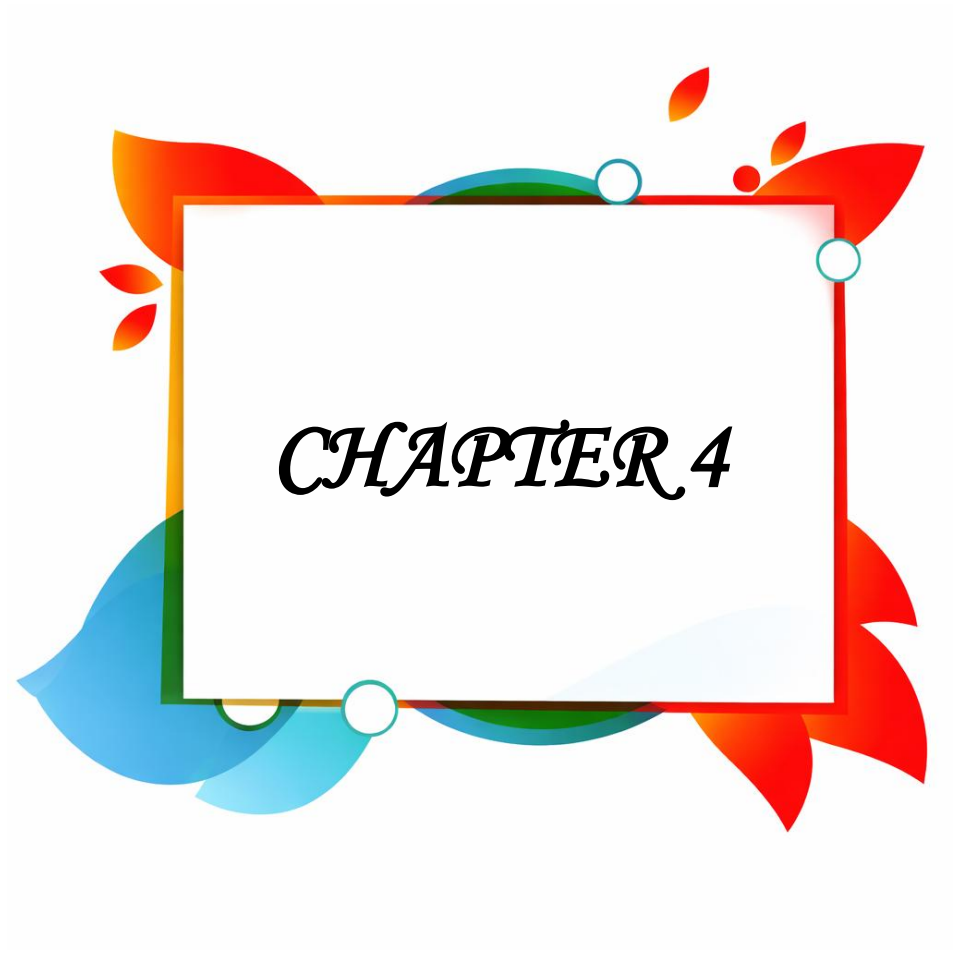
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Building-Integrated Photovoltaic (BIPV) Systems in Retrofit Buildings

Elvan Kumtepe¹

1. INTRODUCTION

The building sector, which is responsible for approximately one-third of global energy consumption and a significant share of energy-related carbon emissions, is regarded as one of the priority areas for transformation in the fight against climate change. Considering that a large proportion of the existing building stock will continue to be in use over the next few decades, achieving sustainability targets cannot rely solely on the construction of new buildings designed according to high energy performance standards (Nejat et al., 2015). In addition, the widespread implementation of renovation strategies aimed at improving the energy efficiency of existing buildings is of great importance (Barbosa & Almeida, 2025). In this context, energy renovation or retrofit practices are considered significant interventions that extend the service life of existing buildings while reducing their energy consumption, enabling their integration with renewable energy systems, and supporting the transition toward a low-carbon building stock. Building-integrated photovoltaic systems (Building Integrated Photovoltaics – BIPV) are among the renewable energy technologies that stand out in retrofit applications (Scognamiglio, 2017). Unlike conventional building-applied photovoltaic systems, BIPV elements are not merely equipment added to buildings afterward for the purpose of electricity generation; they can also function as integral components of the building envelope, such as roof coverings, façade claddings, window systems, shading devices, balustrades, or skylights. Thus, the protective, aesthetic, and environmental functions of building elements can be combined with energy generation within a single system. Through this multifunctional structure, the need for additional cladding materials can be reduced, and the building envelope can be transformed into an active energy-generating component. This multifunctional approach enables the simultaneous improvement of energy performance and architectural integrity, particularly in the renovation of existing buildings (Aguacil et al., 2024).

2. DEVELOPMENT POTENTIAL AND DESIGN REQUIREMENTS OF BIPV SYSTEMS

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The significant growth potential of BIPV technologies in the coming years is also clearly reflected in international market projections. According to the International Technology Roadmap for Photovoltaic (ITRPV 2026), published in June 2026, the share of standard utility-scale power plant applications, which currently dominate the global photovoltaic market, is expected to decrease from approximately 60% in 2025 to around 46% by 2036. In contrast, special market segments such as building-integrated photovoltaic systems, agro-photovoltaic applications, and floating photovoltaic systems are projected to account for an increasing share of the global market. In particular, the share of BIPV systems in the global photovoltaic market is expected to rise from approximately 1% in 2025 to 8% by 2036 (VDMA, 2026). This corresponds to nearly an eightfold market growth within a period of about ten years. This projection indicates that BIPV technologies will assume a strategic role in the urban energy infrastructure of the future and become an important tool in the energy transformation of the existing building stock (Figure 1) (Fischer, 2026).

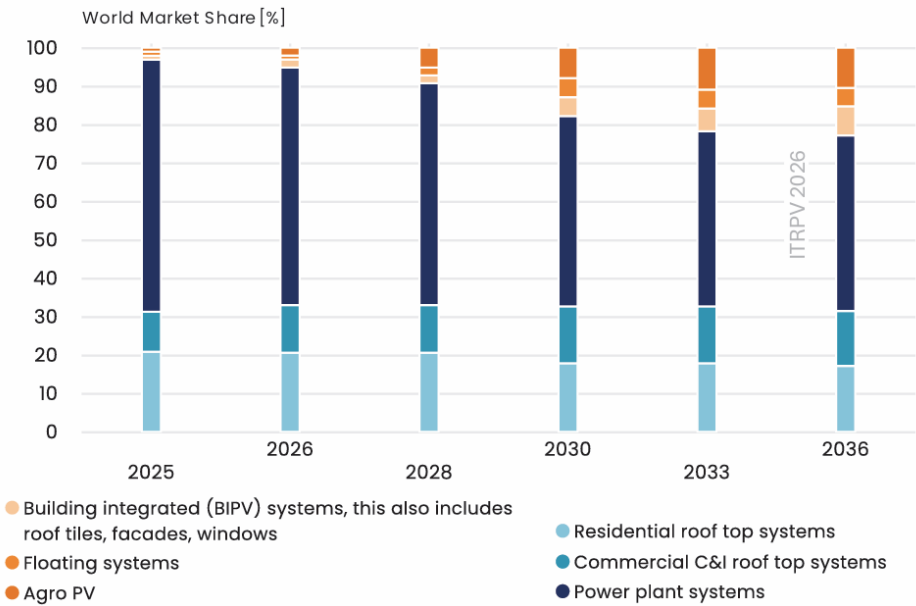


Figure 1. Market share projections of photovoltaic application categories, including building-integrated photovoltaic systems (BIPV), for the 2025–2036 period according to ITRPV 2026.

One of the main reasons why BIPV systems are gaining increasing importance is the growing limitation of land use in highly urbanised areas. The use of existing building surfaces for energy generation without requiring additional land allocation offers significant advantages, particularly in densely populated urban environments. In addition, the widespread adoption of net-zero energy building targets, carbon-neutral city policies, rising energy costs, and concerns regarding energy supply security are among the key factors supporting the development of BIPV applications (Mehta et al., 2025). In retrofit applications, BIPV technologies can be integrated into various components of the building envelope, including ventilated façades, curtain walls, double-skin façade systems, semi-transparent skylights, photovoltaic shading devices, and energy-generating roof systems. These systems not only generate electricity but also provide additional functions such as solar control, daylight management, glare reduction, improved thermal insulation performance, and enhanced indoor comfort conditions. In particular, the air cavity formed in ventilated BIPV façades can contribute to reducing module temperature and thereby increasing electrical efficiency. Similarly, semi-transparent BIPV glazing systems can provide balanced solutions between daylight utilisation and electricity generation. Dynamic photovoltaic shading systems, on the other hand, can contribute to significant reductions in building cooling loads. This multifunctional structure demonstrates that BIPV systems should not be regarded solely as technical energy-generating technologies, but rather as holistic retrofit components that must be considered together with architectural design, building envelope performance, and user comfort. As shown in Figure 2, the evaluation of BIPV systems is based on three main dimensions: aesthetics, energy performance, and structural integration. While characteristics such as colour, texture, and transparency determine the compatibility of the system with the architectural appearance and façade character, photovoltaic efficiency, thermal insulation, solar control, and daylight properties directly affect energy performance and indoor comfort. In addition, shape and size compatibility, integration with the structural system and materials, and safety requirements are considered critical design parameters, particularly in interventions on existing buildings. Nevertheless, despite the technical, environmental, and architectural potential offered by BIPV systems, their widespread adoption still faces several limitations. One of the main limitations is the lack of knowledge and experience regarding BIPV technologies among architects, engineers, construction practitioners, and investors. Since BIPV systems combine building materials and energy generation technology within a single component, they require the simultaneous consideration of design, detailing, electrical safety, building physics, and construction processes. Therefore, particularly in retrofit projects, the lack of interdisciplinary knowledge can make it difficult to integrate the system at an early stage of the project. Another important barrier is the higher initial investment cost of BIPV systems compared to some conventional building materials. Although these systems offer

long-term advantages such as energy generation, reduced carbon emissions, increased building value, and balanced maintenance costs, their initial costs can be a deterrent for investors and building owners. For this reason, green financing models, incentive mechanisms, subsidies, and long-term payback analyses play a decisive role in the wider adoption of BIPV applications. Another challenge encountered in BIPV applications is the lack of regulatory frameworks and standardisation. Since these systems are considered both building elements and electricity-generating technologies, they must simultaneously meet requirements related to structural safety, fire safety, electrical safety, durability, water and air tightness, and energy performance. This makes approval, certification, and implementation processes more complex compared to conventional photovoltaic systems. Furthermore, unlike standard rooftop photovoltaic systems, BIPV systems are directly integrated into the building envelope and therefore require a higher level of design sensitivity during planning and implementation. Since the structural system, façade geometry, orientation, shading conditions, material characteristics, and architectural identity of existing buildings vary from project to project, BIPV solutions should not be treated as standard products (Singh et al., 2021). Rather, they often need to be developed as building-specific design strategies. This situation complicates the integration process, particularly in retrofit applications, and increases the need for specialised expertise. In addition, the fragmented structure of the BIPV market among building material manufacturers, photovoltaic module producers, electrical system providers, façade companies, and architectural offices can limit the development of integrated supply and implementation processes. Therefore, cross-sector collaboration, the development of common standards, the wider use of modular and prefabricated solutions, and the strengthening of interdisciplinary design processes are of critical importance for the broader adoption of BIPV systems in the future. Despite these challenges, the multidimensional advantages offered by BIPV technologies in terms of energy generation, architectural integrity, user comfort, and sustainable building transformation make these systems an increasingly strategic solution for retrofit applications (Martín-Chivelet et al., 2026).



Figure 2. Evaluation criteria for BIPV systems in retrofit buildings in terms of aesthetics, energy performance, and structural integration.

Research on high-efficiency crystalline silicon technologies, thin-film photovoltaics, coloured opaque modules, hidden-cell designs, semi-transparent glazing systems, and next-generation perovskite-based photovoltaic materials has further expanded the architectural integration potential of BIPV applications. In particular, aesthetically compatible solutions developed for the renovation of historic buildings enable BIPV technologies to be considered not only as energy-generating systems but also as important components of architectural renewal, cultural heritage conservation, and sustainable urban transformation strategies. Therefore, the successful implementation of BIPV systems in retrofit buildings requires the simultaneous consideration of energy generation, building physics, architectural aesthetics, safety, and construction techniques. In this context, the design, application, and energy performance assessment of building-integrated photovoltaic systems constitute a critical research and practice area for the development of a future low-carbon and energy-efficient building stock (Zhao & Gou, 2025).

3. BIPV SYSTEMS IN RETROFIT BUILDINGS

When evaluated from engineering, design, and standardisation perspectives, BIPV systems can be classified into different categories depending on the building envelope components to which they are applied. This classification not only defines the position of photovoltaic modules but also determines the design, installation, maintenance, safety, and performance requirements of the systems. In line with IEC 63092-1, published by the International Electrotechnical Commission (IEC), BIPV applications are generally grouped into three main categories: roof systems, façade systems, and photovoltaic systems that are

externally positioned yet integrated with the building. Each application category has its own structural characteristics, environmental effects, and performance expectations (Chivelet et al., 2024). Therefore, in the design process of BIPV systems, criteria such as energy generation, aesthetic expectations, structural integrity, durability, fire safety, water and air tightness, maintenance accessibility, and user comfort should be evaluated together. In retrofit applications in particular, the preservation of the existing building geometry, the load-bearing capacity of the structure, façade modulation, and the continuation of the original character of buildings with historic or architectural value can make the design process more complex. From an engineering perspective, BIPV solutions differ not only in terms of their energy generation potential but also in terms of their physical relationship with the building envelope, installation details, maintenance requirements, and level of architectural integration. For this reason, the classification of BIPV systems that can be used in retrofit buildings is important for selecting the appropriate technology, guiding the design process, and identifying the technical constraints that may arise during implementation (D'Ambrosio et al., 2021).

In this section, BIPV systems used in retrofit buildings are examined under the categories of roof systems, ventilated façades, curtain walls, double-skin façades, semi-transparent skylight systems, photovoltaic shading devices, and externally integrated systems positioned outside the building envelope. The technical characteristics, design criteria, effects on energy performance, and integration potential of each application type in existing buildings are evaluated. Subsequently, international case studies of building-integrated photovoltaic retrofit applications carried out in different climate zones and various building types are discussed, and insights are provided regarding design, implementation, and operation processes.

3.1. International Case Studies on BIPV Applications in Retrofit Buildings

To better understand the integration potential of BIPV technologies in existing buildings, international retrofit case studies carried out in different climate zones and various building types were examined. The selected examples cover different building typologies, including residential, cultural, commercial, and public-use buildings, and include various BIPV application categories such as roof systems, ventilated façades, skylights, and rainscreen systems. Among the retrofit applications evaluated, the BIPV roof renovation implemented in the Andreas Bjørns St. 1 residential building stands out as a notable example of transforming the existing building envelope into an active energy-generating component (Figure 3). Similarly, in the Urban Park in Certosa Island project, a photovoltaic roof system was integrated into the existing building; in the San Antón Market and Edmonton Convention Centre projects, semi-transparent photovoltaic

skylight systems were used to provide both natural daylighting and electricity generation. In the Palazzo Argonauta case, the BIPV application implemented through a ventilated rainscreen system demonstrates how existing building façades can be renovated in an energy-efficient manner (Martín Chivelet et al., 2024).



Figure 3. BIPV roof application in the Andreas Bjørns St.1 retrofit project: building views before and after renovation, and roof detail. Credits: Dorte Krogh.

The Andreas Bjørns St.1 project demonstrates that BIPV systems can be integrated into the roof of an existing residential building without compromising its architectural identity. In this multi-family residential building located in the Christianshavn district of Copenhagen, the deteriorated metal roof covering was removed as part of the renovation process and replaced with opaque monocrystalline silicon BIPV modules. The fact that the modules cover approximately 60% of the roof surface and are integrated with conventional roof elements in a similar colour helped preserve a coherent and simple roof appearance as perceived from street level. The Certosa Island Urban Park project provides an example of the renovation of existing buildings with BIPV systems within a UNESCO heritage site located in the Venetian Lagoon. As part of the retrofit carried out in 2020, BIPV roof tiles were integrated into the roofs of three non-protected buildings (Figure 4).



Figure 4. Architectural integration and detail views of the terracotta-coloured BIPV roof modules applied in the Certosa Island Urban Park retrofit project. Credits: GruppoSTG.

The project used terracotta-coloured glass-glass BIPV modules with a total surface area of 1,100 m² and a roof inclination ranging between 18° and 25°. The frameless design and colour compatibility of the modules with traditional Northern Italian architecture enabled the system to be integrated into the historic environment with visual coherence (Figure 4). In this respect, the project demonstrates that BIPV technologies can simultaneously provide energy generation and architectural compatibility in heritage contexts. The San Antón Market project is one of the successful skylight applications demonstrating the renovation of existing commercial buildings with BIPV systems. Located in the Chueca district of Madrid and dating back to the nineteenth century, the historic market building underwent a comprehensive renovation in 2011, followed by additional improvements in 2021. The three-storey building, with a gross floor area of 7,345 m², accommodates fresh food vendors, restaurants, and various commercial units. As part of the retrofit, a photovoltaic skylight system was integrated into the central part of the building, allowing natural daylight to reach all floors while simultaneously generating renewable electricity (Figure 5).



Figure 5. BIPV skylight system implemented in the San Antón Market retrofit project: exterior view of the building from the pedestrian scale (Photograph: Nuria Martín Chivelet, CEMAT) and interior view of the semi-transparent BIPV skylight system (Photograph: Onyx Solar).

The system covers a total surface area of 168 m² and consists of 54 insulated BIPV glass units based on semi-transparent amorphous silicon technology. It has a solar heat gain coefficient (SHGC) of 12% and a visible light transmittance of 20%. In addition, the connection elements concealed within the skylight frame provide an aesthetic and integrated appearance. With an installed capacity of approximately 6.5 kW, the BIPV skylight system generates 7.7 MWh of electricity annually, and the payback period is reported to be less than two years. In this respect, the project demonstrates that BIPV skylight systems in existing commercial buildings can combine daylight performance, energy generation, and economic feasibility (Lopez et al., 2020).

The Edmonton Convention Centre project is one of the notable skylight applications demonstrating the renovation of existing public buildings with BIPV systems. Located in Edmonton, Canada, the building hosts one of the largest BIPV systems in the country. As part of the renovation carried out in 2020, 696 inclined glass panels on the roof of the multi-storey atrium were replaced with semi-transparent photovoltaic modules. The total installed BIPV area reaches 1,556 m².

The semi-transparent monocrystalline silicon BIPV modules used in the project were designed not only to improve the energy performance of the building but also to strengthen its architectural appearance (Figure 6). In the arrangement of the modules, an artistic composition called “Oculus” was created by encoding a passage from Canadian poet Earle E. Birney’s *Gifts of a River* in Morse code

onto the modules. This design approach demonstrates how BIPV systems can function not only as energy-generating components but also as architectural and cultural expression elements.

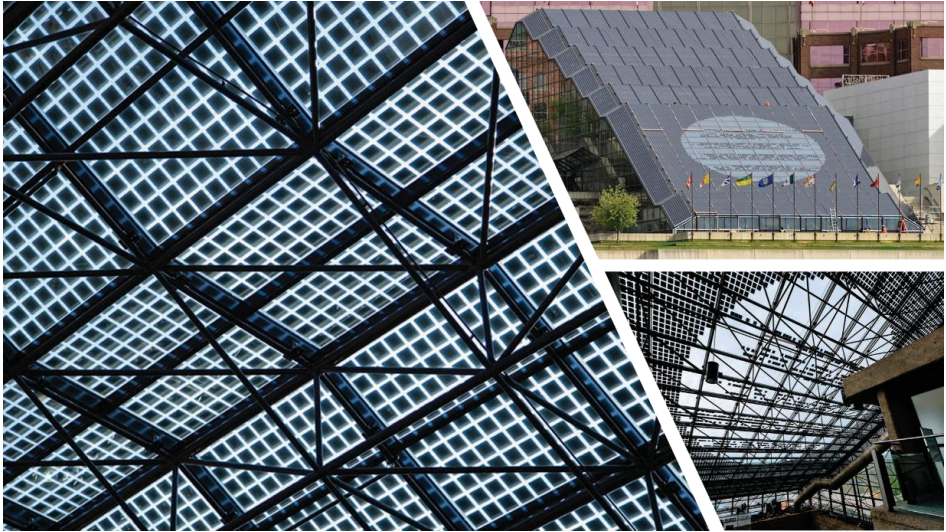


Figure 6. Exterior view of the semi-transparent BIPV skylight system applied at the Edmonton Convention Centre, interior detail, and the “Oculus” installation in the atrium (Photographs: Onyx Solar).

In the Edmonton Convention Centre project, the design approach integrates the building’s energy-generating function with an aesthetic and cultural form of expression. With an installed capacity of approximately 169 kW, the system generates around 200 MWh of electricity annually, contributing to the City of Edmonton’s goals related to sustainability, energy efficiency, and the promotion of art in public spaces. In addition, the BIPV skylight system enhances daylight levels within the atrium, supporting user comfort and fulfilling the criteria of the building’s Public Art Program. In this respect, the Edmonton Convention Centre is considered one of the successful examples demonstrating how BIPV technologies can combine energy generation, daylight performance, and architectural aesthetics in retrofit applications. The Palazzo Argonauta project is another notable example showing how BIPV systems can be applied in the context of façade renovation in existing office buildings in order to provide both aesthetic value and energy performance. Located in Rome, this 10-storey office building, with an approximate floor area of 70,000 m², was renovated in 2019 through the integration of a photovoltaic rainscreen system into its south façade. In addition to the façade renovation, the building’s HVAC and lighting systems were also modernised, thereby providing improved energy efficiency and comfort conditions for approximately 4,000 daily users. The BIPV system used in the project consists of opaque monocrystalline silicon modules based on the

ventilated façade principle. One of the main design objectives was to preserve the existing architectural identity by ensuring that the photovoltaic modules would be perceived as little as possible on the façade. For this purpose, the photovoltaic panels were positioned so as to be perceived as a continuation of the windows and were designed to function as shading elements. In contrast to the active BIPV modules on the south façade, blue enamelled glass panels of similar dimensions were applied on the same supporting system on the west façade, thereby ensuring visual continuity between the active and passive façade surfaces.



Figure 7. Pre- and post-renovation views and façade detail of the BIPV rainscreen façade system applied in the Palazzo Argonauta project (Photographs: DIARC).

With an installed capacity of approximately 145 kW, the system generates around 137.6 MWh of electricity annually. The Palazzo Argonauta example demonstrates that BIPV systems should be considered not only as energy-generating technologies but also as integral components of façade design (Kapsis et al., 2024). Particularly in large-scale office buildings, the architecturally coherent integration of photovoltaic elements into the overall composition shows that aesthetic concerns and energy performance objectives can be addressed simultaneously in retrofit applications (Martín Chivelet et al., 2024).

4. CONCLUSION

The building sector is at the centre of sustainable transformation policies due to its significant impact on energy consumption and carbon emissions. Considering that the existing building stock will continue to be used for many years, designing only new buildings in an energy-efficient manner is not sufficient. Therefore, improving the energy performance of existing buildings, integrating them with renewable energy technologies, and adapting them to a low-carbon built environment emerge as fundamental requirements for

sustainable architecture and energy policies. Building-integrated photovoltaic systems offer an important technological opportunity for retrofit applications. Unlike conventional photovoltaic systems, BIPV systems go beyond being independent energy-generating elements added to buildings and can be integrated with roofs, façades, skylights, shading devices, or other components of the building envelope. In this way, the building envelope is transformed from a passive boundary that only protects against outdoor conditions into an active system that generates energy, provides solar control, regulates daylight performance, and supports architectural identity.

The retrofit examples examined within the scope of this chapter demonstrate that BIPV systems can be applied through different design strategies depending on building type, climatic conditions, and architectural context. Roof-integrated applications stand out particularly in terms of preserving architectural integrity in existing residential buildings and historic environments. When the Andreas Bjørns St.1 and Certosa Island Urban Park projects are compared, it is observed that BIPV systems were used as roof covering elements in both cases. However, while one project aimed to achieve a simple and coherent roof appearance at the residential scale, the other developed a context-sensitive solution within a UNESCO heritage site through terracotta-coloured modules compatible with traditional architecture. This indicates that roof-integrated BIPV systems have the potential not only to generate energy but also to ensure architectural continuity through material, colour, and texture compatibility. Semi-transparent BIPV skylight applications, unlike roof systems, address energy generation and natural daylighting performance together. When the San Antón Market and Edmonton Convention Centre projects are compared from this perspective, it is seen that in both cases BIPV skylight systems perform the dual function of admitting daylight into the interior and generating electricity. However, while San Antón Market provides a successful example in a commercial building in terms of natural lighting, energy generation, and economic payback, Edmonton Convention Centre demonstrates that BIPV systems can also be used as an artistic and cultural expression element in a larger-scale public building. This comparison shows that semi-transparent BIPV systems can create value not only in terms of performance but also in terms of spatial quality and architectural experience. Façade-integrated BIPV applications offer a different potential, particularly in the energy renovation of large-scale buildings. As seen in the Palazzo Argonauta example, the integration of opaque monocrystalline silicon modules into the façade as a ventilated rainscreen system demonstrates that energy generation and façade design can be addressed together. Compared with roof and skylight applications, aesthetic continuity, module arrangement, façade rhythm, and solar control become more decisive design parameters in façade applications. Therefore, façade-integrated BIPV systems can be considered a strong retrofit strategy,

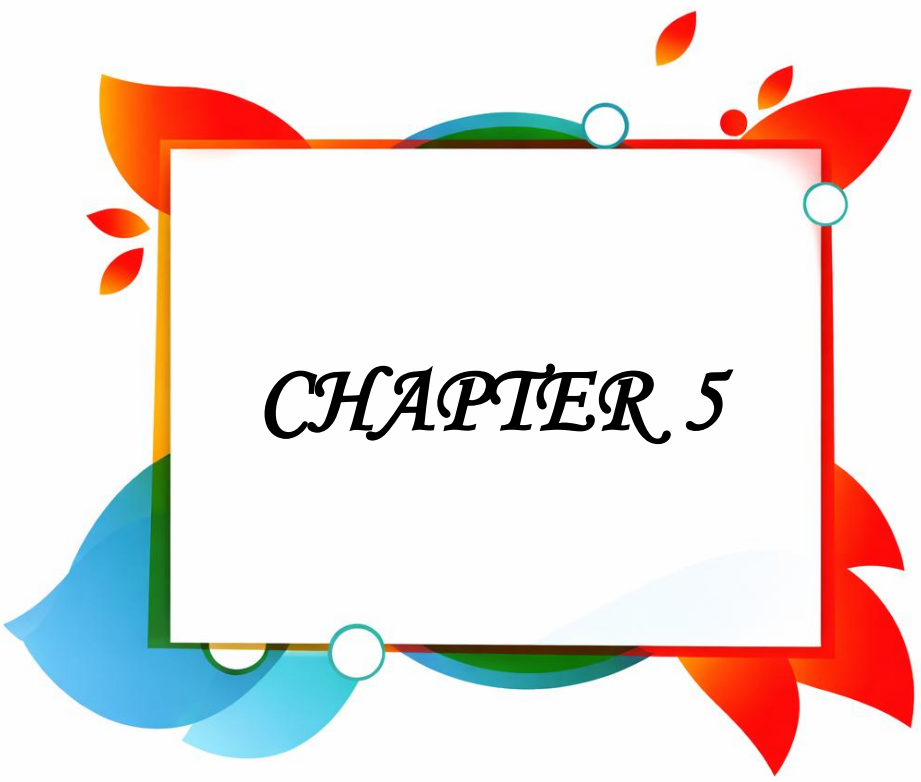
especially for office and commercial buildings, in terms of both energy performance and the visual renewal of the building envelope.

When the case studies are evaluated as a whole, it becomes clear that the success of BIPV systems cannot be explained solely through technical indicators such as installed capacity, annual electricity generation, or module efficiency. In roof applications, architectural integrity and material compatibility come to the fore; in skylight applications, daylight transmittance, solar control, and indoor spatial quality are emphasised; and in façade applications, façade composition, compatibility with the supporting system, and user comfort become prominent. Applications carried out in buildings with historic, cultural, or conservation value show that BIPV technologies are not merely technical additions specific to contemporary buildings. When colour, texture, transparency, module size, and installation details are designed in harmony with the character of the building, photovoltaic elements can be integrated without compromising the existing architectural identity. This demonstrates that BIPV systems can be regarded as an important retrofit solution capable of balancing cultural heritage conservation and energy transformation.

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CHAPTER 5

Competitiveness Dynamics of New Industrial Centers

Kübra Karkın¹

INTRODUCTION

The process of globalization and shifts in technological paradigms have led to space, in the field of economics, evolving from an isolated concept to a fundamental determinant of economic performance and prosperity. In this new period, the focus of development has shifted from the national to the regional and local levels, and regions have become active actors competing with one another to attract a skilled labor force and knowledge (Martin, 2006).

Regional competitiveness is defined as a region's capacity to attract factors of production from other regions, to host firms with high market share, and to sustainably increase the living standards of its residents (Huggins & Thompson, 2017). New economic geography (NEG), one of the powerful theoretical frameworks explaining these dynamics, attributes the concentration of economic activity in specific spaces and the persistence of interregional inequalities to the balance between forces of agglomeration and other (Huggins & Thompson, 2017; Potter, 2009). According to models of new economic geography, when trade costs decrease, centripetal forces, such as market access, specialized labor pools, and the flow of knowledge, become dominant, leading to the polarization of economic activity around specific locations (Potter, 2009).

In the context of Türkiye, this process, marked by the adoption of flexible production structures beginning in the 1970s following the economic crisis and accompanied by policies of economic liberalization after 1980, the rise of provinces such as Denizli, Gaziantep, Kayseri, and Konya, referred to as the new industrial centers or Anatolian Tigers, beyond the traditional industrial centers of Istanbul, Izmir, and Ankara. These centers have shaped Türkiye's industrial landscape through entrepreneurial activities based on local capital, sector-specific specialization in certain industries, and flexible networks of inter-firm collaboration. One of the most fundamental characteristics of new industrial districts is that their development process is driven by the region's own entrepreneurial culture and local capital (Eraydın, 2002).

For example, Denizli is a center that has become highly specialized in the textile and clothing sector, which has a longstanding history. The structure, which developed in the 1970s through extensive contract manufacturing relationships among small firms, began to evolve into larger-scale, integrated facilities in the

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1980s in response to quality demands from foreign markets. Gaziantep has a more diversified industrial structure that has developed in various sectors, such as textiles, food, machinery and metal goods. The metalworking tradition, which began in the 1950s with the repair of woven fabrics and transportation vehicles, has evolved into a modern machinery industry today (Eraydin, 2002).

The process, which began with the repair of agricultural machinery, has transformed Konya into a center specializing in machinery manufacturing, and particularly the automotive supply industry. After 1980, the number of multi-partner companies and holding companies increased rapidly; these structures expanded into various sectors of production while boosting capital accumulation. Kayseri is a successful center with a strong tradition of trade and industry that has been increasing its share of total industrial employment (Eraydin, 2002). However, in order for these centers to gain a sustainable competitive advantage, they must shift to strategies focused on technological upgrades, brand development, and innovation (Huggins & Thompson, 2017).

This study presents an analysis, grounded in a conceptual framework based on the NEG perspective and the concept of regional competitiveness, which examines how the changing economic environment has transformed economic geography, that focuses on the evolution of various competitive dynamics over the past decade in the provinces of Denizli, Gaziantep, Kayseri, and Konya, which were historically referred to as new industrial centers.

THEORETICAL FRAMEWORK

New economic geography is an economic discipline that gained popularity in the early 1990s through the work of Paul Krugman and explains the spatial concentration of economic activity within the framework of general equilibrium models and individual maximization behavior. It seeks to understand the spatial structure of the economy by using specific techniques to develop models in which there are increasing returns and markets are characterized by imperfect competition (Krugman, 1998).

Many economic activities around the world show a tendency toward geographic concentration. There is a tension between centripetal forces that tend to attract geographic concentration (*market size effects, concentrated labor markets, and pure external economies*) and centrifugal forces that counteract this (*immobile factors, land rents, and pure external economic diseconomies*) (Krugman, 1998).

The relative strength of centripetal and centrifugal forces influences the answers to numerous questions, such as the degree of concentration or decline in economic activity, the presence of economic problems, and whether economic activities will have a self-reinforcing or self-weakening effect (Krugman, 1998). The concentration of the branches of activity is taking place across numerous geographic scales with various components. Concentration can be seen in the

emergence of various industrial regions and the emergence of strong regional differences on a national scale (Fujita & Krugman, 2004).

The continuing disparities in key economic indicators among regions indicate that there are differences in the relative attractiveness of various regions and cities. For this reason, as Krugman also emphasizes, the region's ability to attract labor and capital serves not only as a measure of its spatial competitiveness but also as the source of its cumulative competitive advantage (Martin, 2006).

The competitiveness of regions is viewed as the cumulative result of multiple factors (Budd & Hirmis, 2004). In other words, regional competition is defined as an evolutionary process. According to economic geographers, the spatial proximity or clustering of similar and related firms enables them to benefit from locally generated embedded externalities. It is widely argued that these local characteristics are one of the key foundations of the regional economy's success. It also affects learning processes, the nature and scope of innovative activities, and the region's ability to attract the workforce, companies, and institutions (Martin, 2006).

There are different levels, ranging from the macro level, which reflects the country's competitiveness, to the micro level, which reflects the competitiveness of individual firms, and the meso level, which focuses on regions. It is argued that defining competitiveness at the regional level is a more difficult and complex level. It is widely acknowledged that it represents much more than factors such as export potential and the trade balance (Kitson et al., 2004).

In this period dominated by a globalized economic structure, regions are accepted as an important source of development and organization. In this context, the region is viewed as the primary spatial agent competing to attract investment. Knowledge mobility also takes place between regions; knowledge is transferred at this level, resulting in the clustering or concentration of firms (Huggins et al., 2013; Malecki, 2007).

From the new economic geography perspective, regional competitiveness is defined as the ability of regions to attract mobile factors and their relative positions in terms of hosting economic activities. Key drivers of competitiveness include the export base, knowledge and innovation, increasing returns, and the cultural economy (Potter, 2009).

Although the competitive strength of regions is fundamentally influenced by their economic performance, factors such as the level of human capital, the degree of innovative capacity, and the quality of infrastructural facilities affect their competitive advantage in leading and growing activities. Regional competitiveness is founded on key characteristics such as attracting a creative and innovative labor force to the region (Kitson et al., 2004). Entrepreneurship, knowledge, and innovation capacity are recognized as key factors in determining regions' future growth and development pathways (Huggins et al., 2013).

Recent debates have evolved from approaches to competitiveness that focused solely on GDP and productivity to a more holistic framework that encompasses environmental sustainability, the prevention of social exclusion, health infrastructure, and overall living standards (Bristow, 2010).

METHODOLOGY

New industrial centers, known as the Anatolian Tigers, a long tradition of craft culture, and dominated by small and medium-sized enterprises, began to emerge, rapidly developing across the country by taking advantage of the dynamics and strengths they had acquired in the post-1980 period. A culture of collaboration gives these regions, which are becoming increasingly competitive, the ability to increase and guide creativity, inventiveness, and innovation.

In this study, the provinces of Denizli, Gaziantep, Kayseri, and Konya were selected as sample regions from among these focus centers. Several indicators have been used to highlight the performance of these four provinces over the past decade. This study will examine the current situation of these provinces, which experienced rapid growth at the end of the 20th century.

Data Types and Sources

In this study, the past decade was divided into two periods to analyze the current landscape of industrial clusters. The study examines changes in competitive variables and development indicators between the two periods: 2016-2020 and 2021-2025. To this end, Table 1 lists the data and sources used in the analysis.

Table 1. Data Types and Sources Used in the Study

Variables	Data	Year	Source
Production Capacity	The share of the industry in GDP	2016-2024 (Annual)	Turkish Statistical Institute (TURKSTAT)
	GDP per capita (\$)	2016-2024 (Annual)	Turkish Statistical Institute
	Exports (million \$)	2016-2025 (Annual)	Turkish Statistical Institute
Innovative Capacity	Number of patent applications	2016-2025 (Annual)	Turkish Patent and Trademark Office
	Number of utility model applications	2016-2025 (Annual)	Turkish Patent and Trademark Office
	Total number of projects approved for funding	2016-2020 2021-2025 (Periodical)	The Scientific and Technological Research Council of Türkiye (TÜBİTAK)
Level of Human Capital	Number of graduate degree students and Total population	2016-2025 (Annual)	Turkish Statistical Institute

The study identified three dimensions related to the competitiveness patterns of provinces. GDP and export statistics were used to measure the dimension defined as production capacity. However, among these variables, the GDP statistics for 2025 were not available at the time the study was carried out. For this reason, the most recent period covered, 2021-2024, includes data on the industrial sector's share of GDP and average GDP per capita.

For the second dimension, innovative capacity, statistics on the number of patent and utility model applications, as well as the number of scientific and technological projects, were used. The number of graduate degree students, which is the most meaningful statistic available at the provincial level regarding human capital, the final dimension, was used. To obtain comparable values, the number of graduates was ratioed to the population.

Measurement

For this study, four provinces (NUTS 3 regions) that are major industrial centers in Türkiye were selected as the study area. The reason these provinces were included in the analysis is to shed light on the current state of new industrial centers that were of great importance in the past. Accordingly, qualitative analyses were conducted using the data summarized in Table 1.

This study presents an analysis of the competitive dynamics of regions over the past decade across three dimensions: production capacity, innovation capacity, and human capital levels. The analysis includes statistics obtained at the provincial level for the 2016-2020 and 2021-2025 periods, covering the industry sector's share of GDP, GDP per capita, exports, the number of patent applications, the number of utility model applications, the total number of projects approved for funding, the number of graduate degree students, and the total population of the province.

For the first dimension, the averages of the provinces' shares of GDP, GDP per capita, and exports for the years 2016-2020 were calculated, and the value for the period was determined. The same method was applied for the following period as well. The same method was applied to the data for the other categories. To calculate the graduate school completion rates, the number of graduate degree students in each province was divided by its population, yielding the number of postgraduate graduates per 1000 people.

All variables were calculated at the provincial level across the country. The variables representing each dimension are presented graphically for the four provinces that are the focus of this study and for the national average for Türkiye, covering two different periods. This allowed for a comparison of the situation among regions nationwide during the relevant period. It also highlights the changes between the two periods.

In addition, the averages for the two periods have been spatialized at the provincial level. For each period, all variables were divided into three groups separately. The grouping was based on natural break points. The range with the

lowest values among the three groups is labeled low, the next range is labeled medium, and the range with the highest values is labeled high. As the maps are colored, the shades representing the provinces become darker as the values increase from the lowest to the highest.

ANALYSIS AND FINDINGS

Production Capacity

The first topic examined in outlining the competitive framework of industrial centers was production capacity. The production capacity of the provinces has been determined by using data on the share of industry in GDP, GDP per capita, and exports.

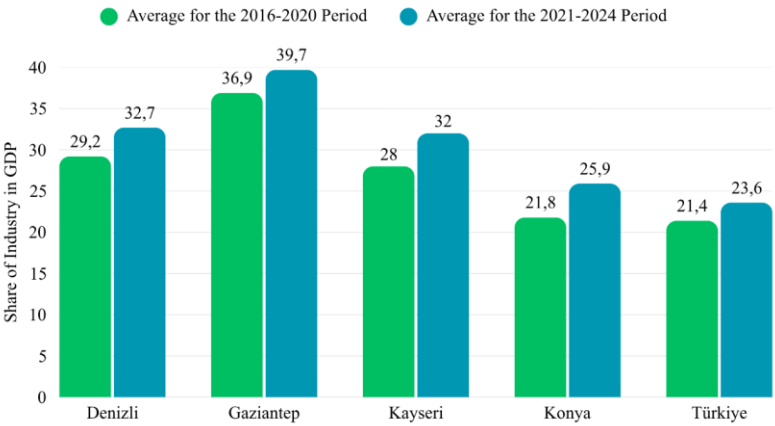


Figure 1. The share of industry in GDP (TURKSTAT)

There has been a positive change in the industrial sector across all regions between the two periods. Figure 1 shows the ratios for the two periods. In both periods, industrial centers recorded values above the provincial average for Türkiye as a whole. Recently, the industrial sector's share of GDP has increased by 10.2% across Türkiye. In the three provinces other than Gaziantep, this change was above the national average. In Gaziantep, however, the rate of change was 7.6%. The highest rate of change was recorded in Konya, with an increase of 18.8%.

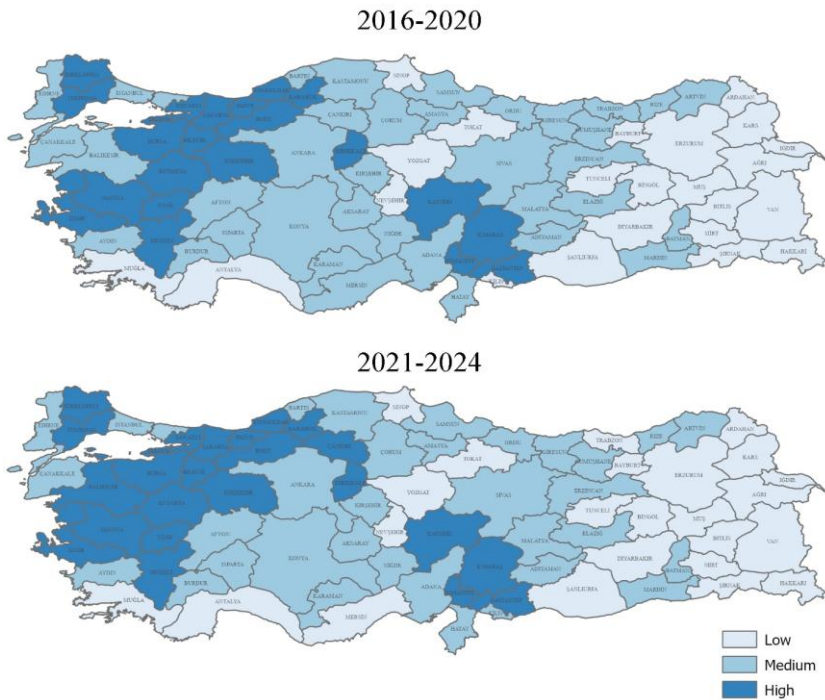


Figure 2. The share of industry in GDP across Türkiye

Figure 2 shows the spatial distribution across Turkish provinces. While some provinces in the western part of the country were classified in the high category during both periods, those in the eastern part were classified in the low category. Among the provinces analyzed, Konya experienced greater change than the others between the two periods but remained in the medium category. The other provinces, however, were classified in the high category throughout both periods.

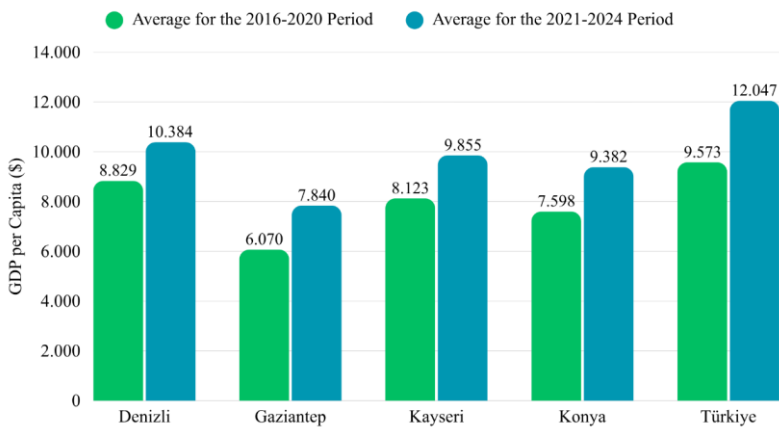


Figure 3. GDP per Capita (TURKSTAT)

GDP, which is frequently used to measure economic development and welfare, is one of the most fundamental indicators of traditional development for the region.

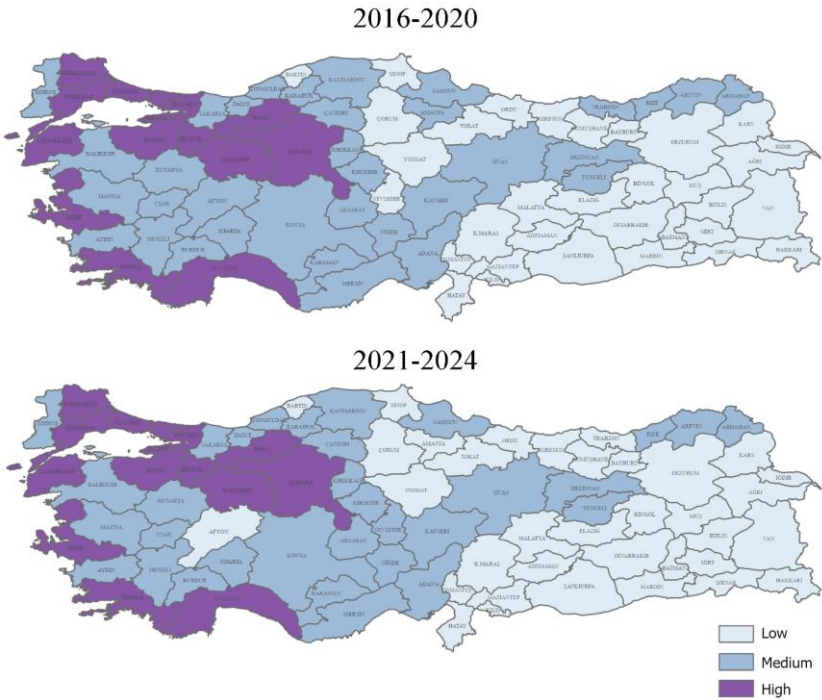


Figure 4. GDP per Capita across Türkiye

Figure 3 shows the per capita GDP figures for the two periods. In neither period was there a province with a per capita GDP above the national average. Although there was a 25.8% increase nationwide, Gaziantep was the only province to experience a change exceeding this rate.

In Figure 4, none of the provinces that are the focus of the analysis fall into the high category in terms of the spatial distribution of GDP per capita. While Denizli, Kayseri, and Konya are classified as medium-level provinces, Gaziantep has remained in the low category despite having a rate of change above the average. It can be seen that the variable in question is highly concentrated in western Türkiye.

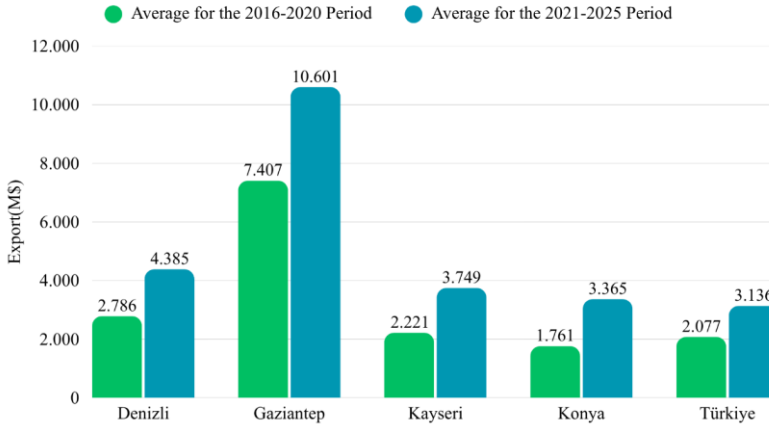


Figure 5. Trade Statistics: Export (TURKSTAT)

Figure 5 shows the averages of export data for the provinces. While total exports across Türkiye increased by 50.9% between the two periods, the rate of change in export values for the provinces of Denizli, Kayseri, and Konya, which were included in the analysis, exceeded the overall average. This rate is particularly notable for Denizli (57.4%), Kayseri (68.8%), and Konya, which saw a 91.1% increase in exports. Gaziantep, with a growth rate of 43.1%, recorded an increase in exports that was below the national average. Unlike the graphs of the previous variables, the averages for the two periods show that Gaziantep stands out from the other provinces. During the 2016–2020 period, the provinces that exceeded the average export level of the 81 provinces were Denizli, Gaziantep, and Kayseri; in the subsequent period, Konya was added to this group.

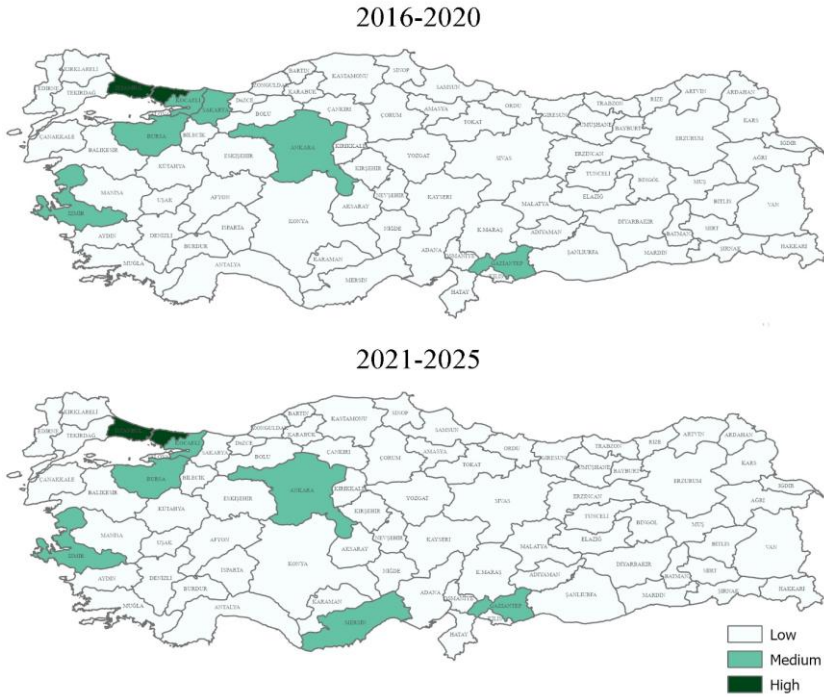


Figure 6. Export across Türkiye

The spatial distribution of export data is shown in Figure 6. As can be seen from these maps, the high values recorded in Istanbul have influenced the inflection points. It can be seen that Ankara, Bursa, Izmir, Kocaeli belong to the medium category. Gaziantep, one of the industrial hubs, is also included in this category. The other provinces, however, remained in the lower category. It is evident that foreign trade activity falls within a similar range nationwide and that there has been no tendency for these provinces to move closer to those appearing darker on the map in recent times.

Innovation Capacity

In the context of the sustainability of regional competitiveness, innovation capacity continues to be a critical determining factor.

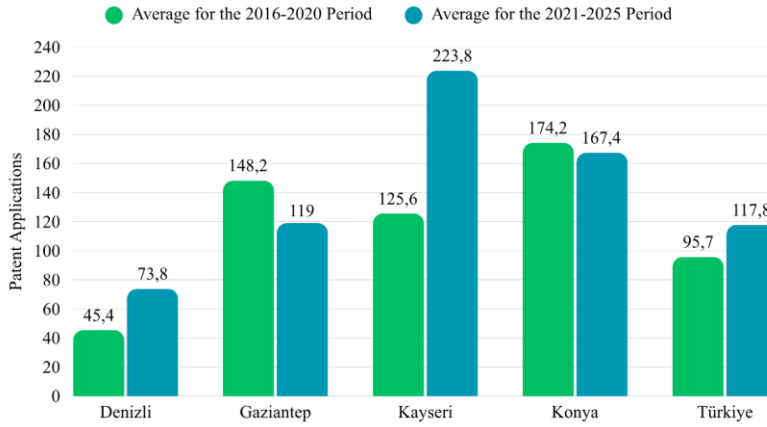


Figure 7. Patent Applications (Turkish Patent and Trademark Office)

The number of patent applications, which is used as an important indicator of innovative activities, is shown in Figure 7. When examining the average number of applications over the two periods for each province, it is evident that Gaziantep and Konya have experienced a negative change. It is understood that while patent applications across Türkiye saw a 23% increase, Denizli gained significant momentum with a 62.6% growth rate, and Kayseri experienced a 78.2% increase. It can be seen that Denizli had a lower than national average number of patent applications in two periods.

Looking at the distribution of the periodic averages of patent applications in Figure 8, it can be seen that Istanbul belongs to the high category, while Ankara, Bursa, Izmir, and Kocaeli belong to the medium category. The four provinces on which the analysis focuses, however, remain in the low category. A spatial distribution parallel to that of the previous variable has emerged.

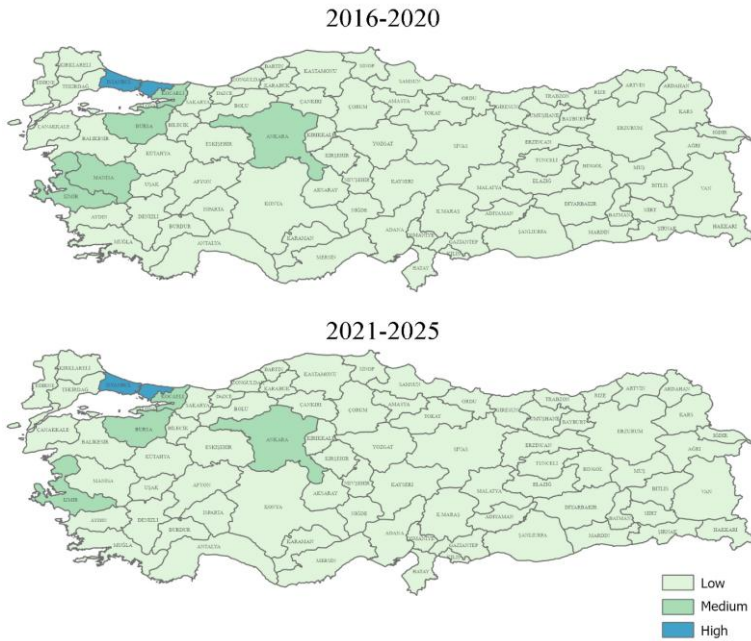


Figure 8. Patent Applications across Türkiye

In a period of increasing global competition, it has become essential for regions to pursue innovation and knowledge-based development. Figure 9 shows the utility model application rates by province. The analysis indicators exceeded the average for all 81 provinces in both periods. Across Türkiye, the number of applications increased by 27.2%. All provinces experienced positive changes during this period. However, there is only one province where the increase was higher than the national average: Denizli. Gaziantep (19.5%), Kayseri (25.8%), and Konya (9.3%) all showed growth rates below the Turkish average.

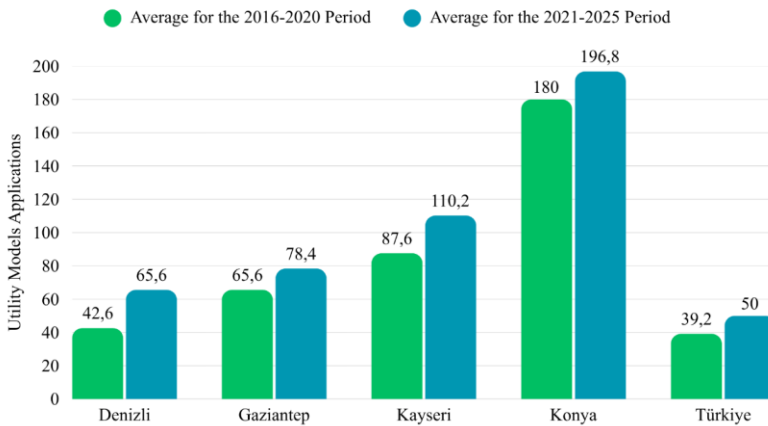


Figure 9. Utility Models (Turkish Patent and Trademark Office)

Figure 10 shows maps in which the average values of utility model applications across 81 provinces during two periods have been divided into three categories using the natural break method. Istanbul was the only province to be in the high category in both periods. Ankara, Bursa, Izmir, and Konya were in the medium category. The other provinces remained in the low category.

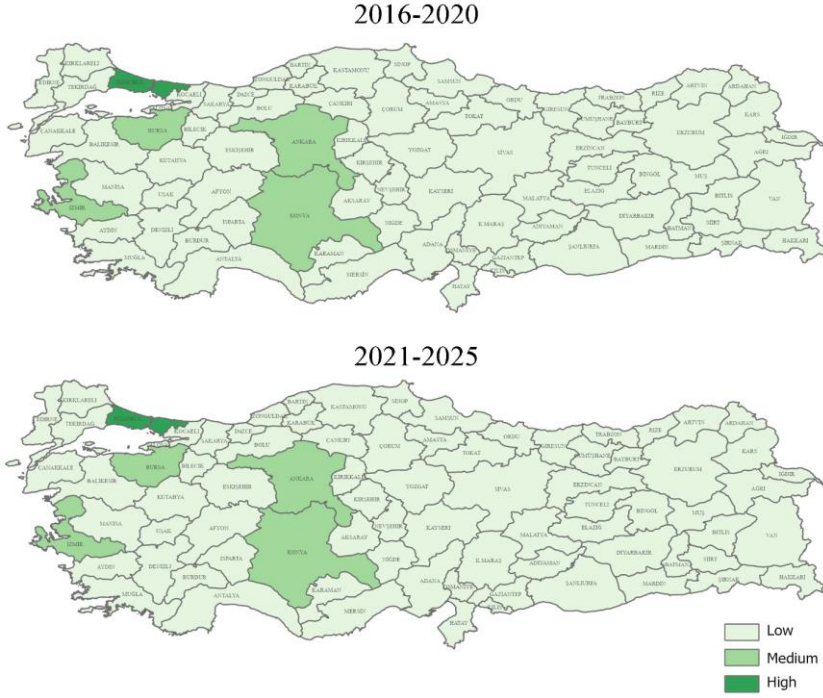


Figure 10. Utility Models across Türkiye

Figure 11 shows the number of projects proposed by universities, public institutions, and the private sector that were approved for funding The Scientific and Technological Research Council of Türkiye. During the 2016-2020 and 2021-2025 periods, the provinces of Kayseri and Konya received support for more projects than the average number of projects per province in Türkiye. In the indicator showing the number of projects, the number of projects in the four provinces analyzed showed a significant increase. There has been a significant increase in project funding across Türkiye, with a rate of 84.7%. The rate of change in Gaziantep and Konya is higher than the overall average. While this rate stands at 42.2% for Denizli, it is 63.3% for Kayseri.

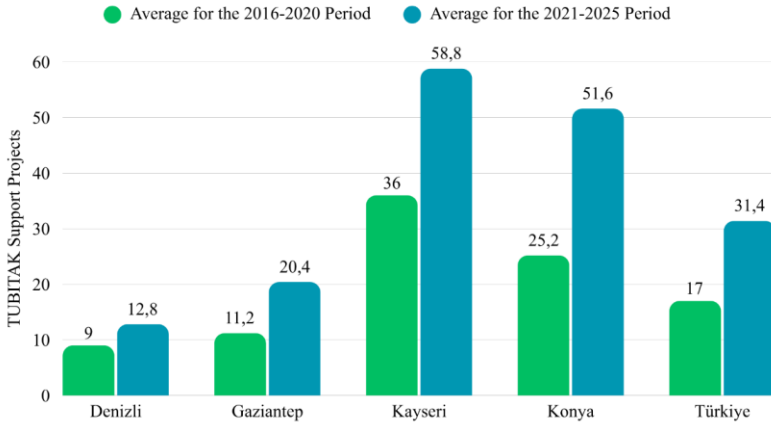


Figure 11. Number of TÜBİTAK Support Projects (TÜBİTAK)

Figure 12 shows the spatial distribution of the averages for projects funded by TÜBİTAK. In both periods, Istanbul and Ankara were the two provinces ranked in the highest category.

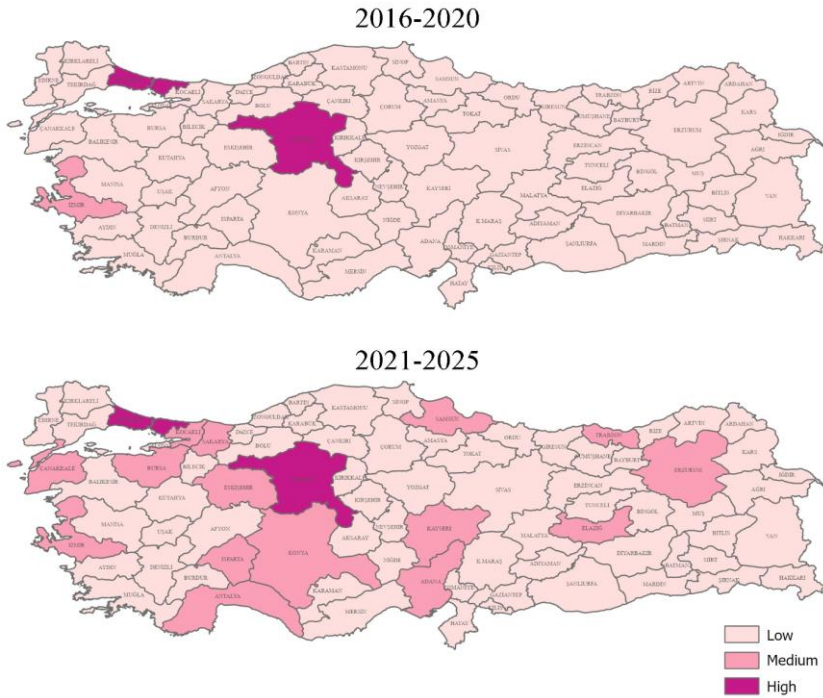


Figure 12. Number of TÜBİTAK Support Projects across Türkiye

While only Izmir was in the medium category during the 2016-2020 period, the number of provinces in this category increased during the 2021-2025 period. Kayseri and Konya are also among these provinces.

Human Capital

Human capital plays a significant role in ensuring regional development and competitiveness. Various variables are used as indicators of human capital. In this study, data available at the provincial level served as the primary basis for this analysis, and the study examined the ratio of postgraduate degree holders per capita in relation to the education level of industrial centers.

The values of the relevant ratios by period are shown in Figure 13. While the change in the national average was 51.4%, among the provinces included in the analysis, Denizli saw a change of 59.3%; Gaziantep, 75.7%; Kayseri, 56.1%; and Konya, 57.3%. In neither of the two analysis periods, there was a province with a higher graduate school completion rate than the national average.

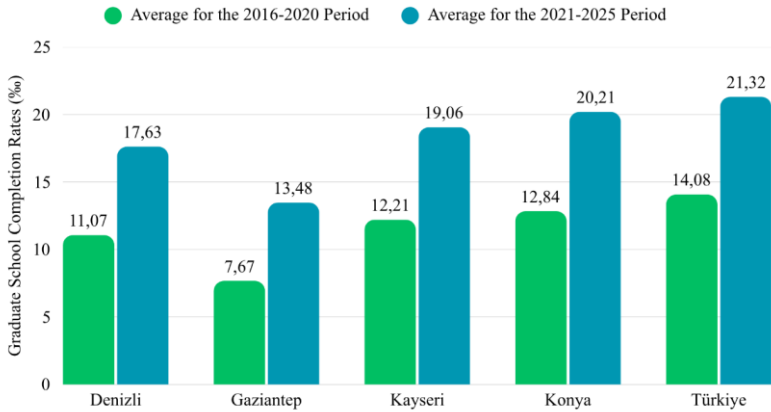


Figure 13. Graduate School Completion Rates (TURKSTAT)

Figure 14 shows the spatial distribution of the graduate degree completion rate nationwide for the 2016-2020 and 2021-2025 periods. As can be seen from these maps, none of the four provinces under analysis fell into the high category. It can be seen that the country as a whole falls into the medium category, and that Denizli, Kayseri, and Konya are also at the medium level. Of the provinces covered by the study, only Gaziantep remained in the low category in both periods.

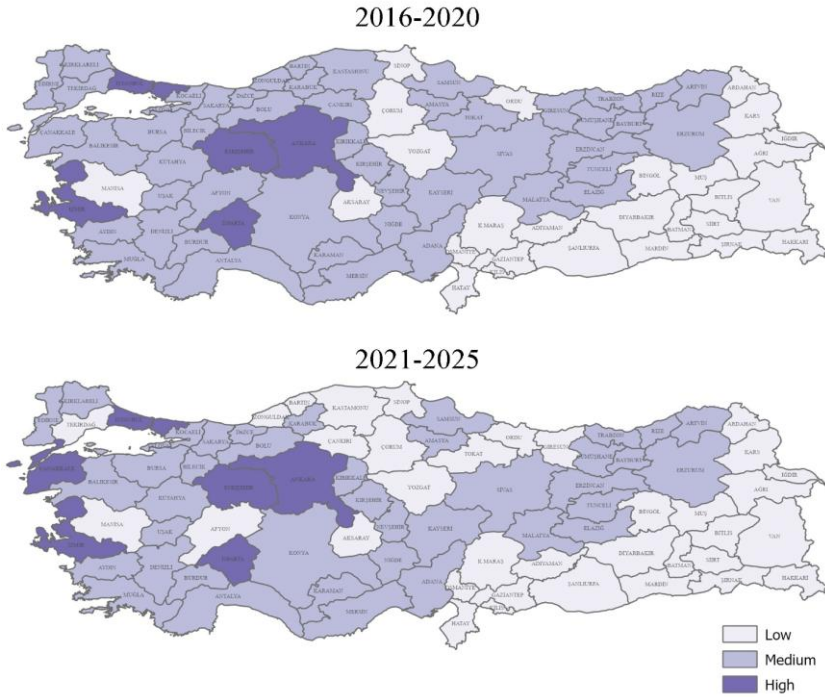


Figure 14. Graduate School Completion Rates across Türkiye

Based on all these distributions, a comparison was made between four provinces and Türkiye as a whole. An attempt was made to analyze the changes that have taken place over the past decade.

CONCLUSION

Significant progress has been made in theorizing the competitiveness of subnational regions and diversifying empirical contributions (Huggins et al., 2013). Empirical evidence shows that some cities and regions perform better than others in terms of growth indicators such as standard of living, employment, and average well-being. It has long been considering the reasons behind these spatial disparities and uneven development. Although this search is not considered under the framework of competitiveness, it is part of the academic field (Martin, 2006). Recently, answers to these questions have also been sought in the context of the discourse on competitiveness.

This study presents a quantitative analysis of the four regions referred to as new industrial centers. The average values obtained by the provinces for the performance metrics evaluated under three headings, as well as the national averages, were examined. In these regions, referred to as industrial centers, the average values for the share of industry in GDP, the first variable in production capacity, exceed the national average in both periods. In the three-category analysis of the 81 provinces, Konya ranked at a medium level, while the other four provinces ranked at a high level. None of the provinces recorded per capita

GDP figures above the national average. In terms of export values, Denizli, Gaziantep, and Kayseri were above the national average in both periods, while Konya rose above the average in the most recent period. In the spatial analysis conducted nationwide, only Gaziantep was at a moderate level, while the other three provinces remained at a low level.

In terms of the innovation capacity dimension, Gaziantep, Kayseri, and Konya outperformed the national average in patent related indicators. All four provinces analyzed also exceeded the Turkish average in terms of the period averages for utility model applications. In the spatial analysis that included 81 provinces, only Konya was found to be at a medium level. In terms of the number of projects funded, Kayseri and Konya scored above the national average. There has been a significant increase in the average number of projects supported between the first and last periods. While four provinces nationwide were in the low category, Kayseri and Konya have moved up to the medium level in the most recent period.

When examining the results regarding the level of human capital, the final dimension, defined solely by the percentage of postgraduate degree graduates, none of the four provinces scored above the overall average. At the same time, in the three-category spatial analyses conducted across all 81 provinces across the country, Denizli, Kayseri, and Konya were classified in the medium category. Gaziantep was the only province among the four to be classified in the low category.

The competitive advantages of regions change and evolve over time. At the same time, the preferences and opportunities of regions are always conditioned, to some extent, by past institutional, technological, structural, and social Dynamics (Martin, 2006). In this context, while the methodology employed in this study is not intended to guide competitive policies on its own, it does aim to highlight the performance of industrial clusters in recent years and to show where they stand in the evolutionary process.

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