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Article

Digitalization and interdisciplinary design process in 21st century architecture offices: Transforming practices and future perspectives

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ABSTRACT

This study analyzes the impact of digitalization and interdisciplinary design approaches on production processes in architectural offices in the 21st century, exploring the implications of this transformation on institutional structure, actor representation and collaboration models, particularly in relation to theory and practice. Architectural offices are considered dynamic spaces where digital technologies, beyond being mere technical tools are also positioned as structural components that transform production culture, while interdisciplinarity is inherently organized within operational practices. The research is based on the content analysis of 45 articles published between 2005 and 2025 and on the comparative evaluation of BIG, MVRDV and Herzog & de Meuron from Europe and Tabanlıoğlu, GAD, and Erginoğlu & Çalışlar from Türkiye. In the content analysis, themes were systematically coded through frequency and co-occurrence relationships, resulting in a conceptual structure concentrated around participatory design, interdisciplinary teamwork and the ecology framework. This structure made visible how production tools such as BIM integration, digital twins, AI-based workflows and parametric modeling are positioned across both computational and organizational dimensions. The findings reveal that in European offices, digital tools are integrated into institutionalized computational cycles from the early stages of design, whereas in the Türkiye examples, these tools diversify more flexibly in relation to local context, multi- actor negotiation and project-based strategies. The study demonstrates that the digitalizing production culture reshapes design processes from linear sequences into data-driven, multilayered and iterative structures. This framework suggests that, for the future of architectural practice, data-driven participation models and the integration of computational–interdisciplinary processes into the early stages of design are becoming increasingly central design approaches.

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INTRODUCTION

The phenomenon of interdisciplinarity has increasingly taken center stage in the scientific and professional production models of the 21st century. This phenomenon is addressed at both theoretical and practical levels in a wide variety of fields, such as architecture, engineering, education, health sciences, environmental design, and technology, and paves the way for innovative production forms that emerge from the coming together of different specialties (Tebes & Thai, 2018; Badawi & Abdullah, 2021). Interdisciplinarity has the capacity not only to bring together different fields of knowledge, but also to simultaneously transform their methodological approaches, conceptual languages, and problem-solving strategies. This interaction, shaped by the internal dynamics of each discipline, enables the production of more holistic solutions for common goals (Pinter-Wollman et al., 2018).

Interdisciplinarity in architecture plays a critical role in areas where global crises, complex urban issues, the sustainable transformation of the built environment, and the integration of digital production technologies are discussed. Architecture offices are required to work in interaction with topics such as social behavior, materials science, energy efficiency, biotechnology, and social participation, not just physical space design; this transforms the design process into a multidimensional and multi-actor structure (McAlister et al. 2025). Applications in the field of education, in particular, ensure early exposure to interdisciplinarity through collaborative studio and workshop models involving students and educators from different disciplines (Jutraz, Zupančič & Juvančič, 2014). However, how interdisciplinarity works in practice, the level of interaction established, and the effects of this interaction on organizational structures have not yet been sufficiently evaluated in a systematic manner. The literature frequently emphasizes the importance of interdisciplinarity; however, dynamics such as limitations encountered in practice, coordination problems between actors, methodological incompatibilities, and communication gaps are often overlooked (Tebes & Thai, 2018; Pinter-Wollman et al., 2018). At this point, fundamental research questions emerge regarding how interdisciplinary design processes are structured, what role architecture offices play in these processes, and how digitalization has become a transformative element in these processes.

Architectural practice is undergoing a fundamental structural transformation in the 21st century with the integration of digital technologies into production processes and the proliferation of multi-actor design organizations. Architectural offices, in particular, are transforming into complex systems that redefine not only technical production strategies but also decision-making mechanisms, actor representation, and information flow structures under the influence of computational tools, parametric modeling processes, and network-based production forms. This transformation brings to the fore new production paradigms in which design is intertwined with interdisciplinary modes of operation at the organizational level.

This study aims to analytically examine the structural, methodological, and organizational transformation of digitalization processes shaped by 21st-century production paradigms in architecture offices, as well as interdisciplinary design processes. The emphasis on the 21st century here represents not merely a historical periodization but a critical transformation context signifying the restructuring of the architectural production environment around information technologies, computational design tools, and multi-actor-based operations. In the literature, the concept of interdisciplinarity is mostly addressed at the level of theoretical definitions and models. However, the extent to which this concept is inherent in current production practices in architecture offices, the forms on which it is based, and how it integrates with digitalization have not been sufficiently analyzed in a systematic manner. Existing studies focus either on individual professional experiences or on singular project processes; thematic analyses based on content analysis of institutional operations, organizational charts, and representational relationships between actors at the office scale remain limited. In this context, the originality of the study lies, on the one hand, in systematizing conceptual patterns through content analysis along the axes of digitalization and interdisciplinarity and, on the other hand, in establishing a criterion-based evaluation model that allows these patterns to be matched with organizational structures and production processes that can be concretely observed in architecture offices. Ultimately, the research aims to reveal how interdisciplinary practices are shaped in digital production environments, which actor structures and decision-making mechanisms they represent, and how they intersect with current trends on a theoretical level. The study structure created in line with the research objective is presented in Figure 1.

In order to establish a multidimensional relationship between the theoretical depth of the research and its practical application, the study has been designed as a comprehensive structure consisting of five sections. The first section examines the effects of digitalization and interdisciplinary design on 21st-century architectural practice, defining the corresponding changes at the office level; the research problem, objectives, and problematic context are established at a technical level. The second chapter evaluates the historical development of the concept of interdisciplinary design, its epistemological dimensions, and its theoretical frameworks in architectural literature. The third chapter explains the methodological structure of the research; the content analysis-based thematic structuring process and how this process is transformed into a criterion system for case-based analysis

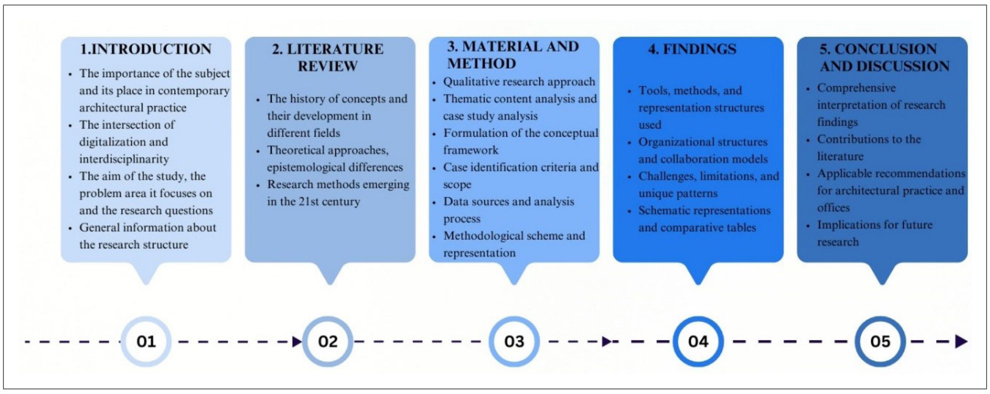

Figure 1. Study structure created within the scope of the research (Designed by the Authors).

are addressed at a technical level. The fourth chapter consists of findings that comparatively analyze the conceptual themes obtained through organizational structures, actor representation, tool usage patterns, and knowledge sharing models in architecture offices. Finally, the fifth chapter provides a holistic interpretation of the findings, presents original contributions to the literature and architectural practice, and suggests possible directions for future research.

LITERATURE REVIEW

Interdisciplinarity provides a theoretical and methodological foundation that is becoming increasingly important in the 21st century's forms of knowledge production and in the architectural environment, alongside structural, technological, and epistemological transformations. The phenomenon of interdisciplinarity has been shaped by epistemological approaches and conditions of knowledge production that have changed over different periods. Kuhn (1962) questioned the epistemological foundations of knowledge production, laying the groundwork for metadisciplinary thinking and explaining the transformation of scientific paradigms. Historically, the concept of multidisciplinarity came to the fore in the mid-20th century, when fields of knowledge were sharply defined, and it referred to different disciplines coming together to solve a specific problem (Piaget, 1973; Vygotsky, 1978; Klein, 1990). These early approaches offered a framework that limited interdisciplinary collaboration rather than a deep integration of knowledge fields. In the 1990s, interdisciplinarity evolved into a more comprehensive understanding that focused on the integration and synthesis of knowledge rather than just the exchange of information. During this period, the interdisciplinary approach was shaped by principles such as integration, contextualization, scale sensitivity, and the re-evaluation of discipline-specific perspectives (Brewer, 1995; Klein, 1996).

The 21st century, in which architectural production processes have been restructured alongside digitalization, represents an era in which interdisciplinarity has evolved beyond being merely a form of collaboration to become the fundamental organizational logic of architectural production practice. With the transition to the information society, interdisciplinarity has evolved into a production paradigm directly shaped by social, environmental, and technological transformations. During this period, Nowotny, Scott, and Gibbons (2001) argued that knowledge was no longer confined to the laboratory but produced within societal contexts, marking the beginning of a new phase in which interdisciplinarity became associated with dynamic, interactive, and transformative knowledge systems. Chettiparamb (2007) interpreted interdisciplinarity not merely as a theoretical orientation but as a phenomenological condition emerging from the inherent interactions between disciplines. The dissolution of disciplinary boundaries enabled not only collaborative working models but also the formation of new domains of meaning and conceptual intersections (Chandler, 2004; Repko, 2008). Within this trajectory, transdisciplinarity emerged as an inclusive model that moves beyond disciplinary categories by integrating local knowledge, cultural experiences, and social practices into the process, foregrounding participatory modes of problem-solving (Nicolescu, 1999; Helmane & Briška, 2017).

The expansion of digital technologies beyond formal production toward redefining the relationships between design, material, and fabrication has transformed the intellectual and technical boundaries of architectural offices. This shift—amplified by the rise of performance-oriented, open-ended, and interactive design approaches—has led to the dissolution of linear design processes and the emergence of integrated workflows in which multiple domains of expertise operate simultaneously (Phocas, 2015). In this period, digitalization has evolved not merely into a tool for formal variation but into the infrastructural backbone of a knowledge-based production system, giving rise to hybrid workflows that integrate engineering analysis, simulation environments, and fabrication processes within design practice. Consequently, the traditional dichotomy between creativity and technical precision has been reconfigured into a production logic continuously informed by performance

Megaron, Vol. 21, No. 1, pp. 101–121, March 2026

parameters. This transformation has become a defining condition for contemporary architectural practice. Digitalization has not merely enabled the coexistence of multiple disciplines; it has facilitated their integration through interactive, data- driven, and continuously evolving information systems. Today, interdisciplinarity in architectural offices is positioned as a production model that synthesizes diverse domains of expertise. In particular, GIS-based analyses, unmanned aerial systems, AI-assisted simulation tools, and scenario-generation techniques deepen the analytical dimension of design processes and are increasingly embedded within the decision-making structures of design offices (Kauffman, 2016; Buchanan, 2019). As a result, the scope of interdisciplinarity has expanded, and its sphere of influence has intensified, strengthened on an epistemological level by principles such as flexibility, continuous learning, and knowledge sharing.

By the 2020s, when digitalization had reached a mature stage, architectural offices had begun to transform into research-driven environments where data analytics, engineering parameters, and digital fabrication were coordinated as integrated processes. Parametric and algorithmic design approaches enabled the dynamic adaptation of systems defined by performance criteria, while digital production dissolved the historical separation between design and construction. During this period, offices evolved into "knowledge hubs" situated at the center of information production, and multi-actor, data-driven design models became widespread through BIM, parametric modelling, and digital fabrication technologies (Knippers et al., 2021). However, the superficial adoption of this transformation has, in some practices, placed the creative process at risk of becoming overly technical. Although digital tools have the potential to deepen collaboration, when they remain confined solely to formal production, they may compress the discipline into a reductionist framework. This situation continues to generate a persistent zone of tension within the organizational structures of architectural offices (Knippers et al., 2021). These technologies enable architectural offices to engage not only with physical design, but also with themes such as energy efficiency, temporary housing, and environmental sustainability. This new interdisciplinary model— integrated with digital production processes—transforms digitalization in architecture from a mere tool into a strategic and holistic component of the design process itself (Borgman, 2015).

In the same period, the concept of the digital twin began to be understood as an integral component of systemic thinking within architectural offices. The integration of digital twins into the management of smart infrastructures placed them not only at the center of performance analyses but also of knowledge sharing among stakeholders (Broo, Bravo-Haro & Schooling, 2022). Digital twin technologies have further transformed the organizational structure of architectural design and production processes. When integrated with cyber-physical systems, digital twin models link CAD environments, software frameworks, simulation tools, and functional models from different disciplines within a unified digital environment, ensuring continuous information exchange (Ashtari Talkhestani et al., 2019). This approach enables the entire project—from initial design to operational phases—to be conceived collaboratively and allows interdisciplinary teams to produce data-driven decisions synchronously. In this respect, the growing role of digital twins signals an organizational-scale transformation within architectural practice. Similarly, artificial intelligence and big-data infrastructures based on bidirectional data flows between physical and digital systems have brought advanced applications such as predictive modelling, performance analytics, and dynamic decision systems into architectural offices (Qian et al., 2022). These technologies shift the design process from static representation to a continuously learning and adaptive system. Thus, digitalization is no longer merely a tool that accelerates production; it now constitutes a cognitive infrastructure that reshapes decision-making processes.

Debates on the organizational dimension of interdisciplinarity have simultaneously revealed the limits of the digital collaboration culture within design offices. Although diverse expertise is brought together in sustainable and nature-based design practices, decision-making and knowledge production often remain centralized. This condition reflects the prevalence of formal, surface-level collaboration models in the literature, termed "tokenistic collaboration" (Butt & Dimitrijević, 2022). A genuine transition toward interdisciplinarity requires not only the adoption of digital tools but also the transformation of the social and organizational relationships surrounding them. In this sense, digitalization is more than a technical process; it is a mechanism that reshapes the epistemological structure of architectural offices.

Interdisciplinary integration has also introduced new challenges in architectural programming, such as data management, information security, and social representation. While the interaction between physical and digital environments enhances information exchange, gaps in standardization and security constraints continue to limit digital transformation. The insufficient representation of social participation on digital platforms leads to the exclusion of user experience and societal engagement from design and production processes (Jin, 2024). This reveals that digital transformation is not solely a technological evolution but also a process requiring a redefinition of social inclusivity. Within this transformation, digitalization has played a decisive role; AI-supported generative design tools, BIM integration, sensor technologies, the Internet of Things, and big data analytics have enabled multi-actor, data-driven, and interactive design practices within architectural offices (Li et al., 2024). In this context, urban data ecosystems established within the socio-technical and urban governance framework shaped by smart cities, along with real-time data flows, are increasingly making interdisciplinary collaboration models visible at the scale of architecture firms. These models can interpret design decisions alongside environmental performance, usage scenarios, and operational data.

This chronological trajectory demonstrates that, for architecture offices, digitalization has become more than a purely technological innovation; it has turned into a structural necessity that compels the transformation of modes of production, the circulation of knowledge, and decision-making mechanisms. The simultaneous management of complex urban systems, sustainable modes of production, and data-driven decision-making processes is no longer achievable through individual expertise alone, but rather through integrated network structures. At the same time, the literature indicates that digital transformation has not been institutionalized in a holistic and in-depth manner across all contexts, and that BIM-based digitalization can advance in a fragmented way, particularly due to process standardization issues and mismatches between macro- and micro-level planes (Awe et al., 2025; Kassem & Ahmed, 2022). Moreover, in multi-stakeholder production environments, knowledge sharing and interdisciplinary coordination can become fragile depending on the management of common data environments, the transfer of knowledge and experience, and the establishment of institutional collaboration mechanisms, while coordination difficulties may constrain the continuity of BIM-supported collaborative processes (Miao et al., 2024; Shim et al., 2024).

In sustainability- and nature-based design agendas as well, interdisciplinarity is emphasized in some cases as remaining at a merely formal level; due to asymmetries in decision-sharing and levels of representation, the risk of tokenistic collaboration persists (Butt & Dimitrijević, 2022). For digitalization to become a lasting paradigm in architecture offices, these shortcomings must be overcome and technological infrastructures must be integrated with ethical, social, and organizational principles. To the extent that architectural practice achieves this integration, it will transform digitalization from a mere instrument of production into a carrier of interdisciplinary creativity.

MATERIAL AND METHOD

Research Design and Methodological Approach

In the study, a two-stage qualitative research design was constructed. The methodological framework of the first stage is based on the systematic structuring of the content analysis process. In this context, a bibliometric literature review was conducted around the themes of the role of interdisciplinarity in the architectural domain, digital production technologies, and the organizational structure of architectural offices. To identify the gap in the literature, international peer-reviewed articles published between 2005 and 2025 were compiled using the keywords *"architectural practice," "digitalization," "interdisciplinary design," "collaborative design models,"* and *"digital fabrication in architecture."* After the dataset was established, an inductive thematic analysis approach was adopted; the studies were decomposed into multilayered conceptual networks, and common themes were systematically coded. In the second stage, based on the themes derived from the analysis, the main criteria reflecting the relationship between interdisciplinarity and digitalization in production processes, as well as their corresponding sub-parameters, were identified. The research strategy integrates systematic literature review, thematic coding, and frequency analysis into a comprehensive structure, enabling the conceptual synthesis of the findings and the exploration of contemporary trends. The methodological workflow of the study is visually summarized in Figure 2.

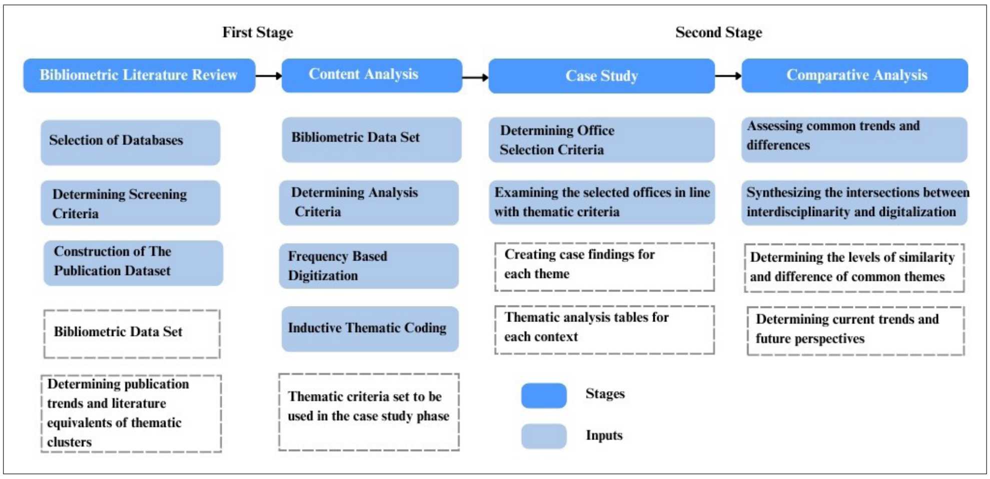

Figure 2. Methodological workflow structured in line with the aim of the study (Designed by the Authors).

The second stage consists of the comparative analysis of selected architectural offices from Europe and Türkiye. Within the framework of the thematic findings obtained from the content analysis, architectural offices characterized by digital production and interdisciplinary organizational structures were evaluated as part of the case study. The selected offices are those that have both national and international work and have adopted interdisciplinary and digitally based production models. After identifying the sample offices, the criteria derived from the content analysis were examined within the context of each office; the selected cases were first compared internally and subsequently synthesized to form a comparative evaluation between Europe and Türkiye. The findings emerging from the analysis provide a unique context for assessing how the organizational structures and production processes of architectural offices demonstrate a tendency toward restructuring in order to identify contemporary trends and adapt to them.

Creating a Data Set Based on Architecture, Interdisciplinarity and Digitalization

The research is conducted through a two-stage process. In the first stage, a systematic search was conducted in the Scopus, Web of Science, and ScienceDirect databases using the keywords *"architectural practice," "digitalization," "interdisciplinary design," "architecture and technology," "collaborative design models,"* and *"digital fabrication in architecture."* The search process was limited to the years 2005–2025. A total of 186 articles were screened in the preliminary review, and only those studies that demonstrated a direct or indirect conceptual relationship with production processes and addressed digitalization and interdisciplinary design approaches in a comprehensive manner were selected. In the second stage, a case study and comparative analysis were structured based on the results obtained from the content analysis. The architectural offices included in the study within the European and Türkiye contexts were examined through the thematic criteria, and their technical and organizational approaches to interdisciplinarity and digitalization were incorporated into the analysis, enabling a cross-contextual comparison.

As a result of the evaluations conducted in the first stage, 45 articles were selected as the sample to be included in the content analysis. In the selection process, the primary criterion was that the studies discuss the themes of digitalization and interdisciplinarity not only at a technical level but also through the conceptual representations of production processes, methodological approaches, and organizational models. In addition, the fact that the articles were published in reputable indexed journals (SCI, SSCI, AHCI, ESCI) and appeared in peer-reviewed outlets with high scientific credibility constituted a second determining factor that enhanced the quality of the dataset. Furthermore, the extent to which the reviewed studies could be directly associated with the contemporary design practices of architectural offices—particularly the use of digital production technologies, the implementation of interdisciplinary collaboration models, and the management of design–construction integration—was another essential criterion considered during the selection. The 45 studies situated at the intersection of these three criteria formed the most appropriate sample set representing the interaction between digitalization and interdisciplinarity within architectural production processes.

During the construction of the dataset, the search was conducted at a macro scale through the lens of interdisciplinarity and the themes directly or indirectly associated with this concept, thereby aiming to approach architectural production processes from a holistic perspective. The selection of the last 20 years was a deliberate choice to capture rapidly evolving contemporary trends in digitalization and interdisciplinarity and to identify the dynamics of conceptual transformation in the field. This approach enabled the research to relate its theoretical depth to current professional practices.

The general characteristics of the dataset—including the databases consulted, the publication range, and the common themes highlighted in the content analysis—are summarized in Table 1. Throughout the thematic analysis process, interdisciplinarity and digital production technologies emerged as a shared focal point in the majority of studies, while variations were observed in the emphasis placed on themes such as the transformation of organizational structures, collaborative design models, and participatory production cultures.

During the content analysis dataset creation process, common themes and thematic differences identified across articles are presented in Table 2. Thematic similarities and differences identified during this process were structured through contextual analyses of how each article addressed the concepts of interdisciplinarity and digitalization at the level of production processes. Common themes were defined as clusters that recurred at a high frequency across studies and represented conceptual intersections, while divergent themes were systematically classified by considering their contextual variations based on context, scale, technology use, and organizational models.

The data obtained from the content analysis were subjected to a multilayered thematic coding process to understand how themes of interdisciplinarity and digitalization are patterned in architectural production processes. The next section presents in detail the common conceptual clusters derived from the dataset and their analysis methods.

Thematic Coding: Identification of Prominent Common Themes

During the content analysis process, the resulting dataset was analyzed using a multilayered coding method, taking

Table 1. General characteristics of the constructed dataset

Criterias	Features
Scanned Databases (INDEXES)	Publications indexed in Scopus, Web of Science, ScienceDirect databases, AHCI, SCI, SSCI, ESCI
Keywords Used	"Architectural practice", "digitalization", "interdisciplinary design", "architecture and technology", "collaborative design models", "digital fabrication in architecture"
Publication Year Range	2005–2025 (to monitor current conceptual and technological trends)
Total Number of Publications Scanned	186 publications were subjected to systematic preliminary review.
Number of Publications Analyzed in Depth	45 articles that met the selection criteria were included in the content analysis.
Selection Criteria	The studies should address the themes of digitalization and interdisciplinarity in a reciprocal manner, with theoretical and methodological integrity; the studies should be included in Scopus, Web of Science, and ScienceDirect databases; the content should be directly relatable to the use of digital tools in the current production practices of architectural offices, interdisciplinary interaction, design-practice integration, and organizational collaboration models.
Content Analysis Method	Inductive thematic analysis, multilayer coding, frequency-based digitization
Thematic Similarities	The concepts of interdisciplinarity, digital production technologies, knowledge sharing and cooperation between actors have formed a common ground in most studies.
Thematic Differences	Organizational structure transformations, participatory production culture, digital tool use, and scale-based practical differences varied across contexts.

intoaccount thematic focuses and conceptual intersections. Within this scope, the reviewed articles were first classified according to their core conceptual areas, focusing on how digitalization and interdisciplinarity are represented in architectural offices. In the first stage, studies that addressed the theme of interdisciplinarity solely at a theoretical level were categorized. In the second stage, publications that intersected the concepts of architecture and interdisciplinarity but did not emphasize digital production technologies were identified. In the third stage, studies that explored the relationship between interdisciplinarity and digital technologies and referenced design practices in architectural offices were coded. In the fourth stage, publications that simultaneously addressed the themes of architecture, dig-

Table 2. Thematic similarities and differences regarding the data set

Common Themes	Diverging Themes
Integration of interdisciplinarity dynamics into production processes	Differences in organizational structures' adaptation levels to digitalization
ntegration of digital production technologies (BIM, digital twin, parametric design) into processes	Differences in the intensity of use of digital technologies and in-process integration
The impact of information sharing and collaboration between actors on production culture	Positioning collaborative models as central or supportive
Participatory production culture and multi-actor design processes	The reflection of user participation and actor representation directly or indirectly on production processes
Prevalence of parametric design and computational manufacturing techniques	Computational techniques vary depending on project scale and context
Use of digital twins and data-based production models	Differentiation of digital twin applications into infrastructure-scale and building-scale focuses
Supporting innovation culture with digitalization	Adoption of innovation processes at different levels in organizational structures
Digitalization integration between education and practice	Whether or not practical production processes are directly contributed to in education-based studies
Relating sustainability themes to digitalization and interdisciplinarity	In some studies, the sustainability approach is addressed only at the conceptual level, while in some studies it is integrated into operational processes

italization, and interdisciplinarity, presenting a holistic approach to production practices, were identified.

In addition, articles that focused solely on interdisciplinarity but did not directly engage with digital transformation, or only superficially referenced interdisciplinarity within the context of digitalization, were also classified according to their thematic density. This multilayered classification process enabled the analytical evaluation of thematic patterns in terms of their impact on production processes in architectural offices. Each article was positioned based on its conceptual intersection and coded based on this position. The resulting thematic clusters formed the basis for frequency analyses and conceptual modeling conducted in the next stage, enabling the systematic generation of inferences regarding the interdisciplinary digitalization strategies of architectural offices. Based on this, a systematic structure was constructed to identify which conceptual areas were more intensively addressed and which thematic areas were less frequently represented in the dataset (Table 3).

Based on the detailed content analysis of the 45 articles included in the study, the sub-themes situated along the axis of digitalization and interdisciplinarity were systematically coded, and a co-occurrence matrix was constructed to make the interrelationships between themes visible. During the coding process, the patterns of simultaneous appearance among these themes were quantified through the matrix. The results indicate that digital production technologies—such as digital integration, BIM integration, digital twin applications, and parametric design— strongly intersect with system architecture and studio integration, while organizational and actor-oriented elements such as interdisciplinary teamwork, team science, and user-centered approaches also produce notable overlaps. These findings reveal that certain themes form a defining core within production processes, whereas others constitute a coherent background that supports this core. The numerical coding matrix showing the co-occurrence patterns of the sub-themes clustered under the main themes is presented in Table 4.

To enable a more objective and comparable analysis of the conceptual clusters derived from the thematic coding process, a frequency-based quantification method was employed in this study. The identified sub-themes were expressed through numerical values according to their intensity of representation within each article, allowing the distribution and co-occurrence frequencies of these themes across the dataset to be captured in a measurable structure. This approach provided an objective basis for comparing the common themes related to digitalization and interdisciplinarity in architectural offices and established a foundation for the subsequent stages of analysis.

Frequency-Based Digitization Method

The frequency-based analysis process was structured in two stages. In the first stage, each main theme and subtheme were converted to numerical values based on the number of times they were directly or indirectly represented in the reviewed articles. In this context, the density of representation of specific conceptual codes in the literature was measured and a thematic distribution map was created. The graph, created based on the findings of this stage, visualizes the unique frequency of each thematic code, revealing the most dominant conceptual clusters within the study. Figure 3 has

Table 3. Grouping of main themes and sub-themes according to general trends

Main Themes	Sub-Themes	Explanation
Interdisciplinarity Digitalization	Digital_Twin, System_Architecture, Metaverse_Environment	Digital production technologies and data-based structures were approached from a theoretical perspective; the framework of interdisciplinarity was discussed through digital twins and system models.
Architecture-Interdisciplinarity	Cross_Discipline_Practice, Studio_Integration, Education_Model, Sustainability_In_Education	Focus was placed on interdisciplinary collaborations within architecture; methodological solutions were developed through design processes, representation, education and participation models.
Architecture Digitalization	Parametric_Design, Participatory Design, Digital_Integration, Generative_Design, Climate_Awareness	The integration of digital fabrication technologies into architectural processes is analyzed, including parametric design, BIM, algorithmic modeling, and administrative digitalization. Sustainability in education, climate-focused planning, and interdisciplinary ecological approaches are discussed alongside digital and pedagogical models.
Case Studies Addressing Three Themes Holistically	Bim_Integration, Interdisc_Teamwork, AI_Based_Workflow, Green Design	It includes studies based on production environments and case studies, where the themes of architecture, digital production and interdisciplinarity are addressed simultaneously.
Interdisciplinarity (Theoretical Approach)	Systems_Thinking, Interdisc_Teamscience, Ecology_Framework, User_Centered_Approach	The theoretical dimensions of interdisciplinarity were discussed through systems theory, collaboration models, ecological integrity and social science perspectives.

Table 4. Co-occurance matrix based on the intersection status of sub-themes

BIM-INT
(Bim_Integration) | ID-TWK
(Interdisc_Teamwork) | AI-WFL
(AI_Based_Workflow) | DIG TWN
(Digital_Twin) | PAR-DSN
(Parametric_Design) | MTV-ENV
(Metaverse_Environment) | DIG-INT
(Digital_Integration) | SYS-THK
(Systems_Thinking) | STN-EDU
(Sustainability_In_Education) | STD-INT
(Studio_Integration)
CRD-PRC
(Cross_Discipline_Practice) | GRN-DSN
(Green_Design) | CLM-AWR
(Climate_Awareness) | EDU-MDL
(Education_Model) | ECO-FRM
(Ecology_Framework) | SYS-ARC
(System_Architecture) | PTR-DSN
(Participatory_Design) | GEN-DSN
(Generative_Design) | ID-TSC
(Interdisc_Teamscience) | UCA-APP
(User_Centered_Approach)

Sub-Themes	BIM-INT	ID-TWK	AI-WFL	DIG-TWN	PAR-DSN	MTV-ENV	DIG-INT	SYS-THK	STN-EDU	STD-INT	CRD-PRC	GRN-DSN	CLM-AWR	EDU-MDL	ECO-FRM	SYS-ARC	PRT-DSN	GEN-DSN	ID-TSC	UCA-APP
BIM-INT	0	9	5	15	10	5	8	5	7	15	8	11	9	9	5	14	6	3	12	7
ID-TWK	9	0	8	7	8	6	5	8	7	12	7	9	9	7	5	3	12	2	13	8
AI-WFL	5	8	0	6	5	7	6	5	5	7	9	9	8	7	3	9	6	4	6	3
DIG-TWN	11	7	6	0	6	4	11	9	10	6	10	10	8	6	8	3	3	2	3	5
PAR-DSN	10	8	5	6	0	9	8	5	6	11	5	10	8	6	3	2	1	6	0	1
MTV-ENV	5	6	7	4	9	0	6	5	5	9	6	9	4	3	2	1	1	1	1	0
DIG-INT	8	5	6	11	8	6	0	8	9	8	9	7	7	4	6	15	8	7	10	3
SYS-THK	5	8	5	9	5	5	8	0	2	1	15	4	4	4	9	11	4	2	10	5
STN-EDU	7	7	5	10	6	5	9	2	0	6	4	4	6	5	6	4	2	1	3	1
STD-INT	11	12	7	6	11	9	8	1	6	0	5	2	3	5	9	12	10	6	9	12
CRD-PRC	8	7	9	10	5	6	9	15	4	5	0	8	6	7	3	6	9	2	2	3
GRN-DSN	11	9	9	10	10	9	7	4	4	2	8	0	3	2	2	4	3	1	2	1
CLM-AWR	9	9	8	8	8	4	7	4	6	3	6	3	0	1	2	1	1	4	2	1
EDU-MDL	9	7	7	6	6	3	4	4	5	5	7	2	1	0	1	5	10	0	2	4
ECO-FRM	5	5	3	8	3	2	6	9	6	9	3	2	2	1	0	4	4	0	4	3
SYS-ARC	14	4	9	3	2	1	15	11	4	12	6	4	1	5	4	0	2	2	3	2
PRT-DSN	6	12	6	3	1	1	8	4	2	10	9	3	1	10	4	2	0	2	7	9
GEN-DSN	3	2	4	2	6	1	7	2	1	6	2	1	4	0	0	2	2	0	2	1
ID-TSC	12	13	6	3	0	1	10	10	3	9	2	2	2	2	4	3	7	2	0	2
UCA-APP	7	8	3	5	1	0	3	5	1	12	3	1	1	4	3	2	9	1	2	0

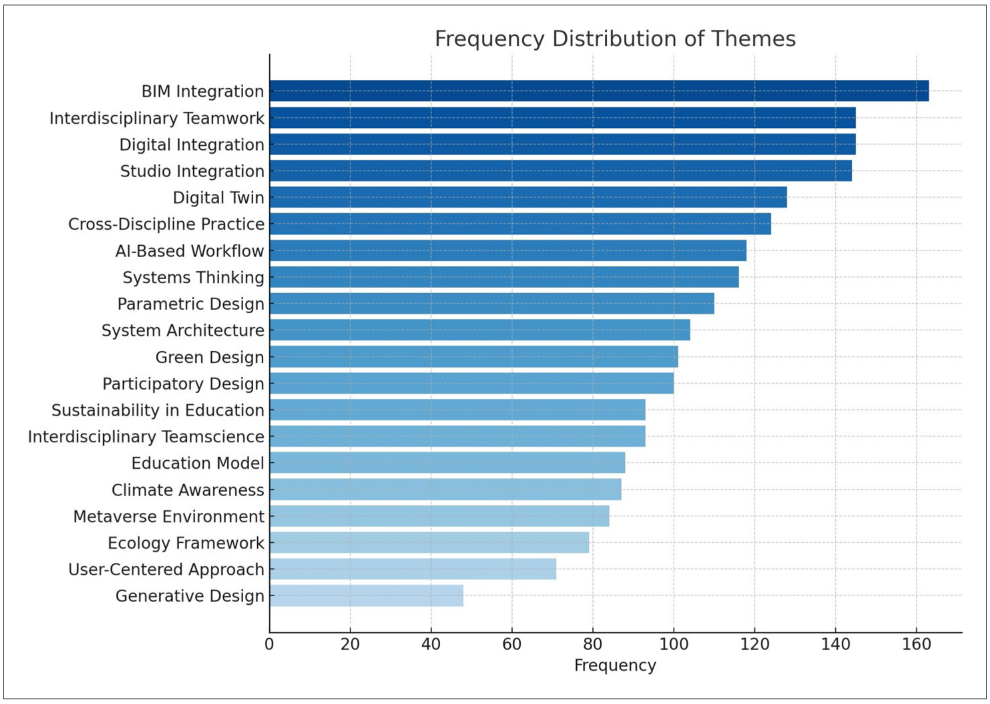

Figure 3. Individual frequency distribution of thematic codes (Designed by the Authors).

been reorganized to show the individual frequencies of the total 20 thematic codes defined in the content analysis.

The frequency distribution presented in the graph shows that the prominent themes in the context of digitalization and interdisciplinarity in architectural offices are particularly concentrated on the axes of BIM integration, interdisciplinary teamwork and digital integration. Furthermore, the high representation of themes such as studio integration, digital twins, cross-disciplinary practices, and AI-based workflows indicates that data- driven decision-making and parametric/computational design approaches are increasingly being systematically integrated into institutional design processes. These findings, obtained through the frequency of representation of these themes, allow for the holistic structuring of the content framework for the evaluation criteria to be used in the subsequent case studies.

FINDINGS

Synthesis of Content Analysis Findings

The thematic pattern presented in Figure 4 visualizes the integrated structure of the content analysis and reveals both the representational intensity of the themes in the literature and the structural relationships they establish with one another. The visual illustrates that the studies cluster within a multilayered interaction across the axes of digitalization, interdisciplinarity, and design, demonstrating that these conceptual domains have converged into a shared framework within the contemporary production practices of architectural offices. Two primary data sources were used in constructing this pattern. First, the single-frequency analysis identified the level at which each theme is represented in the literature, thereby producing an objective distribution of the intensity of approaches within the dataset. In the second stage, the co-occurrence matrix uncovered the relationships between the themes and revealed which concepts are positioned together and which diverge. Thus, the themes were validated not only through their visibility levels but also through their relational structures, resulting in the multilayered context that forms the basis of the thematic map presented in Figure 4.

Through this integrated analysis, Participatory Design, Interdisciplinary Teamwork, and the Ecology Framework were structured as three core themes that provide an analytical backbone due to both their differing levels of representation and their relational positioning. This triad brings together the high-, medium-, and low-visibility levels of the literature within a single framework, integrates the relational tendencies that explain thematic clustering, and grounds the theoretical model developed for architectural offices in a multidimensional conceptual depth (Figure 4).

The themes within the thematic pattern, beyond their definitions in the literature, were examined through case studies to determine the extent to which they are reflected in architectural design practice and the methods employed. The tools and responses these themes provide in architectural offices, and ultimately their impact on current interdisciplinary digitalization trends, are crucial for defining and evaluating the transition between theory and practice in the literature.

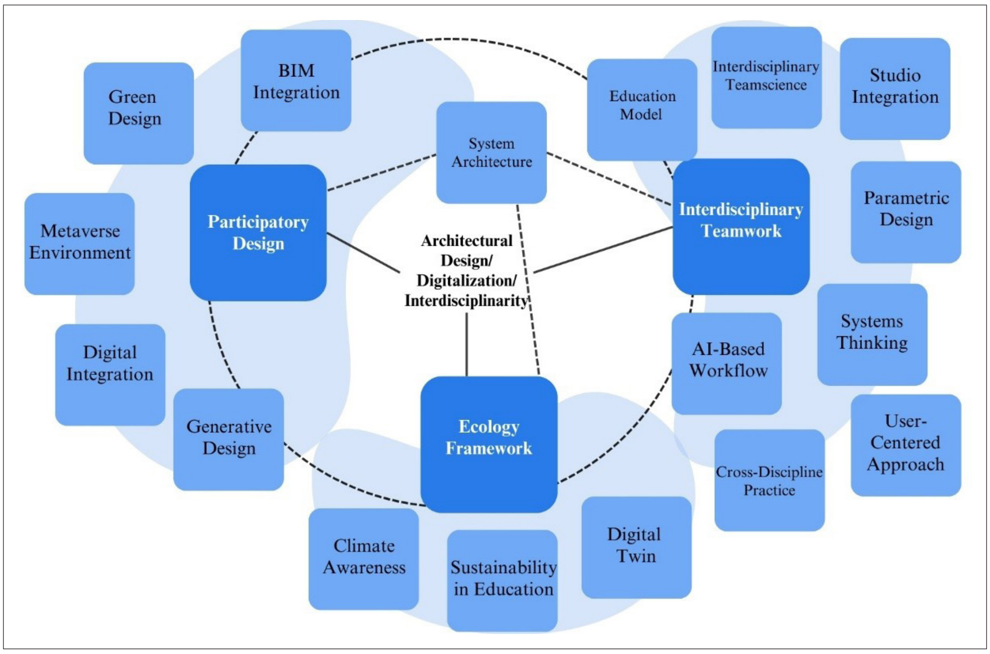

Figure 4. Thematic pattern of results based on content analysis (Designed by the Authors).

In the case selection process, the determining criteria were the architectural offices' ability to produce diverse design outputs at both national and international scales, their adoption of a digital production culture, and their implementation of interdisciplinary approaches within their organizational structures. The selected cases were analyzed on the basis of a Europe–Türkiye comparison, with Europe regarded as a pioneering geography where architectural and design practices are addressed holistically within a sustainable and interdisciplinary framework, supported by strategic programs such as Horizon Europe and the United Nations Sustainable Development Goals. Within the scope of the study, BIG, MVRDV, and Herzog & de Meuron from Europe, and Tabanlıoğlu Architects, GAD Architecture, and Erginoğlu & Çalışlar Architects from Türkiye were selected for the sample due to their effective use of digital design tools, their interdisciplinary collaborations, and their integration of sustainable design approaches into their projects. These offices stand out with their projects implemented across different geographies and their institutional identities that integrate local and global design approaches.

Architecture Offices in Europe and Interdisciplinary Design Approaches

The Europe-based offices examined in this study—BIG (Bjarke Ingels Group), MVRDV, and Herzog & de Meuron—are institutional structures that stand out internationally for their effective use of digital production technologies and their interdisciplinary design approaches.

The literature on BIG describes the offices "engineered without engines" approach as an ecological and interdisciplinary production model that transforms climatic data into a fundamental driver of form (Ingels, 2013). In projects such as the Shenzhen International Energy Mansion and West 57, environmental data becomes an operative core directly shaping mass morphology; this requires the early integration of performance design with engineering, material, and environmental simulation teams (Ingels, 2013). The Superkilen project reveals hybrid participatory practices in which representation and identity are foregrounded, yet decision-making authority remains concentrated among professional actors (Iborra Pallarés & Capdevila Castellanos, 2016). Productions such as Yes Is More and Hot to Cold strengthen the offices interdisciplinary organization by integrating digital representation, graphics, media, and user movement into the design process (Balık, 2017). As seen in 8 House, The Mountain, and Urban Rigger, programming becomes a dynamic tool simultaneously processing context, user behavior, and ecological requirements (Redyantanu, 2025). The office's open-studio structure, model–digital model cycles, and climate-scenario simulations form a horizontal production ecosystem in which all processes operate concurrently. In The Twist, Rhino–Grasshopper–based rule sets enable simultaneous optimization of structure and geometry, establishing a high-precision coordination between digital production and engineering (Margnelli & Tibuzzi, 2024).

MVRDV's production model is built upon synchronized data flows between MVRDV NEXT, The Why Factory, and the Modelmaking Lab. Density maps, microclimate simulations, and carbon calculations are integrated into parametric platforms at the early design stage; the co-design clusters bring together engineering, landscape, data analytics, and municipal technical teams within a shared decision-making environment. Digital tools are matched with user profiles and program scenarios, shifting participation to the early phases of design. The ecological framework is shaped through LIDAR-based topography, heat island models, solar–wind simulations, and LCA calculations (Tempestini, 2025). The Why Factory's "datascape" approach—seen in projects such as Pig City, Skycar City, Vertical Village, and What-If Nederland 2100—makes data-intensive design processes and multi- actor interactions visible (Yücel & Bekdaş, 2025). Tools such as RoofScape and VillageMaker provide interactive platforms where users can experience typology variations in a digital environment. The "nature-based stacking" approach reorganizes pixelated masses, topography, and natural layers through an ecology-oriented logic centered on diversity (Van Rooyen, 2022).

Herzog & de Meuron's methodology is built upon a hybrid structure that integrates the offices analog model culture with DTG's parametric modeling, scripting, and BIM-based geometric management. In projects such as Stamford Bridge and Tate Modern TM2, parametrically controlled systems—where each brick becomes a data point—strengthen the digital–physical prototyping cycle. The design process operates through a multi-actor negotiation model that foregrounds phenomenological parameters such as material behavior, atmosphere, light refraction, and tactility in the early stages. Dominus Winery and the Ricola Warehouse exemplify ecological and interdisciplinary production models in which material, climate, and construction techniques are interpreted simultaneously. The office's model room functions as a multi-scalar experimental environment where digital simulations are cross-validated with physical samples. In the Elbphilharmonie, topological acoustic panels are produced iteratively through digital analysis, CNC prototyping, and resonance testing. As Quesada-García notes, biomorphic material scans—fiber orientations and crystalline structures—are directly transferred into structural and surface geometries, illustrating a deeply interdisciplinary production culture.

The dynamics of the offices' technical and organizational processes were structured in relation to the themes identified through the analyses (Table 5).

BIG, integrates parametric simulations, VR-based user feedback, and performance data into a single design core, transforming the form-climate-user relationship into a dynamic system. MVRDV integrates extensive datasets, from LIDAR scans to density models, into its scenario engines through its "datascape" and "diagrammatic practice" approaches, transforming the design process into a plural production environment where urban, ecological, and programmatic layers can be simultaneously interpreted. Meanwhile, Herzog & de Meuron, with its hybrid digital- analog prototyping cycle led by the Digital Technology Group, activates micro-scale performance parameters such as material behavior, surface haptic, light refraction, and acoustic resonance in the early stages of design. When these three approaches are considered together, offices are being redefined through user experience, ecological data analytics, and multi-actor technical negotiation mechanisms.

Architectural Offices and Interdisciplinary Design Approaches in Türkiye

Within the scope of the study, the Türkiye-based offices Tabanlıoğlu Architects, GAD Architecture, and Erginoğlu & Çalışlar Architects were evaluated based on their engagement with digitalization and interdisciplinarity across different scales and design contexts, both nationally and internationally.

Tabanlıoğlu Architects operates with an integrated decision-making model in which participatory design, interdisciplinary digital integration, and ecological considerations function as a unified framework. In Teknopark Istanbul, user, investor, and management data were transformed into active design inputs through joint workshops, scenario modeling, and flow diagrams; spaces were reconceptualized as interfaces mediating the production cultures of different actors (Aydın, 2023). In the Atatürk Cultural Center (AKM), acoustic, structural, and stage technology teams worked as co-equal actors within a shared BIM-based model; the acoustic shell, balcony configuration, and volumetric decisions were defined through iterative comparisons of multilayered simulations (İlkhan Söylemez, 2022). The conversion of laser-scan and photogrammetry data into a digital twin, combined with CNC prototyping and full-scale material tests, enabled acoustic and lighting behavior to be directly integrated into material decisions (Özel, 2011).

In GAD Architects, parametric modeling, performance simulations, and user data constitute a simultaneously operating iterative computational ecosystem (Ertuğrul & Altın, 2022). GAD Lab transforms architectural practice into computational knowledge production by integrating software development, simulation, and advanced geometries; some projects are produced entirely through software-based workflows (Özcan, 2011). In Andalus Villa and GADtown, cellular automata and environmental inputs shape form through evolutionary processes, while Bulgur Palais re-generated topography- and culture-based geometries using new computational tools (Özcan, 2011). Participation is articulated through the early integration of field data and user density into the digital model, and ecological optimization is supported through material and microclimate testing (Ertuğrul & Altın, 2022).

Erginoğlu & Çalışlar Architects adopts a performance-driven model that integrates function, materiality, and environmental performance through digital analyses (Kurnalı, 2025). Its multi-actor negotiation system transforms daylight, thermal control, and usage scenarios into concurrent

Table 5. Evaluation of selected examples from europe on the axis of interdisciplinarity and digitalization

Related Themes	BIG	MVRDV	Herzog & de Meuron
User Centered Approach Participatory Design BIM Integration Parametric Design Digital Integration Systems Thinking	Collects user data using VR, GPS heat maps, and climate behavior maps; this data is linked to Grasshopper-based behavior simulations to determine form-decision relationships. The BIM model modifies scenarios in real time based on user flow.	Feeds LIDAR scans, social data, and density analytics into the MVRDV NEXT datascope system, where user profiles are matched to spatial typologies to perform variation tests.	Collects user data through phenomenological measurements of light, odor, acoustics, and surface contact; atmospheric decisions are structured by data based on sensory experience.
BIM Integration User Centered Approach Parametric Design Digital Twin AI Based Workflow	Automatically incorporates user feedback into the BIM model, enabling mass re-optimization for sun, wind, and shade scenarios. The design is constantly updated based on data.	User input is fed into the scenario engine; behavior data directly changes program decisions, and the design is continuously tested with digital variations.	User feedback is evaluated through material–light–acoustic performance tests; decisions such as surface transmittance, density, and light refraction are shaped by this testing cycle.
Interdisciplinary Teamwork Cross-Discipline Practice Interdisciplinary Teamscience Digital Integration	Project Room model enables municipal technical teams, engineers, and community representatives to work simultaneously on the same parametric model.	Co-design clusters structure combines the municipality–data analyst–landscape–architect interaction into a single diagrammatic decision environment; each actor's input layer is transparent.	The architect, acoustician, material scientist and structural engineer work around the physical model without hierarchy, simultaneously negotiating the design.
Participatory Design User-Centered Approach Parametric Design Digital Integration	VR-based feedback transforms parametric variable panels and digital user scenarios into an engagement tool.	Tools such as VillageMaker and RoofScape allow the user to experimentally produce their own typology.	Prioritizes sensory prototyping experience over digital engagement; user feedback is gathered through physical testing.
Parametric Design Digital Integration Ecology Framework Climate Awareness Green Design	They connect energy, wind, shade, and passive climate simulations to a single parametric kernel; mass automatically updates with changing parameters.	NEXT integrates topography, density, heat island and carbon data into a single model.	Considers material behavior (light scattering, permeability, heat accumulation) as the main input for ecological performance.
Ecology Framework Climate Awareness Green Design Parametric Design Digital Integration	Tests sunshade mock-ups, passive ventilation surfaces and roof landscaping with prototypes.	Validates digital microclimate scenarios with wind tunnel, light chamber and topographic models.	Conducts ecological performance tests such as light refraction, resonance, and heat storage on 1:1 material panel.
Green Design Ecology Framework Parametric Design Climate Awareness Digital Integration	Cutting optimization manages modular systems and the use of recycled materials with parametric calculations.	It embeds LCA calculations into the design scenario engine; material selection is determined by carbon footprint.	Material is judged based on fiber direction, density and permeability tests; ecological performance is the main criterion.
Digital Integration BIM Integration Parametric Design Digital Twin	It integrates the BIM–Grasshopper–simulation trio.	MVRDV NEXT connects all data layers to a script-based processing system.	It combines point cloud, script, CNC and BIM in one flow via DTG.
Interdisciplinary Teamwork Interdisciplinary Teamscience Cross-Discipline Practice	With horizontal organization, it operates all expert groups in a single cycle	It establishes a tripartite structure that puts research–digital model–physical model in a continuous loop.	Brings together different experts in the same volume with a non-hierarchical team-science organization.
Digital Integration Interdisciplinary Teamwork Systems Thinking	Establishes a digital variation–model–simulation–revision cycle.	Progresses cyclically as diagram–scenario–model–data analysis.	Uses the 1:1 panel–performance test–CNC update cycle.

Megaron, Vol. 21, No. 1, pp. 101–121, March 2026

decision-making inputs; material selections are aligned with energy consumption and microclimatic effects. In the Palanga project, compacted earth walls, nail- less timber structures, passive stack ventilation, and microclimate strategies embedded into the topography produce an ecological construction model grounded in local techniques (Kariptaş & Kariptaş, 2025).

The dynamics of the offices technical and organizational processes were structured in relation to the themes derived from the analyses (Table 6).

Tabanlıoğlu Architects integrates digital design processes with a focus on sustainability and spatial quality in large-scale mixed-use projects and public buildings. GAD Architects supports its innovative design pursuits with digital production technologies and AI-based analysis, developing flexible design processes based on collaboration with experts from various disciplines. Erginoğlu & Çalışlar Architects combines local context and cultural values with contemporary architectural language, producing environmentally sensitive projects using digital design tools and sustainable materials.

Synthesis: Comparison of Examples of Architectural Offices in Europe and Türkiye Based on Digital

Table 6. Evaluation of selected examples from Türkiye on the axis of interdisciplinarity and digitalization

Related Themes	Tabanlıoğlu Architects	GAD Architects	Erginoğlu & Çalışlar Architects
User-Centered Approach Participatory Design Parametric Design Digital Integration Climate Awareness Ecology Framework Systems Thinking	User profiles, investor expectations, and operational flows are collected through hot-desk meetings, scenario testing, and usage flow diagrams; data is transformed into live inputs that are constantly updated.	User density, behavioral patterns, and field observations are directly linked to the parametric model; the data redefines the form with each iteration.	User needs are evaluated together with the social-cultural context; behavioral data is integrated into daylight, ventilation and plan typology analyses.
User-Centered Approach Participatory Design Climate Awareness Ecology Framework	Common areas and circulation decisions are repeatedly revised according to user practices; the design program is shaped by multi-actor negotiations.	User inputs directly produce variation in performance scenarios; the model is constantly recalibrated based on environmental and social data.	User behavior is evaluated simultaneously with interior organization and climatic strategies; the digital model is updated with user data.
Interdisciplinary Teamwork Interdisciplinary Teamscience BIM Integration Digital Integration Parametric Design	At AKM, acoustics, structural, stage technology and conservation teams work as peers around a BIM-based common model; decisions mature through an iterative negotiation process.	Parametric design, data processing, software development, and materials research proceed through parallel task-sharing; all actors feed into the same model.	Engineering, material, landscape and user representatives meet on a common platform at the early stage; multi-actor negotiation creates the decision chain.
Digital Twin BIM Integration Participatory Design	Laser scanning, photogrammetry and digital twin models make expert feedback visible; the BIM platform acts as a technical engagement tool.	VR-based feedback, parametric variable panels, and density analyses transform digital participation into active design input.	Digital tools enable participation through performance testing; field observation and digital verification go hand in hand.
Climate Awareness Green Design Parametric Design	Wind, shadow, heat island, courtyard morphology and permeable façade scenarios determine the mass organization as initial design input.	Material behavior, light transmittance, thermal performance and microclimate data are integrated with parametric control layers; the form is reshaped with ecological performance.	Digital models are built simultaneously with climatic data; environmental analyses define the performance infrastructure.
Green Design Ecology Framework Digital Integration	Performance is verified by testing acoustic panels, ceiling sections and facade surfaces in models close to 1:1.	Sun-shade surfaces, passive ventilation elements and roof landscaping are tested with hybrid (digital + physical) prototypes.	Compressed earth walls, horasan mixtures and wooden purlin-rafter system are tested in the field and turned into an ecological prototype.

Table 6. Continue

Related Themes	Tabanlıoğlu Architects	GAD Architects	Erginoğlu & Çalışlar Architects
Ecology Framework Green Design Parametric Design	Glass-ceramic blended modules are tested with digital optimization at the material level according to light transmittance, thermal mass and energy behavior.	Recycled material, cutting optimization and performance data are managed within the parametric system.	Materials are selected based on their maintenance cycle, microclimate impact and performance in relation to local techniques.
Digital Twin BIM Integration Parametric Design Climate Awareness	Digital twin, laser scanning, photogrammetry, BIM integration creates a common platform for both analysis and design.	BIM–Grasshopper–script-based variation generation–simulation infrastructure merges into a single computational backbone.	Digital models that combine daylight, airflow, heat and structural analysis are established at an early stage.
Interdisciplinary Teamwork Digital Integration	During the AKM construction process, different technical teams work on the same model without a hierarchy; the organization is based on a simultaneous negotiation system.	Parallel teams of architects, engineers, software developers and materials researchers carry out synchronized production.	Engineering, materials, landscape and user teams meet on a single platform at an early stage; decisions are shaped by collective production.
BIM Integration Ecology Framework	Acoustic simulation, structural analysis and scene scenarios are constantly compared with the BIM model, establishing an iterative loop of information integration.	The digital variation–mock–performance test–revision cycle forms the computational core of the design.	A cyclical flow of information is established between usage scenarios, climatic data and plan typologies; design progresses according to performance.

Production and Interdisciplinary Design Approaches

A holistic reading of the European (BIG, MVRDV, Herzog & de Meuron) and Türkiye (Tabanlıoğlu, GAD, Erginoğlu & Çalışlar) cases demonstrates that the emphases on interdisciplinarity and digitalization take shape with varying intensities across the two contexts. Architectural offices in Europe adopt a highly integrated, data- driven, and iterative production approach in which processes—from user data collection to digital twin and BIM integration, from parametric variation generation to microclimate testing—are supported by both computational tools and physical prototypes. While BIG and MVRDV link user behavior, topographic information, density analytics, and climate scenarios to a single parametric core, Herzog & de Meuron foregrounds phenomenological measurements and material behavior as primary inputs shaping ecological performance.

In contrast, within the Türkiye context, although the transfer of data and participatory processes into design is strong, team organization and digital infrastructure integration tend to operate more at the scale of individual projects and through platform-based, multi-actor models. Tabanlıoğlu's multi-actor negotiation systems, GAD's incorporation of field data into parametric control layers, and Erginoğlu & Çalışlar's site-oriented approach that transforms local material–microclimate relations into ecological prototypes collectively indicate that participation and ecological sensitivity are strong in Türkiye offices, yet computational cycles are not as deeply integrated as in the European examples.

Across both geographies, a shared tendency is the emergence of a triad—user data + environmental data + material performance—as a progressively decisive core in early design stages. However, the European context reinforces this core through digital twin workflows, script-based processing, and high-resolution performance testing, whereas the Türkiye context deepens it through local contextualization, physical prototyping, and multi-actor negotiation. The comparative evaluations developed to analyze the thematic approaches of European and Türkiye offices are presented in Table 7.

In Europe-based offices, the culture of digital production and interdisciplinary organization appears to have evolved into an integrated and institutionalized structure in which parametric modeling, BIM, and AI-based optimization tools are embedded from the early stages of design. In the Türkiye examples, however, these approaches tend to concentrate more at the project scale and within specific domains such as energy efficiency, performance analysis, and spatial organization, while the use of artificial intelligence and advanced digital production tools remains comparatively limited. This

Megaron, Vol. 21, No. 1, pp. 101–121, March 2026

Table 7. Comparison of European and Türkiye examples based on digital production and interdisciplinary design approaches

Related Themes	European Context (BIG – MVRDV – H&dM)	Türkiye Context (Tabanlıoğlu – GAD – E&C)
User-Centered Approach	User behavior data is collected in high resolution using digital tools (VR, GPS, LIDAR, sensory measurements). The data is directly linked to the model and guides the design.	User inputs are collected through the social-cultural context and field observations. There is integration with the model, but the digital data density is not as high as in Europe.
Participatory Design	Participation takes place in digital environments; users are directly involved in variation production. At H&dM, the sensory prototype experience is at the forefront.	Participation is mostly conducted through joint table meetings, negotiations, and field-based actor interactions; a hybrid structure prevails.
BIM Integration	It is tightly integrated with BIM, simulation, digital twins, and performance models.	The BIM common model ensures multi-actor equality; integration is strong, but data density is more limited compared to Europe.
Parametric Design	The parametric kernel comprehensively handles climate, density, user flow, and topography.	Parametric decisions combine field data, interior organization, and performance analysis.
Digital Integration	Script-based processing, automatic transfer of data sets, and digital twin flows are highly integrated.	Digital models are established early on; field data and prototypes are processed simultaneously.
Digital Twin	Point cloud, laser scanning, and physical test data are integrated with the digital twin.	The combination of digital twin + photogrammetry + BIM offers a common platform.
AI-Based Workflow	Data-driven automation and scenario engines approach AI-based flows.	AI-based flows are limited; more parametric and data-driven systems are implemented.
Interdisciplinary Teamwork	Highly disciplined teams work simultaneously and transparently on a shared model.	Technical teams come together early on; the BIM model supports equal representation.
Interdisciplinary Teamscience	The findings show that teams synchronize communication through shared workspaces while bringing together different areas of expertise within the same production cycle, establish information integration through digital integration and prototyping feedback loops, and conduct decision-making processes through iterative negotiation rather than hierarchy.	It demonstrates that multidisciplinary expertise approaches equivalent representation, particularly in large and complex projects; communication and coordination are mostly established around common platforms such as BIM/digital twins; and information integration is achieved through project-based integration and parallel task sharing.
Cross-Discipline Practice	Architects, data analysts, landscape architects, and engineers interact in a single decision-making environment.	Software developers, engineers, and materials researchers come together on a single platform through parallel production.
Ecology Framework	It is verified by ecological performance tests; it is the primary input for the design.	Local materials, microclimate measurements, and ecological prototypes are decisive factors.
Climate Awareness	Climate data is linked to the parametric model at an early stage; it generates variation.	Sunlight, ventilation, and microclimate data are evaluated in parametric models.
Green Design	LCA, carbon footprint, and energy analyses are important.	Local materials, recycling, and field-tested prototypes are emphasized.
Systems Thinking	A circular flow is established between data, performance, and environmental inputs.	A circular flow of information is created between the usage scenario, climate data, and plan typology.
Studio Integration	In-house production is structured around studio–laboratory continuity. The digital model–physical model/prototype cycle is carried out simultaneously in the same production environment, allowing decisions to be refined iteratively.	Studio integration is primarily visible through task sharing between in-house R&D/computational production units and project teams.
Sustainability in Education	Data-driven scenario generation, ecological frameworks, and climate modeling institutionalize a learning system through which research outputs inform project decisions.	Sustainability knowledge is mostly generated through environmental analyses, material performance, and field-validated ecological prototypes within the project workflow and shared across teams.

Table 7. Continue

Related Themes	European Context (BIG – MVRDV – H&dM)	Türkiye Context (Tabanlıoğlu – GAD – E&C)
Metaverse Environment	Metaverse/immersive environments appear in the literature more as a secondary layer in the context of the expansion of digital representation and interactive decision environments.	The metaverse environment theme is represented in a limited way; digital participation and interaction are established on a project basis, mostly through tools such as VR-based feedback/parametric variation panels, and are not discussed in the context of an institutionalized plane as a continuous metaverse ecosystem.
Generative Design	Generative design functions as a mechanism that feeds early-stage option generation through script/parametric rule sets and scenario engines; data-scenario-based variation generation at MVRDV and the derivation of mass decisions using Grasshopper-based behavior/climate inputs at BIG demonstrate how generative logic is tied to the design core.	Computational models, software-based manufacturing, and approaches where form is derived evolutionarily through environmental inputs (e.g., cellular automata and project-specific computational manufacturing) are highlighted. In Tabanlıoğlu and E&C, however, generative logic, parametric control layers, and performance scenarios come into play in a more selective/project-focused manner.

indicates that, whereas participation and collaboration in European offices are systematically organized through digital models, similar processes in Türkiye are structured in a more contextual and project-based manner.

DISCUSSION: ANALYTICAL INFERENCES

In the 21st century, architectural design has become intertwined with digital production technologies that develop on the basis of interdisciplinarity, and this multilayeredness has become a necessary design approach. New design paradigms have transformed both the organizational structure and production processes of architectural offices, paving the way for the emergence of multilayered, holistic, and flexible design models. The findings of this study demonstrate that digitalization in 21st-century architectural offices is a holistic restructuring process that has radically transformed production culture, decision-making dynamics, and inter-actor interactions through interdisciplinary processes.

The comparative analyses of the European (BIG, MVRDV, Herzog & de Meuron) and Türkiye (Tabanlıoğlu, GAD, Erginoğlu & Çalışlar) cases demonstrate that contemporary architectural offices are restructuring their design processes around three fundamental axes: (1) data-driven participatory design, (2) computational–interdisciplinary integration, and (3) the embedding of ecological performance into the early stages of design. The European examples presented in the tables—BIG, MVRDV, and H&dM—have developed a high-intensity participation model in which user data are collected through VR, LIDAR, GPS behavior maps, and sensory measurement protocols, and design variations are generated through real-time digital scenarios. In Türkiye, Tabanlıoğlu, GAD, and Erginoğlu & Çalışlar operate through multi-actor negotiation systems that integrate user input primarily with programmatic, climatic, structural, and local behavioral data. However, whether this backbone transforms into an "enterprise pipeline" in production represents a critical threshold. In European examples, standardizing script-based variation, simulation, and prototyping cycles as a repetitive workflow transforms tools from a project-specific repertoire into enterprise capacity. In Turkish examples, while digital twin, BIM common model, and hybrid prototyping practices are strong, the fact that these components often operate as a system that is rescaled according to project requirements and configured according to context produces institutionalization on a more selective and situation-specific plane.

In this study, the European and Turkish cases examined reveal the contextual differences in how digitalization reshapes the design process. In Europe, BIG, MVRDV, and Herzog & de Meuron turn digitalization into the computational backbone of design by integrating data collection techniques—such as VR-based behavioral mapping, LIDAR, GPS density measurements, and sensory protocols—with script-based variation systems and high-resolution performance simulations within a single operational loop. In contrast, in Türkiye, Tabanlıoğlu Mimarlık, GAD Architecture, and Erginoğlu & Çalışlar employ digitalization more as a project-based toolkit that varies according to contextual requirements, developing methods such as BIM-based shared models, digital twin integration, parametric geometry, and hybrid prototype production in ways that focus on energy efficiency, climatic performance, and spatial organization problems. When these two contexts are compared, it becomes evident that the European cases have transformed high-intensity data flows and script-based computational decision chains into an institutional production culture, whereas the Turkish cases have adopted a more flexible and situation-specific model of digital production by associating digital tools with local context, multi-actor negotiation, and field-based ecological validation. Therefore, although digitalization functions as a guiding component of design in both contexts, its scale of implementation, computational depth, and level of institutionalization differ according to context. The key factor that makes the difference at this point is whether technology is positioned as a tool that reduces uncertainty in the early design phase or as a flexible space that is continuously recalibrated with contextual data. This positioning directly affects at which stage and with what role distribution BIM and AI-based tools will be included in the process.

In the Turkish cases, the concentration of digital approaches in specific areas such as energy efficiency, performance analysis, and spatial organization may be associated not only with the fact that these domains are more conducive to justifying design decisions through measurable short-term indicators, but also with their capacity to generate a shared consensus among project stakeholders. When performance analysis and energy efficiency are addressed together with BIM-based coordination, they constitute the layers of design that can be managed with the lowest degree of uncertainty in terms of both technical verification and implementation coordination. For this reason, the areas in which the return on investment of digitalization becomes visible most rapidly tend to cluster around these themes. This becomes particularly evident in the cases of Tabanlıoğlu, GAD, and Erginoğlu & Çalışlar, where concepts such as digital twins, shared models, and parametric modeling are deployed strategically არა at the earliest stage of design, but rather to verify performance and maintain the consistency of spatial organization.

The more limited use of AI-based optimization and advanced digital production technologies in Turkish architectural practice is related to whether the data flow and verification mechanisms required by optimization can be sustained at an institutional scale. AI-based option generation requires the translation of design goals into measurable criteria, the maintenance of data consistency, and the definition of how the generated variations will be linked to the hierarchy of design decisions. When this connection is not established, optimization outputs may remain as supportive secondary components at particular stages rather than becoming lasting decision inputs within the design process. In this context, the critical threshold for the broader adoption of these technologies lies in the definition of target functions, the continuity of data, and the way decision responsibility is distributed within the design team.

The barriers that prevent the embedding of BIM- and AI-based tools into the early stages of design become concrete in the tension between uncertainty and the data clarity demanded by the model. When uncertainty is intended to be preserved in early design as a driving force for creative exploration and alternative generation, the premature structuring of the model may pose risks; this, in turn, makes it difficult for BIM and automation-based decision chains to function as the backbone of design from the outset. In the European cases, the operation of data collection protocols—such as VR, LIDAR, and GPS—as a systematic framework that feeds option generation in the early stages provides a form of feedback that reduces uncertainty, whereas in the Turkish cases the early stage is often positioned as a phase in which contextual negotiation predominates and the model serves to carry decisions only once they have become clearer. For this reason, the decisive threshold in early-stage integration is less a matter of modeling capacity than of process consensus regarding which tools will be used to manage uncertainty, and at what stage.

Organizational culture, project procurement models, professional competencies, and market conditions should be considered together as the broader framework in which these differences become visible. Standardized digital workflows at the institutional scale require the continuity of interdisciplinary teams, the stability of role definitions, and the documentation of organizational learning. When these conditions are met, digitalization can move beyond being a project-specific toolkit and become an institutional and educational capacity. Conversely, in environments where project procurement models encourage fragmented service production, delivery schedules are compressed, and the balance between fees and performance is fragile, offices may tend to concentrate their digital investments in more goal-oriented areas. Within this framework, the difference between the institutionalized processes observed in the European cases and the contextual, project-based flexibility that stands out in the Turkish cases depends on the risk conditions under which offices position digitalization and the logic of return through which they evaluate it.

CONCLUSION: FUTURE PERSPECTIVES AND CONCEPTUAL EXPLANATIONS

In light of these findings, the future perspective suggests three core axes of transformation for architectural practice:

(i) Data-driven, multi-actor, iterative negotiation platforms that structure the design process;

(ii) Hybrid design ecologies that integrate computational modeling, software development, digital twins, and performance testing into a single loop;

(iii) Digital simulation models that unify material, climate, topography, and behavioral data within a shared performance backbone.

The findings demonstrate that digitalization and interdisciplinary design operate together in architecture offices across three concrete planes. On the first plane, BIM integration and digital integration emerge as the operational ground of interdisciplinary teamwork. The high frequencies and co-occurrence relations identified in the content analysis reveal that production settings in which coordination is established through a shared model occupy a central place in the literature. On the second plane, the pattern in which parametric design intersects with digital integration and systems thinking indicates that design decisions are produced through feedback-based loops rather than through isolated stages. This suggests that the decision-making process is expanded through multiple layers of data. On the third plane, the reading of ecology framework and climate awareness themes together with digital simulation and green design codes shows that environmental performance is positioned as one of the guiding inputs of design.

The comparative case reading demonstrates that these three planes correspond to different modes of organization in the European and Turkish contexts. In the European cases, digital workflows appear to generate a more continuous coordination structure from the early stages of design onward, whereas in the Turkish cases similar components are reconfigured according to project scale and contextual requirements. This finding analytically renders visible the study's distinction between institutionalized computational loops and project-based adaptive digitalization, suggesting that the transformation of digitalization into institutional capacity is associated less with the diversity of tools than with the level of continuity and integration within the workflow.

The practical counterpart of the first axis lies in the fact that participatory design does not remain at the level of isolated feedback, but is connected to the same chain of production as in-house interdisciplinary teamwork. The findings show that user-centered approach and participatory design themes become meaningful when read together with digital integration and interdisciplinary collaboration. For this reason, the function of multi-actor negotiation platforms is not merely to bring actors side by side, but to make transparent the inputs and tools through which design decisions are produced. Within the scope of the study, the themes of BIM integration and digital integration point to the shared infrastructures through which this transparency can be produced in practice.

The second axis clarifies how offices construct hybrid design ecologies. In the European cases, digital integration is seen to turn into a recurring loop together with script/parametric production, simulation logic, and prototyping culture, whereas in the Turkish cases BIM, parametric modeling, digital twins, and interdisciplinary collaboration mostly operate as a combination reconfigured according to project requirements. This finding is more explanatory when digitalization is evaluated not in terms of which tools exist, but in terms of how those tools are connected to one another. The themes of BIM integration, digital integration, parametric design, and interdisciplinary teamwork, which establish strong co-occurrence relations in the content analysis, constitute the core of this relationality.

The third axis brings the relationship established between ecology framework and climate awareness themes and digital production to the level of practice. The findings indicate that, in some cases, ecological parameters become determining inputs of the model in the early stages of design, while in other cases they enter the process mainly at the stages of verification or improvement. This differentiation can be explained by the fact that, in the European context, digital simulation is embedded earlier into the guiding backbone of design, whereas in the Turkish context ecological decisions advance more selectively in relation to local context, material conditions, and implementation constraints. Accordingly, the study demonstrates that the operationalization of ecological performance through digitalization is directly related to the stage at which interdisciplinary collaboration and data layers are connected to design.

The results generate implications for practitioners, educators, and policy makers. For practitioners, the continuity of interdisciplinary teamwork is strengthened under conditions in which digital integration ceases to be a project-based toolkit and becomes part of the culture of production. For educators, the intersection of studio integration and education model themes with digitalization and interdisciplinarity in the content analysis suggests that this field should be approached as a framework that teaches mechanisms of collaboration and representation. For policy makers, as indicated by the risk of tokenistic collaboration, ensuring that interdisciplinarity does not remain merely formal is related to the definition of data sharing, interoperability, and representational mechanisms within the process.

The limitation of the study lies in the fact that the findings are derived from the content analysis of 45 articles selected from the 2005–2025 period and from the comparative reading of office practices through data reported in secondary sources. While this framework systematically renders thematic patterns and conceptual relations visible, it is not intended to directly test causal explanations regarding the internal processes of offices, such as which institutional factors determine role distribution, decision hierarchies, or tool selection. In addition, since the content analysis approach reveals the intensities and co-occurrence patterns of themes represented in the literature, the results reflect the tendencies of practices that have a counterpart in the literature.

Future research may deepen the thematic framework established in this study. First, the same coding system can be reapplied to expanded samples across different geographies and different scales of practice (small, medium, and large offices) in order to compare the continuity and axes of differentiation in digitalization–interdisciplinarity patterns across contexts. Second, the criteria derived from the content analysis can be combined with primary data—such as in-office workflow documentation, project process records, and multi-actor coordination protocols—to analyze the organizational mechanisms that determine the level of institutionalization of digital integration. These two directions would strengthen the relationship between theory and practice in the study, while making it possible to discuss, on an empirical basis, how a digitalizing culture of production can be transformed into a sustainable capacity within architecture offices.

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