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Prof. Dr. Özlem ATALAN
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CHAPTER 1

SEISMIC RESILIENCE ANALYSIS OF BUILDINGS WITH REGULAR AND IRREGULAR PLAN GEOMETRIES

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1. INTRODUCTION

Earthquakes, arising from the dynamic characteristics of the Earth, are one of the most destructive natural events and directly affect the safety of settlements and the built environment. Particularly in countries located on active tectonic belts, earthquake-induced risks hold a central significance not only from an engineering perspective but also from socio-economic planning and public administration standpoints. Türkiye, located on the Alpine–Himalayan seismic belt, is among the regions with the highest seismic activity worldwide. Major earthquakes of the past century—including the 1939 Erzincan, 1999 Marmara, 2011 Van, and 2023 Kahramanmaraş events—have demonstrated that a large portion of the country's building stock fails to perform adequately under seismic loading, with severe damage occurring especially in irregularly shaped and poorly designed structures. Consequently, correctly understanding the parameters that determine a building's seismic performance and ensure their effective control during design is indispensable both for engineering practice and disaster-risk-reduction policies (AFAD, 2023).

The earthquake engineering literature clearly shows that the geometric regularity of buildings and the balanced distribution of structural components are among the most critical factors affecting seismic behavior. Plan irregularities, incompatibility between centers of mass and stiffness, uncontrolled increases in torsional effects, and abrupt changes in story stiffness lead structures to experience demands in unexpected directions, frequently triggering collapse mechanisms. Foundational references such as Bozorgnia & Bertero (2004), Kappos (1999), Chopra (2020), Paulay & Priestley (1992), as well as recent research, demonstrate that buildings with regular geometry and regularly distributed structural elements not only experience lower stresses but also display more predictable dynamic responses. Conversely, buildings with recessed or protruding floor plans—such as L, T, or U shapes—and asymmetric column-beam layouts exhibit elevated torsional demands and uncontrolled story drifts under earthquake loading. This was evident in the 2023 Kahramanmaraş earthquakes, where numerous structural failures stemmed from soft-story, weak-story, and torsional irregularities.

The Turkish Building Earthquake Code (TBDY, 2018) systematically categorizes plan irregularities—such as torsional irregularity (A1), diaphragm discontinuities (A2), and excessive recesses/projections (A3)—and defines quantitative limits due to their negative effects on seismic behavior. These irregularities require specific design considerations because they cause uncontrolled distribution of seismic forces among stories. Additionally, vertical irregularities (B1, B2) describe conditions where vertical load transfer is interrupted, or abrupt changes in stiffness occur. Ensuring that such irregularities are limited or mitigated is essential for seismic safety.

Recent studies on the dynamic behavior of regular versus irregular buildings emphasize that plan geometry is particularly influential on modal behavior. The relationship between mode shapes and torsional components, story drift distribution, locations of plastic hinge formation, overturning moments, and horizontal force distribution directly depends on plan symmetry. Symmetric buildings exhibit more predictable modal patterns, whereas irregular buildings often display torsional participation even in the first mode, resulting in complex and potentially hazardous dynamic responses. Plan irregularity also impacts construction costs: irregular geometries typically require more structural members and more complex detailing, leading to higher material consumption and construction complexity (Doğangün, 2004; Kılıç & Akbaş, 2007; Fardis, 2009; Gupta, 2025).

This study aims to comparatively examine the seismic behavior of reinforced-concrete buildings sharing identical plan dimensions but different internal spatial organizations and to demonstrate, through quantitative analysis, the clear advantages of regular plan geometry. Three reinforced-concrete building models with identical rectangular footprints but different spatial configurations were analyzed using the Equivalent Earthquake Load Method and Modal Analysis. Story drifts, mode shapes, centers of mass and stiffness, seismic force distribution, and overturning moments were compared. Additionally, the effects of plan irregularity on construction cost were evaluated based on quantity take-offs and cost estimation, enabling a combined structural-economic performance assessment.

This study contributes to literature in three keyways:

(i) It provides a holistic comparative framework for understanding how different spatial configurations within identical plan boundaries influence seismic behavior.
(ii) It simultaneously evaluates static and dynamic analysis results to present directly comparable performance parameters.
(iii) It combines structural and economic assessments to highlight the importance of plan regularity in cost-effective seismic design.

The findings are expected to guide architectural and structural design decisions at early planning stages.

2. FUNDAMENTAL CONCEPTS OF SEISMIC RESILIENCE

Seismic resilience is one of the fundamental concepts used to evaluate the safety of structures under earthquake loading. Rather than representing only the structural capacity to remain standing, seismic resilience encompasses the ability of a building or system to continue functioning—either partially or fully—before, during, and after an earthquake. The resilience of structural systems depends on several engineering parameters, such as stiffness, ductility, energy-dissipation capacity, and the continuity of the load-bearing system (Bruneau et al., 2003; Chopra, 2020; Bassurucu et al., 2025).

The behavior of structures under seismic effects involves complex mechanisms beyond linear elastic limits, where plastic deformations play a significant role. Therefore, understanding seismic resilience requires defining fundamental concepts related to structural dynamics, deformation capacity, vibration period, mode shapes, and energy transfer mechanisms.

2.1. Definition and Scope of Seismic Resilience

Seismic resilience is a holistic concept covering the behavior of a structure before, during, and after an earthquake. According to the "Resilience Framework" developed by Bruneau et al. (2003), the resilience of a structural system is measured by its performance in four stages: mitigation, preparedness, response, and recovery. In this context, seismic resilience refers not only to "damage resistance" but also to "functionality preservation". On the scale of individual buildings, seismic resilience is defined by the capacity of a structure to (McAllister, 2015):

- Undergo deformation without collapse under a specified seismic demand,
- Possess adequate energy-dissipation and energy-absorption capacity,
- Limit permanent damage to repairable levels,
- Ensure occupant safety throughout the seismic event.

Therefore, seismic resilience is directly associated with safety, serviceability, and economic sustainability criteria (De Stefano & Pintucchi, 2008).

2.2. Fundamentals of Structural Dynamic Behavior

The seismic response of a structure is governed by its natural dynamic characteristics, which depend on its mass (m), stiffness (k), and damping ratio (c). The simplest representation is the equation of motion for a single-degree-of-freedom (SDOF) system:

$$M * \ddot{u}(t) + C * \dot{u}(t) + K * u(t) = -M * \ddot{u}_g(t) \quad (1)$$

Where:

- $\ddot{u}_g(t)$: Ground acceleration,
- $u(t)$: Displacement of the mass,
- C: Damping coefficient,
- K: Stiffness coefficient.

The inertial forces acting on the structure during an earthquake can be expressed as $F = m * \ddot{u}_g(t)$. The structural response is influenced by its natural period T, given by:

$$T = 2\pi\sqrt{\frac{m}{k}} \quad (2)$$

Thus, increasing mass increases the period, while increasing stiffness decreases it. This relationship is crucial for understanding the effects of plan irregularity: irregular structures have non-uniform stiffness distributions, resulting in varying local periods and increased torsional and resonance effects (Humar & Kumar, 1999).

2.3. Stiffness, Ductility, and Energy Dissipation Capacity

2.3.1. Stiffness

Stiffness represents a structure’s resistance to deformation under external loads. Under seismic actions, maintaining uniform and continuous stiffness is critical for balanced load transfer. Discontinuities in stiffness—such as sudden changes in column dimensions or abrupt termination of shear walls—give rise to vertical irregularities. According to TBDY (2018), a story exhibits stiffness irregularity if its average stiffness is less than 70% of the story above. Such irregularities significantly alter dynamic behavior and may contribute to collapse mechanisms.

2.3.2. Ductility

Ductility is the capacity of a structure to undergo plastic deformation beyond the elastic limit without losing load-carrying capacity. It is defined as:

$$\mu = \frac{\Delta_u}{\Delta_y} \quad (3)$$

Where:

- u_{max}: maximum displacement,
- u_y: yield displacement.

Ductility depends on both material properties (reinforcement ratio, concrete grade, steel yield strength) and detailing (shear-wall placement, beam-column joint design). High ductility enables structures to dissipate seismic energy without collapsing, making it a key requirement in modern seismic codes (CEN, 2004; TBDY, 2018).

2.3.3. Energy Dissipation

During an earthquake, energy enters the structural system and is dissipated through:

- Hysteretic behavior (material inelasticity),
- Soil–structure interaction,
- Energy losses at connections and joints.

Reinforced-concrete structures typically use a 5% damping ratio (Chopra, 2020). However, irregular buildings exhibit non-uniform energy-dissipation patterns, which can cause unbalanced energy distribution and localized damage (De Stefano & Pintucchi, 2008).

2.4. Natural Vibration Period and Mode Shapes

The natural vibration period is one of the most critical indicators of seismic response. Short-period (stiff) structures are sensitive to high-frequency ground motions, while long-period (flexible) structures respond more strongly to low-frequency components. Eurocode 8 and TBDY (2018) provide empirical expressions for estimating the fundamental period:

$$T = C_t \cdot h^{3/4} \tag{4}$$

Where:

- h: building height (m),
- C_t: coefficient depending on structural type (for reinforced concrete type, ≈0.085).

Irregular buildings have asymmetric stiffness and mass distributions; thus, multiple mode shapes influence overall behavior. Torsional modes often appear in the first or second mode, causing amplified story drifts and unpredictable response patterns (Yılmaz & Öncü, 2025).

2.5. Seismic Energy and Performance-Based Design

Earthquake energy is transferred to the structural system in the form of kinetic energy (K) and potential energy (V) components. The performance of the structure depends on how much of this energy is dissipated as elastic deformation and how much as plastic energy dissipation.

The total seismic energy input can be expressed as (Chopra, 2020):

$$E_I = E_K + E_S + E_H \tag{5}$$

Where:

- E_I: input energy,
- E_K: kinetic energy,
- E_S: elastic strain energy,
- E_H: hysteretic (plastic) energy.

Performance-based seismic design evaluates these energy components and classifies structural performance into levels such as Immediate Occupancy, Life Safety, and Collapse Prevention (FEMA 356). In irregular buildings, energy concentration occurs in specific regions due to asymmetric stiffness, causing localized plastic hinges (Kappos, 1999).

2.6. Seismic Resilience Requirements in Regulations

Both the Turkish Building Seismic Regulation (TBDY, 2018) and Eurocode 8 (CEN, 2004) define quantitative limits that determine seismic resilience

TBDY 2018 limits:

- Stiffness irregularity (η_k) ≤ 0.7
- Mass irregularity (η_m) ≤ 1.5
- Torsional irregularity (η_{bi}) ≤ 1.2
- Flat displacement ratio (Δ/h) ≤ 0.02

Eurocode 8 requirements:

- Center of mass and center of rigidity must align within 5% of the plan dimensions,
- Damping ratio %5,
- Flat stiffness reduction must not exceed 30%.

Irregular buildings require advanced analysis such as 3D modal analysis or nonlinear pushover analysis.

2.7. Multidimensional Evaluation of Seismic Resilience

Seismic resilience is not solely a structural concept; it must be evaluated with consideration of soil conditions, material properties, structural geometry, diaphragm behavior, and architectural decisions. Soil–structure interaction becomes more pronounced in irregular structures, creating complex dynamic behavior throughout the system (Mahi et al., 2025). Therefore, modern earthquake engineering views resilience not as a single value but as a "performance spectrum."

3. EFFECTS OF PLAN REGULARITY AND IRREGULARITY ON STRUCTURAL BEHAVIOR

Plan regularity refers to the geometric continuity and symmetry of a building in the horizontal plane and is one of the most fundamental factors governing the seismic response of structures. Balanced distribution of lateral forces, controlled dissipation of seismic energy, and limitation of torsional effects are all strongly influenced by the quality of plan configuration. While buildings with regular and symmetric plans distribute lateral forces more uniformly, plan-irregular structures typically exhibit concentration of forces and deformation demands in critical regions.

3.1. Concept of Plan Irregularity

Plan irregularity occurs when a structure lacks geometric symmetry or continuity in the horizontal plane. Such irregularities lead to significant separation between the center of mass and the center of rigidity, inducing torsional moments under seismic loading. Increased torsional effects influence even the first mode of vibration in relatively low- to mid-rise buildings and cause unexpected rotational demands.

The Turkish Building Earthquake Code (TBDY, 2018) classifies plan irregularities under three categories:

- **A1 – Torsional Irregularity:** Occurs when the ratio of maximum to average story drift exceeds a specified limit. Torsional irregularity is almost unavoidable in nonsymmetric plan geometries.
- **A2 – Diaphragm Discontinuity:** Occurs when significant openings, cut-outs, or large voids exist in slabs, impairing diaphragm action.
- **A3 – Plan Re-entrant Corners (Projections and Recesses):** Applies to floor plans with prominent re-entrant corners—such as L, T, U shapes—which lead to discontinuities in shear flow and complex paths of seismic force transfer.

The three models analyzed in this study were selected to evaluate the effects of A1, A2, and A3 irregularities within identical plan boundaries.

3.2. The Effect of Plan Geometry on Seismic Behavior

The effect of plan irregularity on seismic performance has been widely studied in earthquake engineering. Numerous experimental and numerical studies indicate that regular-plan buildings experience:

- Lower torsional demands,
- Reduced story drift values,
- More predictable modal patterns.

In contrast, irregular-plan buildings exhibit:

- Increased torsional participation in early modes,
- Greater eccentricity between mass and stiffness centers,
- Nonuniform lateral force distribution,
- Concentrated deformation demands on specific columns and shear walls.

Studies on L-, T-, and U-shaped structures consistently show that such configurations behave differently in different loading directions, causing asymmetric stiffness and irregular lateral-force paths. This often results in structural elements experiencing demands beyond their design capacities, increasing the risk of collapse. Additionally, irregular modal behavior reduces the accuracy of simplified static analysis methods, making advanced dynamic analysis necessary.

3.3. Importance of Mass–Stiffness Center Alignment

The most critical consequence of plan irregularity is the misalignment between the mass center and the stiffness center. The center of mass represents the distribution of weight, while the center of rigidity represents the distribution of lateral-force resistance. As the distance between these two points increases, seismic forces generate torsional moments.

Regular plan buildings typically exhibit:

- Low torsional moments,
- Uniform story drift distributions,
- Predictable mode shapes.

Irregular plan buildings exhibit:

- Significant mass–stiffness eccentricity,
- Torsional components in the first mode,
- Amplified deformation demands in selected structural elements,
- Nonlinear displacement profiles through the height.

Figure 1 illustrates the difference between regular (square) and irregular (L-shaped) plans in terms of mass (M) and stiffness (R) center alignment. In irregular buildings, part of the seismic shear transforms into torsional moment due to eccentricity, causing asymmetric deformation patterns even when materials and structural systems remain identical.

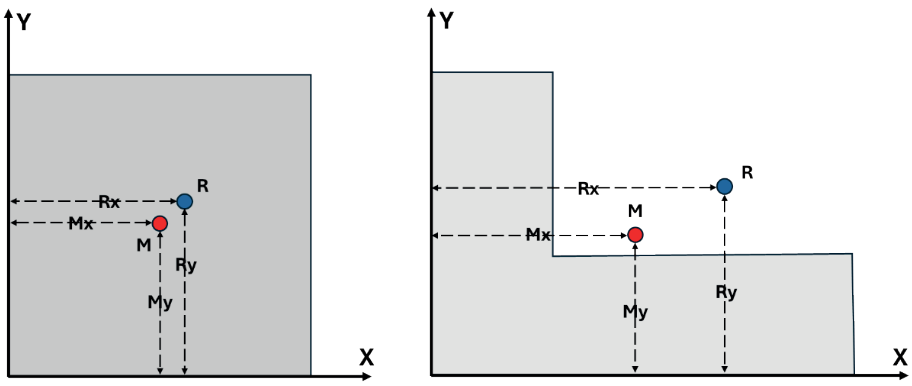

Figure 1. Centers of stiffness and mass of regular (square) and irregular (L-shaped) planned structures

The effects of this misalignment are analyzed in detail in Section 6.

3.4. Economic Impact of Plan Regularity

Plan irregularity not only affects structural performance but also contributes to significant economic consequences. Irregular geometry results in:

- Increased total length of beams and columns,
- Higher demand for formwork,
- Additional reinforcement detailing,
- More complex and labor-intensive construction processes.

These factors lead to higher construction costs and reduce structural efficiency. The quantity and cost analyses performed in this study (Tables 8–10) confirm that the regular-plan model is substantially more economical than irregular alternatives.

4. STRUCTURAL ANALYSIS METHODS

This study employs both the Equivalent Earthquake Load Method and Modal Analysis to assess the seismic performance of the three reinforced-concrete building models with different plan configurations. These methods follow the provisions outlined in TBDY (2018) for linear-elastic seismic analysis, allowing direct comparison of the effects of plan geometry on seismic behavior.

4.1. Analysis Approaches

Equivalent Earthquake Load Method

This linear-elastic method applies seismic effects to the structure as a lateral load pattern. For each model, seismic loads were determined considering:

- Design response spectrum,
- Building mass,
- Modal participation factors,
- Vertical mass distribution.

This method is particularly suitable for low- and mid-rise buildings where fundamental-mode behavior is dominant.

Modal Analysis Method

Modal analysis determines natural vibration modes and their corresponding periods. In structures with irregular plan geometry, the first few modes often include torsional components. The following parameters were extracted for each model:

- First three natural periods,
- Mode shapes,
- Torsional contributions,
- Effective modal mass ratios.

This allows direct comparison of how plan geometry influences dynamic characteristics.

4.2. Modeling Assumptions

All models share identical material and element properties. Only the plan configuration is varied to isolate its influence. Common assumptions:

- Concrete grade: C30,
- Steel grade: S420,
- Soil type: ZB,
- Damping ratio: 5%,
- Rigid diaphragm assumption applied,
- Cracked-section stiffnesses assigned per TBDY (2018)

These consistent assumptions ensure that observed differences stem solely from plan geometry.

4.3. Loads and Seismic Parameters

Dead and live loads were assigned according to TS 498. Earthquake loads were applied separately in both X and Y directions. Seismic spectrum parameters, consistent for all models, are:

- short-period map spectral acceleration coefficient (Ss) = 0.415,
- Map spectral acceleration coefficient for a 1.0-second period (S1) = 0.104,
- short-period design spectral acceleration coefficient (SDs) = 0.609,
- Design spectral acceleration for a 1.0-second period (SD1) = 0.249

These values were used to generate the design acceleration spectrum.

5. MODEL DESCRIPTIONS

Plan irregularity is widely recognized as one of the most influential factors affecting the seismic performance of buildings. The literature documents extensive numerical and experimental investigations comparing regular and irregular structures (Naeim, 2001; Antoniou & Pinho, 2004; Barros & Almeida, 2005; Kumar & Rai, 2011; Bhandari & Kumbhar, 2013; Pantaj & Reddy, 2017).

To compare the influence of plan geometry, three reinforced-concrete building models with identical footprint area were created:

- **Model 1:** Regular plan (Figure 2)
- **Model 2:** Semi-regular plan (Figure 3)
- **Model 3:** Irregular plan (Figure 4)

All models have identical structural elements—columns, beams, shear walls (where applicable), and rigid diaphragms. Despite their similar spatial layouts, the plan configurations differ in ways that alter the relationship between mass and stiffness centers.

Model 1 exhibits the closest mass–stiffness center alignment, Model 2 shows the largest offset, and Model 3 contains symmetric and asymmetric axes, many short beams, and plan protrusions, influencing torsional behavior. These alignments are quantitatively evaluated in Section 6.

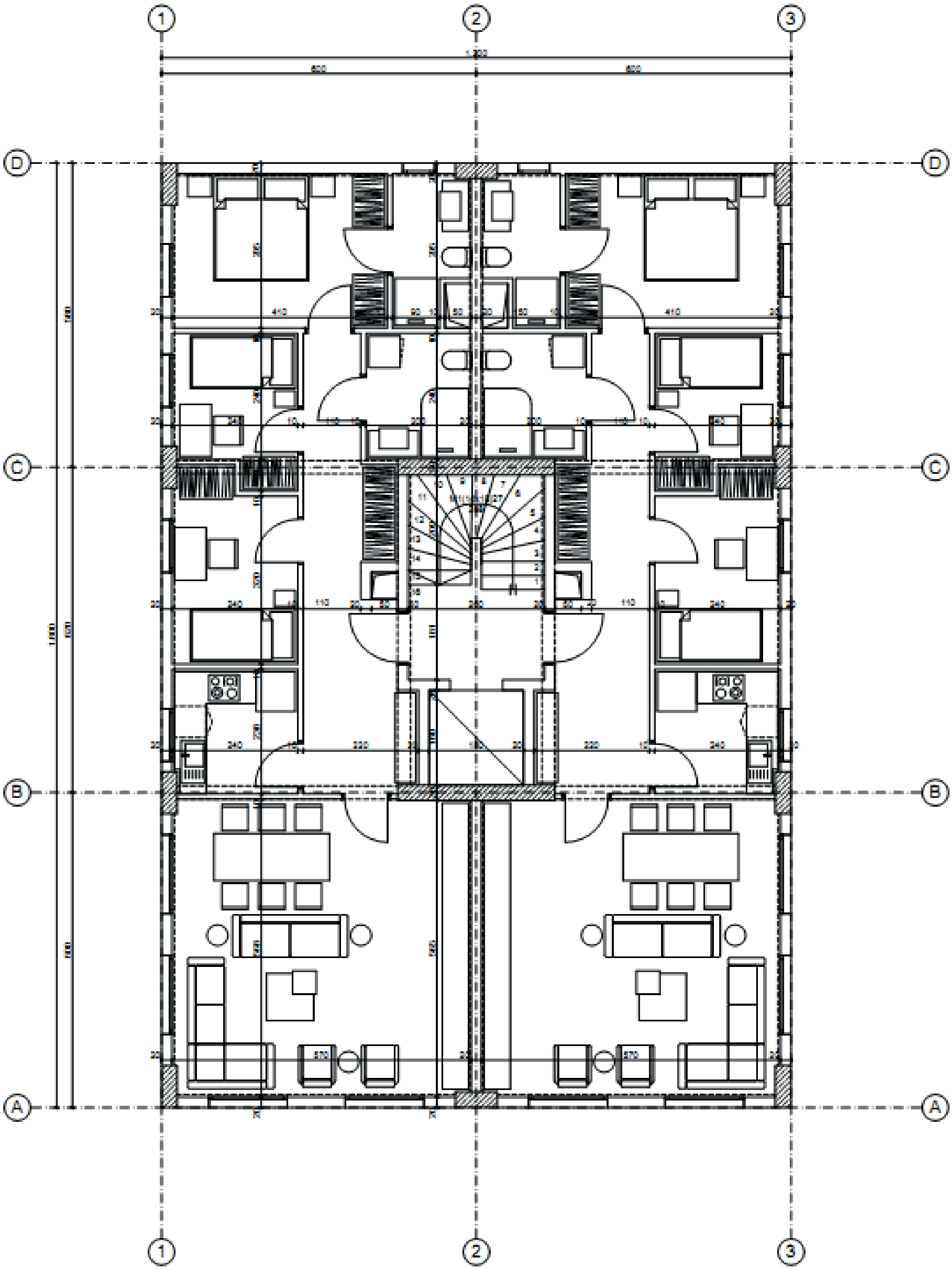

Figure 2. Floor plan of a building with a regular layout (Model 1)

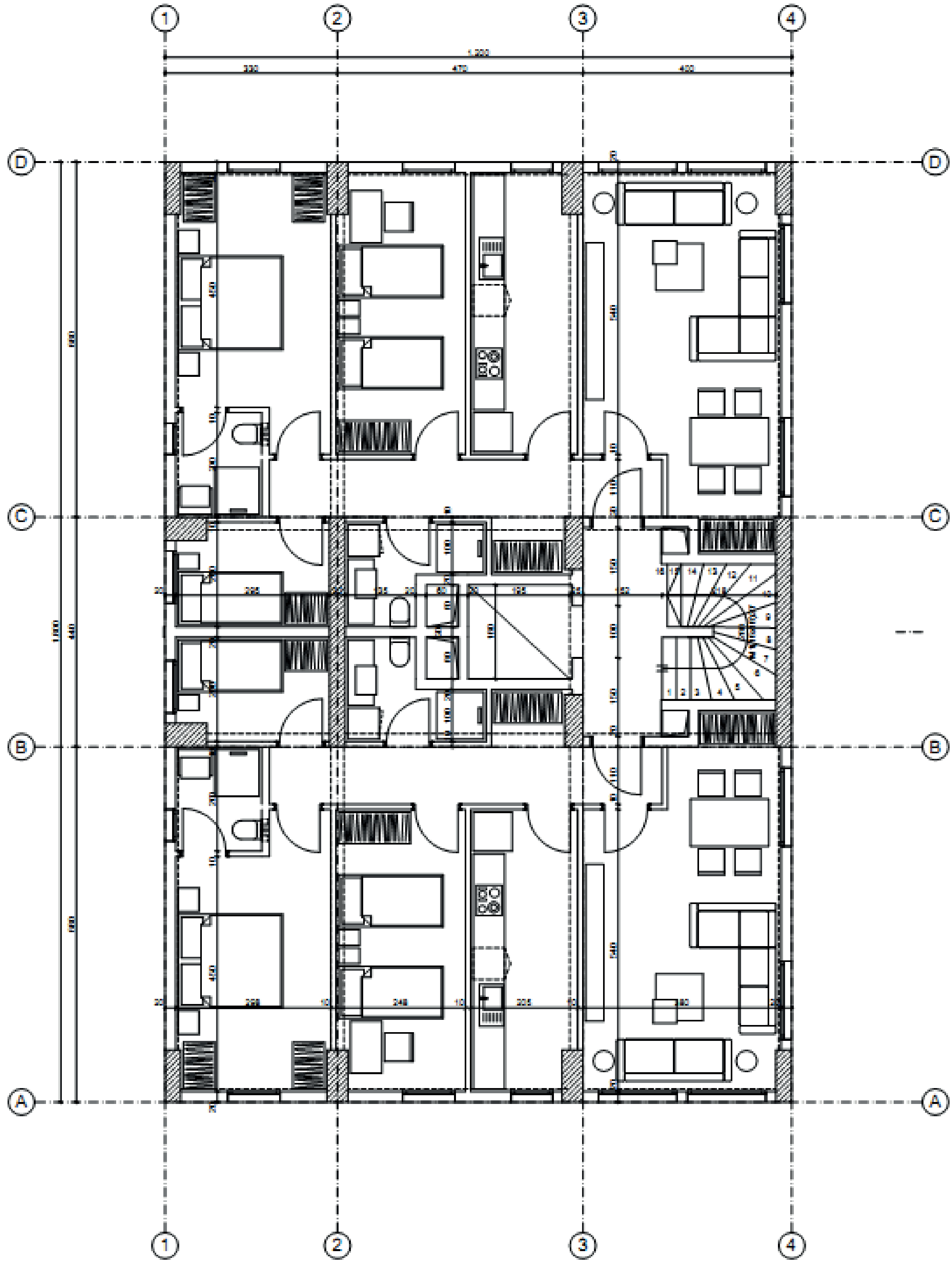

Figure 3. Floor plan of a building with a semi-regular layout (Model 2)

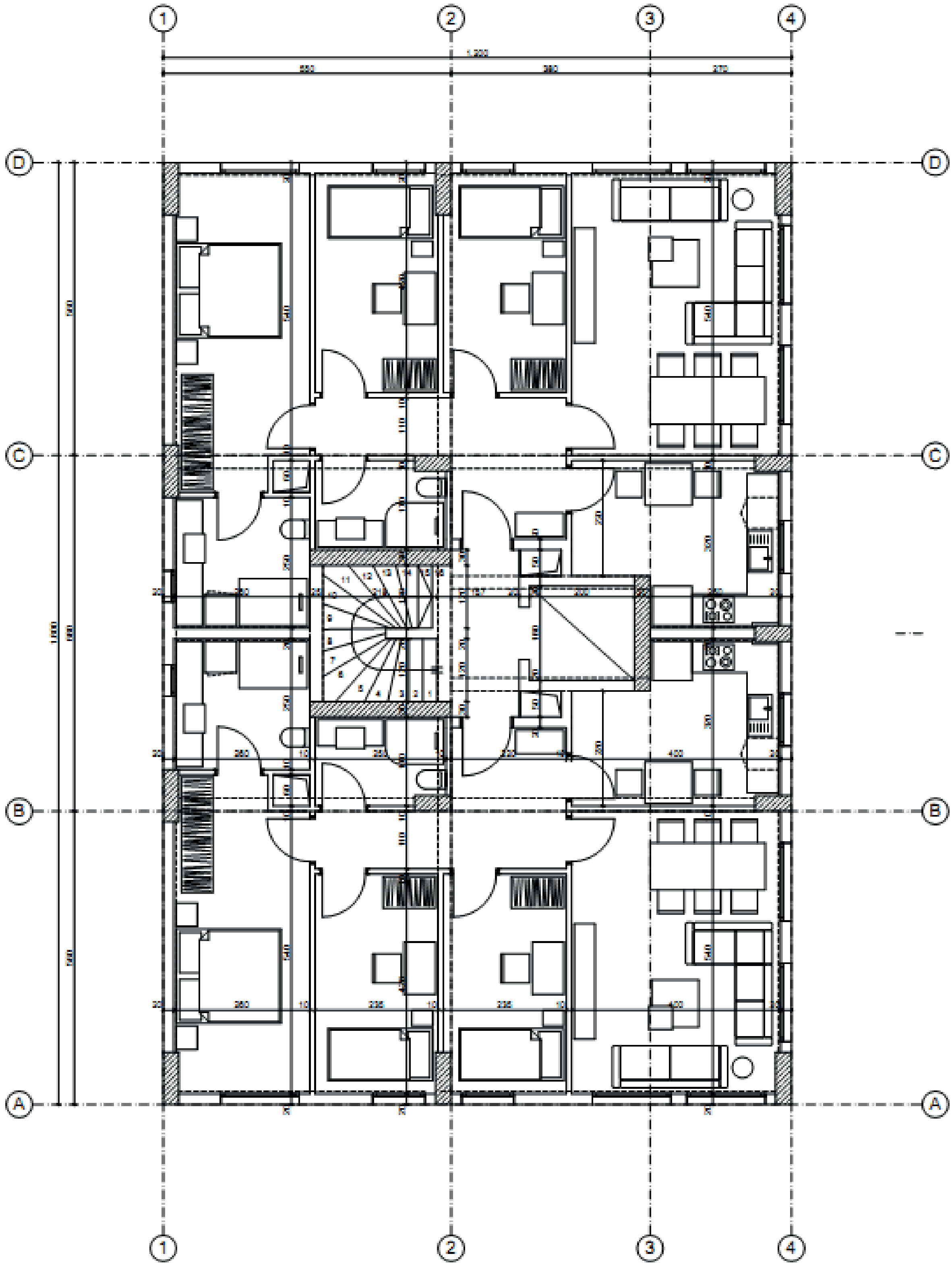

Figure 4. Floor plan of a building with an irregular layout (Model 3)

6. RESULT AND DISCUSSION

This section provides a comprehensive evaluation of the structural analysis results obtained for the three reinforced-concrete building models exhibiting distinct plan configurations. The assessment concentrates on critical seismic performance indicators — including natural vibration periods, story drift distributions, base shear demands, and the spatial alignment of mass and stiffness centers. The findings clearly demonstrate that variations in plan geometry exert a decisive influence on the global dynamic response of the structures and substantiate the theoretical premises outlined in the preceding sections.

The comparisons of the models were examined considering the criteria of the Turkey Building Earthquake Regulation, which was updated in 2018. The basic building characteristics considered during the comparison are as shown in Table 1.

Table 1. Building Basic Characteristics (Geometry and Structural System)

Parameter	Model 1	Model 2	Model 3
Building Location		İzmir	
Number of Floors		6	
Floor Height (m)		2.88	
Total Height (m)		17.28	
Plan Dimension (X–Y) (m)		12.00 – 18.00	
Structural System	Reinforced Concrete Frame System		
Blade Column/Frame Ratio	0.412	0.364	0.423
Building Importance Factor		1	
Building Usage Class		3	
Total Mass (t)	1173.52	1273.93	1296.18
Ground Class		ZD	
Earthquake Parameters			
Ss:		0.415	
S1:		0.104	
SDs:		0.609	
SD1:		0.249	

Calculations were performed using IdeCAD software to enable sound comparisons. Findings from the calculations include torsional irregularity (A1), floor discontinuity (A2), plan projection/recess irregularity (A3), weak floor irregularity (B1), soft floor irregularity (B2), and structural element discontinuity (B3).

These checks are as shown in Table 2. During the checks, The analysis indicates that the majority of the control criteria specified for all three models were met. Only Model 3 was found to exceed the control criterion specified for torsional irregularity.

The results of the analysis, which was performed considering the structural designs of the models, show that the eccentricity originating from the mass and stiffness center causes torsion in the buildings, leads to displacement due to the asymmetric load distribution between the floors, and consequently makes the seismic behavior uncertain. The results for all three models are given in Table 3.

Table 2. Irregularity Checks (According to TBDY)

Irregularity Type	Check Criteria	Model 1	Model 2	Model 3
A1–Torsional Irregularity	If $\eta_{bi} > 1.2$	≤1.18	≤1.17	>1.20 (fail)
A2–Floor Discontinuity	Discontinuity in clearance/gap	Yok	Yok	Yok
A3–Plan Projection/Recess	Mass–stiffness mismatch	Yok	Yok	Yok
B1–Weak Floor Irregularity	> 0.8	<0.8	<0.8	<0.8
B2–Soft Floor Irregularity	> 2.0	1.72>	1.59>	1.58>
B3–Discontinuity of Load-Bearing Elements	Discontinuity between upper and lower floors	Yok	Yok	Yok

The results of the irregularity checks (Table 3) show that all models meet the A2, A3, B1, B2, and B3 irregularity criteria. However, it was determined that Model 3 exceeded the A1 torsion irregularity criterion ($\eta_{bi} > 1.2$). This result reveals that irregular plan geometry directly increases the torsion effect and that the mismatch between mass and stiffness centers becomes more pronounced in irregular structures.

Table 3. Mass–Rigidity Centers

Floor		M_x Center	M_y Center	R_x Center	R_y Center	e_x (m)	e_y (m)
Model 1	5th Floor	5.99	9.10	6.00	9.09	0.01	0.01
	4th Floor	6.00	9.01	6.00	9.06	0.00	0.05
	3rd Floor	6.00	9.01	6.00	9.06	0.00	0.05
	2nd Floor	6.00	9.01	6.00	9.05	0.00	0.04
	1st Floor	6.00	9.01	6.00	9.06	0.00	0.05
	Ground	6.00	9.01	6.00	9.06	0.00	0.05
Model 2	5th Floor	7.63	9.00	7.92	9.00	0.09	0.00
	4th Floor	5.90	9.00	6.57	9.00	0.67	0.00
	3rd Floor	5.69	9.00	6.46	9.00	0.77	0.00
	2nd Floor	5.69	9.00	6.51	9.00	0.82	0.00
	1st Floor	5.69	9.00	6.68	9.00	0.99	0.00
	Ground	5.69	9.00	6.41	9.00	0.72	0.00
Model 3	5th Floor	3.55	9.00	5.41	9.00	1.86	0.00
	4th Floor	6.07	9.00	6.08	9.00	0.01	0.00
	3rd Floor	6.26	9.00	6.58	9.00	0.32	0.00
	2nd Floor	6.26	9.00	6.70	9.00	0.44	0.00
	1st Floor	6.26	9.00	6.87	9.00	0.61	0.00
	Ground	6.26	9.00	6.88	9.00	0.62	0.00

According to Table 3, eccentricity values (e_x, e_y) in Model 1 are negligible (0.00–0.05 m). In Model 2, eccentricity in the x-direction ranges from 0.67 to 0.99 m; despite its semi-regular structure, the center of rigidity changes significantly between floors. In Model 3, eccentricity reaches up to 1.86 m in the top floor, indicating a significant torsional effect consistent with A1 irregularity. These data show that plan asymmetry dramatically increases the distance between mass and stiffness centers.

As a result of the calculations, the behavior in the first three modes according to the modal analysis findings is given in Table 4. At the same time, according to the analysis results, the displacement and relative displacement results of each model are also obtained as given in Table 5.

The modal analysis results (Table 4) present the following key findings:

- Model 1: Due to the regular pattern, a balanced distribution is observed between modes, with the torsion mode in second place and an effective mass ratio of around 78%.
- Model 2: Although the torsion mode is again dominant in the second mode, the translation in the Y direction carries a very high mass ratio in the first mode.
- Model 3: The first period has the longest period value at 1.50 s, which is an indication of stiffness loss and asymmetric behavior. The effective mass ratio of torsion (%77.35) is the highest among the three models.

This analysis demonstrates that irregularly planned buildings have both longer periods and increased torsional effects on mode dominance.

Table 4. Modal Analysis Results (First 3 Modes)

Model	Mode No	Period T (s)	Frequency f (Hz)	Dominant Mode Shape/ Direction	Effective Mass Ratio X (%)	Y (%)	Rz (%)
Model 1	**Mod 1**	0.8467	1.186	Y-direction (UY) displacement	0.52	77.43	3.97
	Mod 2	0.6384	1.566	Torsion (RZ)	5.13	10.14	78.15
	Mod 3	0.8183	1.221	X-direction (UX) displacement	74.72	2.57	7.15
Model 2	**Mod 1**	1.1274	0.887	Y-direction (UY) displacement	76.86	0.06	2.21
	Mod 2	0.6406	1.561	Torsion (RZ)	3.98	27.80	73.9
	Mod 3	0.6051	1.654	X-direction (UX) displacement	0.73	78.95	0.96
Model 3	**Mod 1**	1.5022	0.665	Y-direction (UY) displacement	0.66	77.36	6.52
	Mod 2	0.6863	1.458	Torsion (RZ)	6.39	3.26	77.35
	Mod 3	0.6504	1.537	X-direction (UX) displacement	77.35	3.46	6.51

Table 5. Floor Displacement and Relative Displacements

Story No	Model 1 ΔX (mm)	ΔY (mm)	Displacement X (%)	Y (%)	Model 2 ΔX (mm)	ΔY (mm)	Displacement X (%)	Y (%)	Model 3 ΔX (mm)	ΔY (mm)	Displacement X (%)	Y (%)
5th Floor	3.59	3.27	0.40	0.41	2.52	2.71	0.32	0.30	3.57	2.92	0.41	0.32
4th Floor	4.07	3.28	0.45	0.41	3.15	2.79	0.40	0.31	2.99	3.45	0.34	0.39
3rd Floor	4.56	4.36	0.50	0.55	4.19	2.94	0.53	0.33	3.43	4.16	0.39	0.46
2nd Floor	4.75	5.19	0.52	0.65	4.99	2.88	0.63	0.32	3.65	4.69	0.41	0.52
1st Floor	4.35	5.17	0.48	0.65	5.12	2.51	0.65	0.28	3.50	4.66	0.40	0.51
Ground	2.70	3.09	0.30	0.39	3.31	1.63	0.42	0.18	2.59	3.32	0.29	0.37

When examining the displacements in Table 5, the displacement distribution in Model 1 is balanced, with a maximum displacement of approximately 5.19 mm. In Model 2, relative displacements in the X direction reach up to 0.65%, which is higher than in the regular structure. In Model 3, displacements in both the X and Y directions are higher than in Model 1, but the most notable feature is the displacement profile, which shows a distinct irregular increase and decrease between floors. These results indicate that plan irregularity directly negatively affects floor displacement performance.

During the analysis of the models, the horizontal seismic forces acting in both directions on each floor of each model are as shown in Table 6. The overturning moments and ratios generated in the models are also provided in Table 7.

Table 6. Seismic Loads Affecting Floors

Story No	Model 1		Model 2		Model 3	
	F_x (tf)	F_y (tf)	F_x (tf)	F_y (tf)	F_x (tf)	F_y (tf)
5th Floor	4.71	3.40	6.58	13.11	8.57	7.52
4th Floor	31.54	22.81	24.81	49.42	47.58	41.70
3rd Floor	30.36	21.95	22.52	44.87	46.06	40.37
2nd Floor	22.77	16.46	16.89	33.66	34.55	30.28
1st Floor	15.18	10.98	11.26	22.44	23.03	20.19
Ground	7.59	5.49	5.63	11.22	11.52	10.09

According to Table 6, Model 3 has the highest seismic loads on all floors. In particular, the Fx and Fy values on the 4th and 3rd floors show increases of up to approximately 50% compared to the regular model. This situation reveals that seismic loads affect the structure more irregularly and intensely due to asymmetry in stiffness and mass distribution.

When Table 7 is evaluated, the Mx ratio is similar in Model 1 and Model 3 (0.113%), but lower in Model 2 (0.091%). My ratio, on the other hand, reaches its highest value in Model 3 (0.150%). This result indicates that Model 3 is particularly disadvantaged against overturning due to vertical eccentricity and torsion effects.

Table 7. Comparison of Overturning Moments

Parameter	Model 1	Model 2	Model 3
ΣMx(vertical) (tfm)	10499.54	10499.40	16125.52
ΣMx(siesmic) (tfm)	1191.45	957.39	1828.22
Ratio	0.113	0.091	0.113
ΣMy(vertical) (tfm)	15734.08	16655.26	10657.93
ΣMy(seismic) (tfm)	861.43	1907.42	1602.39
Ratio	0.055	0.115	0.150

7. CONCLUSIONS

In this study, the seismic behaviors of three reinforced-concrete buildings with regular (Model 1), semi-regular (Model 2), and irregular (Model 3) plan geometries were compared in accordance with the criteria of TBDY (2018), and the obtained findings were evaluated particularly in terms of torsional effects, mode shapes, story drifts, earthquake loads, and overturning moments.

Based on the analysis results presented above, it is evident that Model 1 exhibited the most efficient seismic performance among the three models, while Model 3 contains several seismic vulnerabilities.

The overall findings of the study reveal the following key conclusions:

1. The regular plan (Model 1) demonstrated the most balanced behavior in terms of eccentricity, torsion, and drift. This confirms that the concept of plan regularity, as defined in contemporary seismic codes, directly contributes to improved seismic performance.
2. The semi-regular plan (Model 2) produced higher drift and earthquake load values in certain directions; however, it remained within the allowable torsional irregularity limits.

3. The irregular plan (Model 3) exhibited the poorest performance across all dynamic parameters. It's very high eccentricity, dominant torsional modes, longer natural periods, increased seismic loads, higher overturning moment ratios, larger drift values, and the highest material/cost demand indicates that it represents the least favorable option from a seismic engineering perspective.

In conclusion, plan regularity is a decisive factor influencing the seismic resilience of buildings; moreover, the results quantitatively demonstrate that architectural design decisions, not only structural engineering considerations, have a significant impact on earthquake safety. In addition to these findings, the evaluation of the buildings in terms of formwork, concrete, and reinforcement quantities, as presented in Tables 8 and 9, clearly shows that a regular-plan building offers substantial economic advantages compared to an irregular-plan building.

Table 8. Quantity Distribution of Structural Elements in Models

Model 1	**Formwork**	**Concrete**	**Reinforcement**							
			∅8	**∅10**	**∅12**	**∅14**	**∅16**	**∅18**	**∅20**	**∅22**
	(m^2)	**(m^3)**	**(kg)**							
Floors	908.45	136.27	7049.63							
Beams	478.91	57.79	2142.23		2252.20	1023.27	1150.17			
Shear Walls	186.52	31.10		1857.01				3315.75		
Columns	306.31	36.86		4137.66				4176.38		
Foundations	60.00	216.00			1119.92		197.70	34.64		14482.39
Total	**1940.19**	**478.02**	**9191.86**	**5994.67**	**3372.12**	**1023.27**	**1347.87**	**7526.77**	**-**	**14482.39**

Model 2	**Formwork**	**Concrete**	**Reinforcement**							
			∅8	**∅10**	**∅12**	**∅14**	**∅16**	**∅18**	**∅20**	**∅22**
	(m^2)	**(m^3)**	**(kg)**							
Floors	870.98	130.65	6284.91							
Beams	501.65	60.763	2415.98		2554.14	928.79	872.74			
Shear Walls	265.64	45.619		2597.74				4681.05		
Columns	466.45	68.832		7594.51				7509.23		
Foundations	60.00	216.00			1119.92		173.82	41.90	60.84	14362.79
Total	**2164.72**	**521.86**	**8700.89**	**10192.25**	**3674.06**	**928.79**	**1046.56**	**12232.18**	**60.84**	**14362.79**

Model 3	**Formwork**	**Concrete**	**Reinforcement**							
			∅8	**∅10**	**∅12**	**∅14**	**∅16**	**∅18**	**∅20**	**∅22**
	(m^2)	**(m^3)**	**(kg)**							
Floors	876.57	108.98	6420.65							
Beams	548.41	65.41	2967.42	139.57	3702.74	388.75	348.34			
Shear Walls	648.75	78.35		5091.7				8658.72		
Columns	417.65	48.10		5276.21				5839.05		
Foundations	48.88	180.73			1011.26		212.79	2821.07		
Total	**2540.26**	**481.56**	**9388.07**	**10507.48**	**4713.99**	**388.75**	**561.13**	**27318.84**	**-**	**-**

Table 9. Comparison of Models Quantity Take-off

		Model 1	**Model 2**	**Model 3**
Formwork	**(m^2)**	1940.19	2164.72	2540.26
Concrete	**(m^3)**	478.02	521.86	481.56
Reinforcement				
(∅ 8- ∅ 12)	**(kg)**	18558.65	22567.2	24609.54
(>=∅14)	**(kg)**	24380.29	28631.16	28268.72
(Total)	**(kg)**	42938.95	51198.36	52878.26

Assuming that all three models are feasible for construction, an economic assessment of the material quantities presented in Table 9 was conducted to clearly illustrate the cost differences among the models. Considering İzmir-scale construction unit prices—including material, transportation, and labor costs—the following rates were adopted: 20.80 USD/m² for formwork**,** 92 USD/m³ for concrete, and 1.23 USD/kg for reinforcement**.** Based on these unit costs, the results shown in Table 10 were obtained. According to these results, when the total cost difference between the regular-plan building (Model 1) and the irregular-plan building (Model 3) is examined, the results clearly demonstrate irregular buildings inevitably incur an additional cost of approximately 18.25%**.**

Table 10. Comparative Cost Analysis of the Models

	Model 1	**Model 2**	**Model 3**	**Difference**	**% Difference**
Formwork	$40356	$45026	$52837	$12481	30.93
Concrete	$43978	$48011	$44303	$325	0.74
Reinforcement	$52813	$62974	$65040	$12227	23.15
Total	$137147	$156011	$162180	$25033	18.25

With the acceleration of urban transformation processes, the building production culture in our country is expected to undergo significant transformation soon. The fact that earthquake-induced damages arise not only from construction defects but also from shortcomings in the architectural design process makes the responsibilities of architects increasingly visible within the scope of urban transformation. This circumstance heightens the necessity for architects to produce qualified and holistic designs in transformation projects, while also obligating contractor firms to recognize the critical role of design in ensuring safe and sustainable building production.

Within this framework, it becomes essential for contractor firms to adopt the principle of creating "regular and resilient structures" in urban transformation and to demand higher-standard, earthquake-resistant design solutions from architects. To cultivate such awareness, it is necessary for the Chamber of Architects to expand its professional training programs to include the technical and regulatory knowledge required for urban transformation and to ensure the active participation of both architects and representatives of contractor firms in these programs.

Such a shared platform of training and awareness will strengthen communication between design and construction practices throughout the urban transformation process and will make a significant contribution to the development of safer, healthier, and longer-lasting urban environments.

REFERENCES

AFAD (2023). *Türkiye Deprem Tehlike Haritası ve Risk Değerlendirme Raporu*.

Antoniou, S., Pinho, R. (2004). Development and verification of a displacement-based adaptive pushover procedure. *Journal of Earthquake Engineering, 8*(5), 643–661.

Barros, R.C., Almeida, J. (2005). Nonlinear analysis of irregular RC buildings: Torsional effects. *Engineering Structures, 27*(3), 319–334.

Bassurucu, M., Yıldız, Ö., Kına, C., (2025). Seismic performance assessment of an RC building due to strong ground motion records: A case study from Adıyaman, Türkiye. *Buildings*, 15(4), 521.

Bhandari, M., Kumbhar, P. (2013). "Seismic Analysis of Building with and without Plan Irregularity." *International Journal of Emerging Technology and Advanced Engineering*, 3(9).

Bozorgnia, Y., & Bertero, V.V. (2004). *Earthquake Engineering: From Engineering Seismology to Performance-Based Engineering*. CRC Press.

Bruneau, M., Chang, S.E., Eguchi, R.T., Lee, G.C., O'Rourke, T.D., Reinhorn, A.M., Von Winterfeldt, D. (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthquake Spectra*, 19(4), 733–752.

CEN (2004). *Eurocode 8: Design of Structures for Earthquake Resistance*.

Chopra, A.K. (2020). *Dynamics of Structures: Theory and Applications to Earthquake Engineering.* 5th ed., Pearson.

De Stefano, M., Pintucchi, B. (2008). Structural irregularities in plan and seismic response: State of the art. *Engineering Structures*, 30(2), 361–371.

Doğangün, A. (2004). "Performance of Reinforced Concrete Buildings During the May 1, 2003 Bingöl Earthquake in Turkey." *Engineering Structures*, 26(6), 841–856.

Fardis, M.N. (2009). *Seismic Design, Assessment and Retrofitting of Concrete Buildings.* Springer.

Gupta, S.K. (2025). Seismic Response of Regular and Irregular Buildings with Different Soil Conditions. *International Journal for Multidisciplinary Research*, 7(3), 1-12.

Humar, J. L., Kumar, P. (1999). "Effect of In-Plan Torsional Irregularity on Seismic Response of Buildings." *Earthquake Engineering & Structural Dynamics*, 28(11), 1191–1212.

Kappos, A. J. (1999). *Seismic Design and Performance Assessment of Reinforced Concrete Buildings*. Springer.

Kılıç, S., Akbaş, B. (2007). "Burulma Düzensizliklerinin Betonarme Binaların Deprem Davranışı Üzerindeki Etkileri." *İMO Teknik Dergi*, 18(3), 4393–4412.

Kumar, S., Rai, D.C. (2011). Seismic performance of buildings with plan irregularity. *Proceedings of the 8th International Conference on Earthquake Resistant Engineering Structures*.

Mahi, Md.S.H., Ridoy, T.A., Hasan, S., (2025). Seismic Performance Assessment of Regular and Irregular RC Buildings Under BNBC 2020 Using ETABS. *Disaster in Civil Engineering and Architecture*, 2(1), 1-18.

McAllister, T. (2015). *Developing Guidelines and Standards for Disaster Resilience of the Built Environment*. NIST Report.

Naeim, F. (2001). *The Seismic Design Handbook* (2nd ed.). Springer.

Pankaj, J.S., Reddy, G. S. (2017). Seismic Analysis of Irregular Buildings with Varying Soil Conditions: A Review. *Journal of Engineering Science and Technology*, 12(8), 2073-2089.

Paulay, T., Priestley, M.J.N. (1992). *Seismic Design of Reinforced Concrete and Masonry Buildings*. Wiley-Interscience.

Rutenberg, A. (1982). “Torsional Effects in Multistory Buildings.” *Journal of the Structural Division*, 108(12), 2685–2701.

Taranath, B.S. (2013). *Structural Analysis and Design of Tall Buildings: Steel and Composite Construction*. CRC Press.

TBDY (2018). *Türkiye Bina Deprem Yönetmeliği*. Ankara: T.C. Çevre ve Şehircilik Bakanlığı.

Yılmaz, A., Öncü, M.E. (2025). Deprem etkisi altında yumuşak kat düzensizliğine sahip betonarme binaların hasar görebilirlik analizi. *Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi*, 28(3), 1574-1590

CHAPTER 2

CLIMATE-RESPONSIVE THERMAL PERFORMANCE AND PASSIVE DESIGN OF ROCK-HEWN ARCHITECTURE IN CAPPADOCIA, TÜRKIYE

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Introduction

The building sector stands at a critical crisis, responsible for approximately 34% of global energy demand and related CO_2 emissions (United Nations Environment Programme, 2025). This reality necessitates a fundamental shift away from a reliance on fossil-fuel-based mechanical systems toward a paradigm of climate-responsive design. In this context, vernacular architecture, refined through centuries of local adaptation, offers a profound repository of time-tested passive strategies. Among these, rock-hewn and earth-sheltered architecture stands out as a prime example of climate-responsive design, utilizing the immense thermal mass of the earth to provide natural thermal comfort (Crespo et al., 2009:611; Mangeli et al., 2023).

Among the most distinctive examples of vernacular architectural heritage is the architecture of Cappadocia in central Türkiye, a UNESCO World Heritage site. While the thermal benefits of these structures are widely acknowledged, they are often treated as monolithic entity. Previous research has established a foundational understanding of the region's building practices (Özata, 2015). However, a lack of comparative, quantitative analysis that differentiates the performance of these various rock-hewn typologies is a critical gap that remains in the literature. It is not yet fully understood how factors such as the degree of earth-sheltering and the integration of masonry create a distinct hierarchy of thermal performance.

This paper addresses this specific gap by presenting an in-situ, comparative analysis of four distinct architectural typologies in Cappadocia. By systematically measuring and comparing the hygrothermal performance of deep underground, shallow underground, hillside rock-cut, and rock-cut and masonry (integrated) structures, this study moves beyond a general appreciation of vernacular knowledge. The aim is to quantify the performance differences and establish a clear hierarchy of strategies. Ultimately, this research provides empirical data and actionable principles derived from this proved knowledge, offering a robust foundation for future climate-responsive architectural design. The paper begins by establishing the theoretical framework, followed by a detailed methodology, a presentation of the quantitative results, a discussion of their implications, and a conclusion that summarizes the key findings and their significance.

Theoretical Framework of Climate-Responsive Practices

The principles of climate-responsive design have evolved through a union of intersecting architectural philosophies. This progression, conceptualized in Figure 1, maps the expedition from the foundational wisdom of vernacular architecture to more contemporary concepts. "The historical timeline in the diagram is established based on the publication start years of influential works from the ScienceDirect database and other key academic sources.

This framework highlights how bioclimatic and passive design emerged in the mid-20th century by systematizing the performance-based strategies inherent in vernacular traditions. These principles subsequently informed a range of modern approaches, including green architecture and bio-inspired design, which all contribute to the broader goals of sustainable building. This paper focuses on the theoretical and practical continuum that extends from vernacular architecture to modern bioclimatic and passive design. To this end, the study presents a performance analysis of the rock-hewn dwellings of Cappadocia, a significant example of historical bioclimatic practice. The aim is to derive evidence-based principles that are applicable to contemporary climate-responsive design.

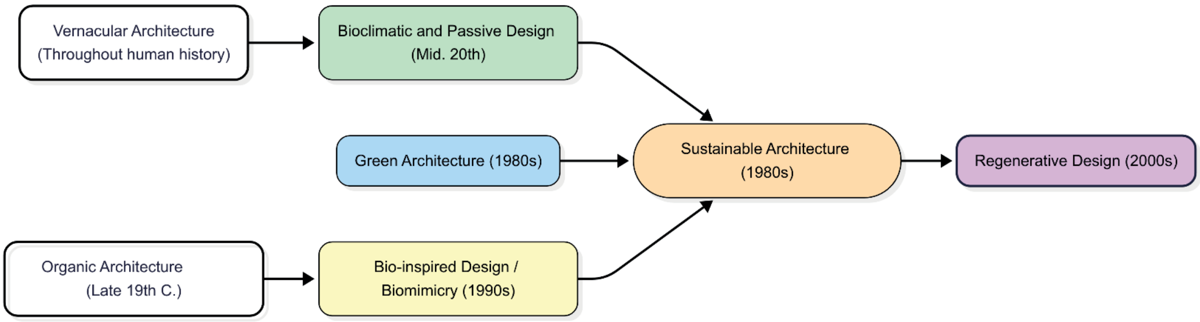


Figure 1. The evolution of climate-responsive architectural concepts (Prepared by the author)

The existing literature provides a strong foundation for this study, as summarized in Table 1. A primary theme is the design and construction of rock-cut architecture, which explores the global history and unique techniques of this typology. This is complemented by research on the performance of rock-cut & earth-sheltered buildings, providing empirical evidence of their thermal efficiency. These specific analyses are underpinned by the foundational principles of climate-responsive & vernacular architecture, a broader set of literature that articulates the theoretical link between climate, form, and energy. Finally, to understand the core mechanism behind this performance, the study also draws upon literature concerning the critical role of thermal mass.

As the key literature demonstrates, while the benefits of subterranean architecture are widely acknowledged, performance data is often specific to a particular region's unique climate and geology. For instance, significant research has focused on the temperate Mediterranean climate of Spain (Crespo et al., 2009:613), the diverse climatic zones of China (Zhu et al., 2020:1641) and the hot-arid conditions of Iran (Mangeli et al., 2022:21, 2023:443) and Jordan (Sharaf, 2020:4). Although foundational principles have been established through these valuable studies, there is a clear need for in-situ measurements to validate and adapt these principles within the distinct context of Cappadocia's volcanic tuff formations and continental climate. This study addresses this gap by conducting a detailed field investigation to quantify the thermal performance of these rock-hewn structures. The methodology for this investigation is detailed in the following section.

Table 1. Literature review of passive design principles in rock-cut, subterranean, and vernacular architecture

Thematic Area	Key Findings and Contributions	Relevant References
Design and Construction of Rock-Cut Architecture	• This architectural approach represents a universal and timeless practice with global examples holding potential for modern adaptation. • It employs specific excavation techniques that are fundamentally dependent on the geological properties of the local rock, such as tuff. • To achieve climatic adaptation, these structures utilize core design principles like spatial layering (the onion principle), minimal exterior openings, and deep integration with the topography.	(Crespo et al., 2009:614; Davidová & Uygan, 2017:9; Finneran, 2009:421; Jain & Garg, 2004:201; Ozata, 2015:139; Ozata & Arun, 2018:87)

Performance of Rock-Cut and Earth-Sheltered Buildings	• Research has quantified that these structures provide superior thermal comfort with minimal to zero energy consumption, primarily due to their high thermal mass and significant thermal lag. • It is proven that earth-sheltering can reduce heating and cooling energy needs by up to 75% compared to conventional buildings. • They also function as effective climatic buffers by moderating extreme daily and seasonal temperature fluctuations.	(Anselm, 2012:132; Mangeli et al., 2022:20, 2023; Mihalakakou et al., 2024:19; Wen et al., 2023:14; Zhu et al., 2020:1642)
Foundational Principles of Climate-Responsive and Vernacular Architecture	• Modern climate-responsive design evolves directly from the wisdom of vernacular precedents, which refined passive strategies like orientation and natural material use over centuries. • A core principle is the established scientific link between a region's climate, its architectural forms, and the resulting building energy performance. • This contrasts with some modern "green" buildings, which are critiqued for lacking the deep analysis of local context that is a core strength of vernacular solutions.	(Ayçam et al., 2020:14 ; Beccali et al., 2018:1731; Benachir et al., 2023:1025; Canas & Martín, 2004:1490; Kartal & Chousein, 2016:20; Özata & Arun, 2018:9; Pan et al., 2024:19; Xu et al., 2024:15)
The Critical Role of Thermal Mass / Inertia	• High thermal inertia is identified in the literature as a fundamental and universally applicable passive strategy for modulating indoor temperatures. • Studies consistently demonstrate a direct correlation between a building's thermal mass and its overall energy consumption. • The literature also confirms that the optimal level of thermal inertia is highly dependent on the specific climatic zone, requiring careful analysis for each application.	(Mushtaha et al., 2025:15; Sharaf, 2020:4; Toroxel & Silva, 2024:13; Verbeke & Audenaert, 2018:2312)

Methodology

This study employs a quantitative, in-situ field measurement approach to analyze the thermal performance of traditional rock-cut architecture in Cappadocia, Türkiye. The research is designed as a comparative case study focusing on capturing empirical data to understand how distinct architectural typologies respond to seasonal climate variations. A key aspect of this methodology, distinguishing it from many previous studies, is the inclusion of interior wall surface temperature measurements to accurately assess the role of thermal mass in radiant heat exchange.

Case Study Area and Context

The research was conducted in the Cappadocia region of Central Anatolia, Türkiye. The specific structures selected for this field study are all located within the central Cappadocian district of Ürgüp and its immediate vicinity. This area is known for its dense concentration of historical rock-cut dwellings, a fact underscored by recent surveys identifying over 1250 rock-cut storage spaces alone (Dinçer et al., 2020:134).

The area provides an ideal natural laboratory for this study due to its climate and geology. The region is characterized by a semi-arid, continental climate (Köppen-Geiger: BSk) with significant daily and seasonal temperature swings (Beck et al., 2018:8). The climate features cold, snowy winters and hot, arid summers. Figure 2 illustrates the region's high solar potential, highlighting the importance of the passive strategies embedded in its architecture.

Complementing the climate, the region's unique geology, composed of soft but massive volcanic tuff, has enabled the creation of extensive rock-hewn settlements over centuries. The classification of these settlements is central to the methodology of this research.

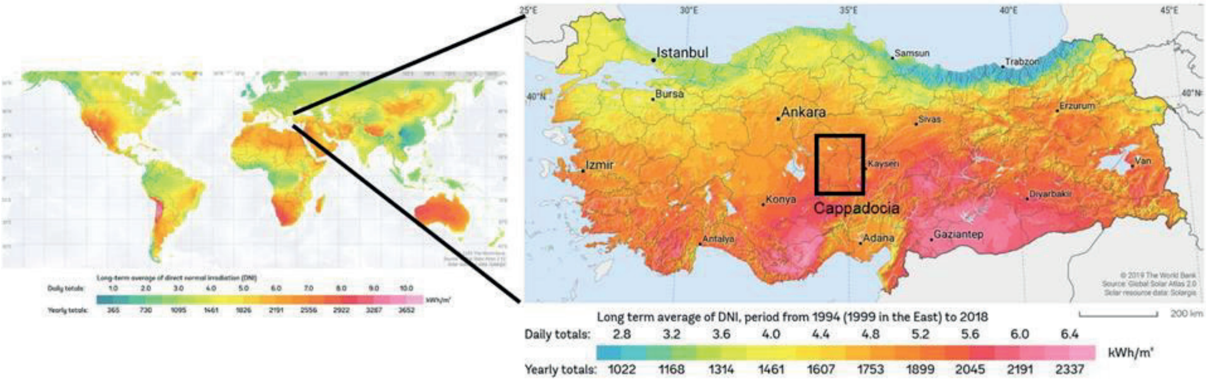


Figure 2. Solar resource map of direct normal irradiation (DNI) in Türkiye, highlighting the location of Cappadocia (adapted from (The World Bank, 2025)

Typology Selection and Data Collection

Rock-cut spaces are broadly defined as underground voids, mostly opened by human power, that are formed by carving a rock mass for various purposes (Özata, 2015). The selection of case study spaces for this research is grounded in the established typologies of subterranean architecture found in the literature. These structures are often categorized into general prototypes based on their relationship with the topography, such as slope, earth-sheltered, and buried configurations. Figure 3 illustrates these conceptual prototypes alongside their corresponding examples found in the Cappadocian context.

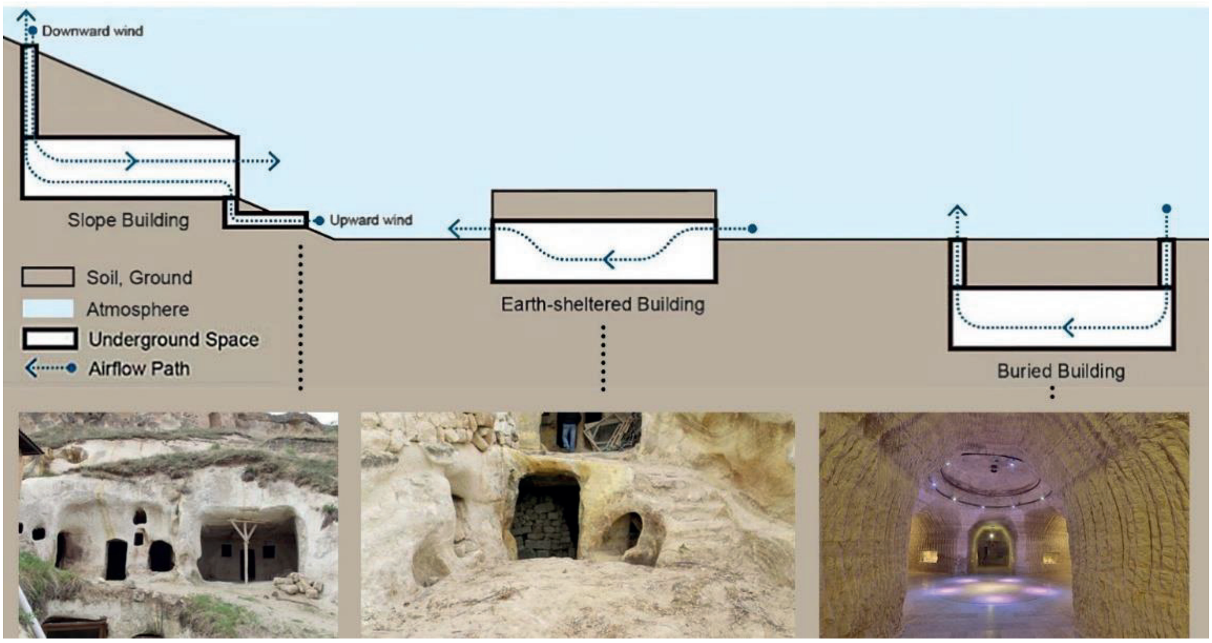


Figure 3. Common typologies of earth-sheltered and underground buildings (Wen et al., 2023:2) and their examples in Cappadocia (Personal archive of the author, 2023))

Building upon this established framework, this study defines and analyzes three primary typologies adapted to the Cappadocian context, with the first being further subdivided to allow for a more nuanced analysis. For each architectural typology, measurements were taken in a range of 5 to 15 different spaces to ensure the data represents the general performance of the category.

Figure 4 provides schematic representations of these typologies. The plans illustrate how rock-cut spaces are often formed organically, with new rooms being excavated adjacent to existing ones according to evolving needs. The sections, in turn, depict the distinct topographical relationships that define each typology analyzed in this study. The selected typologies are detailed below.

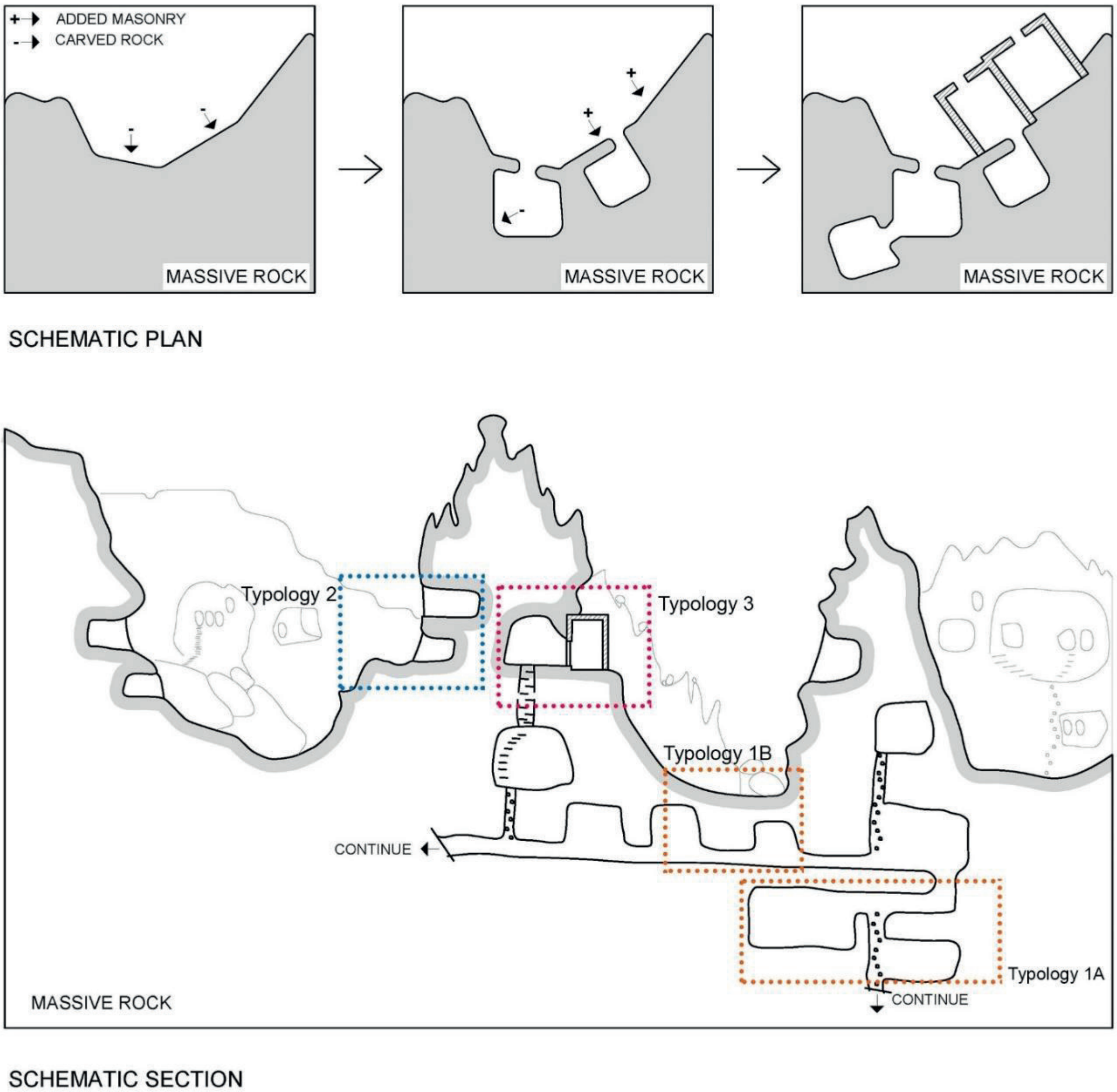


Figure 4. Schematic plans and sections of the selected typologies (Drawn by the author)

Typology 1: Underground Structures

This category corresponds to the buried building prototype in the literature. To investigate the specific impact of depth and the insulating properties of the surrounding earth mass, this typology is further subdivided into two groups:

1a. Deep underground: These are spaces situated well below the typical frost line, where the influence of daily and seasonal surface temperature fluctuations is minimized (Figure 4).

1b. Shallow underground: These are subterranean spaces located closer to the surface (Figure 4), making them potentially more susceptible to heat exchange with the upper ground layers.

Typology 2: Hillside Rock-Cut Structure

This typology is a direct equivalent of the slope building prototype, featuring a single exposed facade that directly interfaces with the outdoor environment (Figure 4).

Typology 3: Integrated Rock-Cut and Masonry Structure

This common hybrid form represents a combination of the slope building prototype with a conventional above-ground masonry structure, often incorporating windows and other openings (Figure 4).

Field measurements were conducted during the region's climatic extremes: winter (February 2023) and summer (July 2023). An ambient thermo-hygrometer was used to record the indoor air temperature (T, °C) and relative humidity (RH, %). A Protimeter Surveymaster was utilized to measure the interior surface temperature (T, °C). To ensure data reliability, measurements were taken at multiple (at least three) points within each space, and the final values reported in the analysis represent the average of these readings.

Results

The in-situ measurements provided quantitative data on the thermal performance of the four architectural typologies. This section presents these findings by first detailing the individual performance of each typology across seasons, supported by graphical analysis, and then by providing a summary comparison.

Performance of Underground Structures

The two underground typologies (Typology 1a & 1b) demonstrated a significant thermal buffering capacity, though their performance varied based on their depth. In winter, the average indoor ambient temperature was 2.5°C for Typology 1a (Deep) and 5.4°C for Typology 1b (Shallow). In summer, Typology 1a provided superior cooling with an average temperature of 17.4°C, compared to 22.8°C in Typology 1b. The distinct thermal behavior of each sub-typology, including the passive heating and cooling effects, is visualized in Figure 5a and Figure 5b.

Performance of Hillside Rock-Cut Structure

The hillside rock-cut structure (Typology 2) exhibited a pronounced radiant effect. In winter, while the average ambient temperature was low at 0.9°C, the average surface temperature was significantly warmer at 2.9°C. Conversely, in summer, the structure recorded the highest average ambient temperature of all types (26.8°C), but its surface remained the coolest (19.8°C). This strong radiant cooling phenomenon in summer is clearly illustrated in Figure 5c.

Performance of Integrated Structures

The integrated rock-hewn and masonry structure (Typology 3), with its exposed masonry and window elements, performed as the most thermally dynamic typology. It was the warmest in winter, with an average ambient temperature of 9.9°C, clearly benefiting from passive solar gains. In summer, it was the second warmest typology with an average temperature of 24.2°C. As shown in Figure 5d, the data points for this typology cluster indicate less of a temperature difference between the surfaces and the ambient air.

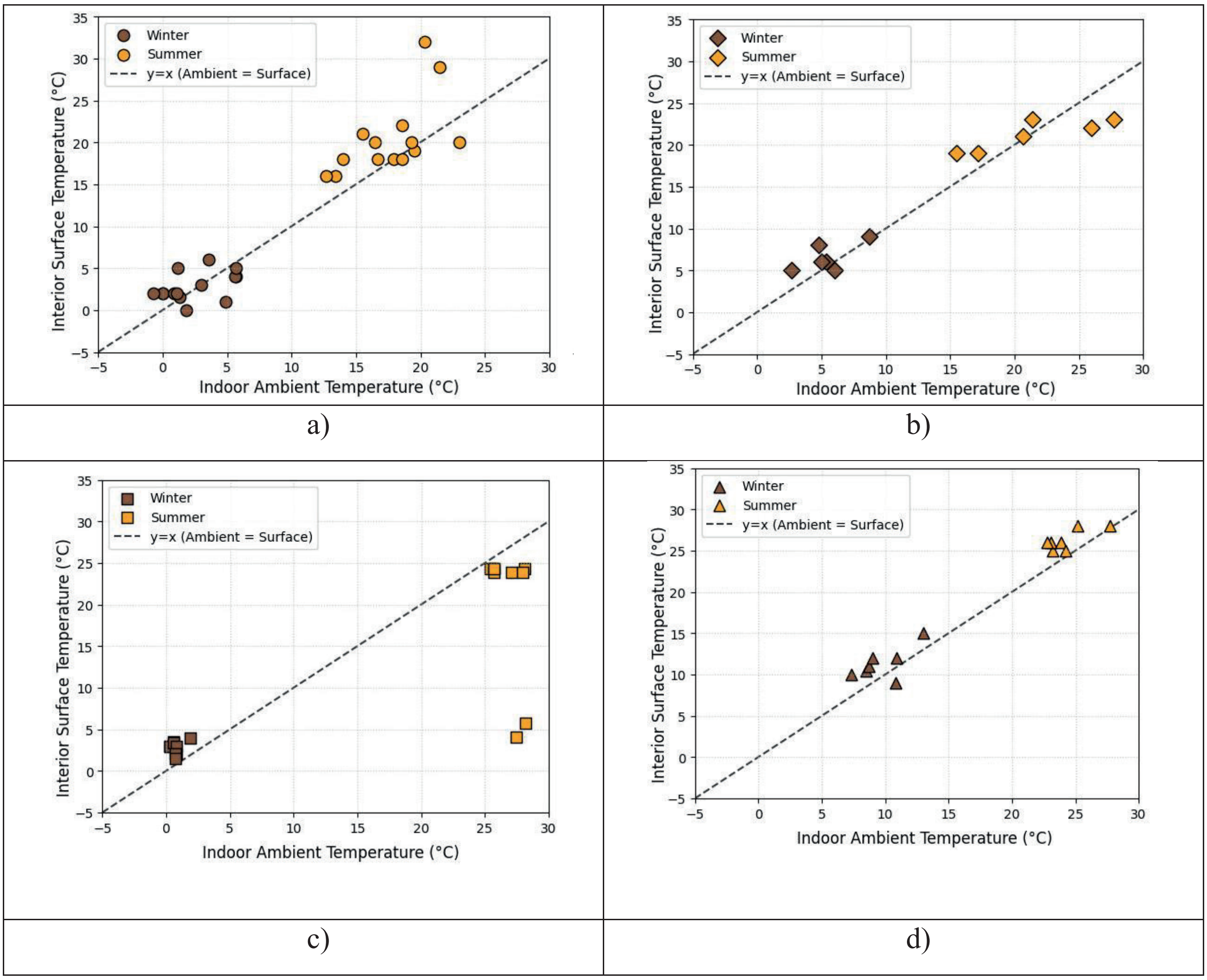


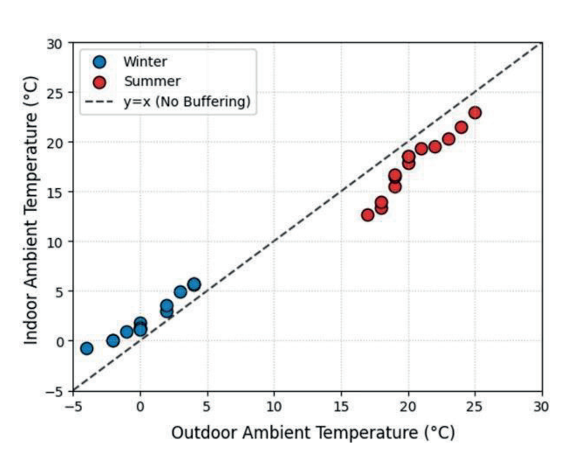
Figure 5. Interior surface temperature vs. indoor ambient temperature for (a) Typology 1a; (b) Typology 1b; (c) Typology 2, and (d) Typology 3

Analysis of Thermal Behavior

The integrated rock-hewn and masonry structure (Typology 3), with its exposed masonry and window elements, performed as the most thermally dynamic typology. It was the warmest in winter, with an average ambient temperature of 9.9°C, clearly benefiting from passive solar gains. In summer, it was the second warmest typology with an average temperature of 24.2°C. As shown in Figure 5d, the data points for this typology cluster indicate less of a temperature difference between the surfaces and the ambient air.

To visualize the distinct thermal behaviors, the relationships between key environmental parameters were plotted for each typology. Figure 5 illustrates the relationship between interior surface and indoor ambient temperatures. This plot highlights the passive heating and cooling effects of the thermal mass. In winter, most data points lie above the y=x line, indicating surfaces warmer than the air. In summer, the points shift below the line, indicating surfaces cooler than the air, particularly for the fully rock-cut typologies (Fig. 5a, 5b, 5c), while the integrated typology (Fig. 5d) shows a behavior closer to the neutral y=x line.

Figure 6 demonstrates the thermal buffering capacity of each typology by comparing indoor ambient temperatures against fluctuating outdoor temperatures. The deviation of data points from the y=x line represents the degree of insulation and thermal stability. The underground typologies (Fig. 6a, 6b) show the most significant buffering, with indoor temperatures remaining remarkably stable despite wide outdoor swings. In contrast, the hillside and integrated typologies (Fig. 6c, 6d) exhibit a stronger correlation with outdoor temperatures, indicating less thermal buffering due to their exposed facades.



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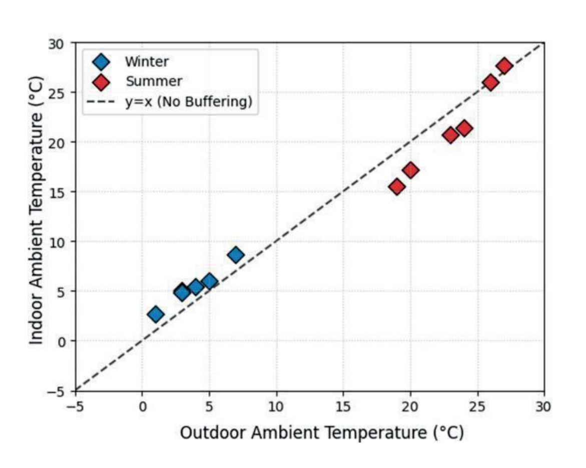

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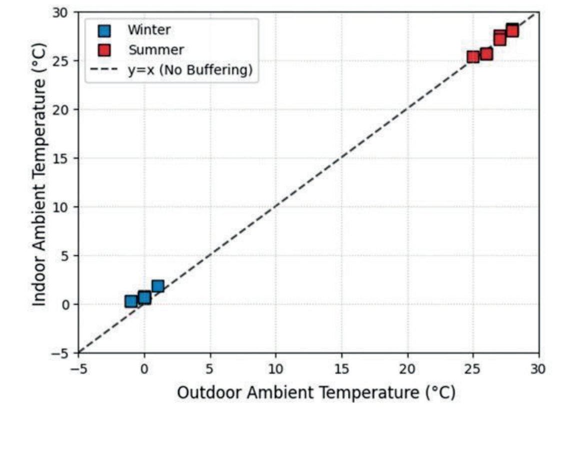

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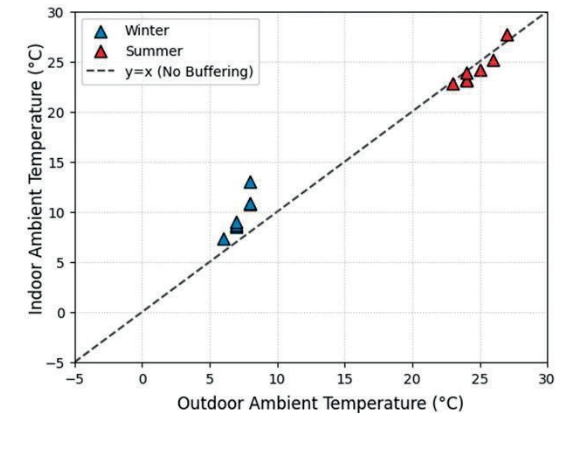
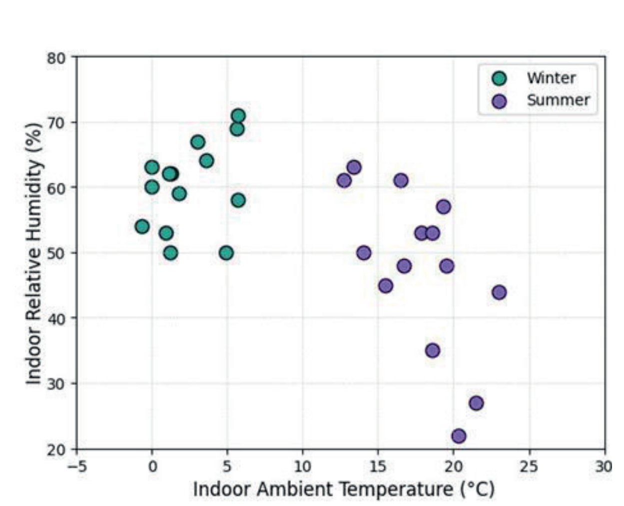


d)

Figure 6. Indoor vs. outdoor temperature for **(a)** Typology 1a; **(b)** Typology 1b; **(c)** Typology 2, and **(d)** Typology 3

Figure 7 explores the relationship between indoor temperature and relative humidity. The plots generally show an inverse relationship, where higher temperatures correspond to lower humidity. The underground typologies (Fig. 7a, 7b) maintain a more humid environment in summer compared to the other types. The integrated structure (Fig. 7d) shows the widest temperature range, while the hillside structure (Fig. 7c) displays a very tight clustering of data points, particularly in summer, indicating a consistent hygrothermal condition.



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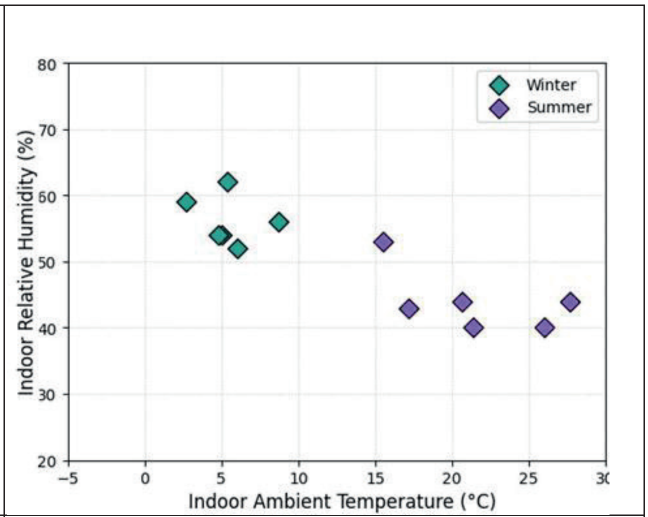

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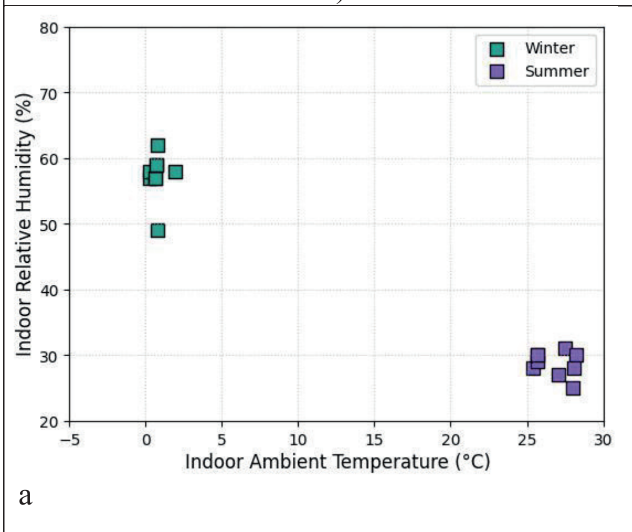

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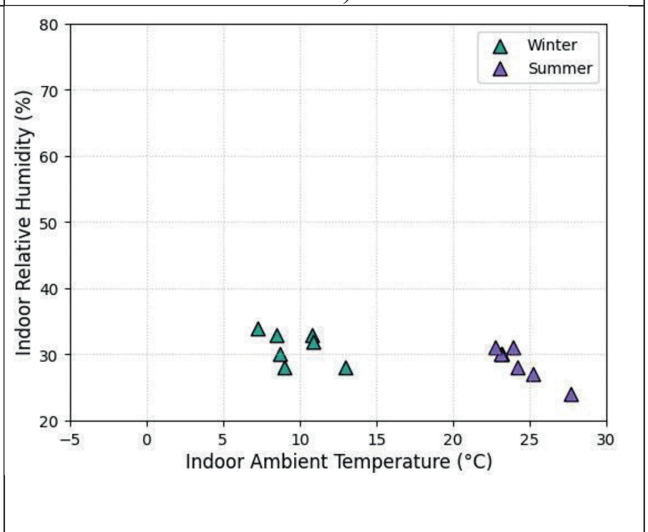

d)

Figure 7. Indoor Temperature vs. relative humidity relationship for **(a)** Typology 1a; **(b)** Typology 1b; **(c)** Typology 2, and **(d)** Typology 3

Summary of Comparative Performance

The overall comparative performance of all four typologies across both seasons is summarized in Table 2 and Table 3. These tables provide a quantitative basis for the analysis in the following section.

Table 2. Summary of winter thermal performance data

Typology	Indoor Ambient Temp. (Avg)	Indoor Surface Temp. (Avg)	Key Observation
1a. Deep Underground	2.5 °C	3.1 °C	Stable, buffered from frost
1b. Shallow Underground	5.4 °C	7.2 °C	Warmer than deep underground
2. Hillside Rock-Cut	0.9 °C	2.9 °C	Coldest ambient temperature
3. Integrated	9.9 °C	11.5 °C	Warmest due to solar gains

Table 3. Summary of winter thermal performance data

Typology	Indoor Ambient Temp. (Avg)	Indoor Surface Temp. (Avg)	Key Observation
1a. Deep Underground	17.4 °C	18.8 °C	Coolest and most stable
1b. Shallow Underground	22.8 °C	21.0 °C	Warmer than deep, cooler than others
2. Hillside Rock-Cut	26.8 °C	19.8 °C	Warmest ambient, but coolest surfaces
3. Integrated	24.2 °C	26.4 °C	Warm indoor & surface temperatures

Discussions

The quantitative results presented in the previous section confirm that Cappadocia's rock-hewn architecture provides a spectrum of sophisticated climate-responsive solutions. This discussion interprets these findings by analyzing the underlying physical principles, contextualizes them within the existing body of literature, and explores their implications for contemporary sustainable design.

Interpretation of Thermal Performance

The distinct thermal behaviors detailed in the results section become even clearer when all typologies are plotted on a single, three-dimensional hygrothermal profile (Figure 8). It reveals a clear performance hierarchy, where each typology occupies a unique zone within the 3D space, defined by its relationship with the earth and its architectural configuration. The data points form two distinct macro-clusters corresponding to winter and summer, within which each typology's unique fingerprint emerges. This overarching view allows for a deeper interpretation of each typology's strategy.

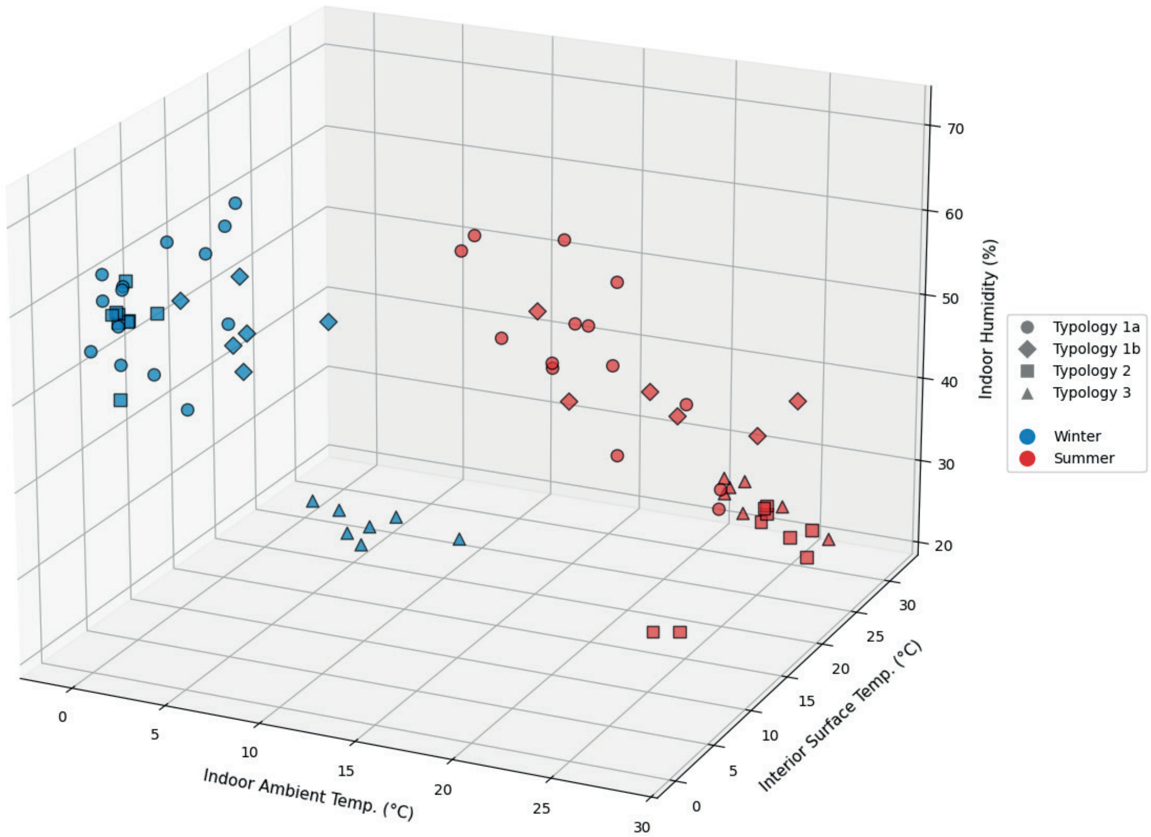

Figure 7. 3D Hygrothermal performance profile across typologies

Geothermal Stability in Deep Underground (Typology 1a) Structures

This typology, situated deep below the frost line, represents the purest form of passive design driven by geothermal inertia. As shown in Figure 6a, it is almost completely decoupled from outdoor temperature swings, providing the most stable indoor environment year-round. In summer, it offered the coolest refuge (17.4°C avg.), acting as a natural heat sink. In winter, it remained consistently above freezing (2.5°C avg.), demonstrating the deep earth's capacity to store and slowly release geothermal heat. This behavior aligns perfectly with the foundational principles of earth-sheltering documented by Anselm (2012:145) and validates this approach as a baseline for maximum passive survivability.

Surface-Influenced Buffering in Shallow (Typology 1b) Structures

In contrast, the shallow underground structures were consistently warmer than their deeper counterparts in both winter (5.4°C avg.) and summer (22.8°C avg.). This finding reveals a critical nuance: proximity to the surface introduces a new dynamic. These structures are more influenced by the temperature of the upper ground layers, which are in turn affected by seasonal solar radiation. While this makes them less stable than deep structures (as seen by the wider data spread in Fig. 6b compared to 6a), it results in a warmer, potentially more comfortable, indoor environment during the cold winter months, suggesting a deliberate adaptation for habitability.

The Critical Role of Radiant Exchange in Hillside (Typology 2) Structures

This typology presented the most complex and interesting behavior. It recorded the coldest ambient air in winter (0.9°C) and the warmest in summer (26.8°C). This might initially suggest poor performance. However, the surface temperature data reveals the true story. As visualized in Figure 5c, the interior surfaces were significantly warmer than the air in winter (+2.0°C) and dramatically cooler in summer (-7.0°C). This large difference highlights the dominance of radiant heat exchange for achieving thermal comfort. In summer, even if the air is warm, the cool rock surfaces provide significant comfort by absorbing radiant heat from occupants. This finding underscores a limitation of relying solely on-air temperature to assess comfort and proves the critical role of high thermal mass surfaces in passive cooling.

Seasonal Performance Shift in Hybrid (Typology 3) Structures

This typology clearly demonstrates the thermal consequences of combining vernacular rock-cut forms with conventional masonry. As expected, its south-facing windows and less massive masonry walls made it the warmest in winter (9.9°C avg.), effectively capturing passive solar gains. However, this advantage became a liability in summer (24.2°C avg.). The masonry elements heat up more quickly than the tuff rock, leading to higher indoor temperatures. As seen in Figure 5d, the proximity of data points to the y=x line indicates a reduced radiant cooling effect compared to the other types. This highlights the inherent trade-off in hybrid structures: improved winter comfort at the expense of reduced summer passive cooling capacity, a critical consideration for modern designers.

Contextualizing the Findings Within Existing Literature

These findings both align with and expand upon previous research. The exceptional thermal stability of the deep underground structure (Typology 1a) echoes the findings of Mangeli et al. (2022:20, 2023:448) in Iran and Canas & Martin (2004:1439) in Spain, who also attributed the comfort in subterranean dwellings to the high thermal inertia of the surrounding earth.

However, this study adds a crucial layer of nuance by providing a comparative, quantitative analysis of four distinct typologies within the same climatic region. While Davidová & Uygan (2017:9) identified spatial layering and airflow as key factors in Cappadocia, the findings of this study empirically demonstrate that the degree of earth-sheltering (deep vs. shallow) and the nature of the exposed facade (rock vs. masonry) are dominant parameters governing performance. The significant performance difference between Typology 1a and 1b, for instance, provides new data on the impact of depth, a factor not previously quantified in this specific context. Furthermore, the dramatic radiant cooling effect observed in Typology 2 (Fig. 5c) provides strong empirical evidence for a phenomenon that is often discussed theoretically but rarely measured in-situ in this manner.

Conclusion and Implications

Transcending mere historical insight, this study distills the thermal performance of Cappadocian vernacular architecture into a practical, evidence-based guide, serving as the conclusion of this research and outlining its direct implications for contemporary sustainable architecture.

A clear hierarchy of application emerges from the data. For programs that demand the most stable year-round temperature and humidity such as museums protecting sensitive artifacts, long-term food storage facilities like Cappadocia's numerous rock-cut depots, or climate-controlled archives the principles of Typology 1a (Deep Underground) are demonstrably superior. Its unparalleled geothermal stability naturally maintains a cool, consistent environment with minimal deviation. The success of the Güray Museum in Avanos, a modern subterranean facility operating almost entirely without mechanical HVAC, serves as a powerful, large-scale validation of this approach, proving that deep-earth integration is the most effective strategy where stability is the primary goal.

For functions where human comfort is paramount, such as in hospitality or year-round residential use, a more delicate approach is required. The slightly warmer and less damp conditions of Typology 1b (Shallow Underground) and Typology 2 (Hillside Rock-Cut) offer a more habitable baseline. These typologies strike an effective balance, leveraging significant thermal mass for buffering while allowing for greater (though still limited) interaction with the external environment. This strategy is visible in the successful adaptation of hillside structures by boutique hotels in the region, such as the Kayakapı Premium Caves. These establishments often place bedrooms in the deep, stable rock-cut rooms while situating common areas in more dynamic, integrated spaces, thus optimizing the performance of each vernacular form.

Finally, for mixed-use buildings, workshops, or community spaces where passive solar heating in winter is a desirable feature, Typology 3 (Integrated) provides a valuable model. Its application, however, requires careful design to mitigate the inherent risk of summer overheating. Modern design can enhance this typology by incorporating strategies like high-performance glazing, operable shading devices, green roofs on the masonry portions, and effective cross-ventilation schemes. This hybrid approach, when executed thoughtfully, offers the flexibility to create bright, daylit spaces without completely sacrificing the thermal benefits of the earth-sheltered components.

Ultimately, in an era demanding radical energy efficiency and sustainable building practices, this research demonstrates that Cappadocia's vernacular architecture is not a monolithic entity but a sophisticated toolkit of climate-responsive strategies. By understanding the specific performance hierarchy from the deep-earth stability of Typology 1a to the solar-responsive nature of Typology 3, designers can select and adapt these timeless principles to create energy-efficient, comfortable, and contextually appropriate buildings for a sustainable future.

REFERENCES

Anselm, A. J. (2012). Earth Shelters: A Review of Energy Conservation Properties in Earth Sheltered Housing. In Energy Conservation (pp. 128–149). InTech. https://doi.org/10.5772/51873

Ayçam, I., Akalp, S., & Görgülü, L. S. (2020). The application of courtyard and settlement layouts of the traditional diyarbakir houses to contemporary houses: A case study on the analysis of energy performance. Energies, 13(3), 1–17. https://doi.org/10.3390/en13030587

Beccali, M., Strazzeri, V., Germanà, M. L., Melluso, V., & Galatioto, A. (2018). Vernacular and bioclimatic architecture and indoor thermal comfort implications in hot-humid climates: An overview. Renewable and Sustainable Energy Reviews, 82(June 2017), 1726–1736. https://doi.org/10.1016/j.rser.2017.06.062

Benachir, N., Mouhib, T., & Bendriaa, F. (2023). Bioclimatic Architecture. SSRN Electronic Journal, 5(5–8), 1021–1027. https://doi.org/10.2139/ssrn.4541490

Canas, I., & Martín, S. (2004). Recovery of Spanish vernacular construction as a model of bioclimatic architecture. Building and Environment, 39(12), 1477–1495. https://doi.org/10.1016/j.buildenv.2004.04.007

Crespo, I. J., Barrera, M. del M., Ramos, L., & de Cárdenas, J. (2009). La arquitectura popular excavada: técnicas constructivas y mecanismos bioclimáticos (el caso de las casas-cueva del valle del Tajuña en Madrid). Actas Del Sexto Congreso Nacional de Historia de La Construcción: Valencia, October 2015, 603–618.

Davidová, M., & Uygan, E. (2017). Living in Bio-Climatic Layers: An Investigation of Cappadocian Caves in Relation to Today's Design and Its Futures. International Design Conference: DESIGN EVOLUTION [Education and Practice], February 2017, 1–12.

Finneran, N. (2009). Built by angels? Towards a buildings archaeology context for the rock-hewn medieval churches of Ethiopia. World Archaeology, 41(3), 415–429. https://doi.org/10.1080/00438240903112344

Jain, R. K., & Garg, R. (2004). Rock-cut congregational spaces in Ancient India. Architectural Science Review, 47(2), 199–203. https://doi.org/10.1080/00038628.2004.9697044

Kartal, S., & Chousein, Ö. (2016). Utilization of renewable energy sources in bioclimatic architecture in Greece. World Journal of Engineering, 13(1), 18–22. https://doi.org/10.1108/WJE-02-2016-002

Mangeli, M., Aram, F., Abouei, R., & Mehdizadeh Saradj, F. (2022). A New Look at Excavation Techniques and Design of Rock-Cut Architectures. Designs, 6(4), 1–23. https://doi.org/10.3390/designs6040064

Mangeli, M., Aram, F., Balderlu, S. A., Babayi, S., & Mosavi, A. (2023). Assessing indoor thermal comfort of rock-cut architecture in Meymand world heritage site during winter and summer. Energy Reports, 10, 439–450. https://doi.org/10.1016/j.egyr.2023.06.056

Mihalakakou, G., Paravantis, J. A., Nikolaou, P., Menounou, P., Tsangrassoulis, A. E., Malefaki, S., Fotiadi, A., Papadaki, M., Giannakopoulos, E., Romeos, A., Escobar-Hernandez, H. U., & Souliotis, M. (2024). Earth-sheltered buildings: A review of modeling, energy conservation, daylighting, and noise aspects. Journal of Cleaner Production, 472(August), 143482. https://doi.org/10.1016/j.jclepro.2024.143482

Mushtaha, E. S., Belpoliti, V., Hussien, A. A., Abdeen, A., Maksoud, A., Ghenai, C., Alsyouf, I., Almualim, A. A., Hamad, R., & Husein, L. A. (2025). Bibliometric analysis and multi-criteria decision-making (MCDM) approach for ranking passive design strategies in hot climates. Results in Engineering, 27, 106270. https://doi.org/10.1016/j.rineng.2025.106270

Ozata, S. (2015). Ecological Approaches from Past to Present: Traditional Architecture of Cappadocia Region. International Journal of Engineering and Technology, 7(4), 294–298. https://doi.org/10.7763/IJET.2015.V7.807

Özata, Ş. (2015). Kapadokya Bölgesi Kaya Oyma Yapı Sorunları ve Çözüm Önerileri. Yildiz Technical University.

Ozata, S., & Arun, E. G. (2018). Damage assessment for rock-cut dwellings and warehouses: A case study in Bahceli village, Cappadocia. Masonry International, 30(3), 81–90.

Özata, Ş., & Arun, E. G. (2018). Damage Assessment of Rock-Cut Ortahisar Castle in Cappadocia Region. Gazi University Journal of Science, 31(1), 1–11.

Pan, Y., Zhong, W., Zheng, X., Xu, H., & Zhang, T. (2024). Natural ventilation in vernacular architecture: A systematic review of bioclimatic ventilation design and its performance evaluation. Building and Environment, 253(February), 111317. https://doi.org/10.1016/j.buildenv.2024.111317

Sharaf, F. (2020). The impact of thermal mass on building energy consumption: A case study in Al Mafraq city in Jordan. Cogent Engineering, 7(1), 1–18. https://doi.org/10.1080/23311916.2020.1804092

The World Bank. (2020). Solar Resource Maps & GIS Data. Global Solar Atlas 2.0. https://globalsolaratlas.info/download/turkey (21.08.2025)

Toroxel, J. L., & Silva, S. M. (2024). A Review of Passive Solar Heating and Cooling Technologies Based on Bioclimatic and Vernacular Architecture. Energies, 17(5), 1–28. https://doi.org/10.3390/en17051006

United Nations Environment Programme. (2025). Global Status Report for Buildings and Construction 2024/2025: Not just another brick in the wall - The solutions exist. Scaling them will build on progress and cut emissions fast. In Engineering and Technology (Vol. 17, Issue 1). United Nations Environment Programme. https://doi.org/10.59117/20.500.11822/47214 (22.08.2025)

Verbeke, S., & Audenaert, A. (2018). Thermal inertia in buildings: A review of impacts across climate and building use. Renewable and Sustainable Energy Reviews, 82(August 2017), 2300–2318. https://doi.org/10.1016/j.rser.2017.08.083

Wen, Y., Lau, S.-K., Leng, J., Zhou, K., & Cao, S.-J. (2023). Passive ventilation for sustainable underground environments from traditional underground buildings and modern multiscale spaces. Tunnelling and Underground Space Technology, 134, 105002. https://doi.org/10.1016/j.tust.2023.105002

Xu, Y., Yang, Z., Zheng, X., Ren, J., Feng, C., & Tang, M. (2024). Thermal environments of vernacular dwellings and the adjacent alley in summer: An experimental study in Southwest China. Building and Environment, 261(May), 111634. https://doi.org/10.1016/j.buildenv.2024.111634

Zhu, J., Tong, L., Li, R., Yang, J., & Li, H. (2020). Annual thermal performance analysis of underground cave dwellings based on climate responsive design. Renewable Energy, 145, 1633–1646. https://doi.org/10.1016/j.renene.2019.07.056

Figure References

Figure 2: The World Bank. (2020). Solar Resource Maps & GIS Data. Global Solar Atlas 2.0. https://globalsolaratlas.info/download/turkey (21.08.2025)

Figure 3: Wen, Y., Lau, S.-K., Leng, J., Zhou, K., & Cao, S.-J. (2023). Passive ventilation for sustainable underground environments from traditional underground buildings and modern

multiscale spaces. Tunnelling and Underground Space Technology, 134, 105002. https://doi.org/10.1016/j.tust.2023.105002 (28.08.2025)

CHAPTER 3

ADAPTIVE SHADING SYSTEMS IN ARCHITECTURE: A COMPREHENSIVE REVIEW OF DYNAMIC FAÇADE STRATEGIES AND ENVIRONMENTAL PERFORMANCE

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1. INTRODUCTION

The building sector is one of the largest consumers of global energy and emitter of green house gases. The need for architects and engineers to transform the building envelope from a passive protective barrier into an active interface between the indoor and outdoor environments has become urgent because of climate change, rapid urbanization and stricter environmental regulations. Façades are a component of the building envelope and they manage solar radiation, heat exchange and visual comfort and thus directly impact building performance and occupants' comfort. Consequently, façade design has progressed from being a static passive element to being a responsive performance-oriented system.

Static passive shading elements, such as fixed louvers and overhangs, are the most common types of shading devices used to limit excessive solar gain and glare. Although fixed solutions can be efficient in specific climates, the performance of fixed shading devices is always limited due to the inability to adjust for temporal variations in solar position, weather patterns, and user needs. Consequently, these fixed shading devices often result in suboptimal daylight utilization, wasteful energy use, and compromised thermal comfort at various times throughout the year.

In order to address the shortcomings of fixed shading devices, new technologies have been developed through advancements in digital design tools, materials science, and building automation that enable the development of adaptive shading systems (also known as dynamic, responsive or kinetic façade systems). Adaptive shading systems have components that may alter their shape, function or behavior as the environment changes or if the system receives input from occupants. In addition to improving building energy efficiency, adaptive shading systems can also maintain both high levels of thermal and visual comfort by controlling solar access, daylighting and heat transfer at any moment in time.

As adaptive shading systems are an integration of architectural, engineering and environmental performance disciplines (Loonen et al., 2013) they have the potential to bring together mechanical devices, smart materials, sensors and control logic to enable real-time response. The ability of adaptive solutions to concurrently optimize multiple performance factors (such as, energy efficiency, occupant comfort and visual quality) makes adaptive shading a strategic methodology for creating contemporary sustainable and high-performance building designs (Moloney, 2009).

While adaptive shading systems are becoming more common in high-profile and experimental architectural projects; there are significant barriers to adoption including the high costs of implementing an adaptive solution, the inherent technical complexity of these systems, the necessity for ongoing maintenance and the need for end-user acceptance. In addition, the environmental effectiveness of adaptive shading systems is heavily reliant upon design decisions, the chosen control strategy and the regional climate in which the system is being operated. Thus, in order to effectively integrate adaptive shading systems into architectural practice, a detailed understanding of the type(s), operation and performance of adaptive shading systems must be developed.

The purpose of this book chapter is to create a comprehensive review of adaptive shading systems in architecture focusing on dynamic façade strategies and their impact on environmental performance. By integrating existing knowledge through literature reviews, this chapter will categorize adaptive shading systems, discuss the methods of control employed in adaptive shading systems and evaluate their effects on thermal comfort, daylighting performance and building energy consumption. In addition, this chapter will highlight selected case studies to demonstrate the application and performance of adaptive shading systems in real-world scenarios. Finally, this chapter will provide a structured and critical overview to assist researchers, designers and practitioners to understand both the potential and limitations of adaptive shading systems, and to identify areas of future development.

2. EXTERIOR SUN SHADING DEVICES: PRINCIPLES AND PASSIVE STRATEGIES

In the last few decades, there has been an increase in the use of buildings made with passive solar architecture principles to reduce energy consumption. It has become important to consider how buildings consume energy in addition to how buildings are insulated, ventilated, heated, and cooled. As a result, façade related components, especially those that provide exterior sun shading have become increasingly significant in the overall performance of buildings. The current use of environmentally friendly design principles to construct buildings has resulted in a renewed focus on natural ventilation and passive solar control systems, especially in locations with shading systems employed to manage solar gains before reaching the building envelope. Research on both passive and active solar control systems has demonstrated their potential to significantly reduce the amount of energy consumed by buildings.

A number of research projects that examine the incorporation of shading systems into façades have illustrated their effectiveness to reduce excessive solar heat gain and consequently reduce cooling loads and enhance indoor thermal comfort. Like those that study enhanced building envelopes, many studies of enhanced heating and cooling systems emphasize the need to take an integrated (holistic) approach when designing buildings for maximum energy efficiency (Kıyılmaz et al., 2021). Due to their relative high thermal transmission coefficients compared to other parts of the building envelope, exterior sun shading devices are commonly employed to reduce unwanted solar heat gains through windows.

With a growing emphasis in contemporary architecture on incorporating larger expanses of glass (in the form of curtain walls), and larger window openings to create a greater sense of transparency and connection between the interior and exterior of a building, there is an increased need to implement effective solar control strategies due to the increasing size and number of glazed components. Exterior sun shading devices are primarily used to increase thermal comfort and aid in energy-efficient designs by decreasing overheating and glare associated with solar radiation while allowing adequate daylight to penetrate into the building. Properly designed, shading systems may successfully modulate direct, diffused, and reflected solar radiation to create indoor environments that are well-balanced.

Historically, the broad application of mechanical air-conditioning systems in the early 20th century led to a general abandonment of traditional architectural strategies of passive cooling, including passive cooling by means of shading (Givoni, 1998). Architectural shading strategies were generally ignored until the energy crisis of the 1970s stimulated renewed interest in passive design principles (Givoni, 1998). Although initially the renewed interest in passive design principles was mainly directed toward commercial buildings in the 1990s, exterior sun shading devices have become increasingly important to a broader array of building types in recent years as a result of energy conservation objectives and sustainability agendas (Pérez-Lombard et al., 2008).

Shading systems represent one of the most flexible and simplest to implement passive cooling strategies across a wide range of climates where solar radiation has a major impact on building performance (Givoni, 1998). The thermal and daylighting performance of a building's envelope is directly related to the design of the envelope, and therefore shading devices are a component of the envelope. While shading devices are anticipated to provide sufficient solar protection during cooling seasons, they should also allow for beneficial solar gains during heating seasons, maintain daylighting access, and prevent restrictions on natural ventilation (Reinhart & Walkenhorst, 2001). Depending on design requirements, shading devices can be mounted on either the exterior or interior façade surfaces, embedded within double- or triple-glazed window systems, or as part of curtain wall assemblies.

Of these configurations, exterior shading devices are normally considered to be the most effective in preventing the buildup of solar heat in interior spaces, since they intercept solar radiation prior to the radiation reaching the building envelope. Regardless of whether interior shading devices possess reflective surfaces, a portion of the solar radiation they absorb is transferred into the interior space via convection. Therefore, the strategic placement of shading devices and consideration of the building's orientation, latitude, and climate will be essential to maximize the benefits of natural ventilation and daylight utilization.

In addition to enhancing the energy efficiency and indoor environmental quality of a building, exterior sun shading devices are also beneficial to the aesthetic and architectural value of a building. When appropriately chosen and incorporated, solar shading systems can significantly enhance the performance of a building, especially in areas with high solar exposure. Thus, solar shading elements are recognized as one of the most effective façade-based passive solar control strategies.

Building integrated solar shades are structural elements installed on an exterior façade to obstruct excessive amounts of solar radiation that enters a building while allowing natural daylight to enter a building's interior. By reducing excessive solar radiation, solar shading devices will provide improved thermal comfort to occupants of a building; reduce the amount of energy needed to cool a building; and also reduce the potential for glare that may cause visual discomfort (Tzempelikos, et al., 2007). Well-designed solar shading devices will also help create opportunities for passive heating through the greater amount of solar access they allow during the cooler months of the year, which occurs when the sun is located at lower angles. The ability of solar shading devices to be seasonally flexible provides an opportunity to create visual and thermal comfort for occupants of a building throughout the year.

Solar shading devices, in addition to being environmentally efficient, also have architectural value as they represent a combination of energy efficiency and aesthetic expression. Solar shading devices that are properly designed can contribute to the sustainability of buildings, the comfort of occupants, and contemporary architectural identity. Due to these factors, exterior sun shading devices are increasingly becoming recognized as essential parts of the design process for passive and sustainable building design. These devices serve as a foundation for developing more sophisticated and adaptable and dynamic shading systems that are discussed in detail in the subsequent sections.

3. FROM STATIC TO ADAPTIVE SHADING SYSTEMS: CONCEPTUAL FRAMEWORK AND TERMINOLOGY

With the intent to transform facades from static to adaptive systems, adaptive facade systems studies have become a primary focus for today's architectural community; due to an increasing recognition of the necessity to improve the energy performance and indoor air quality of buildings. Studies on dynamic system design have also grown, as part of a broader range of research efforts to develop materials, concepts and technologies that will improve the energy performance and environmental responsiveness of buildings. Ergin (2019) stated that Frei Otto was the first person to describe the concept of "Adaptive Architecture" and referred to adaptive systems as structures that can alter their form based on the change in the environment they exist in.

Due to increasing exposure to various types of climate-related change as a result of global warming, dynamic or adaptive facades have recently gained a significant amount of interest. Specifically, Dynamic Controlled Adaptive Building Facades were developed to react to variations in environmental parameters, including but not limited to; solar radiation, temperature, wind, or user needs. Therefore, it is essential to consider how we can use technology to make our buildings adaptive and responsive to changes in their environment. The use of the terms "Adaptive," "Dynamic," "Kinetic," "Smart," "Intelligent" and "Active" to describe façade systems are common in the literature, although these terms are often interchangeable to identify façade systems that are able to react to changing conditions, as opposed to simply operating statically.

The process of designing a façade involves the analysis of several parameters, all of which can potentially determine and affect the character and performance of a building. The degree of thermal and visual comfort experienced by occupants within interior spaces is heavily influenced by the control of solar radiation entering through the façade. The quantity of daylight that enters interior environments and influences indoor temperatures illustrates the interdependency between visual and thermal performance. One of the most basic and effective means to regulate solar access and establish a logical solar control strategy at the façade level is the application of shading devices (Ergin, 2019).

Dynamic facade systems have many benefits to users and to the environment. For users, adaptive facades can improve thermal and visual comfort, interior environmental quality and generally satisfy occupants better. Environmental benefits include improved energy efficiency, lower operating cost, less emission, and greater sustainable design for buildings. Therefore, developing adaptable facade systems with integrated technology to optimize energy use based on changing environmental conditions is central to the development of dynamic facades.

Static facade systems, or traditional facade systems, cannot adapt to changes in climate and user needs. Dynamic facade design advocates believe that building envelopes with adaptive shading systems are no longer simply static elements regardless of how transparent and glass-heavy they may be (Hraska, 2018). The ability to adjust the behavior of facades based on indoor and outdoor variables allows for improvements in energy efficiency, economic performance, and thermal comfort simultaneously.

Adaptive Facades may be defined as a type of control system with the ability to regulate both occupant comfort and the overall energy consumption of the building through the integration of a variety of systems. In this regard, simple adaptive shading devices (such as adjustable shades) are capable of providing superior thermal performance compared to fixed shading systems. Additionally, simple adaptive shading devices have the potential to provide further savings in cooling and lighting energy use. At the building level, the most significant concerns regarding indoor environmental quality affect to thermal comfort, which is influenced by both exterior climatic factors and interior architectural factors including building orientation, facade composition and design, and shading strategies (Nady, 2017).

As a result, choosing and designing façade systems is an integral component of the design process in Architecture and has a direct influence on both the thermal and visual conditions of indoor environments. Adaptive shading systems, as integral parts of dynamic facades, allow for regulating the flow of solar radiation, daylighting and heat transfer in a responsive manner. As such, the above represents the theoretical basis for classifying adaptive shading systems and evaluating their environmental performance. These topics will be explored further in the remainder of this chapter.

4. TYPOLOGIES OF ADAPTIVE SHADING SYSTEMS

Adaptive Shading Systems can be classified based on their principles of operation, materials and how they respond to changing environmental factors. In contrast to static shading systems (which have a specific purpose for a given set of conditions) Adaptive Shading Systems can alter either the method of operation or the way it operates as a result of changing climatic and indoor conditions. Through its ability to adapt to these changes, an adaptive shading system is able to better control the amount of solar radiation entering a space, daylight penetration into the space, and heat transfer between indoors and outdoors; all of which contribute to improving both energy efficiency and occupant comfort. From a review of the available literature, adaptive shading systems can generally be grouped by type into mechanical/kinetic adaptive systems, adaptive systems that utilize materials, and climate responsive/hybrid adaptive systems.

4.1 Mechanical and Kinetic Shading Systems

Kinetic or Mechanical Shading Systems (MSS) represent the most popular type of Adaptive Shading System (ASS) used in current architecture. MSS typically include movable parts, like Rotating Louver, Folding Panels, Sliding Screens and Retractable Components, all of which can be mechanically or electromechanically operated (Loonen et al., 2013; Reinhart & Walkenhorst, 2001). The operation of MSS can be either manual (by the occupant), or automated by Sensors and Control Algorithms (SCAs) based upon environmental input from parameters like Solar Radiation, Outdoor Temperature, or Daylight Level.

A principal benefit of MSS is the ability for them to dynamically alter the Shading Geometry as a function of Sun Angle at different times of day and seasonally (Tzempelikos & Athienitis, 2007). By changing the angle or position of the shading elements, MSS can significantly reduce Direct Solar Gains when cooling loads need to be minimized while allowing beneficial Solar Access when heating loads need to be maximized. Because of this capability, MSS have shown significant potential for reducing Cooling Loads, Glare Mitigation, and Enhancing Daylight Distribution in Interior Spaces (Bakker et al., 2014).

Despite their potential benefits, MSS have several drawbacks. The inclusion of mechanical components in MSS increases system complexity which could increase the cost of purchasing, maintaining, and potentially lead to failures of the MSS over time. In addition, the movement of façade elements could affect Architectural Expression and User Perception; therefore, careful integration into the overall Building Design will be necessary. Due to their established efficacy and technological maturity, MSS continue to dominate the area of Adaptive Façade Design.

4.2 Material-Based Adaptive Shading Systems

Adaptive shading systems that are based on materials utilize their inherent characteristics to produce a level of "smartness" with minimal mechanical action (Favoino et al., 2016). The system responds to environmental stimuli (e.g., temperature, solar radiation, humidity) by changing its physical properties; e.g., through shape transformation, phase transition, and/or optical property modification. Examples include shape-memory alloys, phase-change materials, thermochromic/photochromic materials and adaptive textile-based shading systems.

Smart materials offer many benefits when used for shading systems, primarily due to their relatively low mechanical complexity and the possibility of having lower maintenance requirements compared to mechanically driven systems. Smart materials have the capability to provide passive/semi-passive adaptation of shading elements as they continually respond to environmental changes without the need for additional energy input or complex control systems (Favoino et al., 2016). As such, smart materials are ideal candidates for low-energy/low-cost applications as well as retrofitting existing buildings. However, material-based adaptive shading systems have significant limitations regarding their durability, response times, and reliability over long periods of time. In addition, the performance of material-based systems can be limited due to the lack of precision/control in responding to highly variable environmental conditions to ensure optimal comfort levels. Moreover, the environmental performance of these systems is heavily dependent upon selecting suitable materials, as well as integrating them into the façade assembly. Researchers continue to investigate novel materials, specifically textile-based systems, to further advance material-driven adaptive shading systems, which will help alleviate some of these limitations and increase their applicability.

4.3 Climate-Responsive and Hybrid Shading Systems

Climate Responsive Shading Systems automatically alter the level of shading based on various environmental conditions including sunlight, daylight, wind, and temperature. Sensors and actuators work together to automatically alter the amount of shading a building receives as environmental conditions change. The primary function of Climate Responsive Shading Systems is to optimize a building's facade performance environmentally through multi-metric performance (visual quality, thermal comfort, energy efficiency). This is accomplished by using real-time automated control systems to enable a building's facade to maximize its environmental performance in a variety of climatic conditions. (Pérez-Carriamana et al., 2024)

Hybrid Shading Systems incorporate elements of both Mechanical and Material-based Shading Systems to create better performing and adaptable systems (Le, Bourdais, & Guéguen, 2014). Examples include combining Kinetic Shading Elements with Smart Materials to reduce the mechanical motion necessary to create shading; or combining Textile Shading Systems with sensor-driven controls to enhance response time. Hybrid Shading Systems have greater flexibility and robustness than single-function shading systems, providing designers the opportunity to develop customized shading solutions based on the specific climactic conditions and building types they design for.

Although Climate Responsive and Hybrid Shading Systems have great potential for improving the environmental performance of buildings, their successful application requires the proper integration of all components of the system, as well as reliable control logic and consideration of the needs of users (Le, Bourdais, & Guéguen, 2014). Failure to implement either reliable control logic or coordinate system components properly could result in poor system performance and/or occupant satisfaction. However, when properly developed and controlled, Climate Responsive and Hybrid Shading Systems represent a major advancement in the development of adaptive shading technology.

4.4 Comparative Performance Considerations

While Adaptive Shading Systems can differ in terms of how they operate and in level of complexity, many of the systems have similar factors that impact on how well they perform environmentally (design parameters) such as; location/climate, direction/orientation, amount of transparency/facade, and type of control used. In general, mechanical based systems offer higher levels of control and performance than do systems that utilize materials to control environmental loads, with the mechanical systems having an emphasis on passive responsive systems (material based) (Reinhart & Walkenhorst, 2001). The Hybrid/Climate Responsive systems attempt to provide the benefits of both mechanical and material based systems by providing a balance in performance.

Therefore, in selecting an appropriate Adaptive Shading System, consideration needs to be given to project specific objectives, climatic condition, and operational requirements. A good understanding of the advantages and disadvantages of each system will allow for a comparison of the systems environmental performance and assist in making educated decisions regarding Façade Design (Loonen et al., 2013). This typological approach also serves as the basis for reviewing control strategies and performance results which are reviewed further in the remainder of this chapter.

5. CONTROL STRATEGIES AND TECHNOLOGIES FOR ADAPTIVE SHADING SYSTEMS

The success of Adaptive Shading Systems is dependent upon how well they are controlled as much as how well they are physically designed. The ability to make decisions based on real time data concerning the environment is a critical component in how an adaptive system responds with respect to its exterior facade. Therefore, how an adaptive system is controlled will directly affect its ability to meet its intended environmental performance objectives (improved thermal comfort, optimal daylighting, etc.), as well as the reduction of energy consumption.

There are three general categories of control methods for adaptive shading systems: manual control, automated control and hybrid control. Each category has its own advantages and disadvantages, and each method has its own application criteria (e.g., building type, user habits, climate, etc.) that should be evaluated prior to choosing a control strategy.

5.1 Manual and User-Controlled Strategies

The manual control approach requires occupants to make adjustments to shades to meet their own subjective comfort requirements. Manual controls are usually accomplished through use of adjustable blinds, louvers or shade screens that allow users to manually adjust them to suit their current level of comfort (i.e., reducing glare, heat gain from solar radiation, or excessive light). The user experience is enhanced through manual control as it allows users to feel an immediate sense of control, and enables them to rapidly respond to discomfort caused by glare, excessive heat gain from solar radiation, and excessive lighting.

Despite this, research has shown that manual controlled shading systems frequently do not provide optimal levels of energy performance (Tzempelikos & Athienitis, 2007). Users will sometimes prefer short term visual comfort over long term energy savings. As such, users will leave their shades in one position for an extended period of time (O'Brien, Kapsis, & Athienitis, 2013). The variability in user behavior also makes it difficult to predict how users will interact with these systems and therefore leads to variable levels of performance of the building envelope. Although manual control can increase user satisfaction, its ability to optimize energy performance is limited as a stand-alone strategy.

5.2 Automated and Sensor-Based Control Strategies

Fully-automated control strategies utilize sensors to obtain information from the environment and algorithms to make decisions about how to modify the behavior of the shading system; however, these systems do not require a person to directly intervene or provide input to function. The most commonly utilized sensors are those which measure the amount of solar radiation, indoor and outdoor temperatures, the amount of daylight entering the building (daylight illuminance), and the amount of glare that exists within the building space. Using data from sensors, fully-automated systems will continue to adjust the position of the shading system in "real-time" until the desired comfort levels and/or performance levels have been achieved.

Sensor-based control systems allow an adaptive shading device to continuously monitor its surroundings (environmental conditions) and therefore can provide a consistent and predictable level of performance as compared to non-sensor based shading systems (Kuhn, 2017). Sensor-based control systems provide a means by which the amount of solar radiation (solar gains) and daylight entering the building can be continuously adjusted, thus reducing cooling loads and preventing overheating, improving the visual comfort of the building occupants and allowing the shading system to follow the most optimal schedule possible relative to seasonal changes and the movement of the sun.

The use of sensor-based control systems has provided many benefits, including improved performance of the shading system(s) and increased predictability and consistency of the performance of the building's facade. However, a potential drawback of using sensor-based control systems is the ability of the users/occupants to accept the use of such systems. Specifically, some users/occupants may disable the automated operation of the shading system because they feel they have lost control over their own personal comfort (Galasiu & Veitch, 2006). As a result, designers of automated control systems must develop strategies that optimize the performance of the shading system while also satisfying the needs and desires of the users/occupants.

5.3 Hybrid Control Approaches

Hybrid control strategies provide a combination of automated system control and the opportunity for user input (Meerbeek et al., 2012). Therefore, in a hybrid control system, the primary method for controlling the operation of a shading device is through sensors and algorithms that users may also adjust to be outside of predetermined limits. The ultimate goal of hybrid control systems is to offer the dependability and efficiency of an automated system along with the flexibility and responsiveness associated with user input.

Hybrid control systems have demonstrated the ability to achieve both improved energy performance and increased user acceptance. As hybrid systems will provide the user with a level of flexibility to interact with the system to satisfy their personal comfort needs, these hybrid systems will continue to follow the same overarching control logic as the automated system to ensure the building achieves its energy efficiency goals. As occupant comfort directly affects the productivity of students and employees, hybrid control models are best suited for application in office buildings and educational facilities (Heschong Mahone Group, 1999).

5.4 Integration with Building Management Systems

Building Management Systems (BMS) are being increasingly used with adaptive shading systems that enable the coordination of building facade elements; lighting systems; heating, ventilation & air conditioning (HVAC) systems; and other BMS components. The use of adaptive shading systems as part of a BMS allows for a comprehensive or whole-building optimization strategy, where the control of all systems is coordinated through the operation of the adaptive shading system (Shen, Hu, & Patel, 2014).

The example of an automated shading system controlling HVAC systems and lighting systems provides an illustration of how a coordinated control strategy can be implemented. During peak sunlight exposure, an automated shading system can reduce the cooling load on the HVAC system by reducing direct sun penetration. Additionally, when an automated shading system detects sufficient daylight available for visual tasks, it can dim the artificial lighting systems. Both actions contribute to reduced energy consumption and lower operational costs for buildings. However, for these two systems to work together effectively, they need to be accurately calibrated, have a reliable method of communicating their status to each other, and have defined hierarchical structures that define who controls what so that both systems do not provide conflicting responses.

5.5 Advanced and Predictive Control Technologies

Recent advancements in adaptive facade technology has provided an advanced means of controlling adaptive facades with predictive models and artificial intelligence (AI) as well as various forms of smart technologies. Using forecasting of future weather events along with historical performance data and simulation-based models, predictive systems are able to predict a variety of environmental changes prior to those events occurring and therefore provide proactive adjustments to shading behavior (Loonen et al., 2013). In contrast to reactive control systems which respond to current environmental conditions; predictive control systems are attempting to optimize performance over time through reduction of energy usage while providing consistent comfort levels.

Predictive control systems can be enhanced using AI and machine learning that allow adaptive facades to continually learn from past performance and improve upon it (Tabadkani et al., 2021). As such, AI/Machine Learning holds great promise for increasing long term efficiency and reliability of adaptive shading systems however they remain underutilized due to data requirements, system complexities and cost associated with implementation.

5.6 Performance Implications of Control Strategies

Adaptive Shading Systems (ASS) are highly dependent upon the selected Control Strategy to perform well environmentally. While manual systems allow for great flexibility with respect to usage and operation, they can offer little in terms of optimizing energy consumption. Automated systems provide consistent performance and optimal operation with regards to energy savings; however, may impact User Satisfaction as a result of reduced flexibility of operation and/or reduced ability to manually override system operation. A hybrid approach combines elements of both manual and automated control systems to optimize performance and user satisfaction as part of an adaptive solution to high-performance facade requirements (Daum, Haldi, & Morel, 2011). Predictive control strategies seek to create an even better balance among competing objectives, providing potentially high-performance facade options.

Therefore, it is important to understand how different control strategies relate to environmental performance in order to develop effective adaptive shading systems through proper design and assessment. Therefore, when selecting the most suitable control technology for use within an adaptive shading system, consideration should be given not only to technical feasibility, but also to user behavior, the intended use of the building or space, and the climatic conditions under which the ASS will operate (Tabadkani et al., 2021). These factors will serve as the basis for evaluating the environmental performance of adaptive shading systems, and are discussed in greater detail in the next section.

6. ENVIRONMENTAL PERFORMANCE ASSESSMENT OF ADAPTIVE SHADING SYSTEMS

The assessment of Adaptive Shading Systems is mainly related to their ability to improve the environmental performance of buildings in terms of thermal comfort, visual comfort and energy efficiency. Static shading devices are only able to regulate performance based on fixed design criteria, whereas adaptive systems allow for continuous changes in facade performance as an active response to changing environmental conditions. For this reason, the assessment of adaptive systems must be based on a multiple criterion methodology that will consider the thermal, visual, and energy aspects at the same time (Loonen et al., 2013).

Performance assessments of Adaptive Shading Systems can be carried out using a combination of experimental data collection (using sensors), simulation tools (e.g., software) and/or post-occupancy evaluations (e.g., surveys). The methodologies mentioned above can help understand how adaptive facades affect both indoor environmental quality and building energy consumption during different climate conditions.

6.1 Thermal Performance and Thermal Comfort

The thermal performance of an adaptive shading system has been identified as a key factor in evaluating its overall performance. Through the ability to adjust solar heat gain through adaptive changes in shading, adaptive shading devices can provide substantial reductions in indoor overheating particularly in regions with significant levels of solar radiation and primarily cooling dominated energy usage profiles. Adaptive shading systems can respond to the diurnal and seasonal variations in solar radiation by modifying the geometry and/or material properties of the shading device which creates a greater variability in the temperature within the building.

Previous studies have shown that Adaptive Shading Systems can measurably reduce the cooling loads of buildings during peak summer periods due to reduced excessive solar gains and allow for the benefits of solar radiation during the winter months to assist in passive heating (Bellia, Marino, Minichiello, & Pedace, 2014). The adaptive nature of shading systems provides a unique benefit over static shading systems which are generally designed for a specific set of conditions.

In addition to influencing air temperature, thermal comfort is also affected by radiant temperature, air movement, and solar exposure. Adaptive shading systems influence all of these factors by managing the amount of solar radiation incident upon both interior surfaces and occupants.

Previous research utilizing thermal comfort indices (Predicted Mean Vote PMV and Predicted Percentage of Dissatisfied PPD) have shown that adaptive shading systems increase the range of thermal comfort and reduce the length of time that occupants experience thermal discomfort when compared to static facade solutions (Favoino, F., et al., 2016).

6.2 Daylighting Performance and Visual Comfort

The ability of adaptive shading systems to control how much light enters a building is a key element to consider when examining their impact on the environment. In addition to creating a visually comfortable working or living environment and increasing occupants' overall satisfaction with their indoor environment, the effectiveness of managing daylight can reduce the need for artificial lighting within a building (Reinhart & Walkenhorst, 2001). The ability of adaptive shading systems to manage both the direction of the sun and the total quantity of solar radiation entering a building makes them essential in balancing the quantity and direction of solar radiation entering a building (Loonen et al., 2013).

Previous studies have utilized daylight performance metrics such as Daylight Autonomy (DA), Useful Daylight Illuminance (UDI) and Glare Index when assessing daylight performance. Previous research has demonstrated that adaptive shading systems can improve daylight distribution throughout an interior space through reduction of excessive luminance contrast between interior areas and mitigation of glare at windows adjacent to glass façades. As opposed to traditional fixed shading components which remain static based on building geometry and exterior climatic conditions, adaptive systems can dynamically respond to changes in sky conditions by maintaining satisfactory daylight illumination levels while minimizing visual discomfort.

However, daylight performance results from the use of adaptive shading systems are highly dependent upon both the design of the adaptive shading system and its associated control strategy, as well as the orientation of the building's glazing area. Additionally, it has been found that excessive shading control can result in decreased daylight levels entering into a building thereby increasing the demand for artificial lighting. Therefore, it is essential to integrate adaptive shading systems with lighting control systems to achieve maximum visual comfort and energy efficiency.

6.3 Energy Performance and Building Energy Demand

The goal of assessing energy performance for adaptive shading systems is to understand how they affect the energy usage of buildings specifically through the use of heating, cooling and lighting. Through simulation-based studies that used energy modeling software (such as EnergyPlus), radiosity software (Radiance) and hybrid building performance simulation platforms (e.g., IESVE, Ecotect), researchers have shown that when compared to static shading methods, adaptive shading systems can provide a substantial reduction in building energy consumption (Reinhart & Walkenhorst, 2001).

The biggest impact of adaptive shading systems will be on the cooling energy load since adaptive shading systems will block direct sunlight from entering into the building (and thus reducing the amount of solar heat gain) during times of high outside temperature. In addition, by controlling the amount of daylight entering into the building through the use of daylight responsive lighting controls, adaptive shading systems can decrease lighting energy consumption. Additionally, adaptive shading systems could possibly help to reduce heating energy consumption in climates where heating is dominant by allowing greater amounts of solar energy to enter the building during cooler periods.

Although adaptive shading systems can provide many possible energy benefits, the degree of those benefits are highly dependent upon several factors including but not limited to climate, building type, facade orientation, glazing characteristics and the specific control method(s) being utilized. If an adaptive system has poor calibration or is not properly controlled then the energy performance improvements realized from its use will likely be very limited or completely unpredictable; therefore, energy assessments for adaptive systems place great emphasis on the need for well defined, optimized and contextualized designs.

6.4 Simulation-Based and Experimental Evaluation Methods

The complexity of adaptive shading systems necessitates advanced evaluation methods capable of capturing dynamic façade behavior. Simulation based approaches enable both researchers and designers to create models of multiple control schemes, and evaluate how these models will perform under a variety of climatic conditions. A key benefit to using parametric simulations is to compare adaptive and static shading strategies across a broad spectrum of design parameters. (Loonen et al., 2013).

Experimental research, such as full scale testing and monitored case studies, provides empirical evidence of how a shading system actually performs in real world conditions. In addition, post-occupancy evaluations help to understand the relationship between adaptive shading behaviors, occupant satisfaction with their space, and actual energy consumption. However, experimental research is generally constrained by high costs associated with conducting the study, the time needed to monitor the building over a long period of time, and the difficulty of isolating the effects of the shading system from all other aspects of the building.

6.5 Limitations and Performance Trade-Offs

Although adaptive shading systems represent a considerable amount of improvement in terms of environmental performance, there is also the possibility that these systems will create new trade-offs. The added complexity to the system could be associated with an increase in the amount of embodied energy in the building, increased demands for maintenance and potentially an increase in the number of operational challenges. Additionally, in certain cases, the total amount of energy needed to operate and manage the system could potentially be enough to reduce or even eliminate the amount of energy saved due to the improvements in solar regulation.

Performance of adaptive shading systems is also directly impacted by the occupants' actions/behavior as well as how the users interact with the shading systems. A significant difference between the performance of the designed operation of the system and the actual performance of the system will result in a performance gap. The above highlights the need for user centered design and simple to use control interfaces, which would help in minimizing performance gaps. As such, environmental performance assessment needs to assess both the technical efficiency of the adaptive shading systems as well as the human factor elements of the systems to provide a complete evaluation of adaptive shading systems.

6.6 Summary of Environmental Performance Impacts

Adaptive Shading Systems can contribute to greater levels of Thermal Comfort, Visual Comfort, Energy Efficiency, etc., as long as they are properly integrated with Building Design and Control Systems. Adaptive Shading Systems' ability to be dynamic allows them to respond and adapt to different conditions in a manner that is much more responsive than static Shading Devices. It also requires that the systems be properly designed, and the systems (design and controls) be properly integrated to achieve Optimal Environmental Performance.

The evaluation of environmental performance is an important element for assessing both the advantages and disadvantages of adaptive shading systems. The information developed from this process can aid in making Informed Design Decisions, and provide a framework for evaluating Real-World Applications of adaptive shading systems; which is illustrated through selected Case Studies in the next Section.

7. CASE STUDIES AND BUILT EXAMPLES OF ADAPTIVE SHADING SYSTEMS

Practical application of adaptive shading systems is best illustrated by examining case studies of built examples as well as existing case studies. While theoretical models and performance-based simulations offer valuable insight into how adaptive shading systems work in theory; actual field implementations illustrate how these systems function within actual climates, user behaviors, and operational constraints. Therefore, case studies will play an important role to evaluate the viability, efficiency, and limits of adaptive shading systems in architecture.

The following section present several examples of structures that employ adaptive shading systems at the building envelope (façade) level. These case studies are examined according to system type, control method, environmental performance metrics, and architectural integration.

7.1 Institut du Monde Arabe, Paris

Jean Nouvel's Institute of Arab World is generally regarded as an early and possibly the first major example of adaptive façade design, and its south façade includes motorized panels based on the mashrabiya pattern from Arabic architecture, which can be opened or closed depending on exterior light levels to modulate daylight (Meagher, 2014).

While the intent of the adaptive shading system was to reduce glare and solar gain through the operation of these diaphragms, technical issues and difficulty in maintenance have limited the long term performance of the system (Meagher, 2014). However, the Institute has been used for many years as a model reference point for the development of adaptive shading systems. This is due to its ability to demonstrate that mechanically responsive facades may be used to combine functional environmental characteristics with cultural and aesthetic aspects of the building design.

7.2 Al Bahr Towers, Abu Dhabi

The Adaptive Shading System of Al Bahr Towers in Abu Dhabi uses an adaptive system to adapt to extreme solar conditions found in a desert/arid climate. A central component of this system is a Kinetic Façade made up of triangular modules that move with the sun to either shade the interior space or allow for sunlight to enter into the building. This system uses a central automated control strategy to determine when to open or close the triangular modules in order to regulate temperature, and it controls the movement of the modules based upon solar angle and intensity of solar radiation.

According to performance data from the towers, the adaptive shading system has demonstrated significant reductions in summer cooling load and reduction in summer peak cooling load; and the use of the system has preserved exterior view opportunities and daylighting opportunities within the building (Karanouh & Kerber, 2015). This tower is a prototype for the application of adaptive shading systems at a high-rise level and demonstrates both sustainable design principles, and the ability to create iconic architecture through the integration of innovative technology in the design process. Al Bahr Towers are often referenced as a model for designing climate responsive façades in hot climates.

7.3 Kiefer Technic Showroom, Austria

The Kiefer Technic Showroom uses an adaptive kinetic facade system using moving aluminum panels that are responsive to users and environmental conditions; the adaptive shading elements can be controlled individually to create a unique and dynamic façade pattern at all times, while also providing variable shading to regulate the amount of direct sunlight entering the space.

Studies of the building show that this adaptable facade system has significantly contributed to improving the overall thermal comfort level of occupants and reducing the need for cooling energy loads, especially during the warmer months. The Kiefer Technic Showroom is a prime example of how adaptable shading systems can contribute to both environmental and aesthetic characteristics in a temperate climate. (Loonen, R. C. G. M., et al., 2013)

7.4 Media-TIC Building, Barcelona

The Media-Tic building incorporates a variety of exterior wall strategies; such as an adaptable, dynamic system to shade from solar radiation and temperature fluctuations through use of etfe cushions and movable shading components which are used in conjunction with the building's environmental controls to achieve both optimal internal comfort and optimal energy efficiency

Post occupancy evaluation has shown that the use of the dynamic shading devices has contributed to lower cooling loads and improved daylighting performance (Wong, 2017). Therefore, it is demonstrated through The Media-Tic building how the integration of dynamic shading systems (as well as other advanced materials) may be utilized to design highly effective exterior walls for use on mixed-use and commercial office buildings.

7.5 Results and Implications for Architectural Practice

Many of the repeated trends and patterns that exist throughout the application of adaptive shading systems were identified through an analysis of the case studies listed above. The first trend is the effect of climate on the performance of an adaptive shading system; there appears to be a direct correlation between climate and the amount of solar radiation an area receives and therefore, how much the adaptive shading system will provide benefit (e.g., warmer climates offer greater potential for cooling via adaptive shading) (Attia, 2016). Secondly, as demonstrated by the case studies, the reliability of the environmental performance of the adaptive shading system is directly related to the control strategy and the way in which the system has been integrated into the overall building environment. Specifically, projects that have implemented well-calibrated automatic or hybrid control strategies generally produce more consistent results relative to their environmental performance than those projects without such effective control strategies. Finally, similar to other types of mechanical systems, the case studies also identify some of the common problems associated with the application of adaptive shading systems, namely: required maintenance; expected system durability; and users' willingness to accept an adaptive shading system (Attia et al., 2018). The need for consideration of life-cycle performance and operational feasibility (i.e., ease of use) in addition to environmental performance during the design phase is clearly illustrated by these common problems associated with adaptive shading systems.

Case studies demonstrate how to develop adaptive shading systems as an example of how you can use a dynamic facade strategy to increase the environmental sustainability of your building while increasing the aesthetic appeal of the architecture. However, the development of these types of dynamic facade systems will be dependent upon multidisciplinary teamwork between architects, engineers, and other building professionals involved in the operation of buildings (Loonen et al., 2015). Lessons learned through case studies will be beneficial to all parties that are developing new adaptive shading systems; they include contextual design decisions, effective control methodologies, and ongoing assessment of system performance. A broad-based review of the benefits and barriers to using adaptive shading systems has been completed in the final section of this chapter based on the lessons learned from actual applications of adaptive shading systems.

8. DISCUSSION AND CONCLUSION

Adaptive shading systems have shifted the way we think about the "building envelope" from static protective layers to responsive performance-based interfaces. In this chapter, we have studied adaptive shading systems by studying their principles, types, controls, environmental performance and built examples. It is evident that there is a large opportunity for adaptive shading systems but there are also many challenges associated with their use.

From a perspective of environmental performance, adaptive shading systems provide a number of advantages over static solutions. Adaptive systems can adjust their response to varying levels of solar radiation, daylight availability and thermal condition to provide a greater level of control over solar heat gain and visual comfort. Many of the studies referenced in this chapter have shown measurable reduction in cooling energy consumption, increased daylight distribution and improved indoor thermal comfort in regions where the sun's rays are strong. One of the primary reasons adaptive systems are beneficial to sustainable building design is they are capable of optimizing multiple performance criteria at once.

The degree to which an adaptive shading system can achieve its intended performance is heavily dependent on the combination of several related variables. The climatic region where a building is located; the orientation of the façade; the type of shading system used; and the control logic employed in the system all directly influence how the system performs. Systems that are well matched to the local climatic conditions and are integrated into a building energy management system perform best. Conversely, poorly designed and overly complex systems often fail to meet the projected performance and sometimes cause an increase in operational energy use.

The importance of control strategies to the ultimate effectiveness of adaptive shading systems has been illustrated through a variety of studies reviewed in the literature review. It appears that although automated systems utilizing real-time environmental information may generally outperform manually operated systems in terms of energy savings; however, hybrid systems which offer users the opportunity to override the automated control strategy appear to effectively blend energy efficiency with user satisfaction. However, the studies reviewed also clearly indicate that when users perceive an adaptive system as being unreliable or overly intrusive they will frequently lose interest in using adaptive systems; therefore, it is apparent that user centered design and transparent operation of adaptive facade control systems are crucial to the successful implementation of these technologies.

Adaptive shading systems have tremendous potential to improve the performance of buildings and contribute to a reduction in greenhouse gas emissions. However, a variety of barriers exist to the widespread adoption of adaptive shading systems. Economic barriers (e.g., high initial costs) are a primary barrier to the use of adaptive shading systems; in addition, mechanical complexities associated with adaptive systems, maintenance requirements and durability issues may limit their use. The studies examining the long-term performance of case study adaptive shading systems found that failures of technical components and required maintenance could result in reduced performance over time. Thus, while innovative designs for adaptive facades are essential; life cycle considerations, robustness, and simplicity should be considered equally with other design criteria.

In addition to providing a method of improving the environmental performance of buildings, adaptive shading systems offer architects with new methods to develop architectural identity, cultural expression and visual dynamics. A survey of examples of adaptive shading systems provided in the literature indicates that dynamic shading elements can be used to develop unique architectural experiences and visually enhance the appearance of a building. As demonstrated by the example projects however, achieving a balance between aesthetic ambitions and technical reliability represents a significant design challenge. The successful integration of adaptive shading systems into a building's design is likely to occur when the adaptive system is part of the overall architectural concept of the building and not simply an additional technology added to the building.

In summary, adaptive shading systems have tremendous potential as a method of improving the energy efficiency, thermal comfort and daylighting performance of buildings in the context of climate-responsive design. In addition to being responsive to changes in environmental conditions, adaptive shading systems are a critical element of future high-performance building envelopes. However, the effective application of adaptive shading systems requires careful attention to the climatic characteristics of the location, the design of the control system, the interaction with occupants and the long-term performance of the system.

Therefore, the development of more affordable, durable and low-maintenance adaptive shading systems and improvements in the methods for assessing the performance of adaptive shading systems through long-term post-occupancy assessments, are needed. Interdisciplinary collaborations among architects, engineers, and materials scientist will be necessary to develop and promote adaptive shading technologies from laboratory-scale applications to mainstream architectural practices. With the understanding of existing problems and the implementation of proven strategies, adaptive shading systems can assume a central role in the continued development of sustainable and resilient building design.

9. REFERENCES

Attia, S. (2016). Evaluation of adaptive facades: The case study of Al Bahr Towers in the UAE. QScience Proceedings, 2016, 8. https://doi.org/10.5339/qproc.2016.qgbc.8

Attia, S., Bilir, S., Safy, T., Struck, C., Loonen, R., & Goia, F. (2018). Current trends and future challenges in the performance assessment of adaptive façade systems. Energy and Buildings, 179, 165–182. https://doi.org/10.1016/j.enbuild.2018.09.017

Bakker, L. G., Hoes-van Oeffelen, E. C. M., Loonen, R. C. G. M., & Hensen, J. L. M. (2014). User satisfaction and interaction with automated dynamic facades: A pilot study. Building and Environment, 78, 44–52. https://doi.org/10.1016/j.buildenv.2014.04.007

Bellia, L., Marino, C., Minichiello, F., & Pedace, A. (2014). An overview on solar shading systems for buildings. Energy Procedia, 62, 309–317. https://doi.org/10.1016/j.egypro.2014.12.392

Daum, D., Haldi, F., & Morel, N. (2011). A personalized measure of thermal comfort for building controls. Building and Environment, 46(1), 3–11. https://doi.org/10.1016/j.buildenv.2010.07.016

Ergin, Ö. (2019). Uyarlanabilir cephe sistemlerinde güncel yaklaşımlar ve akıllı malzemelerin kullanımı (Yüksek lisans tezi). Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü. https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

Erturk, M., & Keçebaş, A. (2021). Prediction of the effect of insulation thickness and emission on heating energy requirements of cities in the future. Sustainable Cities and Society, 75, 103270. https://doi.org/10.1016/j.scs.2021.103270

Favoino, F., Fiorito, F., Cannavale, A., Ranzi, G., & Overend, M. (2016). Optimal control and performance of photovoltachromic switchable glazing for building integration in temperate climates. Applied Energy, 178, 943–961. https://doi.org/10.1016/j.apenergy.2016.06.107

Galasiu, A. D., & Veitch, J. A. (2006). Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: A literature review. Energy and Buildings, 38(7), 728–742. https://doi.org/10.1016/j.enbuild.2006.03.001

Givoni, B. (1998). Climate considerations in building and urban design. Van Nostrand Reinhold.

Heschong Mahone Group. (1999, August 20). Daylighting in schools: An investigation into the relationship between daylighting and human performance (Detailed Report). Submitted to George Loisos, The Pacific Gas and Electric Company, on behalf of the California Board for Energy Efficiency Third Party Program. Heschong Mahone Group.

Hraska, J. (2018). Adaptive solar shading of building. International Review of Applied Sciences and Engineering, 9(2), 107–113. https://doi.org/10.1556/1848.2018.9.2.5

Karanouh, A., & Kerber, E. (2015). Innovations in dynamic architecture. Journal of Facade Design and Engineering, 3, 185–221. https://doi.org/10.3233/FDE-150040

Kıyılmaz, M. B., Keçebaş, A., & Ertürk, M. (2021). Sanayide enerji yönetimi sistemi için bir gıda tesisinin enerji verimliliğinin iyileştirilmesi. International Journal of Pure and Applied Sciences, 7(1), 51–62. https://doi.org/10.29132/ijpas.815077

Kuhn, T. E. (2017). State of the art of advanced solar control devices for buildings. Solar Energy, 154, 112–133. https://doi.org/10.1016/j.solener.2016.12.044

Le, K., Bourdais, R., & Guéguen, H. (2014). From hybrid model predictive control to logical control for shading system: A support vector machine approach. Energy and Buildings, 84, 352–359. https://doi.org/10.1016/j.enbuild.2014.07.084

Loonen, R. C. G. M., Trčka, M., Cóstola, D., & Hensen, J. L. M. (2013). Climate adaptive building shells: State-of-the-art and future challenges. Renewable and Sustainable Energy Reviews, 25, 483–493. https://doi.org/10.1016/j.rser.2013.04.016

Loonen, R. C. G. M., Rico-Martinez, J. M., Favoino, F., Brzezicki, M., Menezo, C., La Ferla, G., & Aelenei, L. (2015). Design for façade adaptability: Towards a unified and systematic characterization. In 10th Conference on Advanced Building Skins, 3-4 November 2015, Bern, Switzerland (pp. 1284–1294). Economic Forum.

Meagher, M. (2014). Responsive architecture and the problem of obsolescence. Archnet-IJAR, 8, 95–104. https://doi.org/10.26687/archnet-ijar.v8i3.498

Meerbeek, B., van Loenen, E., Kulve, M., & Aarts, M. (2012). User experience of automated blinds in offices.

Moloney, J. (2009). Kinetic architectural skins and the computational sublime. Leonardo, 42(1), 65–70. https://doi.org/10.1162/leon.2009.42.1.65

Nady, R. (2017). Dynamic facades: Environmental control systems for sustainable design. Renewable Energy & Sustainable Development, 3(1), 118–127. https://www.researchgate.net/publication/316615517

O’Brien, W., Kapsis, K., & Athienitis, A. K. (2013). Manually-operated window shade patterns in office buildings: A critical review. Building and Environment, 60, 319–338. https://doi.org/10.1016/j.buildenv.2012.10.003

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and Buildings, 40(3), 394–398. https://doi.org/10.1016/j.enbuild.2007.03.007

Pérez-Carramiñana, C., González-Avilés, Á. B., Castilla, N., & Galiano-Garrigós, A. (2024). Influence of sun shading devices on energy efficiency, thermal comfort and lighting comfort in a warm semi-arid dry Mediterranean climate. Buildings, 14(2), 556. https://doi.org/10.3390/buildings14020556

Reinhart, C. F., & Walkenhorst, O. (2001). Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. Energy and Buildings, 33(7), 683–697. https://doi.org/10.1016/S0378-7788(01)00058-5

Shen, E., Hu, J., & Patel, M. (2014). Energy and visual comfort analysis of lighting and daylight control strategies. Building and Environment, 78, 155–170. https://doi.org/10.1016/j.buildenv.2014.04.028

Tabadkani, A., Roetzel, A., Li, H. X., & Tsangrassoulis, A. (2021). A review of occupant-centric control strategies for adaptive façades. Automation in Construction, 122, 103464. https://doi.org/10.1016/j.autcon.2020.103464

Tzempelikos, A., Athienitis, A. K., & Karava, P. (2007). Simulation of façade and envelope design options for a new institutional building. Solar Energy, 81(9), 1088–1103. https://doi.org/10.1016/j.solener.2007.02.006

Wong, I. L. (2017). A review of daylighting design and implementation in buildings. Renewable and Sustainable Energy Reviews, 74, 959–968. https://doi.org/10.1016/j.rser.2017.03.061

CHAPTER 4

RELATIONSHIP BETWEEN GENERATIVE ARTIFICIAL INTELLIGENCE AND CREATIVITY IN DESIGN EDUCATION: AN ANALYSIS ON IDENTITY IN FURNITURE COURSE

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1. INTRODUCTION

In recent years, artificial intelligence, which has entered human life very rapidly in many fields from science to technology, from medicine to economy and finance, from design to production stages, plays important roles in education, training and creativity processes (Russell & Norvig, 2010). In addition to artificial intelligence, which is a branch of science that models the characteristics of machines, especially computer systems, and the human brain such as learning, reasoning, problem solving, perception, and language comprehension, generative artificial intelligence (GAI) is a relatively new technology in which patterns and patterns are learned by examining examples, and as a result, different content can be created using digital data such as audio, video, text, image/graphics (Wang, 2019). This technology, which works with information processing methods such as deep learning using algorithms, data sets and modeling techniques, has started to change the design processes today. With artificial intelligence technology, which is a harbinger of important steps in the field of education, it is possible to personalize learning experiences, increase productivity with performance monitoring, and help students better prepare for the future business world by supporting creative thinking (Karabulut, 2021). In addition, integrating this technology, which sometimes leads to prejudices, into education with appropriate conditions is one of the issues discussed today.

In this research, which was carried out within the scope of the Identity in Furniture course in the undergraduate program at Mimar Sinan Fine Arts University, Department of Interior Architecture in the Fall Semester 2023-2024, it was aimed to examine the interaction of generative artificial intelligence with the fields of thinking, designing and visualization. In the project, which was carried out with students who conducted research on different identity definitions and furniture designs for two months, no guidance was given for the use of artificial intelligence, but it was observed that most of them spontaneously turned to this new technology. At the end of the process, interviews were conducted with the students through a semi-structured interview form and the projects were analyzed. A qualitative approach was adopted in the research.

The distinctive feature of the study is to assess student orientations and achievements regarding generative AI technologies, to determine which of the current applications are more preferred and their role in the field of design. Aimed at academics, researchers and students working on design education, this research aims to explore the role of AI technology in developing and visualizing students' ideas, to draw attention to the importance of design definitions in the design process, and to propose an improvable methodology that educators can use. Accordingly, the research consists of a theoretical framework based on a literature review, followed by an explanation of the methodology and study steps, examples of student projects, findings based on the interviews, and interpretation of the results. In the discussion section, the final thoughts on the subject are conveyed, directions for future research are indicated and the study is concluded.

1.1.Definition of Artificial Intelligence and Generative AI

Artificial intelligence is a technology that mimics human intelligence and can iteratively improve itself based on the information it collects. The term was coined in 1950 by Alan Turing, a pioneer of computer science, who posed the question "Can machines think?"; it was later proposed by John McCarthy in 1956. Due to the immaturity of the theory and technology, artificial intelligence research was slow in the 1970s and 1980s. Today, it is being included in human life with increasing momentum.

According to Nilsson (2019), artificial intelligence is an activity that aims to make machines have human-like intelligence and abilities. In this context, it includes the ability of computers and computer-controlled machines to perform human-specific mental processes such as understanding, reasoning, generalizing, and learning by experience (Yıldırım & Demirarslan, 2020). According to Li et al. (2018), artificial intelligence is characterized as a functioning similar to human intelligence that machines exhibit in certain tasks. Mehmood (2023) defined artificial intelligence as 'a broad spectrum technology in which machines imitate human intelligence' (Figure 1). These definitions show that artificial intelligence is the science of building machines that can perform tasks that require intelligence by individuals.

Artificial intelligence can be evaluated at three levels: Narrow AI, general AI, superintelligent AI (Badgers, 2021; Kandiyoti, 2023). Artificial intelligence systems designed to accomplish a single goal or a specific task are examples of narrow AI (Artificial Narrow Intelligence or ANI). Examples include voice assistants, image recognition systems or AI characters in games. General artificial intelligence (Artificial General Intelligence or AGI) aims for a more conscious level of thinking than narrow AI, with the ability to learn and solve problems independently; its most important feature is the ability to learn on its own without a programmer. This is referred to as deep learning in the terminology (Guo et al., 2016). Superintelligent artificial intelligence (Artificial Super Intelligence or ASI) refers to a level of intelligence significantly above human intelligence. This type of artificial intelligence can surpass human comprehension and solving abilities in all domains and even improve human intelligence (Jajal, 2018). According to Kaplan and Haenlein (2019), super AI is interpreted as "truly self-aware and self-aware systems that make humans redundant".

Figure 1. Artificial intelligence technology and its basic components (Mehmood, 2023).

The main elements that make artificial intelligence technology possible today can be exemplified as follows (Kurt, 2023).

- Machine Learning: It is a sub-branch of artificial intelligence that enables computer systems to learn from their experiences and gain the ability to generalize from data sets. It includes different learning methods such as supervised learning, unsupervised learning and reinforcement learning.
- Deep Learning: A sub-branch of machine learning that builds complex models using multilayer neural networks. It usually requires large data sets and high computational power.

- NLP; Natural Language Processing: It is a branch of artificial intelligence used for computer systems to understand, interpret and produce human language. It can perform tasks such as speech recognition, language understanding and text generation by working with text-based data.
- Image Processing (Computer Vision): It covers an area that enables computer systems to analyze visual data. It can perform tasks such as face-object recognition and image classification.
- Explainable Artificial Intelligence - XAI (Explainable AI): Refers to the ability of AI systems to explain their decisions and outcomes in an understandable way. This helps users and stakeholders understand why AI systems make a particular decision.

Along with these features, advances in technology in recent years have made it possible to produce creative digital content with generative artificial intelligence technology, a subtype of artificial intelligence Hu, 2022). Generative artificial intelligence (GAI) is a field where patterns and patterns are learned by examining examples, and as a result, new and different content can be created by using digital data such as audio, video, text, image/graphics (Jovanović, 2022, Abukmeil, et al., 2021; Gui, et al., 2021). For example, chatbots for customer service, inventory management and forecasting business systems can be built with AI, while content in many different formats such as text-to-image, text-to-video, image-to-text, image-to-text, text-to-music or text-to-text can be produced with generative AI (Table 1). Recent models such as DALL-E and Midjourney are technologies based on analyzing and visually reproducing text-pattern relationships with this logic and are frequently preferred in the field of design. In the field of education, generative artificial intelligence is expected to play a major role in the future.

Table1 *. Observed differences between traditional AI and generative AI (Mehmood, 2023).*

	Traditional AI (Narrow or Weak AI)	Generative AI (Next-Gen AI)
Focus	Responds to a predefined set of inputs and follows rules.	New generation AI.
Function	Analyzes data, makes predictions based on predefined rules.	Learns patterns from data and then creates new content.
Creativity	No	Yes
Examples	Siri or Alexa, recommendation engines on platforms like Netflix.	ChatGPT, image generators like DeepAI.

1.2.Using Generative Artificial İntelligence in Design Education

The 21st century is creating a rapidly changing landscape in the field of education as in every other sector due to advances in artificial intelligence technologies (Looney, 2009; Baidoo-Anu & Owusu Ansah, 2023). These advances seem to have the potential to radically change and transform the way students, educators and educational institutions learn and teach. Through data analytics and adaptive learning systems, students' individual learning styles, needs, levels and goals can be better understood and customized learning plans and materials can be created with this information. Artificial intelligence also offers fast and efficient assessment opportunities. Student performances can be quickly analyzed and personalized feedback can be provided. In addition, AI applications such as virtual learning assistants and chat bots, which can provide 24/7 support to students, can guide students and answer their questions in and out of the classroom. AI technologies also offer significant improvements for educators. These include adapting lesson plans based on analytics data, content generation, preparing effective presentations, creating exams and questions, automatic grading and feedback, making effective content recommendations on online education platforms, plagiarism checkers and virtual assistants to increase academic integrity. Technologies such as virtual reality (VR) and augmented reality (AR), gamified learning environments, AI-based smart boards, digital libraries, and classroom management software have the potential to encourage students' in-depth understanding and even help them acquire vocational skills while concretizing various concepts by overcoming time and space limitations (Holmes et al., 2019; Arslan, 2020; UNESCO, 2023).

When we look at the design field, it is seen that these applications, with the promise of enhanced creativity, have the advantages of being able to work quickly, interactively and efficiently on different parameters in inspiration, concept development, design, design visualization and production processes. (Luckin et al., 2016; Mclnnes, 2023; Gupta, 2023; Lee et al., 2023). According to Li (2020), these technologies can increase efficiency in design processes by enabling innovative and impressive designs. The ability to analyze data and the capacity to make different styles, trends, cultures, and historical contexts easily accessible to students by drawing inspiration from a wide array of sources is likely to change the processes that have been operating in design education to date. With applications such as Canva, Wombo, Midjourney, students can access many different form alternatives, experiment with materials, textures, shapes and colors by entering design definitions as commands. By uploading their design sketches to applications such as Playground AI and Promeai, they can access three-dimensional design visuals that look like they were modeled in a drawing program in a short time; they can experiment with many different materials and textures on them with written instructions and create different alternatives at the point of expressing themselves. Artificial intelligence applications enable rapid transitions between the second and third dimensions in three-dimensional modeling and prototyping processes that previously took long hours. In addition to all these, at the point of visualization, artificial intelligence has become prominent in creating customized presentations by creating motion graphics, animations, even sound and music content in the style appropriate to the desired content. Table 2 exemplifies productive AI applications in design and design education processes.

***Table 2** . Generative artificial intelligence applications in design and design education processes (Mclnnes, 2023; Gupta, 2023; Lee et al., 2023).*

Application Area	Generative AI Applications
Design Development	**Sketch development feature:** Turning hand drawings into three-dimensional by supporting them with written commands and various styles. **Personalized design solutions:** Developing alternatives based on user preferences. **Color palettes and style guides:** Providing aesthetic harmony and style recommendations. **Inspiration boards and trend analysis:** Preparing information presentations on design trends.
Rapid Prototyping and Design Production	**Autonomous design tools:** Developing prototypes and sample designs. **3D modeling and animation:** 3D modeling and animation processes. **Layout and composition optimization:** Aesthetic and functional analyses.
Design Education	**Student performance analyses:** Evaluating student achievements. **Educational material suggestions:** Directing to appropriate learning tools. **Project evaluations:** Analyzing and interpreting student projects.
Ethical and Sustainability Analysis	**Ethical design principles:** Evaluating the design's compliance with ethical principles. **Sustainable design analysis:** Material selection and energy consumption analyses.
Multidisciplinary Collaboration	**Design team communication and collaborations:** Ensuring collaboration between different disciplines. **Cultural and versatile design:** Making suggestions regarding cultural diversity.

Alongside these advantages, design institutions and educators have begun to face the challenges of productive AI use. Mustafa (2023) and Fatima (2023) emphasized in their research that the unconscious use of these tools can lead to similarity and uniformity of designs, which is not suitable for an industry that requires creativity and originality. Manovich (2018) wanted to emphasize that artificial intelligence can affect human aesthetic understanding and diversity with the question "Does the integration of artificial intelligence into cultural production lead to a decrease in aesthetic variability?". The quality of data and machine hallucinations caused by disinformation can give people false or biased information. The nature of technology, which develops at an accelerating pace, requires constant updating of knowledge and skills, and users may have difficulty adapting to this pace. In addition, issues such as the ethical dimensions of studies produced by artificial intelligence, A.I. bias and property rights are also discussed. Aiming to establish global ethical rules, standards and an international reference point on the subject, the Beijing consensus, led by the United Nations Educational, Scientific and Cultural Organization (UNESCO), was adopted by UNESCO's member states in 2019. The 44-article consensus is a guide that aims to ensure that AI technologies respect human rights, openness, accessibility and accountability, and also includes the integration of AI into the education system and curriculum, and the productive use of AI in work, life and education (Kurtuluş, 2023).

With all these developments, it is necessary to develop alternative suggestions for the efficient and education-supportive use of artificial intelligence technologies that are being used at every stage of design. The use of artificial intelligence in education is important in terms of training future professionals who will work in environments where these technologies will actively take place in the future. In the current data age, it is only possible to understand artificial intelligence, which consists of algorithmic data, by being data literate. Yılmaz (2023) stated that in the future, the primary impact of artificial intelligence will be experienced in working life, some professions will disappear, some professions will be transformed, those who can work with artificial intelligence tools will come to the fore, the ability to use artificial intelligence ethically and safely, and the ability to analyze data accuracy will gain importance. In addition, it is predicted that the skills in working life will also differentiate and soft skills will come to the fore instead of hard skills. Hard skills are the technical knowledge and abilities required to work on specific subjects, such as software engineering and programming languages. Soft skills, on the other hand, include critical thinking, evaluation, maintaining curiosity to learn, empathy and sensitivity, written and oral communication skills, strategic and analytical thinking, and teamwork skills. Based on all of these data, it is thought that it will become increasingly important for educators to turn towards the active use of artificial intelligence technologies in education instead of avoiding them, and to adopt approaches that do not ignore current technologies while preserving students' creative thinking, imagination, drawing and visualization skills.

1.3. The Relationship Between Productive AI and Creativity

AARON is one of the systems in which artificial intelligence exhibits visual art and design products by harboring the element of creativity (Karabulut, 2021). Developed by British painter Harold Cohen in 1973, AARON is one of the first known software that produces successful visual art products. Cohen programmed AARON to create drawings using an iterative design process at each stage. At each stage, Cohen evaluated the output of the program and then modified it to reflect his own aesthetic judgment about the results (Figure 2). Initially working abstractly, AARON evolved in the process, and by 1986 it was producing colored drawings. He then learned to design many objects in three-dimensional space, such as stones, various objects, animals, plants and people (Sawyer, 2012).

Artificial intelligence, modeled on human thinking, is improving itself day by day in terms of creative thinking and achieving more and more complex results. The ever-increasing learning capacity, understanding the nuances of language, making decisions based on probabilities, pattern recognition and problem solving are some of the similarities between AI and humans. Humans are able to integrate new information into existing knowledge by learning from their experiences. Similarly, artificial intelligence systems learn from data through machine learning and deep learning techniques and continuously improve their performance with these gains.

Figure 2 . Examples of AARON's drawings changing over time (URL1)

Generative AI works with a parameter defined as the 'temperature' value when pulling relevant data from the knowledge pool, which controls the variety, originality or predictability of the outputs produced and directly affects the level of creativity of the model. Especially in models used in natural language processing or artistic content generation, this parameter has a significant impact on how the model responds. This parameter, which works like the creative thinking in human beings, has an impact on the diversity of the output produced. When the temperature is low (e.g. 0.1), the model produces more predictable and reliable responses. This causes the model to select more common or usual responses, which works like a convergent thinking process in creative thinking. A high temperature value (e.g. 1.0 or more) causes the model to generate more random and unexpected responses. This works like the divergent thinking process in creative thinking, allowing the model to select responses that may be more creative or novel. For example, in natural language models, using a higher temperature value when writing a story or creating a poem makes the text more original and unusual. In artificial intelligence tools used in visual arts or music production, a higher temperature setting allows for more original and unexpected results.

With all these features, productive artificial intelligence technologies have enabled users to produce effective projects in the field of design in recent years. In addition, directing AI technologies correctly requires a learning process. In a study conducted by Kulkarni et al. (2023), it was observed that amateur designers improve the prompts (command/starting statements) they use when creating images with artificial intelligence while experimenting and achieve increasingly successful results. The research shows that people who are not experienced in the field of design can also make creative designs using these tools and thus actively participate in the design process.

However AI creativity should not be seen as a spontaneous, original and completely free process like human creativity. Since AI systems work within certain parameters and predefined goals, their creativity is based on algorithms designed for a specific purpose or to solve a specific problem. In humans, creative thinking can be defined as the process of associating observations, information, experiences, or thoughts in a way that can produce concepts and creating original ideas, perspectivesways of seeing, and ways of understanding from these relationships (Durukan & Satılmış, 2021; Barnard, 2002; Williams et al., 2011; Cohen, 2014; Brown, 2015; So et al., 2016; Doorley et al., 2018; Ni et al., 2022). It involves combining existing knowledge and experiences in different and innovative ways, thinking fluently, flexibly and uniquely, finding new solutions to problems and developing unusual perspectives (Eragamreddy, 2013, Çimşir, 2019, Guilford, 1968, Torrance, 1974). Creative thinkers are generally defined as individuals who have a developed sense of curiosity, have the ability to produce original ideas in large numbers and dimensions, are open to innovations, can take risks by trying various ways, enjoy the process, have the ability to reach order from chaos, exhibit patient behavior while producing solutions, and have rich imagination. These emotional and cognitive characteristics are the cornerstones of creative thinking and feed the creativity of the individual (Aktan, 2013).

When training programs on creative thinking are examined, it is seen that creative thinking techniques are generally included, and most of these studies work with verbal techniques such as cognitive mapping, brainstorming, attribute sorting, concept map, mind map (Atakan, 2019, Özcan, 2009, Özçam 2022). There are many studies on the positive role of verbal representations on the preliminary stages of design such as inspiration and establishing the conceptual infrastructure. Herring et al. (2009) emphasized the positive role of verbal representation and sketching in providing inspiration. In this sense, verbal expression and especially reflective writing activities are thought to provide a good basis for visual representations. According to Goldschmidt and Sever (2011), words and sentences support original thinking by leaving a wide space for visual images in the translation process. In the preliminary stages of design, the verbal thinking act undertakes tasks such as finding cause-effect relationships, selecting important information within the thought or topic, seeing the relationships between thoughts and events and following their development, extracting concepts, and accessing key words that explain the topic. All these strengthen the processes of definition, framing and reflection in design (Atakan, 2014). Casakin and Krietler's (2005) research shows that working with different methods such as hand drawing, written thinking, collage, sketching, modeling or computer modeling supports flexible and creative thinking, while progressing with a well-defined conceptual infrastructure increases the rate of consistency in design. Design is a process of representation, and it is important in this sense that one's communication with oneself, the design idea and the form is carried out efficiently by establishing rich associations and reaching the result (Schön, 1983).

Considering that design is actually an act of definition and that the forms, materials, textures and colors reached in parallel with the definitions correspond to certain meanings and identities in design, the importance of verbal representation studies is understood. In addition, today's visual culture and the abundance, continuity and complexity of the data available on the internet make it difficult for students to think deeply about concept-form relationships and to distinguish between concepts. The Identity in Furniture course, which is programmed with this perspective, is a course in which the definition-design relationship is addressed in the first stage with verbal and visual studies, followed by projects and modeling studies in the field of furniture design. In the next section, the content of Identity in Furniture course and definition-identity maps will be discussed.

1.4. Identity in Furniture Course Content

Identity in Furniture is a compulsory course taught in the first semester of the 3rd year of the Department of Interior Architecture at Mimar Sinan Fine Arts University with a quota of 75 students. The students, who learned about dimensioning, materials, ergonomics, structure and construction in the previous year's introduction to furniture course, focus mainly on the aesthetic and symbolic aspects of design in the identity in furniture course and work on different identity definitions and styles that furniture can reflect, as well as modeling and drawing studies. Since it has been observed over time that design students may sometimes not perceive the identity definitions that correspond to verbal definitions correctly, therefore they may not be able to reflect the identities they have programmed in their designs as they wish, studies on finding visual equivalents of verbal definitions are given importance.

Within the scope of the course, elements such as form, color, size, material, texture are handled in furniture scale within the predetermined functional and aesthetic needs. In order for people to be happy in the spaces where they live, it is important that the furniture is correctly defined and designed (Kayan, Demirci, & Tuncel, 2023). However, as Ching points out, furniture is not only a functional object of use, but also a design product that affects its surroundings aesthetically, significantly changing the perception of space and visual identity (Ching, 2011). Achieving aesthetic integrity in design is possible by defining identity correctly and using elements such as form, color and texture in the right proportions and in the right ways. The colors used in a feminine space are different from the colors used in a masculine space, while minimal style uses few and concise colors, maximalist style uses many colors, textures and forms together (Figure 3).

Figure3 . Furniture designs with different identities

Working on the scale of furniture by establishing part-whole relationships with the elements that affect visual identity, conducting research and modeling studies in digital environment constitute the scope of the Identity in Furniture course. At the beginning of the semester, students research and make presentations about identities and styles, and towards the middle of the semester, they design furniture with different functions based on these definitions; by the end of the semester, they have acquired knowledge about many definitions of identity.

2. INFORMATION COLLECTION AND ANALYSIS

The population of the research consists of students taking the course Identity in Furniture in the fall semester of 2023-2024 at Mimar Sinan Fine Arts University. Within the scope of the two-month project, students were asked to design a seating and a service element based on three different definitions. The students made research presentations including written narratives and visuals about the verbal identity definitions given before the design, and then proceeded to the design phase. Students were not given any guidance on using artificial intelligence in the inspiration, design or visualization stages. Although it was observed that most of them spontaneously turned to generative artificial intelligence technology at different stages, it was observed that some of them either did not use this technology because they could not master it or they avoided it in principle. At the end of the process, semi-structured interviews were conducted with 14 students in order to include different types of student opinions. The age range of the participants, 5 of whom were male and 9 of whom were female, was between 20 and 55. There is no consensus in the literature on the number of participants that should be reached in qualitative research (Baker et al., 2012). One of the important factors requiring a high number of participants is to quantify qualitative research and make it suitable for statistical analysis (Macefield, 2009). According to Nielsen and Landauer's (1993) calculations with reference to the Poisson process used to model the number of occurrences of a certain event in a certain time, area or volume, 60-90% of possible situations can be detected with a user group of 7 people (Şekerli & Tüker, 2024).

The aim of this study is to interpret students' views on the use of artificial intelligence tools in design processes (inspiration, design development, representation, etc.), to examine the relationships between definition-design awareness, creative thinking and the use of artificial intelligence, to examine the effects of artificial intelligence applications on students' thinking and designing processes, to see what kind of applications and platforms they are predominantly oriented towards, and to make a situation analysis on whether they have knowledge about issues such as machine learning, ethics and security. In this context, interviews were conducted through a semi-structured interview form at the end of the research and design processes conducted during the semester. The research questions to which answers were sought are listed below

- Does clarifying definitions and conducting research before designing facilitate the use of artificial intelligence?
- Does the conscious and programmed use of generative artificial intelligence in the design process encourage creative thinking and increase awareness in furniture design?
- Do emotions such as curiosity, amusement, surprise observed in the use of generative artificial intelligence encourage creative thinking in design?
- Can AI technology be actively used in design, both in inspiration, project development and representation?
- Does artificial intelligence enable students to express themselves better and accelerate the project process?

3. STUDENT WORKS ILLUSTRATING DESIGN STEPS

In this section, two sample student projects are presented to provide a better understanding of the design steps and results. Research, idea development and design steps In the first sheet shown in Figure 4a, the definitions of exotic, ethnic and contemporary were studied. First of all, the student conducted etymological research on the concepts and then focused on finding the connotations of these concepts. At this stage, by defining the different features evoked by the concepts with verbal representations, she captured different associations related to patterns, colors, forms, shapes, materials, styles and textures. She also developed her definition-form awareness with the furniture examples she found on the internet regarding these definitions.

Figure 4b shows the work of the student who started the sketching phase after the written representation studies and conceptual research. The student, who first sketched by hand and recorded his thoughts on formal features in small notes, started to work with generative artificial intelligence after bringing his project to a certain level. After uploading her sketch to the Wombo program, she made directions with descriptive commands, accessed different patterns, motifs and materials in line with these commands; at the same time, she transferred her sketch to a three-dimensional model format. Sharing her thoughts about the process after the study, the student stated that she thought that the productive artificial intelligence gave her ideas especially at the point of creating material, texture and color alternatives and contributed to her project aesthetically.

Figure 4a. Verbal research sheets on the definitions of exotic, ethnic and contemporary

Figure 4b. Sketches and artificial intelligence experiments with exotic, ethnic and contemporary definitions

In the second sample project, the definitions of childlike, shabby and flashy were studied. In the first stage, the student who made mind maps about the definitions and tried to reach more concepts in this way, then started to make design experiments with the Wombo program. The student, who could not reach the targeted visual in the first stage, directed the artificial intelligence with the keywords he determined in advance, reached a furniture design as he wanted after various trials (Figure 5).

Figure 5. Artificial intelligence experiments with the definitions of childish, shabby and flashy

4. FINDINGS AND EVALUATION

The responses obtained as a result of the interviews with the students were first transcribed and then subjected to thematic analysis. As a result of the analysis, themes, sub-themes and codes were determined. Of the students who contributed to the analysis shared in Table 3, 5 were male and 9 were female. Apart from one male student having a high level of interest and knowledge, 1 female student stated that she was against the use of artificial intelligence in design projects during university. 1 male student stated that he was far away from artificial intelligence applications due to his age and busy working life. The responses of these two students were not included in the analysis.

Table 3 *. Themes, Subthemes and Codes*

No	Theme	Response
1	Frequency of using AI applications in daily use	-Rarely -3 times a week -5 times a week -In general -Frequently
2	The most frequently used Al apps	-Canva, Promeai, ChatGPT -ChatGPT -ChatGPT, Christopher AI, Wombo, Mid Journey -ChatGPT, Wombo -Google voice assistant -Midjourney -Midjourney, ChatGPT -Promeai -Promeai, Canva, Playground AI, Art Breeder, ChatGPT -Wombo -Wombo, BARD -Wombo, Promeai, Adobefirefly, Lineby
3	Using artificial intelligence in furniture design	-In the inspiration phase (4) -Design development (2) -Representation phase (2) -Ideation phase -Design development, representation phase -Inspiration and visualization of the idea -Design development, inspiration
4	Distribution of artificial intelligence use by stages	-In the inspiration phase (5) -Design development (3) -Representation phase (3) -Idea stage (followed by 3D Max, Sketch up, Reddit, Solidworks)
5	artificial intelligence technologies utilized in design	-Canva, Playground AI, Chrome AI, Art Breeder -Canva, Promeai -GPT, Christopher AI, Wombo, Mid Journey -MidJourney -Midjourney, ChatGPT, Dall-e -Promeai -PromeAi, Wombo, Canva, Playground -Wombo -Wombo, BARD -Wombo, MidJourney, Leonardo AI -Wombo, Promeai -Wombo, Promeai, Adobefirefly, Lineby
6	The contribution of artificial intelligence to the design process	-Fast results (fast processing of materials, more realistic form transfer, faster rendering) -Development, fast results (sketch to direct rendering, negative prompt entry) -Inspiration

		-Inspiration (application of the material) -Inspire, develop, accelerate design -Inspiration, accelerating design -Self-expression -Self-expression, fast results -Expressing oneself, getting quick results (realistic result, material assignment) -Self-expression, inspiration
7	Design definitions impact on learning	-Researching design definitions to design (10) -Positive impact beyond definitions -High
8	The impact of generative artificial intelligence on the design process	-High (questioning and rethinking) -High (drawing products that were dreamed of, postponed with the thought that they could not draw) -Middle -Middle (molding the thought, drawing the general framework) -Medium (original initial idea, inspiration) -Low
9	The impact of artificial intelligence on fluent thinking	-High -High (can be restrictive and lazy with excessive use) -High (increasing productivity and fluent thinking) -High (much more effective when used with mind mapping technique)
10	The impact of AI on flexible thinking	-High -High (discouraged, unthinkable additions) -High (can break flexibility, cause tripping) -High (diversity in forms) -Middle
11	The impact of artificial intelligence on original thinking	-High -Middle -Medium (restrictive filters) -Low
12	The impact of artificial intelligence on idea development	-High -High (many quick trials) -High (turning sketch into direct rendering, realizing the idea) -High (in terms of materials, making new additions) -Medium (features applied to the legs of the furniture)
13	Emotions in the use of AI	-Fun, curiosity -Curiosity -Curiosity, amusement, surprise -Curiosity, excitement, surprise -Curiosity, surprise -Curiosity, surprise, amusement -Don't be surprised -Surprise, amusement, curiosity -Surprise, curiosity -Surprise, curiosity

		-Surprise, curiosity -Surprise, wonder, amusement
14	Producing a design project using artificial intelligence	-In a project -Part of a project -Numerous projects (3) -Classes -First space project and furniture design course -In the fictional space lesson -Furniture design course (4)
15	Knowledge of artificial intelligence	-Low -Middle -High
16	Basic concepts (Machine learning, deep learning, data mining, etc.)	-Start -Low -Middle -High
17	Level of knowledge on ethics and safety	-Beginning -Low -Middle
18	Taking a course or research on artificial intelligence	-Personal effort (10) -Friend -Fictional space lesson
19	Recommendations	-The results of the 3d print stages should be evaluated -Conscious use should be taught -Integrate into lessons -Educators should be constructive, not devaluing -Educators should be trained -Equipment and internet infrastructure should be improved -A general artificial intelligence workshop should be established, workshops should be organized -Take advantage of the incentive to learn -There should be a course on design and artificial intelligence -Ensure efficient use and make things easier

- Most of the participants stated that the use of artificial intelligence in furniture design gives the most efficient results in the stages of inspiration, getting fast results and self-expression. This result is in line with the idea put forward in the studies of Şekerli and Tüker (2024) and Kulkarni et al. (2023) that 'artificial intelligence can be a very useful tool for designers in idea development and sketching stages, it can be a good source of inspiration by increasing speed and efficiency in design processes and supporting the formation of new ideas'. The inspiration phase is followed by the design development and representation processes. The distribution according to the stages is similar.
- Artificial intelligence has been found to contribute to idea development in furniture design. It is thought that these technologies can increase the productivity of designers in the design process, especially in the concept development and preliminary research stages. Similarly, Li (2020) stated that this technology can be useful in creating original designs.

The data in the table provides important information about the frequency of users' use of AI applications, the most frequently used AI applications and the use of AI in furniture design. The frequency with which users use these applications varies considerably. Some of them rarely use them, while others use them 3 or 5 times a week , often or frequently. This result points to how AI technologies are integrated into different rhythms of daily life and provide flexibility in use according to personal needs.

Among the most frequently used AI applications, ChatGPT, MidJourney, Promeai and Wombo stand out. While applications such as Canva, Promeai, ChatGPT are popular among users, Google voice assistant and some other specific AI tools are also widely used. These applications offer solutions for various needs of users and provide practical benefits in different areas.

When the tendency towards artificial intelligence in furniture design is examined, it is seen that these applications are mostly used in the inspiration phase. Design development and representation stages are other areas where artificial intelligence plays important roles. The intensive use in the inspiration phase shows that artificial intelligence acts as a catalyst at the beginning of creative processes. The advantages provided by artificial intelligence in the design development and representation stages, starting from the idea stage, make the work processes of designers more efficient and innovative.

Artificial intelligence technologies used in design vary. Tools such as Canva, Playground AI, Chrome AI, Art Breeder are frequently preferred. In fact, applications such as Wombo, Promeai, MidJourney and ChatGPT have become indispensable in users' creative processes. These applications provide benefits in different ways at every stage of design and help users create more original and innovative products by supporting their creative processes.

The contributions of artificial intelligence to the design process are manifested in various aspects. Users emphasized the practical advantages of artificial intelligence such as getting fast results, fast processing of materials, transferring the form more realistically and speeding up rendering processes. In addition, important contributions to creative processes such as inspiration, accelerating design and self-expression were also mentioned. Some users stated that artificial intelligence facilitated the application of the material in the inspiration process and helped in the design development phase with features such as entering negative prompts.

Regarding the impact on learning design definitions, most users indicated that AI helped them to search for the definitions needed to design. This shows that AI has positive effects on the training and knowledge acquisition process. A few users reported a positive impact beyond the definitions.

The impact of the use of generative AI on the design process was generally rated as 'high'. Users emphasized the contributions of AI in supporting the questioning and rethinking processes with the ability to draw products that are imagined but cannot be drawn. Those who saw a moderate impact expressed the benefits of AI in terms of molding thoughts and drawing the general framework. Low impact users, on the other hand, rarely described the impact of AI on the design process 'little'.

The effect of AI on fluent thinking was also generally rated as 'high'. It was stated that AI increases productivity and fluent thinking, and that it is much more effective when used with the mind mapping technique. However, some users said that if AI is used frequently, it can restrict people and make them lazy.

The contribution of AI in influencing flexible thinking in design was also found to be high. Users drew attention to the role of AI in making additions that were not encouraged or thought of. It was also stated that AI supports flexible thinking in terms of providing diversity in forms. Some users, on the other hand, felt that AI could inhibit flexible thinking and lead to design fixation. Users who saw a moderate impact reported that AI contributed to a lesser but still significant extent.

Users' opinions on the effects of artificial intelligence on original thinking vary. While some of them observed a high impact, some stated that there was a medium level of impact, some stated that the filters could be restrictive. Some users stated that they saw a low impact.

The impact of AI on idea development was generally rated as high. Users reported that AI provides advantages such as the ability to experiment quickly and in large numbers, and to translate sketches directly into renderings. In addition, the ability to make different suggestions about materials was also considered high. Those who saw a medium impact stated that the AI focused on specific elements of furniture design (e.g. furniture legs).

Curiosity and surprise were among the most frequently mentioned emotions when using artificial intelligence. Users reported feeling a sense of excitement and fun in the face of innovative and unexpected results offered by AI. These emotions show that AI creates positive effects on users and makes the discovery process fun.

Users' experiences of using AI to produce design projects have taken place in a variety of projects and educational settings. Some users used AI in a single project or part of a project, while others utilized the technology in multiple projects. It was also reported that AI was utilized in courses, especially in furniture design courses. This result suggests that AI can be adopted as an important tool in the field of education and practical projects.
The level of knowledge on artificial intelligence also varies. While some of the users have low knowledge on the subject, others stated that they have a medium level of knowledge. There are also users with high levels of knowledge. This diversity shows that AI has been adopted by a wide range of users and that users with different levels of knowledge can use this technology.

Knowledge of basic concepts (machine learning, deep learning, data mining, etc.) ranges from beginner to high level. Most users have a beginner and low level of knowledge, while some have an intermediate and high level of knowledge. This diversity reveals that interest in AI technologies and knowledge levels vary.

In terms of ethics and safety, students seem to have a beginner's level of knowledge. Although there are also those with intermediate level knowledge, it is seen that there is a need for more education and awareness in this area in general. This situation emphasizes the need for awareness on the ethical use and safety of artificial intelligence.

Students' experiences in acquiring knowledge about artificial intelligence were mostly realized through individual efforts. Ten users stated that they developed their knowledge of AI through personal efforts, while some of them benefited from friends, internet resources, and some from the fictional space course. These results show that individual learning and social interaction play important roles in AI in addition to formal education.

Suggestions for the future are quite diverse and constructive. Students who want to use technology consciously stated that it would be useful to integrate artificial intelligence into courses, organize workshops on the subject, and support their work with artificial intelligence with technologies such as 3D printing. In addition, students commented that educators should be constructive about the subject, should not see these technologies as worthless and that they should also receive training. In addition, the establishment of an artificial intelligence workshop in the school and the development of equipment and internet infrastructure were also among the suggestions.

5. DISCUSSION AND CONCLUSION

In this research, which was carried out within the scope of the Identity in Furniture course in the undergraduate program at Mimar Sinan Fine Arts University Department of Interior Architecture in the 2023-2024 Fall Semester, the effects of artificial intelligence technologies on design processes and designers were tried to be examined. At the beginning of the semester, students were asked to design furniture in line with the definitions given. Since it is thought that achieving the intended results in both designing furniture and using productive artificial intelligence is possible by making correct definitions, first of all, research was conducted on the forms of the given definitions, verbal definitions were elaborated, and then the furniture design process was started. Throughout the study, no guidance was given to the students in terms of using artificial intelligence. At the end of the process, semi-structured interviews were conducted with 14 students.

It has been observed that studies conducted with artificial intelligence applications contribute to the idea development process in furniture design. Advantages such as the ability to render hand drawings in three dimensions at a high speed compared to modeling, to create realistic images, and to apply rich material and texture alternatives have shown that the use of these technologies can increase the productivity of designers, especially in the concept development and preliminary research stages.

In order to obtain the desired visual outputs in the use of artificial intelligence technologies, written requests must be written correctly, clearly and in detail. It is important to know what the needs are, to be able to describe them in detail, to have knowledge about the subject and to be able to ask the right questions. In this regard, it is seen that it may be useful to include verbal representation studies aimed at developing literary skills and studies aimed at increasing definition-form awareness in the education process. In addition, when seen as a research tool, it is thought that artificial intelligence provides students with awareness by enabling them to differentiate parameters such as form, shape, material, style and texture.

In the future, studies can be conducted on the integration of AI technologies into educational systems, evaluating the effects of AI on student achievement and creativity, algorithmic, generative and sustainable design with AI, digital prototyping and simulation, the use of AI in multilingual learning environments, and how AI technologies can affect learning environments. This research can cover topics such as monitoring student performance, providing personalized design and learning experiences, and automating teaching methods. Beyond all this, it is predicted that it will become increasingly important for students and educators to become AI literate. When an ideal balance is achieved, it is thought that artificial intelligence can create an important synergy in design education in terms of creative thinking, save time in many areas, and increase productivity with a shift towards student-centered approaches.

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REFERENCES

Abukmeil, M., Ferrari, S., Genovese, A., Piuri, V., Scotti, F. (2021). A Survey of Unsupervised Generative Models for Exploratory Data Analysis and Representation Learning. *Acm Computing Surveys*, 54(5), 1-40.

Aktan, E. (2013). A Research on Creative Writing Skills of 9th Grade Secondary School Students, The Case of Kütahya. *Journal of Adıyaman University Institute of Social Sciences* (11), 701-732.

Atakan, G. (2014). *Yaratıcı Tasarım Sürecinde Bilişsel Yaklaşım ve Üstbilişsel Farkındalık*, Master's Thesis, Hacettepe University, Ankara.

Atakan, G. (2019). *Creative Thinking Training Model for the Concept Development Phase in Space Design*. Proficiency in Art Thesis, Hacettepe University, Ankara.

Badgers, H. (2021). Technology Opening the Doors to the Digital Universe: Artificial Intelligence. *NTT Data.* [https://nttdata-solutions.com/tr/blog/dijital-evrenin-kapilarini-acan-teknoloji-yapay-zeka/]. Access Date (10.09.2024).

Baidoo-Anu, D., Owusu Ansah, L. (2023). Education in the Era of Generative Artificial Intelligence: Understanding the Potential Benefits of ChatGPT in Promoting Teaching and Learning. *Journal of AI*, 7(1), 52-62.

Baker, S.E., Edwards, R., Doidge, M. (2012). How Many Qualitative Interviews is Enough: Expert Voices and Early Career Reflections on Sampling and Cases in Qualitative Research*, National Center for Research Methods* [https://eprints.ncrm.ac.uk/id/eprint/2273/4/how_many_interviews.pdf/] Access Date (10.09.2024).

Barnard, M. (2002). *Fashion as Communication*. Psychology Press, East Sussex.

Brown, T. (2015). When Everyone is Doing Design Thinking, is it Still a Competitive Advantage? *Harvard Business Review Digital Articles*. [https://hbr.org/2015/08/when-everyone-is-doing-design-thinking-is-it-still-a-competitive-advantage/]. Access Date (14.09.2024).

Casakin, H., Kreitler, S. (2005). *The Determinants of Creavity: Flexibility in Design*. Proceedings of the 3rd Engineering and Product Design Education International Conference.

Cohen, R. (2014). Design Thinking: A Unified Framework for Innovation. *Forbes*, [https://www.forbes.com/sites/reuvencohen/2014/03/31/design-thinking-a-unified-framework-for-innovation//] Access Date (14.09.2024).

Çimşir, S. (2019). The Importance of Acquiring Creative Thinking Skills in Basic Education. *Journal of Unlimited Education and Research*, 4(3), 283-299.

Doorley, S., Holcomb, S., Klebahn, P., Segovia, K., Utley, J. (2018). Design Thinking Bootleg. Stanford University Resources [https://dschool.stanford.edu/resources/design-thinking-bootleg] Retrieved 14.09.2024.

Durukan, E., Satılmış, S. (2021). The Relationship Between 7th Grade Students' Critical Thinking, Creative Thinking and Creative Writing Skills. *Journal of Social Sciences in Theory and Practice*, 5(1), 53-70.

Eragamreddy, N. (2013). Teaching Creative Thinking Skills. *International Journal of English Language & Translation Studies*, 1(2), 124-145.

Fatima, I. (2023). *Designing With AI: A User Study to Explore the Future Role of AI as a Collaborative Tool in Graphics Design*, Södertörns University, Stockholm.

Goldschmidt, G., Sever, A.L. (2011). Inspiring Design Ideas with Texts. *Design Studies*, 32(2), 139-155.

Gui, J., Sun, Z., Wen, Y., Tao, D., Ye, J. (2021). A Review on Generative Adversarial Networks: Algorithms, Theory, and Applications. *IEEE Transactions on Knowledge and Data Engineering*, 1-20.

Guilford, J.P. (1968) *Intelligence, Creativity, and Emotional Implications*. Knapp, San Diego.

Guo, Y., Liu, Y., Oerlemans, A., Lao, S., Wu, S., Lew, M. S. (2016). Deep Learning for Visual Understanding: A Review. *Neurocomputing*, 187, 27-48.

Gupta, S. (2023). Generative AI: Revolutionising Design Education in the Digital Age. *Businessline*. [https://www.thehindubusinessline.com/on-campus/generative-ai-revolutionising-design-education-in-the-digital-age/article67284697.ece] Date of Access (14.09.2024).

Herring, S. R., Jones, B. R., Bailey, B. P. (2009). *Idea Generation Techniques Among Creative Professionals*. Proceedings of the 42nd Annual Hawaii International Conference on System Sciences (HICSS) (pp.1-10). Waikoloa, Hawaii.

Holmes, W., Bialik, M., Fadel, C. (2019). *Artificial Intelligence in Education: Promises and Implications for Teaching and Learning*. The Center for Curriculum Redesign, Boston

Hu, L. (2023). Generative AI and Future, *Medium* [https://pub.towardsai.net/generativeai-and-future-c3b1695876f2] Date of Access (14.09.2024).

Jovanović, M. (2022). Generative Artificial Intelligence: Trends and Prospects, *Computer* 55(10), 107-112

Kandiyoti, R.M. (2023). What is Artificial Intelligence (AI)? Properties, Types and Usage Areas. [https://tr.wix.com/blog/makale/yapay-zeka-nedir-yapay-zeka-turleri#viewer-p79zk1371053]. Access Date (14.09.2024).

Kaplan, A., Haenlein, M. (2019). Siri, Siri, in My Hand: Who's the Fairest in the Land? On the Interpretations, Illustrations, and Implications of Artificial Intelligence, *Business Horizons*, 62(1), 15-25.

Karabulut, B. (2021). Creativity in the Context of Artificial Intelligence and the Future of Visual Design. *Electronic Journal of Social Sciences*, 20 (79), 1516-1539.

Kayan, H. Z., Demirci, G., Tuncel, D. (2023). A Literature-Focused Study: The Furniture Structure Course in Design Education. *Gazi University Journal of Science, Part B: Art, Humanities, Design and Planning*, 11 (1), 61-76.

Kulkarni, C., Druga, S., Chang, M., Fiannaca, A., Cai, C., Terry, M. (2023). *A Word is Worth a Thousand Pictures: Prompts as AI Design Material*. Conference acronym XX, Woodstock, NY.

Kurt, A.E. (2023). *The Use of Artificial Intelligence in Marketing Communication and Brand Promotion and a Research on the Use of Artificial Intelligence in Advertising Communication*. Master's Thesis, Bahçeşehir University, Istanbul.

Kurtuluş, Ö. (2023) Artificial Intelligence and the Future of Learning (Presentation). *The Role of Educators in the Age of Artificial Intelligence Seminar,* November 25, 2023, Istanbul, Turkey.

Lee, A.V.Y., Tan, S.C., Teo, C.L. (2023). Designs and Practices Using Generative AI for Sustainable Student Discourse and Knowledge Creation. *Smart Learning Environments* 10 (59).

Li, L., Lin, Y., Zheng, N., Wang F., Liu Y., Cao, D., Wang, K., Huang, W. (2018). Artificial Intelligence Testing: A Case Study of Intelligent Vehicles. *Artificial Intelligence Review,* 50 (10).

Li, Y. (2020). Innovation and Design in the Age of Artificial Intelligence. *Journal of Product Innovation Management*, 37 (3).

Looney, J. W. (2009). *Assessment and Innovation in Education*. OECD Education Working Papers, No. 24, OECD Publishing.

Luckin, R., Holmes, W., Griffiths, M., Forcier, L. B. (2016). *Intelligence Unleashed: An Argument for AI in Education*. Pearson Education, London.

Macefield, R. (2009). How to Specify the Participant Group Size for Usability Studies: A Practitioner's Guide. *Journal of Usability Studies*, 5 (1), 34-45.

Manovich, L. (2018). *AI Aesthetics*, Strelka Press, Russia.

McInnes, R. (2023). Embracing Generative AI as a Co-Design Partner for Designing and Developing Courses. *Times Higher Education* [https://www.timeshighereducation.com/campus/embracing-generative-ai-codesign-partner-designing-and-developing-courses] Date of Access (14.09.2024).

Mehmood, I. (2023). *Role of Artificial Intelligence in Education: Transforming Learning in the Digital Age*, Seminar on the Role of Educators in the Age of Artificial Intelligence, November 25, 2023, Istanbul, Turkey.

Mustafa, B. (2023). The impact of Artificial Intelligence on the Graphic Design Industry. *Social Science Journal*, 1-13.

NATO (2021). Summary of the NATO artificial intelligence strategy, *The North Atlantic Treaty Organization* [https://www.nato.int/cps/en/natohq/official_texts_187617.htm] Date of Access (14.09.2024).

Ni, C. , Lo, H. , Lyu, Y., Lin, R. (2022) Collaborative Creativity in Design Education: A Case Study of the Design Sketch Course. *Creative Education*, 13, 1600-1615.

Nielsen, J., Landauer, T. K. (1993). A Mathematical Model of the Finding of Usability Problems. *Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems*, 206-213.

Özcan, S. (2009). *The Effect of Creative Thinking Activities on Students' Creative Thinking and Project Development*, Master's Thesis, Gazi University, Ankara.

Russell, S., Norvig, P. (2010). *Artificial Intelligence: A Modern Approach*, Prentice Hall Series, USA.

Sawyer, R. K. (2012). *Explaining Creativity: The Science of Human Innovation*, Oxford University Press, New York.

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. Basic books, New York.

So, C., Jun, S., Nah, K. (2016). Configuring Time for Creativity: How to Optimize the Ideation Process in Design Thinking Workshops. *International Journal of Design Management and Professional Practice*, 10(4), 25-33.

Şekerli, T. Tüker, Ç. (2024). A Qualitative Study on the Effectiveness of Generative Artificial Intelligence in Graphic Design Practice. *JCoDe: Journal of Computational Design*, 5(1), 105-138.

Torrance, E. P. (1974). *The Torrance Tests of Creative Thinking: Norms-Technical Manual*, Personal Press, Princeton.

UNESCO (2023). How generative AI is reshaping education in Asia-Pacific. [https://www.unesco.org/en/articles/how-generative-ai-reshaping-education-asia-pacific]. Access Date (14.09.2024).

URL1 (2024). Harold Cohen: AARON Feb 3-May 19, 2024. https://whitney.org/exhibitions/harold-cohen-aaron

Wang, L. (2019). On the concepts of artificial intelligence and innovative design in product design. *IOP Conf. Series: Materials Science and Engineering*, 573(1).

Williams, A., Ostwald, M., Askland, H. (2011). The Relationship Between Creativity and Design and Its Implication for Design Education. *Design Principles and* Practices, 5(1):57-71.

Yıldırım, B., Demirarslan, D., (2020). Evaluation of the Benefits of Artificial Intelligence Applications in Interior Architecture to the Design Process, *Humanities Sciences* (NWSAHS), 15(2), 62-80.

Yılmaz, G. (2023) Artificial Intelligence Tools in Education (Presentation), November 25, 2023, Istanbul, Turkey.

Appendix-1: Semi-structured Interview Form

Preferences

1. How often do you use artificial intelligence applications such as voice assistants, recommendation systems, autonomous vehicles in your daily life?
2. What are the most frequently used artificial intelligence applications in your daily life?
3. Do you use artificial intelligence technology in the furniture design process? If not, which methods do you use in the furniture design process?
4. At which stage of the furniture design process do you think you make more use of artificial intelligence technology, the inspiration stage, the design development stage or the representation stage?
5. Which artificial intelligence technology do you use in the furniture design process?

6. What is the aspect of artificial intelligence that you use in the furniture design process that contributes the most to you in terms of inspiration, self-expression, and getting fast results?

Defining design concepts and the relationship with generative artificial intelligence

7. Did doing research on design definitions in the first place in furniture design help you in the design phase? How much?
8. Has the use of generative AI helped you think about design definitions and supported your design process? How much?

The relationship between productive AI and creativity

9. Has artificial intelligence affected your fluency? How much?
10. Has artificial intelligence affected your flexible thinking? How much?
11. Has artificial intelligence affected your original thinking? How much?
12. Has AI had an impact on enriching/developing your idea? How much?

The role of emotions

13. Can you evaluate your feelings of curiosity, amusement and surprise when using artificial intelligence?

Prevalence of productive AI

14. Have you ever worked on a design project using artificial intelligence? How many times?
15. Do you know about artificial intelligence? How much?
16. What do the basic concepts of artificial intelligence such as machine learning, deep learning, data mining mean to you?
17. Do you know about the ethical and safety issues of using artificial intelligence? How much?
18. Have you taken a course or done research in artificial intelligence? How much?
19. Do you have any suggestions for improving AI education or applications at your university?

CHAPTER 5

A PERSPECTIVE ON THE TRACES OF ARCHAEOLOGICAL HERITAGE IN CULTURAL MEMORY

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1. Introduction

Archaeological heritage represents a multilayered cultural structure that encompasses not only the material remains of past societies, but also the systems of thought, belief patterns, modes of production, and spatial practices transmitted to the present through these remains. In this sense, archaeological heritage transcends its role as a source of historical data and assumes a decisive position in the formation, continuity, and reproduction of cultural memory. Cultural memory, as a dynamic outcome of the relationship societies establish with the past, is shaped through processes of remembering, forgetting, and reinterpretation, and is transmitted across generations. Archaeological sites and architectural remains function as the spatial, tangible, and legible carriers of this memory.

Architecture, as a discipline directly associated with memory, produces the spatial counterparts of individual and collective remembrance. Buildings, urban fabrics, and archaeological sites constitute architectural memory as physical projections of past experiences, social practices, and cultural meanings. Particularly in the context of archaeological heritage, architectural remains bring together different layers of time within the same space, establishing continuity between past and present. In this framework, architectural memory refers not only to the formal and structural characteristics of buildings, but also to the symbolic meanings, patterns of use, and social representations they have acquired throughout history (Rossi, 1982).

The relationship between memory and space constitutes one of the central discussions of contemporary memory studies. According to Halbwachs, memory is shaped within social frameworks rather than being an individual phenomenon, and space is one of the most persistent components of these frameworks (Halbwachs, 1992). Archaeological sites, in this sense, are not merely physical traces of the past, but reference points that enable the continuity of collective memory. They reconstruct, interpret, and reproduce the past through the lens of the present and within contemporary contexts.

Today, accelerating urbanization processes, infrastructure investments, large-scale development projects, and tourism-oriented approaches threaten not only the physical integrity of archaeological heritage, but also its spatial context and layers of meaning. These threats are not limited to physical damage; they also lead to the weakening or even rupture of cultural and architectural memory. As Ahunbay emphasizes, neglecting context in conservation processes results in the fragmentation of architectural memory and the loss of its continuity (Ahunbay, 2019).

This study aims to examine in depth the role of archaeological heritage within cultural memory through the concept of architectural memory. Through theoretical discussions and selected examples from Türkiye, it reveals the multilayered structure of the archaeology–memory relationship and offers a holistic approach that brings together archaeology, architecture, conservation, and memory studies.

2. The Concept of Archaeological Heritage and Architectural Memory

Archaeological heritage is a broad concept encompassing settlement traces, architectural structures, public spaces, and the cultural landscapes formed by these elements across different periods of human history. As emphasized in UNESCO’s definition of cultural heritage, archaeological heritage constitutes cultural assets of universal value that must be protected (UNESCO, 1972). However, the value of this heritage derives not only from its capacity to produce scientific data, but also from its role in embodying the spatial representations of collective memory.

The concept of architectural memory refers to the meanings that buildings and spaces acquire over time. Aldo Rossi emphasizes that cities and architecture are among the most powerful carriers of collective memory, noting that urban artifacts gain meaning through historical continuity (Rossi, 1982). This perspective is equally applicable to archaeological sites. An archaeological site is not merely a remnant of the past, but a spatial archive in which different periods accumulate and where architectural memory can be read in layers.

In Türkiye, evaluating archaeological heritage within the framework of architectural memory is particularly significant in terms of historical continuity and cultural stratification. According to Kuban, Anatolia, as a geography constructed layer upon layer by different civilizations, is one of the regions where architectural memory can be observed most intensively (Kuban, 2010). This multilayered structure demonstrates the necessity of an architectural memory perspective in the conservation and interpretation of archaeological heritage.

2.1. Theories of Architectural Memory and Spatial Memory

The concept of architectural memory provides a theoretical framework that goes beyond individual recollection to examine how social groups construct, select, and transmit the past and past architecture. Maurice Halbwachs argued that memory is shaped within social frameworks and that space plays a decisive role in this process (Halbwachs, 1992). According to him, individuals remember the past through spatial references; thus, space is an indispensable component of memory. Jan Assmann, on the other hand, defines cultural memory through symbolic systems, rituals, and monuments that enable intergenerational transmission (Assmann, 2011). Archaeological sites and architectural remains, in this context, are considered material carriers of cultural memory. However, this role is not always neutral; which remains are preserved and how they are presented reflects the selective nature of memory.

Nora's concept of "sites of memory" (lieux de mémoire) is particularly useful in explaining the symbolic role of archaeological sites in collective memory (Nora, 1989). Archaeological sites function as places where the past is represented, reproduced, and reinterpreted within contemporary contexts. They operate as instruments of both remembering and forgetting. In examining the relationship between memory and architecture, this section also addresses concepts that emerge where individuals interact with both. By defining perception—a key concept linking memory and architecture—the relationship between sensory experience, theories of perception, and memory is discussed. The concept of home, where perception and memory are evaluated together, is also examined in its physiological, psychological, sociological, and cultural dimensions.

Downs and Stea (1973), working within environmental psychology, define perception in conjunction with cognition as the process of encoding, storing, recalling, and decoding information obtained from the spatial environment. What is perceived is transmitted to the brain; to perceive something means to interpret an object through past experiences. Lang (1974), who conducted extensive research on environmental psychology, perception theories, and human behavior, summarizes perception as an active process involving the acquisition of information from the environment (Lang et al., 1974).

Interpretations of spatial elements retained in memory vary according to the type of space, duration of use (experience and accumulated knowledge), and most importantly, the individual using the space. Therefore, physiological characteristics, personality traits, psychological conditions, past experiences (repetition and time), and socio-cultural attributes of the perceiver play a significant role in the formation of spatial memory. These variables influence how an object is perceived, the image formed through the perceptual process, and ultimately how the object is stored in memory. Interpretations of initial images emerging in the physiological process thus vary not only according to the perceiver, but also according to the qualities of the perceived space.

2.2.Archaeology and Layers of Time

Architectural memory is the materialized form of traces accumulated on space over time. Archaeological sites, by containing architectural layers from different periods simultaneously, are among the spaces where this memory can be read most clearly. These layers not only reflect historical succession, but also make visible different social structures, ideological approaches, and life practices on a spatial plane. According to Tekeli, historical environments are not merely physical entities to be preserved, but areas where social memory is produced and continuously reinterpreted (Tekeli, 2010). This perspective necessitates considering archaeological sites in relation to contemporary urban life and social practices. Otherwise, archaeological heritage risks becoming a static narrative of the past, detached from living memory.

Architecture carries forward traces of previously produced architectural forms, urban plans, and monumental structures. Even if a city's name remains continuous, its physical fabric changes, transforms, or adapts to new requirements over time. Social demands and power relations continuously affect urban order; in this sense, the city becomes a stage on which memory is performed (Boyer, 1996). Considering that memory is always reconstructed from the perspective of the present, the construction of the future also emerges as a planned process shaped by the fundamental values of society. In this process, desired values gain visibility in public space through representational forms—narratives and reenactments produced through parts that stand in for the whole.

A significant portion of urban memory is shaped around physical structures and spatial traces; the past is transmitted to the future through these material elements. Streets, monuments, and architectural forms embody powerful narratives of historical processes. Over time, not only the urban fabric changes, but also the symbolic forms representing the city are transformed. Architecture in the city is therefore not merely an arrangement determined by planners and architects, but a dynamic field of production that carries social life and collective memory (Boyer, 1996).

Archaeological heritage plays a decisive role in the construction and reproduction of social memory. Archaeological sites and monumental architectural remains, in particular, are actively used in the formation of national, local, and cultural identities through the selection, emphasis, and public visibility of specific narratives of the past. In this sense, archaeological heritage is not merely a material reflection of the past, but a field of memory that is continuously reinterpreted within contemporary social, ideological, and political contexts. As Smith notes, heritage is not an objective reality inherited from the past, but a discourse produced in the present for specific purposes (Smith, 2006). Which aspects of archaeological sites are highlighted, which periods are emphasized, or which narratives are rendered invisible clearly reveal the selective and often ideological nature of social memory. This transforms archaeological heritage from a neutral field of knowledge into an active component of identity construction and memory politics.

Archaeological sites, as spaces where collective memory materializes, establish a symbolic bridge between past and present. However, this bridge is not always inclusive or holistic. While architectural traces of certain periods or social groups are foregrounded, others may be neglected or deliberately marginalized. Such selectivity undermines the continuity of architectural memory and leads to the reduction of multilayered historical reality into simplified, singular narratives.

Another crucial function of archaeological sites in terms of social memory is their role in establishing a spatial sense of belonging. People largely experience their connection to the past through places. Archaeological sites, as the physical ground of this experience, strengthen individuals' and communities' perception of historical continuity. In this context, architectural memory contributes not only to remembering the past, but also to legitimizing present identities and shaping collective visions of the future. From a conservation perspective, the impact of archaeological heritage on social memory and identity cannot be addressed solely through physical preservation strategies. As Feilden emphasizes, conservation should not freeze the past, but rather sustain historical environments in a balanced and meaningful relationship with contemporary life (Feilden, 2003).

Otherwise, archaeological sites risk becoming spaces detached from living memory, consumed only as spectacles.

Erder's principle of cultural continuity provides a decisive framework at this point (Erder, 2011). In the conservation and presentation of archaeological sites, historical layers must be addressed holistically, considering not only aesthetic or touristic values, but also social and cultural meanings. Approaching archaeological heritage through purely tourism-oriented perspectives leads to the commodification, superficialization, and eventual loss of meaning of architectural memory.

Archaeological sites are spaces where social memory and identity are spatially constructed, negotiated, and reproduced. Their preservation entails not only safeguarding the physical traces of the past, but also making visible the multilayered structure of architectural memory and ensuring the continuity of social memory. Therefore, placing the architectural memory perspective at the center of archaeological heritage evaluation emerges as an indispensable requirement for both conservation policies and debates on cultural identity.

3. Archaeological Heritage Examples from Türkiye and Architectural Memory

3.1. Çatalhöyük (Konya): Spatial Continuity and Its Influence on the Anatolian Housing Tradition

The Neolithic settlement of Çatalhöyük is located in Central Anatolia, within the Konya Closed Basin, approximately 45 km southeast of the city center of Konya and north of the district of Çumra. The settlement developed near the former course of the Çarşamba River (known as the Melas in antiquity). This geographical location provided favorable conditions for agricultural production, access to water resources, and the continuity of sedentary life. Dated to settlement phases between 7400 and 6200 BCE, Çatalhöyük represents not only one of the earliest examples of settled life in the Neolithic period, but also a unique spatial organization in which architectural memory is produced through everyday life practices rather than monumental structures. Situated close to fertile agricultural lands and water sources in the Konya Plain, Çatalhöyük demonstrates that settlement decisions were shaped through a balanced relationship with the natural environment. In this sense, the settlement integrates production, shelter, and social organization—core components of early urbanization thought—into a holistic spatial framework (Hodder, 2012).

The contiguous housing pattern observed at Çatalhöyük, the absence of streets, and circulation provided through rooftop surfaces reveal that space was conceived not merely as a physical shelter, but as a living framework where social relations were established and memory was produced. The dense fabric formed by buildings articulated with one another transforms individual dwellings into components of a collective spatial organization; thus, spatial memory is constructed through shared experiences rather than individual ones. This condition indicates that in early settlements, public space had not yet emerged as a distinct spatial category, yet communal consciousness permeated the entirety of space (Hodder, 2014).

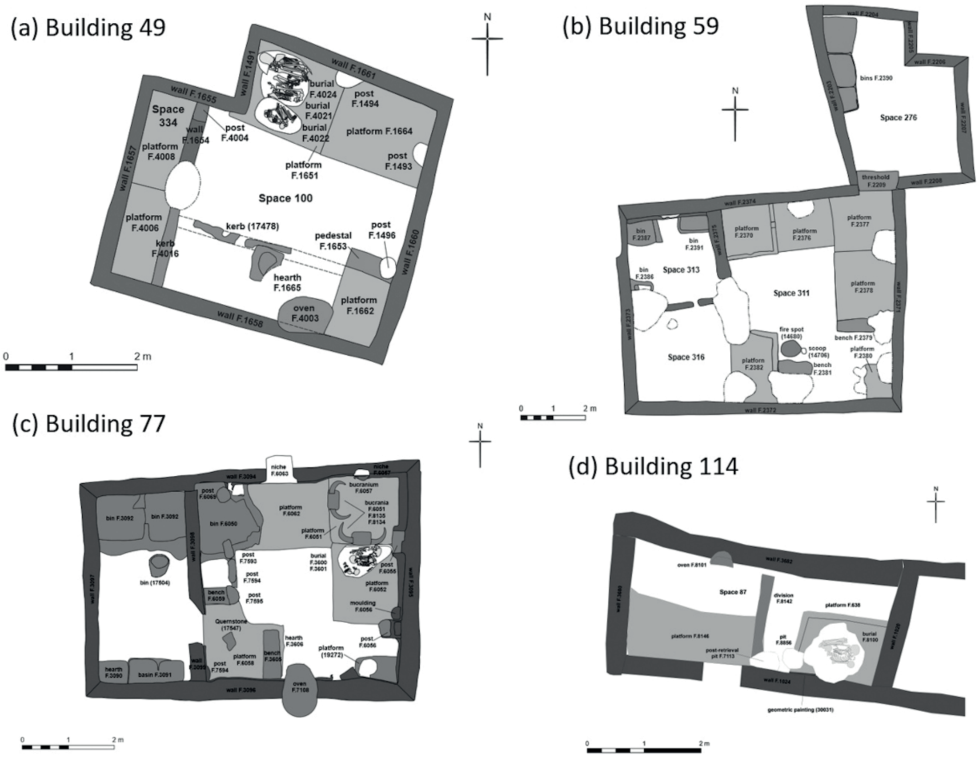

Figure 1. Çatalhoyuk House, Konya (Kay, 2020).

Figure 2. Catalhoyuk Archeological Site , Konya

(Love, 2013).

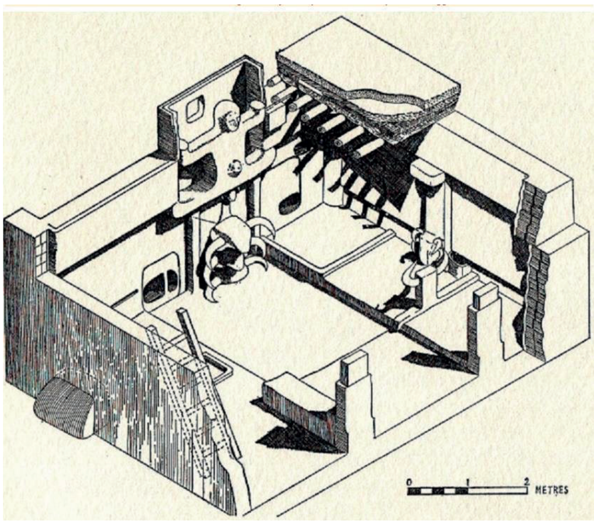

Figure 3. Catalhoyuk Archeological Site , Konya

(URL 1).

The houses of Çatalhöyük should be regarded as multilayered units of memory in which practices of birth, death, burial, and commemoration took place within the same spatial framework. The burial of the dead beneath house floors, wall paintings, reliefs, and recurring symbolic elements demonstrate that memory was transmitted not only as a mental construct, but through bodily, ritual, and spatial experience. This continuity aligns with theoretical approaches that argue memory is produced within social frameworks rather than individual recollection (Halbwachs, 1992). At Çatalhöyük, architectural memory was sustained across generations through the continuous use, repair, and reorganization of space. We often tend to regard "Stone Age" people as primitive not only technologically but also cognitively; however, these communities were biologically identical to modern humans.

One of the most significant contributions of the settlement to architectural memory lies in the absence of a clearly defined distinction between public and private space. The use of roofs as shared circulation and encounter areas, and the accommodation of both everyday life and ritual practices within interior spaces, indicate that spatial memory was produced through a collective consciousness. This spatial flexibility offers an important conceptual background for contemporary discussions on community-oriented space production, shared-use areas, and cultures of cohabitation in today's cities.

One way to understand a society's values is to examine the architecture and spatial arrangements it produces. Throughout history, cathedrals, palaces, and administrative buildings have reflected specific social priorities; in prehistoric societies lacking written language and monumental architecture, such interpretations rely primarily on settlement patterns and domestic architecture. In this context, Çatalhöyük presents a unique example as a settlement without written records, yet with exceptionally well-preserved spatial data.

Figure 4. Neolithic Site of Çatalhöyük (URL 2)

Çatalhöyük was founded in the Neolithic Period approximately five thousand years before the Egyptian pyramids and was continuously inhabited on the same site for nearly one thousand five hundred years (Hodder, 2010). The long-term continuity of the settlement persisted despite major technological transformations, such as the onset of the Chalcolithic Age. After its abandonment, the site remained largely undisturbed for an extended period, allowing detailed archaeological data related to domestic life and everyday practices to survive to the present.

Excavations have revealed no evidence of public squares, temples, or administrative buildings at Çatalhöyük. All structures are residential in nature, and the distinction between public and private space is not clearly defined (Hodder, 2014). This suggests that in a settlement inhabited by thousands of people, there was no governance system based on centralized authority. The settlement consists of contiguous houses, with circulation provided via roof planes rather than streets.

Some houses have been identified as having been used for longer periods, containing denser decorative elements and a greater number of burials. Ian Hodder defines these structures as “history houses” (Hodder, 2012). However, there is no evidence that these houses held privileged positions in terms of food production, storage, or control over basic resources. Indicators of material wealth or permanent political power accumulation are limited.

This suggests that social differentiation at Çatalhöyük may have been shaped primarily through social relations and symbolic practices. Hayden (2014) argues that the circulation of prestige objects such as obsidian and marine shells may have played a role in establishing status relations among individuals, emphasizing that the settlement should not be idealized as a fully egalitarian society. According to Hodder’s evaluations, it is noteworthy that some houses became increasingly ornate over time, followed by an abrupt cessation of this process. Evidence suggesting that certain buildings were deliberately burned indicates that social relations within the settlement may have been periodically reorganized (Hodder, 2012). These cyclical processes may have limited the consolidation of individual or family-based power accumulation.

The example of Çatalhöyük is significant in demonstrating that a small-scale, self-organizing social structure not based on centralized authority can persist over long periods. The settlement offers a unique case illustrating the possibility of alternative spatial and social organizational models in prehistoric contexts.

The architectural memory of Çatalhöyük should be evaluated not only as a historical phenomenon but also within the long-term continuity of the Anatolian housing tradition. Doğan Kuban emphasizes that residential architecture in Anatolia exhibits continuity not through formal schemes, but through life culture, spatial use habits, and social organization. According to Kuban, the inward-oriented living concept observed at Çatalhöyük, the multifunctional use of space, the centrality of the house in daily life, and the permeability between public and private realms were reproduced in different scales and forms in the Turkish house over centuries (Kuban, 1995). Thus, the Çatalhöyük house should be considered not as a direct formal prototype of the Turkish house, but as a foundational precursor in terms of spatial thinking and living practices.

The organization of life around an inner courtyard or *hayat* in the Turkish house, the multifunctional use of rooms, and the spatial configuration based on a balance between privacy and community demonstrate a conceptual continuity with the domestic logic of Çatalhöyük. This continuity reveals that architectural memory is transmitted not merely through building typologies, but through everyday spatial practices, patterns of use, and social values. In this respect, Çatalhöyük should be read as one of the earliest reference points nourishing the cultural memory of domestic architecture in Anatolia.

Çatalhöyük is an exceptional settlement demonstrating how architectural memory can be produced through everyday life, ritual, and spatial continuity, independent of monumental representations. Its spatial organization reveals not only Neolithic life practices, but also the historical roots of concepts of the city, housing, and community in Anatolia. In this sense, Çatalhöyük should be regarded as one of the deep-time carriers of architectural memory that continues to inform the intellectual foundations of contemporary cities and the Turkish housing tradition.

The residential layout of Çatalhöyük is important not only as a prehistoric settlement model but also for understanding the long-term development of the Anatolian housing tradition. The contiguous organization of houses, the use of roof planes instead of streets as circulation spaces, and the transformation of the house into a primary spatial unit accommodating all daily practices can be interpreted as early manifestations of continuities later observed in Anatolian domestic culture.

In defining the Turkish house, Doğan Kuban emphasizes that it is not a monumental representational device, but a flexible, inward-oriented spatial arrangement shaped by the necessities of everyday life (Kuban, 1995). This approach parallels the spatial organization observed at Çatalhöyük, where the distinction between public and private is not sharply drawn and where the house accommodates multiple functions such as production, shelter, ritual, and storage. In both cases, the house is not limited to a sheltering function but serves as the core unit of social life.

Tanyeli (2017), reading the Anatolian housing tradition through continuities and ruptures, argues that the Turkish house is not a fixed “type” but the outcome of a process shaped by local conditions, social relations, and living practices (Tanyeli, 2017). In this context, the houses of Çatalhöyük should be interpreted not as formal prototypes but through their relationship with everyday life. The architectural equality of dwellings, the absence of clearly expressed hierarchical differentiation, and the horizontal organization of the settlement may be considered early precursors of the neighborhood fabric that became widespread in later Anatolian settlements.

Bektaş (2013) defines the Turkish house as a human-scale architectural production that is harmonious with nature and devoid of ostentation (Bektaş, 2013). Similarly, the houses of Çatalhöyük display repeated spatial schemes and standardized dimensions, avoiding monumentality. The near-identical nature of dwellings points to a spatial understanding that prioritizes communal cohesion over individual differentiation. This suggests, as Bektaş emphasizes, that architecture was conceived as a tool supporting social life.

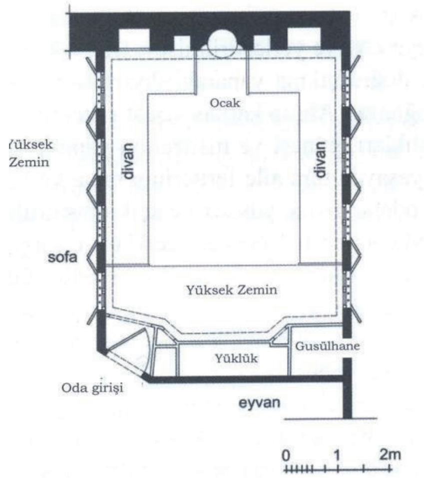

Figure 5. Traditional room plan, Safranbolu (redrawn after Küçükerman, 1991)

The role of semi-open spaces such as the sofa, courtyard, or intermediate zones in the Turkish house as regulators of social interaction, and the use of roofs as shared circulation spaces at Çatalhöyük, indicate the presence of a similar spatial logic despite belonging to different historical periods. In both examples, individual housing units gain meaning within collective spatial systems that enable communal life. Within this framework, rather than asserting a direct formal continuity between the houses of Çatalhöyük and the Turkish house, it is more appropriate to speak of an intellectual and spatial continuity in how domestic architecture relates to social life in Anatolia. The central role of the house, spatial configurations allowing egalitarian or horizontal organization, and the determining influence of everyday life on architecture emerge as the fundamental components of this continuity.

Although it is not possible to speak of a direct typological continuity between the traditional Turkish house room and the house plans of Çatalhöyük dating to the Neolithic period, significant connections can be identified in terms of spatial organization and the reflection of daily life practices in architecture. Houses at Çatalhöyük are generally defined as multi-functional living units organized around a single main space that accommodates all activities of daily life (Mellaart, 1967; Hodder, 2012). Similarly, in the traditional Turkish house, the room constitutes the fundamental spatial unit of the dwelling and is conceived as an integrated living space in which functions such as sleeping, sitting, eating, storage, and even cleaning are accommodated within the same volume (Kuban, 1995). This parallel indicates that, across different historical periods, the concept of concentrating daily life within a single core space represents a shared spatial approach.

In both housing types, the hearth emerges as both a functional and symbolic center of the space. In Çatalhöyük houses, the hearth is not limited to cooking and heating functions; it also plays a determining role in the spatial organization of the interior (Hodder, 2014). According to Doğan Kuban, in the traditional Turkish house room, the hearth likewise constitutes the hierarchical center of the space and defines the rhythm of everyday life (Kuban, 1995). This shared characteristic reveals a form of spatial continuity rooted in a life culture organized around fire, transcending different social and historical contexts.

Another important common feature of Çatalhöyük houses and traditional Turkish house rooms is multi-functionality and spatial flexibility. In Çatalhöyük dwellings, space is defined not through movable furniture but through architectural elements such as wall-adjacent platforms, storage niches, and raised areas (Mellaart, 1967). Similarly, in the traditional Turkish house, architectural components such as the divan, built-in closets (yüklük), and bathing niches (gusülhane) determine the use and organization of space (Küçükerman, 1991). Cengiz Bektaş characterizes this condition as "architecture defining space rather than furniture" and emphasizes that, in this respect, the Turkish house maintains a strong affinity with archaic settlement traditions (Bektaş, 1996).

In this context, rather than suggesting a direct historical continuity between the traditional Turkish house room and the Çatalhöyük house, it is more appropriate to speak of a continuity in cultural memory regarding the relationship between life and space within the Anatolian geography. According to Turgut Cansever, the residential tradition in Anatolia has been shaped throughout history by similar principles, particularly in terms of human scale, multi-functional spatial organization, and the direct reflection of everyday life in architecture (Cansever, 2005). Consequently, the similarities between the Çatalhöyük house and the traditional Turkish house room should be interpreted not as typological equivalences, but as spatial traces of a shared life culture.

3.2. Urban Organization and Selective Memory in Ephesus–Selçuk (İzmir)

The ancient city of Ephesus is located in western Anatolia, within the boundaries of present-day Selçuk district in İzmir Province, between the Küçük Menderes (ancient Kaystros) River delta and Ayasuluk Hill. In antiquity, the city possessed a natural harbor opening directly to the Aegean Sea, and due to this strategic position, it developed as a major center of trade, culture, and transportation connecting the interior regions of Anatolia with the Aegean and Mediterranean worlds. Strabo, in his *Geographika*, describes Ephesus as a great metropolis distinguished by its harbor and sacred areas, emphasizing that the city's geographical advantages directly influenced its political and economic power (Strabo, *Geographika*, XIV.1.24).

Over time, alluvial deposits carried by the Küçük Menderes River caused the harbor to silt up, weakening Ephesus's direct connection with the sea and leading to changes in the city's spatial organization and settlement core. However, this environmental transformation did not interrupt the city's historical continuity; rather, it prompted reorganization around different focal points and the production of a multilayered settlement memory. According to Akurgal, Ephesus is one of the most striking examples in Anatolia of cities' dynamic relationships with natural conditions, having preserved its cultural and architectural continuity despite changing environmental circumstances (Akurgal, 1993).

Ephesus presents a powerful example of architectural memory represented through monumental structures and urban spatial organization. Replanned during the Hellenistic and Roman periods, the city became a spatial stage for imperial ideology through axial order, monumental perspectives, and hierarchical public space organization. Structures such as the theater, agora, Library of Celsus, stoas, and baths were not merely responses to functional needs, but architectural expressions of political power, cultural dominance, and social order. Kuban notes that such monumental urban arrangements solidify particular interpretations of the past, guiding collective memory and shaping subsequent generations' spatial perception (Kuban, 2010).

The city's main axes—particularly Curetes Street and the Arcadian Way—function not only as circulation spines, but also as representational instruments that direct the gaze, stage space, and structure urban memory. The placement of monumental buildings along these axes clearly reveals the selective nature of architectural memory. This selectivity foregrounds certain periods and narratives while relegating others to the background. Within the framework of Nora's concept of "sites of memory," Ephesus can be read not as a space where the past is directly lived, but as a symbolic memory site where the past is re-presented through selected images (Nora, 1989).

The architectural and spatial influence of Ephesus extends beyond the boundaries of the ancient city to the contemporary town of Selçuk. Selçuk's settlement pattern, orientation decisions, and symbolic focal points have been shaped through its historical relationship with Ephesus. Byzantine and Ottoman settlements that developed around Ayasuluk Hill demonstrate how the sacred and public space traditions of the ancient city were reproduced through different architectural languages. Structures such as the Basilica of St. John and the İsa Bey Mosque reveal how Ephesus's multilayered architectural memory was transformed and sustained during the medieval and Ottoman periods (Akurgal, 1993; Kuban, 2010).

In this respect, Ephesus should be regarded not merely as an archaeological ruin, but as a living memory field through its spatial, symbolic, and cultural relationships with surrounding contemporary settlements. Despite changing environmental conditions throughout history, the city's geographical setting allowed for the preservation of architectural and urban continuity; this continuity has become one of the primary references shaping Selçuk's urban identity and spatial perception. The case of Ephesus clearly demonstrates that archaeological heritage is not a static remnant of the past, but an active component that determines cities' spatial orientations, identities, and architectural memory.

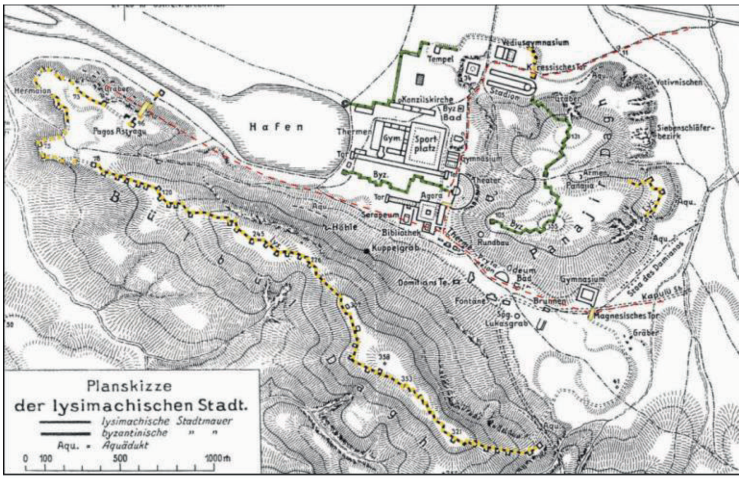

Figure 6. Overall layout of Ephesus with Lysimachian walls and a possible third gate.(Yoncacı,2006)

Figure 7.Site Map of Ephesus (URL3)

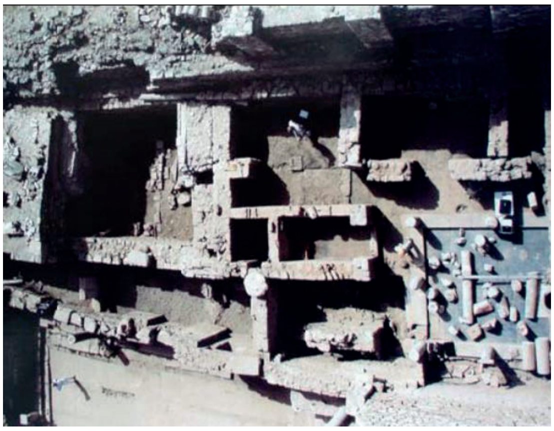

Figure 8. Late Helenistic Perisstyle House on Triodos, (Yoncacı, 2006; Hueber, F.,1997)

3.3. Conservation Approaches, Architectural Memory, and Urban Continuity in Türkiye

In Türkiye, conservation approaches toward archaeological heritage have long focused primarily on preserving the physical integrity of structures, while the social, perceptual, and experiential dimensions of space have largely remained in the background. However, archaeological sites are not merely material remnants of the past; they also function as fundamental reference fields that nourish contemporary urban formations. As discussed in previous sections through the spatial relationship between Neolithic Çatalhöyük houses and the traditional Turkish house room, architectural memory in Anatolia is transmitted not so much through formal typologies as through patterns of spatial use, multifunctionality, and everyday life practices.

The principles observed in Çatalhöyük dwellings—such as life organized around a single main space, the hearth as a spatial center, and the integration of daily functions within a unified volume—also appear in a similar manner in the traditional Turkish house room (Kuban, 1995; Küçükerman, 1991). These shared spatial principles demonstrate that settlement culture in Anatolia possesses a deep-rooted continuity, one that can be traced not only at the scale of the dwelling but also at the urban scale.

Within this context, multilayered archaeological settlements such as Ephesus play a significant role in the formation of new urban traces. The urban structure of Ephesus, which accommodates residential, public, and sacred spaces within a coherent spatial order, serves as a reference for later settlement traditions in terms of human scale, spatial hierarchy, and the interpenetration of everyday life and public space. These characteristics resonate with the spatial understanding observed in the traditional Turkish house and are indirectly transferred to the spatial configurations of contemporary cities.

As emphasized by Ahunbay (2019), treating archaeological sites as isolated conservation areas detached from contemporary urban life weakens the continuity of architectural memory. Conversely, reading archaeological heritage within its urban context and associating it with lived practices not only supports preservation but also enables the emergence of new spatial narratives and urban identities. In this framework, Ephesus can be evaluated not merely as an ancient city to be preserved, but as a productive reference field that nourishes contemporary urban design and spatial perception through its spatial principles.

The traditional Turkish house functions as an intermediary layer between archaeological heritage and contemporary urban life, enabling the transmission of spatial principles traceable from Çatalhöyük within a lived continuity. As Tekeli (2010) notes, cities evolve not through rupture but through transformation; in this process, spatial traces belonging to earlier periods continue to exist in abstracted forms within new urban configurations. Therefore, conservation policies in Türkiye should address archaeological heritage, traditional residential architecture, and contemporary urbanization not as separate domains, but as interconnected layers of a continuous and interactive cultural landscape.

4. Conclusion

Archaeological heritage, as a spatial manifestation of cultural memory, engages with architecture and the city in complex and multilayered ways. Architectural production is not limited to responding to contemporary functional demands; rather, it constitutes a continuous process of reinterpreting inherited spatial experiences, social structures, and cultural meanings. In this respect, archaeological sites function as fundamental spatial references where architectural memory is formed, accumulated, and transmitted across generations.

The relationship between memory and space becomes tangible through archaeological layers. Structural remains, settlement patterns, and configurations of public and domestic spaces belonging to different periods enable architectural memory to be read as a continuous process rather than a fragmented historical sequence. Archaeological sites are therefore not static representations of the past; they operate as dynamic memory fields that shape contemporary spatial perception, orientation, and the relationship between individuals and the city. Through this layered structure, cities emerge not only as entities that grow and transform, but also as spaces that remember.

The influence of archaeological heritage on architectural memory plays a decisive role in the formation and transformation of the urban fabric. Initial settlement choices, relationships with topography, spatial hierarchies, and the organization of open and closed spaces often represent transformed continuities of experiences embedded within archaeological layers. This condition demonstrates that contemporary urban form develops through direct or indirect engagement with inherited spatial knowledge rather than through complete rupture.

Within this framework, the case of Çatalhöyük reveals the conceptual contributions of early sedentary spatial organization to contemporary architectural and urban thought. The contiguous building arrangement, the absence of streets, the use of roofs as communal spaces, and the strong relationship between interior and exterior environments illustrate the inseparability of social life and spatial form. These characteristics offer an intellectual reference for present-day discussions on public space, neighborhood relations, collective living, and spatial flexibility. Çatalhöyük clearly demonstrates that architecture functions not merely as physical construction, but as a spatial reflection of social relations and cultural practices.

The traditional Turkish house room can be interpreted as a mediating architectural layer that translates these deep-rooted spatial principles into lived environments. Through its multifunctional room organization, the central role of the hearth, and the integration of daily life within a single spatial unit, the Turkish house embodies the continuity of architectural memory within the Anatolian context. Rather than representing a direct typological lineage, this continuity reflects the persistence of spatial logic and cultural practice across time.

Ephesus, on the other hand, presents a powerful example of direct spatial continuity between archaeological heritage and the contemporary city. The ancient city's main axes, public space organization, building–open space relationships, and settlement decisions adapted to topography remain legible in the development of present-day Selçuk. In this sense, Ephesus functions not merely as a preserved archaeological site, but as an active spatial reference shaping urban orientation, public space perception, architectural scale, and new urban traces. This case demonstrates that archaeological heritage actively contributes to the spatial character and identity of contemporary cities.

Together, the examined cases reveal that archaeological sites play a fundamental role in the formation of urban identity and in the intergenerational transmission of architectural memory. Individuals and communities living in close interaction with archaeological layers perceive space within a framework of historical continuity, and this perception informs contemporary architectural and urban production. Archaeological heritage, therefore, does not impose constraints on new architectural interventions; on the contrary, it constitutes a productive resource that nourishes design thinking and guides spatial decision-making.

In conclusion, the conservation and interpretation of archaeological cities and their layers should be regarded not only as a responsibility toward the past, but also as a prerequisite for shaping the future of cities in a sustainable and meaningful manner. A comprehensive understanding of the spatial, cultural, and social accumulation embedded in archaeological heritage enables the continuity of architectural memory and supports the development of contemporary cities in harmony with their historical layers. Within this framework, archaeological heritage emerges as an indispensable component that sustains memory, informs urban development processes, and lays a conceptual foundation for the architecture of the future.

References

Ahunbay, Z. (2019). *Tarihi çevre koruma ve restorasyon* (6th ed.). YEM Yayınları.

Akurgal, E. (1993). *Anadolu uygarlıkları* (5th ed.). Net Turistik Yayınları.

Assmann, J. (2011). *Cultural memory and early civilization: Writing, remembrance, and political imagination*. Cambridge University Press. https://doi.org/10.1017/CBO9780511996306

Bektaş, C. (1996). *Türk evi*. Yapı-Endüstri Merkezi Yayınları.

Bektaş, C. (2013). *Halk yapı sanatı*. Yapı-Endüstri Merkezi Yayınları.

Boyer, M. C. (1996). *The city of collective memory: Its historical imagery and architectural entertainments*. MIT Press.

Cansever, T. (2005). *Kubbeyi yere koymamak*. İz Yayıncılık.

Erder, C. (2011). *Tarihi çevre bilinci*. ODTÜ Mimarlık Fakültesi Yayınları.

Feilden, B. M. (2003). *Conservation of historic buildings* (3rd ed.). Architectural Press.

Halbwachs, M. (1992). *On collective memory* (L. A. Coser, Ed. & Trans.). University of Chicago Press.
(Original work published 1950)

Hayden, B. (2014). The power of prestige: Competitive generosity and the emergence of rank societies. In J. Robb & T. Pauketat (Eds.), *Big histories, human lives* (pp. 113–134). School for Advanced Research Press.

Hodder, I. (2010). Cultural heritage rights: From ownership and descent to justice and well-being. *Anthropological Quarterly*, 83(4), 861–882.

Hodder, I. (2012). *Entangled: An archaeology of the relationships between humans and things*. Wiley-Blackwell.

Hodder, I. (2014). *Çatalhöyük: The leopard's tale*. Thames & Hudson.

Kay, K. (2020). Dynamic houses and communities at Çatalhöyük: A building biography approach to prehistoric social structure. *Cambridge Archaeological Journal*, 30(3), 451–468. https://doi.org/10.1017/S0959774320000037

Kuban, D. (1995). *Türk "hayat"lı evi*. Eren Yayıncılık.

Kuban, D. (2010). *Türkiye'de kentsel koruma: Kent tarihi, koruma ve restorasyon*. Tarih Vakfı Yurt Yayınları.

Küçükerman, Ö. (1991). *Türk evi*. Türkiye Turing ve Otomobil Kurumu.

Lang, J., Burnette, C., Moleski, W., & Vachon, D. (1974). *Designing for human behavior: Architecture and the behavioral sciences*. Dowden, Hutchinson & Ross.

Love, S. (2013). The performance of building and technological choice made visible in mudbrick architecture. *Cambridge Archaeological Journal*, 23(2), 1–20. https://doi.org/10.1017/S0959774313000292

Mellaart, J. (1967). *Çatal Hüyük: A Neolithic town in Anatolia*. Thames & Hudson.

Nora, P. (1989). Between memory and history: Les lieux de mémoire. *Representations*, 26, 7–24. https://doi.org/10.2307/2928520

Rossi, A. (1982). *The architecture of the city* (D. Ghirardo & J. Ockman, Trans.). MIT Press. (Original work published 1966)

Smith, L. (2006). *Uses of heritage*. Routledge.

Strabon. (2000). *Geographika: Antik Anadolu coğrafyası* (A. Pekman, Trans.). Arkeoloji ve Sanat Yayınları. (Original work written ca. 1st century BCE)

Tanyeli, U. (2017). *Yıkarak yapmak: Anarşist bir mimarlık kuramı için altlık*. İstanbul: Metis Yayınları.

Tekeli, İ. (2010). *Mekânsal ve toplumsal düşünme*. Tarih Vakfı Yurt Yayınları.

UNESCO. (1972). *Convention concerning the protection of the world cultural and natural heritage*. UNESCO World Heritage Centre.

Yoncacı, P. (2006). *Roman urban space framed by colonnades: Mediating between myth, memory and history in Ephesus* (Unpublished master's thesis). Middle East Technical University.

Online Sources

URL1. Çatalhöyük Research Project. (n.d.). *Çatalhöyük*. Retrieved from https://www.catalhoyuk.com/

URL 2. UNESCO World Heritage Centre. (n.d.). *Neolithic site of Çatalhöyük*. Retrieved from https://whc.unesco.org/en/list/1405/

URL 3. Ephesus Official Website. (n.d.). *Ephesus site map*. Retrieved from https://www.ephesus.co/ephesus-tour-map.html

CHAPTER 6

STRATEGIC PLANNING APPROACHES FOR SUSTAINABLE UNIVERSITY CAMPUSES

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Introduction

Sustainability has emerged as a comprehensive framework that seeks to balance environmental integrity, social equity, and economic viability in response to growing global challenges. Issues such as climate change, biodiversity loss, resource depletion, and widening social inequalities have underscored the urgency of adopting sustainable development strategies across all sectors. Within this context, higher education institutions hold a pivotal position, as they function not only as centers of knowledge production but also as key actors in shaping societal values, policy frameworks, and future leadership.

Universities play a critical role in advancing sustainability by integrating environmental and social responsibility into education, research, and institutional governance. Sustainable universities adopt innovative approaches that encompass energy-efficient systems, sustainable waste and water management practices, climate-responsive campus design, and low-carbon transportation strategies. By embedding sustainability principles into academic curricula and research agendas, universities cultivate environmental awareness, critical thinking, and ethical responsibility among students, thereby contributing to the formation of future decision-makers equipped to address complex global challenges.

Beyond their educational mission, sustainable universities possess the capacity to influence sustainability transitions at local, regional, and global scales. Through interdisciplinary research, international collaborations, and partnerships with public institutions, private sectors, and civil society organizations, universities contribute to the dissemination of sustainable practices and knowledge. Student organizations and campus-based initiatives further reinforce this impact by fostering participatory governance, social engagement, and environmentally responsible behaviors. In this sense, university campuses function as “living laboratories,” where sustainability principles are tested, refined, and demonstrated in real-life settings.

The development of sustainable university campuses requires a strategic planning approach that systematically integrates sustainability objectives into institutional decision-making processes. Strategic planning enables universities to align their long-term visions with measurable sustainability goals, ensuring coherence between policy, spatial planning, infrastructure development, and daily operations. Key components of sustainable campus planning include the integration of renewable energy systems such as solar and wind power, the implementation of comprehensive waste reduction and recycling strategies, the use of water-efficient technologies, and the promotion of sustainable mobility options such as pedestrian-friendly layouts, cycling infrastructure, and electric vehicle charging facilities. Additionally, increasing green spaces, supporting local and sustainable food systems, and preserving ecological diversity enhance both environmental performance and social well-being on campus.

Within the scope of this study, university campuses and their sustainability-oriented practices are examined through the lens of strategic planning. By analyzing selected examples and institutional approaches, the study aims to identify key principles, challenges, and opportunities in the development of sustainable university campuses. Furthermore, strategic planning recommendations are proposed to support higher education institutions in designing resilient, inclusive, and environmentally responsible campus environments that contribute to a more sustainable future.

Sustainable Cities and University Campuses

Rapid population growth and increasing migration from rural areas to urban centers have significantly intensified environmental pressures on cities worldwide. This process has led to unplanned and irregular urbanization, infrastructure deficiencies, escalating waste generation, and the accelerated depletion of fossil fuel–based energy resources (UN-Habitat, 2020; Newman & Jennings, 2008). In order to meet the demands of growing urban populations, industrialization and technological advancement have expanded rapidly; however, when these developments occur without strategic planning, they result in environmental degradation, social inequality, and unsustainable urban growth patterns (Beatley, 2012; Wheeler, 2013).

The increase in consumption rates associated with population growth directly contributes to higher volumes of solid and liquid waste, while inadequate waste management practices exacerbate environmental problems. The widespread use of environmentally harmful fuels in residential and commercial buildings, uncontrolled industrial emissions, the discharge of untreated domestic waste into natural ecosystems, deforestation, biodiversity loss, and the accumulation of hazardous chemical and technological waste are among the most significant anthropogenic environmental threats (Giddings et al., 2002; Steffen et al., 2015). These challenges highlight the urgent need for sustainability-oriented approaches in urban development and governance.

Within this context, sustainability has become a key concept in addressing contemporary urban and environmental problems, and higher education institutions represent one of its most influential application areas. Universities are no longer solely centers for education and knowledge production; they are increasingly recognized as active agents with environmental, social, and ethical responsibilities toward society (Cortese, 2003; Lozano et al., 2015). Sustainable university campuses contribute positively to urban sustainability by reducing resource consumption, minimizing environmental impacts, and fostering social awareness and participation among students, staff, and local communities.

Universities also hold a strategic responsibility in mitigating the impacts of climate change and supporting the transition toward sustainable societies. A sustainable university can be defined as an institution that integrates sustainability into its core missions of education, research, governance, and campus operations; promotes sustainable development values; proposes solutions to pressing societal challenges; and reduces the environmental and social footprint of its campus (Velazquez et al., 2006; Filho et al., 2019). Given their role in shaping future professionals and decision-makers, universities are expected to assume leadership roles in climate action and sustainability-driven transformation processes (Leal Filho et al., 2021).

In recent years, growing interest in sustainable campuses has resulted in the widespread adoption of international sustainability assessment and ranking systems. Evaluation frameworks such as the Green League, the Environmental and Social Responsibility Index, and the UI GreenMetric World University Rankings are increasingly used to measure sustainability performance in higher education institutions (Alshuwaikhat & Abubakar, 2008). Among these tools, the UI GreenMetric ranking system stands out as one of the most comprehensive and widely implemented models for assessing campus sustainability practices globally.

Developed by the University of Indonesia and first implemented in 2010, the UI GreenMetric system aims to address critical global challenges such as environmental pollution, depletion of non-renewable energy resources, climate change–induced drought, biodiversity loss, and ecological imbalance within university campuses (UI GreenMetric, 2023). The core philosophy of the system is structured around four fundamental dimensions: environment, economy, equity, and education. Its categories and indicators are designed to reflect these dimensions, enabling universities to evaluate their sustainability performance systematically and comparatively.

Beyond its ranking function, the UI GreenMetric framework facilitates information exchange and experience sharing among participating institutions while allowing universities to identify strengths, weaknesses, and areas for improvement in their sustainability strategies. As such, it functions as an important strategic planning and monitoring tool that supports higher education institutions in aligning campus development policies with long-term sustainability goals and implementing more effective and integrated sustainability strategies (Kayapınar, Dal & Aşkın, 2019; Filho et al., 2021).

Figure 1. Wageningen University (the Netherlands) ranked first in the GreenMetric 2023 ranking. (URL 1)

Comparison of Universities Worldwide in Terms of Sustainability and Environmentally Friendly Practices

Worldwide Research on Sustainable and Green Universities/Campuses

In recent years, universities around the world have increasingly adopted sustainable and environmentally oriented campus transformation strategies. These initiatives aim to reduce environmental impacts, improve resource efficiency, and contribute to climate change mitigation while simultaneously enhancing campus functionality and quality of life. As higher education institutions expand their physical infrastructure and operational capacities, sustainability-oriented planning and management practices have become an essential component of campus development.

Numerous international examples demonstrate the effectiveness of such approaches. For instance, Stanford University in the United States has implemented comprehensive energy-efficiency measures, including sensor-based lighting systems, quad-pipe heating and cooling systems, and advanced lighting technologies. These interventions have resulted in energy savings of up to 38%. Similarly, the University of California, Berkeley has significantly reduced water consumption by replacing conventional toilet systems with low-flow automatic cisterns, reducing water use from 3.6 gallons to 1.6 gallons per flush. In addition, building-level water meters were installed to monitor consumption patterns, and a dedicated water conservation laboratory was established. Through the development of water-cooling fog systems and vacuum-based water pumping technologies, the university succeeded in reducing overall campus water consumption by approximately 32% (Kayapınar, M. Dal & Aşkın, 2019).

Such practices illustrate how universities can function as experimental environments where innovative sustainability solutions are developed, tested, and implemented. These campus-based initiatives not only contribute to institutional sustainability goals but also serve as replicable models for urban environments and other public institutions.

Within this global context, international sustainability assessment and ranking systems have gained increasing importance as tools for benchmarking and comparative analysis. One of the most prominent platforms in this field is the UI GreenMetric World University Rankings, which evaluates universities based on their sustainability performance. According to the GreenMetric 2023 rankings, the top ten universities worldwide demonstrate exemplary performance in sustainable campus planning and management. In this ranking, Istanbul Technical University (ITU) from Türkiye is positioned 47th reflecting its ongoing efforts toward campus sustainability.

The UI GreenMetric evaluation framework assesses universities using six main indicators, with a total score of 10,000 points. These indicators and their respective weightings are as follows:

- Setting and Infrastructure (15%)
- Energy and Climate Change (21%)
- Waste Management (18%)
- Water Use (10%)
- Transportation (18%)
- Education and Research (18%)

These criteria provide a comprehensive structure for evaluating both the physical and institutional dimensions of sustainability on university campuses. By addressing environmental performance, educational activities, and governance-related aspects simultaneously, the GreenMetric system offers a strategic framework for comparing universities worldwide and guiding future sustainability-oriented campus planning efforts.

Table 1. UI GreenMetric World University Ranking evaluation criteria (Zeybek&Öztürk, 2023)

Area	Description	Weight (%)
Waste Management	Waste management constitutes a critical component of sustainable campus development, encompasscing waste reduction strategies, recycling	18
Water Management	This area focuses on reducing overall water consumption, improving water efficiency, implementing conservation	10
Eco-Friendly Transportation	Campus transportation systems play a significant role in air pollution and carbon emissions. Sustainability-orien-ted transportation policies encourage	18
Education and Training	Universities play a key role in fostering sustainability awareness. The inclusion of sustainability-related courses, research activities, and training programs is essential for educatng environmentally responsible students	18

The table below compares universities around the world in terms of sustainability and environmentally responsible practices (UI GreenMetric World University Rankings, 2023). Each institution is listed along with its country and evaluated across multiple sustainability-related categories. These performance scores reflect the universities' effectiveness in environmental management, resource conservation, and sustainable development initiatives.

Wageningen University & Research (the Netherlands) holds the first position in the ranking. Wageningen is widely acknowledged as a global leader in sustainability education and research. Its consistently high scores derive from comprehensive environmental management systems, innovative waste reduction and recycling programs, and integration of sustainability into both curriculum and campus operations. National policies in the Netherlands that emphasize circular economy, renewable energy adoption, and climate action further reinforce the university's performance.

Second place is occupied by Nottingham Trent University (United Kingdom). Nottingham Trent distinguishes itself through robust environmentally friendly transportation policies, substantial improvements in energy efficiency, and broad campus-wide sustainability initiatives. Its strategic plans promote cycling, public transit use, and reduced carbon emissions. The university's community engagement in sustainability practices has also contributed to its elevated scores.

In third place is Umwelt-Campus Birkenfeld (Trier University of Applied Sciences) in Germany. Germany's strong legislative framework on environmental protection and renewable energy policy supports the university's sustainability achievements. Umwelt-Campus Birkenfeld is particularly recognized for its energy-saving infrastructure, on-site renewable energy generation, and environmentally sensitive campus design. These measures align with national energy transition goals (Energiewende) and reinforce the institution's performance.

Other notable institutions in the ranking include:

University of California, Davis (USA), which scores highly due to its extensive environmental research programs, sustainable agriculture initiatives, and climate action planning. UC Davis integrates sustainability into formal research agendas, academic offerings, and operational policies. University College Cork (Ireland), which is recognized for exemplary water and energy management strategies, biodiversity programs, and community-focused sustainability outreach. University of São Paulo (USP) (Brazil), which demonstrates strength in sustainability through research output, institutional sustainability policies, and resource efficiency efforts.

Additionally, universities such as the University of Connecticut (USA) and the University of Bremen (Germany) are featured in the ranking due to their energy-saving practices, progressive campus sustainability projects, and participatory governance structures that support environmental stewardship. Overall, this table provides a comprehensive comparison of institutional performance in sustainability. It highlights differentiated strengths across universities and illustrates how policy frameworks, research emphasis, and operational strategies contribute to sustainability outcomes.

In recent years, research on sustainable and green university campuses increasingly emphasizes the transition from project-based environmental initiatives to integrated, performance-oriented sustainability systems. Recent studies highlight that leading universities have adopted net-zero carbon targets, campus-wide digital monitoring of energy and water consumption, and data-driven decision-making mechanisms embedded within institutional strategic plans. Sustainability indicators are no longer limited to physical infrastructure improvements but now encompass governance structures, participatory management models, and interdisciplinary research outputs. International assessments reveal that universities achieving higher sustainability performance are those that align campus planning with long-term climate commitments, smart campus technologies, and continuous monitoring frameworks, thereby strengthening both environmental outcomes and institutional resilience. This shift underscores the growing role of sustainability rankings and benchmarking tools as strategic instruments guiding universities toward measurable, transparent, and accountable sustainability practices.

In recent international literature, particularly studies published between 2024 and 2025, sustainable university campuses are increasingly discussed within the framework of strategic planning, digitalization, and performance-based governance. These studies emphasize a clear transition from isolated, project-oriented environmental actions toward integrated sustainability systems embedded within institutional strategic plans. Universities achieving higher sustainability performance are those that have adopted net-zero carbon targets, campus-wide digital monitoring systems for energy, water, and emissions, and continuous performance evaluation mechanisms. Sustainability indicators are no longer limited to physical infrastructure improvements but increasingly include governance models, stakeholder participation, transparency, and data-driven decision-making processes. This shift highlights the role of sustainability rankings and benchmarking tools not merely as comparative instruments, but as strategic planning mechanisms guiding universities toward measurable, accountable, and long-term sustainability outcomes (Leal Filho et al., 2024; Lozano et al., 2025).

Sustainable-Ecological University Practices in Turkiye

Although many universities in Türkiye participate in the UI GreenMetric ranking system and engage in various environmental programs, their overall institutional green vision remains relatively weak. Sustainable campus practices in Türkiye constitute a comparatively recent development, and most initiatives have emerged primarily in response to external assessment frameworks rather than as a result of comprehensive, internally driven sustainability strategies. In this context, sustainable campus practices in Türkiye have largely been initiated and shaped according to the criteria defined by the GreenMetric ranking system.

Several universities in Türkiye have signed international sustainability declarations and are members of various national and international sustainability networks. Within the framework of sustainable university initiatives, Boğaziçi University, Özyeğin University, and Piri Reis University have obtained LEED and BREEAM certifications for selected campus buildings, while Konya Food and Agriculture University later joined this group with certified sustainable structures. Additionally, Akdeniz University has initiated a “Zero Emission Campus” project, reflecting a more ambitious approach to carbon reduction. Boğaziçi University has invested in renewable energy production by constructing a wind power plant at its Sarıtepe Campus, while Istanbul Bilgi University has undertaken projects to supply the energy needs of its Santral Campus through renewable energy sources (Öztürk & Çelik, 2022; Bozat, Topdemir, & Gazi, 2016).

Despite these noteworthy examples, the broader dissemination of sustainability awareness and the initiation of campus-based environmental projects in Türkiye have been significantly influenced by the increasing number of universities participating in the GreenMetric ranking. Participation in such international assessment systems has functioned as a catalyst for institutional visibility and benchmarking rather than as an outcome of deeply embedded sustainability governance. For instance, in 2021, a total of 71 universities from Türkiye—including both state and foundation universities—were included in the GreenMetric ranking (International Cyprus University was also listed under Türkiye) (Öztürk & Çelik, 2022). By 2023, Istanbul Technical University (ITU) ranked 47th globally, standing out as the most prominent representative of Türkiye in the ranking system.

Historically, Sabancı University and Bilkent University achieved positions within the top 200 of the GreenMetric ranking between 2011 and 2012. Within the scope of sustainable and ecological campus practices, Sabancı University has particularly emphasized environmental landscaping and sustainable transportation policies. The campus has been enriched with more than 100 endemic plant species, and landscape planning has been carried out to promote biodiversity and ecological continuity. Furthermore, electric vehicle charging stations have been installed to encourage low-emission transportation modes. Bilkent University, on the other hand, has focused on large-scale afforestation, with approximately 60% of its campus area forested as part of its sustainability-oriented spatial development strategy (Kayapınar, Dal, & Aşkın, 2019). Nevertheless, quantitative assessments reveal that approximately 90% of universities in Türkiye have a green vision index score below 15 out of 100, while scores related to water management, waste management, education, and research generally remain below 10 points (based on available national assessments conducted between 2016 and 2019). According to these findings, no university in Türkiye (except ITU) achieves an index score above the global average. This situation indicates that sustainability initiatives are often fragmented, project-based, and limited to operational improvements rather than being supported by holistic institutional policies.

Considering the accelerating impacts of climate change and the critical role universities play as knowledge producers, innovation hubs, and social leaders, higher education institutions in Türkiye need to develop comprehensive and integrated sustainability policies. Campus planning, architectural design, infrastructure investments, education, and research activities should be aligned with sustainability principles within a long-term strategic framework rather than being driven solely by ranking-oriented motivations (Kayapınar, Dal, & Aşkın, 2019).

Table 3. Sustainability indicators at Middle East Technical University, Türkiye (based on available data, 2016–2018) (URL3)

Average percentage of University's budget for sustainability effort	The total carbon footprint per person	Total campus smart building area
16%	**0.95 metric tons**	**197,612 m^2**
The total number of vehicles in campus per person	Total ratio of research funds dedicated to sustainability research	Number of scholarly publications on sustainability published
0.44	**58%**	**1,300**

At Middle East Technical University (Turkiye), 16% of the average university budget is focused on sustainability. The per capita carbon footprint is 0.95 metric tons. The total smart building area is 197,612 m2 , the number of vehicles per capita is 0.44, and the percentage of funds allocated to sustainability-related studies is 58%. The number of scientifically published publications is 1,300.

Based on available data (2016), Manisa Celal Bayar University's primary carbon footprint was calculated to be 8,953,906 tons of CO_2.It has been determined that 87.85% of this amount (7,865,721 tons of CO2) is due to electricity consumption. In addition, the university's efforts towards sustainability in 2016 included the planting of 4700 saplings on the campuses and the Solar Power Plant (SPP) project as a renewable energy source (Binboğa & Ünal, 2016).

Strategic Planning for a Sustainable University Campus

After the evaluation of university activities and signed declarations on sustainability, it has been determined that the efforts of universities in Turkiye in this field are limited. Günerhan (2016) states that a university that decides to become a sustainable university should first determine its sustainability vision.

Considering that each university has its own unique characteristics, each university should create a sustainability vision by taking into account its own dynamics. The mission of the university should be defined in this context. The university should determine where it is in terms of sustainability. In its vision, it should specify how the goals set will be achieved. Universities should establish a sustainability office where sustainability and green environment studies will be carried out. Initiatives, regulations, projects and activities to be carried out within the university should be coordinated by this office. A committee of experts on the subject should be formed. In this direction, the sustainability goals of the university should be determined. Financial resources should be evaluated (Günerhan A. & Günerhan, H. 2016).

Table. 4. Model of Sustainable University (Günerhan A. & Günerhan, H. 2016).

Planning for Sustainability in University Campuses

Priorities for sustainability on university campuses will be examined in the following order.

Practices to Mitigate the Impacts of Climate Change

Due to climate change, prolonged high temperature weather conditions make pedestrian transportation and circulation within the campus impossible. The campus area, which is shaded and forested with canopies, will provide campus employees and students with a comfortable and healthy life. However, in very hot weather, it will give the opportunity to sit and work in the campus in an air conditioned environment. Air conditioning will reduce energy use.

Figure 2. Colorado University, US (URL4)

Figure 3. Colorado University, US (URL4)

Energy Efficiency and Creation of Renewable Energy Resources

University campuses are like small cities. They provide their students and staff with many amenities such as housing, dining, social space, etc. Campuses can serve as living laboratories to test sustainability strategies and practices and to be agile as new opportunities arise. However, new strategies need to be implemented to make universities more sustainable. A sustainable university campus should reduce its harmful impact on the environment by minimizing energy consumption. To achieve this, energy efficiency measures should be taken and renewable energy sources should be used. New solutions should be built on campus with solar panels, wind turbines and energy efficient buildings. The campus should be able to meet its energy needs in a sustainable way.

Figure 4. Campus-Based Solar Energy Systems (URL5)

Figure 5. Umwelt-Campus Birkenfeld (Germany) ranked 3rd in the UI GreenMetric World University Rankings 2023. (URL2)

Water Efficiency, Waste Management, Recycling, Utilization of Organic Waste,

A sustainable university campus should take a leading role in waste management. It should implement practices such as recycling programs, waste reduction strategies and waste sorting systems. For example, a lot of paper waste in university departments, plastic and paper plates or plastic bottles in canteens, paper towels in wet areas should be reduced and recycling should be supported. Collection and recycling of organic waste from nature must be ensured. Hospital waste should be sterilized and disposed of in a controlled manner.

Protection of Nature, Green Areas and Ecosystem:

Protecting natural habitats and increasing green areas are important elements for a sustainable university campus. Reforestation projects, efforts to support biodiversity and sustainable use of water resources are steps to protect the ecosystems of campuses. However, in university campuses far from the center but focused on agriculture and animal husbandry, studies and practices for sustainable agriculture and animal husbandry should be supported under the supervision of faculties.

Figure 6. Universidade de São Paulo Campus, Brazil, ranked 8th in the UI GreenMetric World University Rankings 2023 (URL2)

Social Responsibility and Community Engagement:

Sustainability is not only an environmental but also a social responsibility. University campuses should educate and raise awareness of sustainability issues among students, academic staff and the local community. Increasing community engagement projects and developing social responsibility projects for sustainability and green environment should be supported. Students should also be trained in this direction.

Figure 7. University of Groningen, Holland, (URL2)

Clean Transportation and Mobility:

In addition to on-campus mobility strategies, the sustainability of university campuses should also be evaluated in relation to students and academic staff commuting from outside the campus. Transportation-related emissions generated by daily commuting constitute a significant component of the overall carbon footprint of universities. Therefore, environmentally friendly transportation policies should not be limited to internal campus circulation but should also be integrated with urban-scale mobility systems. Encouraging the use of public transportation, bicycles, and low-emission vehicles for access to campus, as well as supporting electric vehicle infrastructure in surrounding urban areas, contributes directly to reducing air pollution and greenhouse gas emissions. Sustainable commuting strategies strengthen the relationship between campus and city, improve air quality, and support healthier living environments both within the university and in the broader urban context.

Occupational Health and Safety

Human life is very valuable. Human health and safety must be ensured in all works and constructions to be carried out on campus, and in the machinery and tools to be used. Electrical and elevator controls must be carried out regularly in old buildings. Roads and asphalt within the campus should be constructed according to the rules, and stairs, steps and walkways should be designed or transformed to suit human ergonomics. Human rights, animal welfare and working conditions should be positively promoted in procurement practices.

Conserve Resources, Promote and Ensure Savings

The consumption of electricity, water, natural gas, etc. on campus should be controlled and saved. It should be aimed to utilize solar energy with solar panels and wind energy with wind turbines. Rainwater should be collected and used.

Prevention of On-Campus Pollution,

Places and spaces for education and research occupy a certain space. People living in these places use natural and social resources in the process. However, they also pollute these resources. Universities should support the assessment and reduction of the environmental and social footprint of buildings, on-campus procurement practices or laboratories.

Figure 8. Campus Sanitation and Cleaning Practices (URL6)

Students and groups should actively promote sustainability. Activities, projects and materials used should be environmentally friendly. Students and staff should be able to volunteer for sustainability projects and courses. Departments should encourage studies and projects related to sustainability and green environment.

Smart-Green Buildings

It is very important for the sustainability of university campuses that buildings within the university save energy and recycle waste. Buildings should be equipped with solar cells, good insulation, waste separation or energy-efficient lighting. They should also be certified by sustainability standards such as LEED or BREEAM.

Figure 9. The University of Connecticut (USA) ranked 4th in the UI GreenMetric World University Rankings 2023 (URL2)

Figure 10. The University of Bremen (Germany) ranked 10th in the UI GreenMetric World University Rankings 2023 (URL2)

Cultural Heritage Protection, Sustainable Buildings and Sustainable Campus

Most of the time, campuses are built on tangible and intangible elements that reflect our cultural heritage. They are settlements with original monumental, traditional architecture and all kinds of intangible and tangible cultural heritage elements. These values need to be maintained. Each of the elements of cultural heritage is formed as a result of the harmonious relations that people have established with nature and carries many sustainable design criteria. Therefore, universities located within cultural assets carry the sustainability features of the buildings. For this reason, the protection of cultural assets and cultural heritage will contribute to the sustainability of university campuses.

Figure 11. University College Cork (Ireland) ranked 6th in the UI GreenMetric World University Rankings 2023 (URL2)

Figure 12. Nottingham Trent University (United Kingdom) ranked 2nd in the UI GreenMetric World University Rankings 2023 (URL2)

Ensuring Equality and Removing Barriers for People with Disabilities in Sustainability Life

Sustainability in universities encompasses not only environmental and economic dimensions but also social equity and inclusivity. Ensuring that people with disabilities have equal access to campus resources, programs, and infrastructure is a fundamental aspect of creating a truly sustainable university environment. Inclusive design principles—such as barrier-free buildings, accessible transportation, adaptive learning technologies, and assistive services—enable students, staff, and visitors with disabilities to participate fully in academic, social, and sustainability-related activities.

Integrating disability inclusion into sustainability initiatives reinforces the broader social responsibility of universities. For example, the development of pedestrian-friendly pathways, accessible cycling routes, and electric vehicle infrastructure should consider mobility needs of all campus users. Sustainability policies and campus planning that address accessibility challenges not only comply with legal and ethical standards but also strengthen community engagement, enhance campus diversity, and model socially responsible behavior for future leaders.

Ultimately, embedding equity and accessibility within sustainability strategies ensures that environmental, social, and educational goals are achieved in an integrated manner, reflecting the holistic principles of sustainable university campuses discussed in previous sections. By removing barriers and promoting inclusivity, universities can set a benchmark for socially just and environmentally responsible practices in higher education.

Figure 13. The University of California (USA) ranked 10th in the UI GreenMetric World University Rankings 2023 (URL2).”

Figure 14. Taşkışla Building, Faculty of Architecture, Istanbul Technical University (ITU), Taksim, Istanbul (URL2)

Education and Training of Students, Employees and the City Supported by Sustainability Awareness

Research, projects and practices should be carried out within the scope of the university to increase the awareness of sustainability among students, employees and citizens. Education should be provided on the importance of sustainability. Sustainability education extends beyond formal curricula and infrastructure; it requires active engagement of students, academic staff, administrative personnel, and the surrounding community. Universities play a central role in cultivating sustainability consciousness, fostering behavioral change, and developing practical skills necessary for sustainable living and professional practices. By integrating sustainability into teaching, workshops, seminars, and community outreach programs, universities can promote awareness of environmental challenges, resource conservation, and socially responsible behavior.

Training initiatives may include courses on renewable energy, waste management, climate change adaptation, sustainable urban planning, and green technologies. Additionally, campus-wide campaigns, volunteer projects, and participatory workshops allow students and staff to apply theoretical knowledge in real-life contexts, turning the campus into a “living laboratory” for sustainability practices. Collaboration with local municipalities, NGOs, and community groups further reinforces the impact, ensuring that sustainability awareness transcends campus boundaries and contributes to broader societal transformation.

Embedding sustainability awareness into the culture of universities ensures that graduates, employees, and community members are equipped to make informed decisions and take responsible actions that align with environmental and social goals. Such education not only supports operational sustainability on campus but also strengthens the role of universities as agents of change in achieving regional and global sustainability objectives.

Figure 15. Sustainability Courses Offered by Universities (URL6)

Emission of Sounds from Nature on Campus and Clean Sound and Clean Breath

A sustainable university campus should consider not only energy efficiency, waste management, and social equity but also environmental quality and biodiversity. Allowing natural plant and animal species to thrive on campus should be actively supported, as this enhances ecological resilience, mental well-being, and the overall campus experience. Natural sounds such as bird songs, rustling leaves, and flowing water contribute positively to mental health, create a restorative learning environment, and strengthen the connection between students, staff, and nature.

At the same time, human-generated noise pollution should be minimized through the design of quiet zones, acoustic planning in buildings, and effective traffic management strategies. Preserving and expanding natural areas allows the propagation of flora- and fauna-derived sounds, promoting a calm and environmentally integrated campus atmosphere.

Air quality is a critical dimension of sustainability. Alternative, low-emission transportation methods—such as public transit, bicycles, and electric vehicles—should be encouraged. Environmentally friendly energy use should also be promoted for students and academic staff commuting to campus from outside, and in the cities where campuses are located. Promoting renewable energy use and reducing emissions both on campus and in the surrounding urban areas strengthens the broader ecological impact of the university.

Sustainability education extends beyond formal curricula and infrastructure; it requires active engagement of students, academic staff, administrative personnel, and the surrounding community. Universities play a central role in cultivating sustainability consciousness, fostering behavioral change, and developing practical skills necessary for sustainable living and professional practices. By integrating sustainability into teaching, workshops, seminars, and community outreach programs, universities can promote awareness of environmental challenges, resource conservation, and socially responsible behavior. Training initiatives may include courses on renewable energy, waste management, climate change adaptation, sustainable urban planning, and green technologies.

Moreover, campus-wide campaigns, volunteer projects, and participatory workshops allow students and staff to apply theoretical knowledge in real-life contexts, transforming the campus into a “living laboratory” for sustainability practices. Collaboration with local municipalities, civil society organizations, and community groups further reinforces the impact, ensuring that sustainability awareness transcends campus boundaries and contributes to broader societal transformation.

Embedding sustainability awareness into the culture of universities ensures that graduates, employees, and community members are equipped to make informed decisions and take responsible actions that align with environmental and social goals. These measures not only support operational sustainability on campus but also strengthen the role of universities as change agents in achieving regional and global sustainability objectives.

Conclusion:

Sustainable university campuses have the potential to serve as exemplary institutional environments that integrate environmental stewardship, social responsibility, and educational excellence. By offering future generations the opportunity to study in livable and ecologically conscious settings, universities not only fulfill their educational mission but also exert a broader influence on local communities and societal sustainability practices. As large-scale institutions with complex infrastructures—including buildings, transportation networks, and dense populations—universities generate both benefits and environmental pressures. The daily activities and consumption patterns of students, faculty, and staff produce significant direct and indirect impacts on natural and social ecosystems. For this reason, embedding sustainability into the core functions of universities is essential not only to reduce environmental burdens but also to position higher education institutions as role models for environmental and social responsibility.

The findings of this study underscore that sustainability practices in higher education are most effective when they are systematically integrated into strategic planning, institutional governance, and campus operations. Universities that prioritize sustainability in teaching, research, and operational decision-making are better equipped to foster environmental awareness, reduce campus carbon footprints, and implement green infrastructure solutions such as renewable energy systems, energy-efficient buildings, and integrated water and waste management strategies. Monitoring mechanisms, including sustainability reporting and carbon footprint assessments, play a crucial role in ensuring accountability and enabling institutions to evaluate progress toward long-term sustainability goals.

The analysis of international case studies—such as Wageningen University, Nottingham Trent University, and Umwelt-Campus Birkenfeld—demonstrates that universities with comprehensive and coherent sustainability frameworks achieve tangible improvements in energy efficiency, resource management, and ecological integration. In contrast, while Turkish universities increasingly participate in sustainability rankings and implement LEED- or BREEAM-certified projects, sustainability initiatives often remain fragmented and project-based rather than embedded within holistic institutional strategies. Only a limited number of universities in Türkiye, including Istanbul Technical University, Sabancı University, and Bilkent University, demonstrate strategic coherence through long-term planning, policy integration, and coordinated campus-wide sustainability actions.

To achieve meaningful and lasting progress, sustainability must be treated as a strategic priority rather than a supplementary or ranking-driven initiative. Universities are encouraged to establish dedicated sustainability offices or governance units responsible for coordinating policies, overseeing implementation processes, and promoting a unified sustainability vision across campus. Recent international reports and academic studies published between 2024 and 2025 highlight a significant shift in higher education sustainability toward performance-based, data-driven, and institutionally embedded models. These studies emphasize that universities achieving higher sustainability performance have adopted net-zero carbon targets, integrated digital monitoring systems for energy, water, and emissions, and aligned campus planning with long-term climate action strategies. Sustainability initiatives are increasingly embedded within institutional governance structures and strategic plans rather than being implemented as isolated projects. This emerging body of literature confirms that continuous monitoring, transparent reporting, and measurable performance indicators are now central components of sustainable university campus management.

In conclusion, sustainable university campuses function as living laboratories where environmental innovation, social responsibility, and educational development converge. Through interdisciplinary collaboration, institutional commitment, and continuous evaluation, universities can significantly reduce their environmental footprint while strengthening social engagement and educational quality. The transition toward fully sustainable campuses requires long-term vision and coordinated action, reinforcing the role of universities not only as beneficiaries of sustainability initiatives but also as active agents in shaping resilient, inclusive, and sustainable futures.

References

Ağı, S., Günerhan & Günerhan, H. (2016). Türkiye için sürdürülebilir üniversite modeli. *Mühendis ve Makina, 57*(682), 54–62.

Binboğa, G., & Ünal, A. (2018). Sürdürülebilirlik ekseninde Manisa Celal Bayar Üniversitesi'nin karbon ayak izinin hesaplanmasına yönelik bir araştırma. *Uluslararası İktisadi ve İdari İncelemeler Dergisi*, (21), 187–202.

Bozat, S., Topdemir, F., & Gazi, A. (2016). University sustainability practices in Turkey: Renewable energy and green campus initiatives. *Journal of Cleaner Production, 135*, 123–135. https://doi.org/10.1016/j.jclepro.2016.06.123

Cortese, A. D. (2003). The critical role of higher education in creating a sustainable future. *Planning for Higher Education, 31*(3), 15–22.

Filho, W. L., Manolas, E., & Pace, P. (2019). The role of universities in promoting sustainability: Evidence from the UI GreenMetric ranking. *Sustainability, 11*(3), 543. https://doi.org/10.3390/su11030543

Filho, W. L., Shiel, C., & Paço, A. (2021). Implementing sustainable development in higher education institutions: Insights from international practice. *International Journal of Sustainability in Higher Education, 22*(2), 234–251. https://doi.org/10.1108/IJSHE-02-2020-0075

Giddings, B., Hopwood, B., & O'Brien, G. (2002). Environment, economy and society: Fitting them together into sustainable development. *Sustainable Development, 10*(4), 187–196.

Günerhan, A., & Günerhan, H. (2016). Strategic planning for sustainable university campuses. *Mühendis ve Makina, 57*(682), 63–75.

Kayapınar, S., Dal, M., & Aşkın, M. A. (2019). Türkiye'deki devlet ve vakıf üniversite kampüslerinin sürdürülebilir-ekolojik parametreleri açısından karşılaştırılması. *Balıkesir Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 21*(1), 106–125.

Leal Filho, W., et al. (2024). Sustainability integration and strategic governance in higher education institutions. International Journal of Sustainability in Higher Education, 25(1), 1–18.

Lozano, R., et al. (2025). From green projects to institutional transformation: Strategic sustainability management in universities. Journal of Cleaner Production, 418, 139912.

Lozano, R., Lukman, R., Lozano, F. J., Huisingh, D., & Lambrechts, W. (2013). Declarations for sustainability in higher education: Becoming better leaders through addressing the university system. *Journal of Cleaner Production, 48*, 10–19.

Newman, P., & Jennings, I. (2008). *Cities as sustainable ecosystems: Principles and practices*. Island Press.

Öztürk, M., & Çelik, Z. (2022). Sürdürülebilir ve yeşil kampüsler: Türkiye'deki üniversitelerin yeşil vizyonu. *İdealkent, 14*(Özel Sayı), 315–346.

Steffen, W., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science, 347*(6223), 1259855.

Suwartha, N., & Sari, R. (2013). Evaluating UI GreenMetric as a tool to support green universities development. *Journal of Cleaner Production, 61*, 46–53.

UI GreenMetric World University Rankings. (2023). *UI GreenMetric World University Rankings*. University of Indonesia. https://greenmetric.ui.ac.id/

UN-Habitat. (2020). *World cities report 2020: The value of sustainable urbanization*. United Nations Human Settlements Programme.

Velazquez, L., Munguia, N., Platt, A., & Taddei, J. (2006). Sustainable university: What can be learned from leading institutions? *Journal of Cleaner Production, 14*(9–11), 810–819.

Zeybek, B., & Öztürk, İ. (2023). Üniversitelerin sürdürülebilirliği: UI GreenMetric ve Türkiye'deki üniversitelerin değerlendirilmesi. *Kentsel Sürdürülebilirlik*, 5(1), 45–62.

Internet References

URL1 Yeşil Büyüme Platformu. *Üniversitelerin Sürdürülebilirliği: UI GreenMetric ve Türkiye'deki Üniversitelerin Değerlendirilmesi.* https://yesilbuyume.org/universitelerin-surdurulebilirligi-ui-greenmetric-ve-turkiyedeki-universitelerin-degerlendirilmesi/

URL2 UI GreenMetric World University Rankings. https://greenmetric.ui.ac.id/

URL3 Middle East Technical University – Sustainable Campus. https://sustainablecampus.metu.edu.tr/tr

URL4 University of Colorado Colorado Springs – Sustainability Initiatives. https://communique.uccs.edu/?p=134988

URL5 Boise State University – Sustainable Campus Panel Event. https://www.boisestate.edu/research-hcri/event/panel-event-what-does-it-take-to-be-a-sustainable-campus/

URL6 Green Office Movement – Sustainable University Practices. https://www.greenofficemovement.org/sustainable-university/