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Literature Research for Architectural Design Model Proposal of Technology Development Zones in Türkiye

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Abstract

Technology Development Zones (TDZs) have become significant drivers of innovation and economic development by fostering collaboration between universities, industry, and research centers. However, despite their increasing importance, the architectural design parameters that influence the spatial quality and functionality of TDZs have not been sufficiently examined in the literature. This study aims to address this gap by evaluating the development, conceptual foundations, and design criteria of TDZs, with a specific focus on their architectural dimensions in Türkiye. The research adopts a comprehensive literature review methodology, analyzing international and national models, legal frameworks, and evaluation methods related to TDZs. The first stage of the study examines the historical background, emergence, and key components of TDZs, as well as their evolution worldwide and in Türkiye. The second stage focuses on identifying and categorizing the architectural design parameters and approaches relevant to TDZs, including functionality, flexibility, sustainability, aesthetics, and social context. The findings reveal that while the economic and managerial aspects of TDZs are well-documented, architectural considerations remain underexplored. International evaluation models such as AMIEM emphasize the importance of collaborative environments and adaptable physical spaces. In Türkiye, the lack of architectural standards for TDZs presents challenges for achieving spatial quality and homogeneity. This study highlights the need for holistic architectural approaches in TDZ planning, offering a foundation for further research and practical improvements in the design of innovation ecosystems.

1. INTRODUCTION

In recent decades, the rapid development of science and technology has brought about fundamental changes in the practice of societies and economies around the world. These changes are evident, for example, in the establishment of novel environments known as Technology Development Zones (TDZs) designed to stimulate R&D, enhance innovation and promote close collaboration among universities, industries and research institutions. TDZ is used to mean suitably designed deterministic areas stimulating business knowledge, technology and entrepreneurship.

TDZs have emerged as critical infrastructures supporting innovation and economic growth by facilitating collaboration among universities, industries, and research institutions. While their economic and managerial roles have been extensively discussed in the literature, the architectural design parameters that shape the spatial quality, adaptability, and functionality of TDZs remain significantly underexplored—particularly within the context of Türkiye. This underrepresentation presents a key problem for both academic discourse and practical implementation in the planning and design of innovation ecosystems.

The primary aim of this study is to address this gap by examining the conceptual evolution, physical planning principles, and architectural design strategies relevant to TDZs, with a specific focus on their development and application in Türkiye. By situating TDZs within a broader architectural discourse, the research seeks to contribute to a more holistic understanding of how built environments can support innovation-driven ecosystems.

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The scope of the study encompasses international and national TDZ models, legal and institutional frameworks, and existing evaluation mechanisms. The research adopts a two-phase methodology. In the first phase, it explores the historical trajectory and key components of TDZs, along with their emergence and transformation both globally and within Türkiye. In the second phase, the study identifies and classifies core architectural design parameters that are integral to TDZ performance but often overlooked in practice.

Findings indicate that although the economic and governance-related dimensions of TDZs are well-documented, the architectural qualities of these environments lack systematic evaluation. For instance, international models such as the AMIEM framework emphasize the significance of collaborative environments and spatial adaptability in fostering innovation. In contrast, the absence of well-defined architectural standards in Türkiye hinders the achievement of spatial quality, consistency, and user-centered design in TDZ developments.

In this regard, the study underlines the necessity of integrating comprehensive architectural approaches into TDZ planning processes. It offers both a theoretical foundation and practical implications for advancing the design of innovation spaces that are responsive, inclusive, and conducive to multidisciplinary interaction.

2. TECHNOLOGY AND TDZ

Given the observation, we shall divide the literature review of this study into two sections. This part presents the features that have contributed to the appearance of TDZs, the events that followed, the conceptual components, the evaluation methods, the consequent stages of development, and the legal basis in our country. The second part explores design, architectural design, key architectural parameters, and the conceptual and physical aspects of related architectural approaches.

2.1. Technological Development and Its Interactions with Human Life

Throughout human history, intellectual and technological advances have radically transformed lifestyles and production styles. This process, which began with the discovery of fire, evolved from hunter-gatherer to settled life, from physical labor to machine power, and finally, with digitalization, to life-based on artificial intelligence.

Until the 18th century, people relied on natural resources like muscle power and water for agriculture-based production. As needs grew, traditional methods became inadequate. The Industrial Revolution began in mid-18th century England with steam power’s integration into production and transportation, shifting from workshops to factories. This boosted production and capital, increasing international interaction and knowledge [1]. Higher production capacity led to rural-to-urban migration, the growth of collective settlements, and the rise of the working class, triggering urbanization and changing cities’ architectural needs. The invention of electricity in the late 19th century and the achievements of the 1st Industrial Revolution initiated the 2nd Industrial Revolution. During this period, machine technology accelerated production, transportation, and communication; electrical energy increased product variety, reduced costs, and raised living standards. At the same time, the working class became stronger, and social effects began to be felt on a global scale [2].

Industry 3.0 began in the 1950s with the integration of digital technologies into production; flexible and efficient production was made possible with developments such as transistors, computers, CNC machines, and ERP systems. This digitalization formed the basis of Industry 4.0. Industry 4.0 refers to smart factories equipped with the Internet of things, big data, smart sensors, and autonomous systems, and creates radical transformations in both production and daily life. The basic building blocks of the Industrial Revolution and their effects on human life are summarized in Table 1.

Table 1. *Schematic Summary of Industrial Revolutions*

Industrial Era	Definition	Main Tech	Features	Effects on People's Lifestyles
Industry 1.0 (late 18th century)	Mechanical Production	Steam & water power	Beginning of mechanization, increase in efficiency	Migration from rural to cities, factory work, workforce is physical and tiring
Industry 2.0 (late 19th century)	Mass production	Electrical assembly line	Mass production, increased division of labor, efficiency	Lower cost and standardized products, regulation of working hours, working class
Industry 3.0 (20th century)	Automation	Computers and robots	Automation systems, digitalization, flexibility in production	Improvement in working conditions, access to information technologies, growth in the service sector
Industry 4.0 (21st century)	Smart Production	IoT, artificial intelligence, big data	Smart factories, autonomous systems, data analytics	Digital work environments, remote working, personalized products

2.2. Technology Development Zones

Technology Development Zones (TDZs) are special areas established by universities, research centers, and industry cooperation to support R&D, technology transfer, and innovative initiatives. These zones encourage innovation while also contributing to the economy by strengthening university-industry cooperation.

The origin of technology development zones dates back to the United States in the 1950s. The first example is the Stanford Research Park (1951), which is considered the starting point of technology development zones [3]. Stanford University aimed to support the economic development of the region and to create a bridge between the university and industry by leasing large areas of land in the region to technology companies. This model pioneered the birth of Silicon Valley and became an example for many countries around the world.

Research Triangle Park (RTP) in the USA is one of the first concrete examples of TDZs established in the 1950s to transform the industrial structure of North Carolina. It aimed to attract knowledge-based industries thanks to its proximity to universities such as Duke, North Carolina State, and UNC. It focused not only on industry but also on qualified manpower, quality of life, and cultural opportunities, emphasizing intellectual capital and creating a model that inspired the creative class theory [4].

"To many observers, the RTP strategy had been a success. By 1970, the New York Times reported approvingly that RTP now had 7,000 employees, almost all white, and an annual payroll of about $70 million, and noted that revenues in the three counties had increased by 28 percent, or $1,000, during the 1960s." [4].

From the 1970s onwards, the success of TDZs in the USA inspired similar initiatives in Europe and Asia. Examples such as Cambridge Science Park in England and Tsukuba Science City in Japan were implemented; the first successful model in Europe was Sophia-Antipolis in France [5]. In the 1980s, Japan developed the concept of "technopolis", and countries such as Taiwan, South Korea and Turkey also turned to technology park investments [6]. In 1984, IASP was established to bring together the professionals who manage these structures. IASP defines technology development zones as follows [7]:

"A science park is an organization managed by specialized professionals whose main aim is to increase the wealth of its community by promoting the culture of innovation and the competitiveness of its associated businesses and knowledge-based institutions. To enable these goals to be met, a Science Park stimulates and manages the flow of knowledge and technology amongst universities, R&D institutions, companies and markets; it facilitates the creation and growth of innovation-based companies through incubation and spin-off processes; and provides other value-added services together with high quality space and facilities. The expressions "technology park", "technopole", "research park" and "science

park" encompass a broad concept and are interchangeable within this definition. The acronym STP (science and technology park) is used to refer to all of these expressions."

Studies on the establishment dates of technoparks reveal that there was a 48% increase in the 1990s and this number has been increasing rapidly since the 2000s [8]. During this period, the aim of TDZs is to support technology transfer, strengthen R&D activities and increase national innovation capacities.

As the integration of technological innovations into industry increased from the 1990s onwards, TDZs became widespread worldwide and gained importance in areas such as software, biotechnology and advanced engineering. In the 2000s, the Industry 4.0 process was initiated; information-based production came to the fore, and TDZs became structures that supported university-industry collaboration and innovative initiatives as part of this process.

The main purpose of TDZs, creating an R&D and innovation environment, is important in terms of developing resilience against economic vulnerabilities and supporting sustainable development [9]. Research shows that R&D has positive effects on long-term growth [10], innovation, human capital development and environmentally friendly solutions [11]. Therefore, creating an ecosystem that encourages R&D investments, and innovation is considered critical for countries' development and social problems [12].

With the increasing importance of TDZs, academic research has also begun on these structures. However, studies directly focusing on TDZs in the context of architecture are quite limited. Most of the research in the literature focuses on the fields of economics, law and business development; from an architectural perspective, only indirect and superficial relationships are established [13]. In the bibliometric analysis study conducted by Böyükaslan and Özkara [13] with the keywords "technopark", "technocity", "technology development zones", the researchers reached the results in Table 2. When the Table is examined, no studies were found in the context of architecture, except for the limited and superficial relations of the topics of temporal and spatial distribution and site selection criteria with the field of architecture in the academic studies conducted on TDZs until 2019.

Table 2. *Bibliometric analysis of academic studies on TDZs in the ULAKBİM database as of 2018* [13]

Subject of Study	**Frequency**
University-Industry-Public Cooperation	5
Management Effectiveness, Problems, Solution Suggestions	4
Innovation Impact	3
Tax Advantages	3
Impact on Employment	3
Benefits and Importance of Technoparks	3
Impact on National and Regional Innovation Systems	3
The Impact of Innovative Companies	3
Institutional Transformation, Transition to Information Society	2
Technology Transfer, Technology Transfer Collaboration	2
Contribution to Patent Production	2
Investment Needs, Investment Impact	2
Economic Impact	1
Technopark-University Collaboration	1
Temporal and Spatial Distribution	1
Innovation Performance	1
Establishment Location Selection Criteria	1
Absorptive Capacity	1

2.3. Technology Development Zones in Türkiye

In Türkiye, technoparks are defined as follows in the Technology Development Zones Law No. 4691:

"Technology Development Zone: A site where high/advanced technology or new technology-oriented companies produce/develop technology or software by utilizing the facilities of a specific university or high technology institute or R&D center or institute, operate to transform a technological invention into a commercial product, method or service, and contribute to the development of the region in this way, within or near the same university, high technology institute or R&D center or institute area; where academic, economic and social structures are integrated or a technopark with these features…"

Based on the definition, it is understood that the concept of TDZ covers concepts that appear in literature with different names, such as science park, science and technology park, technology park, technopark, research park, innovation area and technopolis.

The first step to support R&D and innovation in Türkiye was taken with the 1984-1989 Five-Year Development Plan, and then policies for technoparks were developed. [14]. The first steps towards TDZ were taken with the establishment of KOSGEB in 1990 and the commencement of operations of TÜBİTAK-MAM in 1992. [15]; With the law numbered 4691 enacted in 2001, TDZs gained legal ground and began to be supported with various incentives. [16, 17]. Technology development zones have become not only R&D centers but also structures that support entrepreneurship and local economic growth. Countries like Türkiye, as part of regional development strategies, provide incentives and tax advantages to new initiatives. Developing through university, private sector and public cooperation, these zones are key actors in innovation-based development.

As of October 2024, there are a total of 104 Technology Development Zones in Turkey. 91 of the 104 Technology Development Zones continue their activities, while 13 of them have not yet become operational due to ongoing infrastructure work [18]

TDZs are important spatial ecosystems for the discipline of architecture due to their multi-faceted and interactive structures. These structures, which also include the physical infrastructure of innovative environments, are open to evaluation in terms of architectural design. However, in the existing literature, studies that address TDZs with a focus on architecture are quite limited; for example, although Erenler's study focuses on physical planning, it leaves the architectural dimension incomplete [19].

Table 3. *Parameters for examining the physical planning principles of technoparks*

Category	**Parametric**	**Definition**
Site Selection Criteria	Regional Economic Structuring	Economic potential and infrastructure adequacy
	Transportation Facilities	Proximity to transportation networks
	Proximity to Universities and Research Institutions	The situation of benefiting from the knowledge and research opportunities of universities
Planning Principles	Intensity	Area usage rates and building density rates
	Construction Process in Stages	Phased construction process
Characteristics of Physical Areas	Managing Company Locations	Central areas for management and organization
	Service Areas	Social infrastructures such as dining halls, cafeterias, and health services
	Recreational Areas	Rest and green areas to meet the social needs of employees
	Residential Areas	Housing areas for guest workers
	Transportation Network	Transport infrastructure such as pedestrian paths, cycle paths and parking lots

Technological and Economic Context	R&D Areas	High-tech production and research centers
	Relations with Local Industry	Development of local economic structure and industrial modernization
	Technological Adaptation	Technology transfer units
Social and Environmental Parameters	Landscape and Environmental Design	Sustainable environmental planning and green space arrangements
	Quality of Life	High standards of work and living

Another study conducted on the axis of architecture and TDZ reveals analyses regarding the measurement of user satisfaction levels of TDZ buildings based on various architectural criteria [20]. However, in this study, since the subject is handled with a focus on the evaluation of existing structures, the architectural reflections of the conceptual infrastructure of the TDZ phenomenon and the design criteria regarding its requirements are not addressed.

There is no specific legislation regarding the architectural design of TDZs in Türkiye. Decisions such as site selection, design and construction are generally determined by the founding committee and the management company. Projects are evaluated only in terms of compliance with legal regulations; criteria such as design quality, sustainability and functionality are not considered. For this reason, a homogeneous and qualified structure cannot be achieved in architectural terms in TDZs.

As a result of considering the TDZ structures in an architectural context, the following evaluations can be made regarding the subject within the scope of this study:

1. Researching the criteria for TDZ design and making suggestions regarding design parameters can provide resources for academic studies and legal regulations to increase the quality of TDZs in our country.
2. The aim is to minimize the qualitative differences between TDZs and to spread the high-quality TDZ ecosystem throughout the country, thus supporting the establishment of a homogeneous system.
3. TDZ areas and structures that will be built in accordance with architectural design parameters will increase employee productivity and help use resources efficiently.

2.4. TDZs' Evaluation Models

Technology Development Zones consist of versatile components that support knowledge production, technology transfer and innovation; architectural design, functional infrastructure and sustainable innovation ecosystem constitute the basic elements of this structure [21].

In the literature, TDZ evaluation is carried out using models and tools based on certain parameters. Among the main models used in the evaluation of TGBs, the Cabral-Dahab Model offers ten parameters for the provision of qualified R&D personnel [22]. The Estrategigram proposes a seven-part structure and a positive and negative axis rating system that supports the strategic development of technology parks [21]. The CERNE model provides a systematic approach for process organization and maturity level assessment [23].

The AMIEM model, developed by Amaral, seeks to bridge the gap where existing models have focused too strictly upon a single axis and may not be comprehensive enough. It is based on twelve detailed case studies undertaken in Brazil, Uruguay, Italy and France [23] and is an extended version of Da Poian's model.

Table 4. *AMIEM Evaluation Factors Table* [21]

Timeframe	Maturation process of innovation environments (usually 15-20 years)
Government Support	Infrastructure, financing, tax breaks and incentives, etc.
Local Community Involvement	Participation of entrepreneurs, media and local representatives, regional integration of the innovation environment
University and Research Centers Involvement	Universities and R&D institutions, collaborations and patents
Funding and Promotion Agency Support	Venture capital, private and public funds
Presence of Leading Companies	Presence of leading companies and academic institutions
Physical Space and Location	Infrastructure, transportation, communications and cost-effective office spaces, etc.
Management and Operational Management	Dynamic, creative and accessible management, advertising, service provision and development support
Leadership	Competent and committed leadership units, collaboration with leaders, society and stakeholders.
Promotion and Advertising	Promotional activities, courses, seminars and visits
Quality of Life and Work Environment	High quality living and working environment, center of attraction

As per the AMIEM evaluation model, we can group the main factors that TDZ should contain respectively as follows: University-industry-government collaboration, Physical space and infrastructure, Government supports and policies, Leading companies and industrial partners, Community and social participation, Financial supports, Management and operational infrastructure, Technological infrastructure and digital systems.

University-Industry-Public Collaboration

In the literature, which framed the development of TDZs within the scope of the Triple Helix model functional and administrative components have been emphasized. This university-industry-public-cooperation-based model is one of the important underpinning structures and the basis for the sustainability of the knowledge-based economy in our society. In this model, the university contributes to knowledge production, the industry to technology commercialization and the government to the provision of the regulatory framework [21]. It may be suggested that in this context, the TDZ architecture includes units such as joint work areas, R&D laboratories and training centers that will support multi-faceted interaction.

Physical Space and Location

TDZ's sustainability and effective operation depend on the availability of advanced infrastructure and versatile physical spaces. AMIEM model - physical spaces being a manifestation of this, must be flexible and have scope to accommodate the needs of users. One of the main features TDZ are built on physical resources, that is, the physical factors such as buildings, offices, meeting rooms and scientific equipment that are provided to companies [21, 24]. There are two primary roles that physical infrastructure plays in TDZs. For the first, provide clustering space for firms; this structure allows firms to cluster together to reduce cost and access specialized resources. It also promotes the establishment of networks between knowledge-generating organizations and industry. The second function is to help newly established firms, in particular, overcome resource deficiencies by providing common areas and equipment. These shared resources also offer complementary advantages with sustainable income potential [24]

Government Support

Government support and policies are an important component in the development of TGBs, encouraging long-term development through tax advantages, public investments and infrastructure support. This support is valuable not only economically but also in terms of stability. In terms of architecture, this support can be thought of as administrative and legal units that will manage cooperation with legal mechanisms and office spaces that will coordinate incentive practices [21].

Leading Companies and Industrial Partners

Leading companies support the innovation ecosystem by promoting knowledge sharing and collaboration in TDZs. This component can be reflected in spatial solutions such as modular offices, production workshops and collaboration areas [21].

Community and Social Participation

Community and social participation support sustainability by strengthening internal and external interactions in TDZs [21]. This component should be architecturally supported by investor offices, technology transfer units, and meeting areas.

Financial Supports

Financial support is critical to the sustainability of TDZs and ensures the continuity of resources required for R&D projects [21]. This component should be architecturally supported with investor offices, technology transfer units and meeting areas.

Management and Operational Infrastructure

In TDZs, management and infrastructure are required for effectiveness [21]. This management can be met at the architectural level with flexible and multifunctional administrative offices, management centers and logistics areas.

Technological Infrastructure and Digital Systems

In TDZs, technological infrastructure increases efficiency with digital systems such as fast internet and data management. This structure can find architectural counterparts with spaces that support the digital infrastructure and provide security.

When the functional and sustainable essences of TDZ components are evaluated, it is important to consider the architectural design of TDZs with a holistic understanding. TDZ architecture can be considered as a multi-dimensional building design that supports social, economic and environmental sustainability as well as innovation.

3. DESIGN AND ARCHITECTURAL DESIGN

The design process has been addressed using various approaches in different disciplines. Design refers to decisions made under conditions that are not clear and certain [25]. Design is a process that not only analyzes the current situation but also imagines and realizes potential future solutions [26]. Design is a cognitive process in which the human mind is actively involved. In this process, mental activities such as analysis, synthesis, imagination and evaluation come together [27]. The design process is based on past experiences, theoretical knowledge and practical applications. This knowledge is used to develop new and original solutions [28]. Design deals with both clear and vague ideas, with both systematic and chaotic ways of thinking, and with both imagination and mathematical calculations [29].

3.1. Design Models

Unlike traditional sequential models, multidimensional thinking structures developed in the information age offer more comprehensive solutions. Especially in the preliminary design phase, intuitive decisions with limited information are insufficient; therefore, the use of multi-criteria analysis methods is important for sustainable and optimum design solutions [30].

The Integrated Thinking Model is the most comprehensive model that enables designers to produce innovative and flexible solutions to complex problems by combining basic, logical and creative thinking approaches [31]. The Integrated Thinking Model consists of three components: Basic thinking includes the problem definition and solution development process based on the designer's knowledge and experience. Logical thinking is the scientific analysis of data, and methodical evaluation of solution alternatives. Intuition, imagination and creativity to generate innovative ideas underpin creative thinking. The first stage of Integrated Thinking Model is to analyze the design problem and gather information. This work is conducted in a holistic manner, however, considering context, needs of users and cultural aspects. An information-based design consists of the steps of problem definition, alternative generation, as well as solution evaluation and decision making. Merging logical and creative thinking, the theoretical and practical dimensions of the model allow for the emergence of new solutions in the architectural design process [31].

3.2. Architectural Design

Architectural Design is a multi-dimensional process oriented at space and form, and it is also program oriented. The process has layers: layers of technical knowledge, aesthetic feeling and social need and it spans both information based decisions through to creative ones [32]. The architectural design process is a knowledge-based planning process that focuses on producing better solutions by analyzing existing conditions. Each design produces a subjective solution that is specific to the context, user and designer [33]. In recent years the architectural design criteria have gone beyond traditional criteria and into new dimensions like sustainability, flexibility, accessibility and technology. The purpose of this study is to provide a comprehensive view with TDZs by intersection that architecture discipline and all what part of components followed in design process.

Function

The concept of function in architecture came to the fore in the modernist period with Louis Sullivan’s “form follows function” principle; it revealed the understanding that form should be derived from function [34]. However, this approach was criticized by Reyner Banham on the grounds that it led to the limitation of architectural meaning and was evaluated as a superficial slogan [35]. According to Michl, the function is divided into two parts: planned and real; this distinction reveals that the design can transform over time in line with the needs of the user [36]. Hillier and McLeod emphasize that function should be flexible and redefinable not only in physical but also in social and cultural contexts [37, 38].

In modern architecture, the function is defined by focusing on social needs and placing the architect in a position of authority independent of the user. This approach led to architecture gaining a political dimension. New approaches developed from the 1950s onwards emphasized that function could not be considered independent of context and user; they argued that flexible and creative solutions suitable for every situation should be developed [39]. Function is not a hard rule in architecture, it is seen to be a fluid and re-interpretable element that varies depending on context. This is the method that postulates critical and innovative architecture being, which is always intertwined with social, cultural and political specifications [40].

The functional capacity of a structure relies on criteria such as user requirements, spatial organization, accessibility and flexibility. The functionality in the architectural design of technoparks gives a strong need for situational, user-centered and flexible designs. Designing with an understanding of other specialties would be to design for sustainability through adaptability to differing needs — one that acknowledges specialized spatial needs.

Flexibility

Flexibility is a spatial and structural strategy that allows structures to adapt to time, users and functions [41]. Hertzberger [42] talked about flexibility in terms of providing opportunities for multi-purpose usage; Friedman [43] discussed growth and division strategies (in response to changing needs). An approach in architectural design flexibly is to develop more durable and user-friendly facilities, not just functionally but also with social, cultural and economic dimensions.

Flexibility in architectural design is a multidimensional strategy that aims to adapt structures to changing user needs and functions over time. Within the scope of this study, the basic design approaches that provide flexibility can be summarized below:

1. Mobility: It enables the space to be rearranged according to temporary needs, thanks to portable equipment and structural elements [44].
2. Modularity: Creating repeatable units with a grid layout speeds up the production process, reduces costs and increases portability [44, 45].
3. Combinability and Divisibility: With the polyvalence approach, structures can be rearranged for different functions; movable walls and sliding panels support this strategy [42] [46].
4. Neutral Areas: Spaces that are not tied to a specific function can be opened to different uses with the harmony of service and served areas. The “shell and core” approach is an example in this context [47].
5. Additive and Removable: The ability of structures to expand horizontally and vertically is explained through primary and secondary systems within the framework of Habraken’s Open Structure approach [48].
6. Multi-Purpose Use: With the principle of functional ambiguity, a space can be adapted to different functions through open plan and mobile equipment. User participation is an important factor that increases the success of flexibility [49].
7. Different Plan Types: Pre-planning different space organizations that will respond to various user profiles within the same structure provides scenario-based flexibility, albeit limited [45].

These strategies are parallel to each other in terms of the design of sustainable, user-oriented, and transformable spaces, especially with their dynamism, such as TDZ.

Aesthetic

Aesthetics is related to the basic psychological needs of the individual and should not be considered as a luxury alone but as a need that increases the quality of life [50, 51]. In architecture, aesthetics encompasses the sensory and psychological effects of space as well as physical elements [52]. While the aesthetic experience is enriched by visual, tactile and kinesthetic perceptions, it is also deepened by cultural and symbolic contexts [53, 54]. Elements, such as material, form and light, shape this experience. Aesthetics and functionality are complementary elements and should be addressed with a holistic approach in the design process. As in Gehry's Guggenheim Bilbao example, aesthetic superiority should be balanced with functional deficiencies [52].

Aesthetics is directly related to the psychological needs of the individual and is an integral part of both sensory and functional experiences in architecture [50, 51]. Aesthetic experience is not only based on physical form; it is also based on emotional, cultural and social interactions established with the space [52] [52, 53]. In the architectural design of TDZs, aesthetics should be evaluated in terms of geometry, light and color, tactile perception, and volumetric arrangement as parameters affecting the user experience as well as visual identity.

Geometric Perception:
Building form and order affect aesthetic satisfaction. Curvilinear forms produce more positive emotional responses; linear geometries evoke a sense of order and power [55] [56]. In virtual reality and EEG-supported studies, it has been observed that curvilinear forms receive higher scores in aesthetic and emotional evaluations [57].

Light, Color and Material Interaction:
Light is the basis of color perception. The quality of natural and artificial lighting determines the atmosphere of the space[58, 59]. Warm colors create a sense of closeness and energy, while cold colors create a sense of spaciousness and calm. However, color cannot be considered independently of light and material; shiny surfaces reflect colors more vividly, while matte surfaces reflect them more deeply [60] [61]. While natural materials provide warmth and intimacy, artificial materials emphasize modernity. Color-material-light harmony has a direct impact on user psychology and spatial perception.

Aesthetics and Functionality Balance:
Aesthetics should not only be evaluated as visual satisfaction; it should be evaluated together with the usability of the space. Integrating aesthetic values without compromising functionality increases the design quality in multifunctional structures such as TGB. Gehry's Guggenheim Bilbao example emphasizes the importance of this balance [52]. These components are important design parameters that increase the aesthetic quality in TDZs and strengthen the identity of the structure and user interaction.

Sustainability

Incorporating natural environmental components and climatic data into architectural design is fundamental to achieving sustainability goals related to ecology, human well-being, resource conservation, and economic efficiency [62]. Sustainability is a holistic approach developed against global problems such as resource depletion, environmental pollution, climate change and social inequality. Instead of waste accumulation and resource waste caused by the linear economy, a circular economy should be adopted; renewable energy use and carbon emission reduction should be prioritized. While social sustainability requires social justice and participation, economic sustainability should be supported by innovation and responsible resource use [63]. Ecological balance, continuity of natural processes and effective use of renewable resources form the basis of sustainability [64]. Local resource use, recycling and long-term planning are important in this context. Sustainability in architectural design provides both environmental and social benefits by integrating with strategies such as life cycle analysis, circular economy, adaptive management, ecological restoration and community participation. Sustainability in architecture stands out as an approach that considers environmental, social and economic balances with resource management, life cycle-based design and quality of life-oriented solutions [65].

Table 5. *Parameters of the concept of sustainable architecture* [65]

Principle	Evaluation Parameters
Resource Management Policy	Effective Use of Energy
	Effective Use of Water
	Effective Use of Material
	Effective Use of Building Areas
Life Cycle Design Principle	Pre-production Period
	Construction Period
	Post-Production Period
Design Principle for Quality of Life	Protection of Natural Conditions
	Urban Design and Land Planning
	Design for Human Health and Comfort

Social and Cultural Context

Architecture is not just the production of physical environments; it is also closely connected to social and cultural contexts. Social norms, traditions, and cultural values shape spaces and their relationships with users. Emphasizing contextuality and locality, as opposed to modernism's universalism, promotes spaces with distinct identities. "Critical regionalism" supports a sense of belonging by reinterpreting local architectural values in contemporary ways.

Space should be considered as a phenomenon where individuals establish their identities and social ties; cultural heritage, traditional lifestyles and local rituals should be integrated into the design process. While the concept of "non-place" brought by globalization points to the production of spaces without identity and disconnected from context; the context-oriented design supports user experience and social sustainability [66, 67].

Contextual analyses should not be limited to the physical environment but should also include social, cultural, and economic parameters [68]. Physical reflections of the social and cultural context include open spaces interacting with the landscape, spaces that enable socialization, and the use of historical and cultural elements with contemporary interpretations at the material, plan, and form levels. With this approach, architecture not only produces structures but also becomes a social tool that shapes lifestyles.

Economic Feasibility

The construction industry today is under pressure to develop more efficient and cost-effective solutions due to the increasing population, sustainability goals and economic constraints. The resource wastage, low productivity and high costs caused by traditional methods have necessitated the adoption of modern construction methods (MMC) such as prefabrication, modular systems and hybrid structures. MMC can reduce construction time by up to 50% with factory-produced structural elements, while also reducing waste production and energy consumption [69-71]. For example, projects such as the La Trobe Tower, which was completed 30% faster, demonstrate the potential of this method[72]. However, high initial costs, lack of regulation and industry resistance limit the widespread use of MMC [73].

Life Cycle Cost Analysis (LCCA), used together with Building Information Modeling (BIM), which was developed for the purpose of more accurate management of construction processes in terms of cost and performance, enables the planning of costs that will occur throughout the entire life of buildings. This method optimizes investment, operation and maintenance costs starting from the design phase; while also improving visualization and decision support processes [74].
Another digital technology that increases field efficiency, the Internet of Things (IoT), speeds up processes and reduces maintenance costs by monitoring material and equipment management with real-time data. However, inadequate data-sharing infrastructure, security vulnerabilities, and installation costs make implementation difficult for small-scale businesses [75, 76]. Additive manufacturing (AM), on the other hand, attracts attention with its fast production and low material usage. This technology, which can reduce wall production time by up to half [77], offers potential, especially in the production of complex forms, but is still in the development phase due to material incompatibility, lack of standards and limitations in large-scale applications [78]. All these approaches play a transformative role in the construction sector's achievement of cost, speed and sustainability goals.

Technology and Innovation

Architecture has been transformed with technology and innovation throughout history; today, these elements have become even more critical in line with environmental problems and energy efficiency targets. Smart materials, dynamic façade systems and smart building technologies transform architecture into a versatile design area by establishing a bridge between functionality and sustainability. Smart materials increase energy efficiency and improve building performance thanks to their structures, which are sensitive to environmental stimuli [79]. These materials, developed in mechanical, optical, self-healing, energy-generating, coating and composite types, provide durability and environmental compatibility. Dynamic façade systems offer solutions that respond to environmental data in order to increase thermal and visual comfort, provide natural ventilation and reduce energy consumption [80, 81]. Kinetic structures and façade elements designed with smart materials and biomimetic applications increase the functional and aesthetic performance of façades. Smart building systems, on the other hand, offer solutions in multidimensional areas such as energy management, comfort, security and digitalization. While the components cover functional frameworks such as technology, health, flexibility and ecology, they work in integration with systems such as HVAC, lighting, energy and security, improving the sustainability of buildings and user experience [82]. This integration transforms the concept of smart buildings into an indispensable architectural strategy for reducing environmental impacts and improving the quality of life.

Privacy and Security

Privacy and security in the design of workspaces have a decisive effect on employees' psychological comfort, productivity and interaction level. Open-plan office arrangements, in particular, create significant problems that reduce satisfaction due to a lack of visual and auditory privacy [83]. In a research by Kim and de Dear [84], it was statistically demonstrated that lack of visual privacy negatively affects satisfaction (-0.46) and lack of auditory privacy also produces significantly negative results (-0.20). Privacy is addressed in three dimensions: visual, auditory and physical. Glass partitions and semi-permeable panels are recommended for visual privacy, acoustic panels and individual work cabins for auditory privacy, and closed meeting areas and private interview units are recommended for physical privacy [85]. Integrating privacy into design is considered as a holistic strategy that increases not only individual comfort but also collaboration and productivity.

In today's workplaces, security is addressed holistically, not only physically, but also with digital protection, access control, and human-centered design approaches [83] [85] . Multi-layered access control provided by systems such as card access and biometric verification enables both physical security and monitoring of access records. Closed-circuit camera systems, motion detection sensors, and artificial intelligence-supported monitoring technologies support in-building security; data encryption and multi-factor authentication provide protection against cyber threats. Emergency evacuation systems and guidance for fire and disaster scenarios also reinforce the sustainability of security.

Cybersecurity applications have gained a critical place in digitalized business processes. These approaches, supported by firewalls, network monitoring systems, and data encryption techniques, are strengthened with training for employees. Security systems do not only provide physical protection; they also contribute to employee productivity by increasing the sense of psychological security.

Privacy and security stand out as complementary design criteria, especially in open-plan office layouts. The protection of visual, auditory and physical privacy is supported by acoustic solutions, modular furniture and individual areas. Leading office applications exemplify these approaches: Google invests in individual focus areas, Amazon in biometric access systems, and WeWork in flexible and privacy-focused spaces [83]. These examples show that the balanced integration of privacy and security is a fundamental design strategy for sustainability and efficiency in the workplace.

4. DISCUSSION

In line with the criteria addressed by literature sources, it is seen that architectural design processes are not limited to traditional criteria such as aesthetics or functionality but are shaped in line with multi-dimensional approaches. In this context, the basic criteria to be considered in design include functionality, flexibility, aesthetics, sustainability, social and cultural context, economic feasibility and security parameters. It can be said that considering these criteria with a holistic approach forms the basis of contemporary and sustainable architectural design understanding.

Table 6. *Parameters and approaches of the concept of TDZ architecture (Produced by author)*

Design Parameter	Architectural Approach
Functionality	"Form Follows Function", Flexible Design, Adaptability to Social Context
Flexibility	Modularity, Neutral Areas, Different Plan Types, Addition and Removal, Mobility, Combinability, Multi-Purpose Use
Aesthetic	Visual Approach, Sensory Approach, Symbol and Meaning, Function-Aesthetic Balance, Historical and Cultural Context
Accessibility	Parking, Transportation, Access, Accessibility
Sustainability	Resource Management, Life Cycle Design, Design for Quality of Life
Technology and Innovation	Intelligent Material Use, Dynamic and Interactive Building Components, Intelligent Building Systems,
User Experience and Social Life	Design for People, Design with Society and Environment, Design with Cultural Elements, etc.
Security and Privacy	Visual Privacy Design, Auditory Privacy Design, Disaster and Accident Safety Design, Infrastructure and Digital Security Systems Design
Feasibility and Cost (Economic Feasibility)	Modern Methods of Construction (MMC), Building Information Modeling (BIM) and (LCCA), Use of Internet of Things (IOT), Additive Manufacturing

5.CONCLUSION

This study has shown that Technology Development Zones (TDZs) have become an integral part of innovation strategies, with their evolution shaped by ongoing advancements in technology, shifts in policy, and changing economic priorities. Although TDZs were initially established to foster collaboration between universities and industry, their purpose has broadened over time, making them key drivers for research, entrepreneurship, and the growth of knowledge-based economies.

While there is considerable research focused on the economic and managerial aspects of TDZs, the architectural and spatial qualities of these environments remain underexplored. International models reviewed in this study, including AMIEM—Amaral's evaluation model for TDZs—highlight the importance of adaptable and well-designed spaces that can accommodate a diverse range of activities and user needs. In Türkiye, the lack of unified architectural standards for TDZs continues to present challenges in achieving consistency and quality across different sites.

Overall, the findings suggest that a holistic approach to the architectural design of TDZs—one that considers factors such as functionality, flexibility, sustainability, and aesthetics—can play a critical role in enhancing both innovation capacity and user experience. Continued research on the architectural dimension of TDZs could provide valuable guidance for policymakers, designers, and all stakeholders aiming to improve these dynamic environments in the future.

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