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Article

A critical vocabulary for future architectural criticism based on the peripheral unfocused vision of Sancaklar Mosque, Istanbul

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ABSTRACT

This article serves as a platform to invent critical vocabulary for future architectural criticisms, using the Sancaklar Mosque in Istanbul as a compelling case study. The main argument of the article is to show how architects need to understand minimalism in detail. It challenges the use of Minimalism drawing inspiration from Christopher Alexander's paradigms of 'Wholeness'. The study investigates the mosque from various viewpoints, such as ontology, topography, anchoring and emplacement, body and entanglement, temporality and spatiality of time, the cosmogony of light and earth, embodiment, motility, atmosphere, and emotions. The synergistic relationality interprets wholes as dynamic, generative fields sustained by intensive parts that integrally belong to and support the whole. The authors delineate a particular approach to research and criticism based on a 'peripheral unfocused' vision suggested by Ehrenzweig. The study's underlying seminal phenomenological concepts include 'erlebnis,' lifeworld, and 'Dasein.' Ultimately, it argues that Minimalism alone is not a sufficient tool for modern architectural aesthetics to render a building effective, but it sustains the synergistic relationality within the whole. It deals with its architecture's sensory, semantic, and corporeal metaphorical qualities and discusses the mosque in the general context of phenomenology. In conclusion this article seeks the "inner language" of Sancaklar Mosque, as Pallasmaa calls it, and finds it in the building's integration with nature, space, people and even the philosophy of its function.

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INTRODUCTION

This article contributes significantly to architectural criticism by inventing critical vocabulary for future discussions. The main argument of the article is to show how architects need to understand holism in detail. It uses the Sancaklar Mosque in Istanbul, a compelling case study, to boldly challenge the prevalent use of "Minimalism" as a tool for practical designs. This challenge is crucial, as it draws inspiration from Christopher Alexander's (2002a; 2002b)

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paradigms of 'Wholeness'. The study explores the mosque from various viewpoints, such as ontology, topography, anchoring and emplacement, body and entanglement, temporality and spatiality of time, the cosmogony of light and earth, embodiment, motility, atmosphere, and emotions corresponding to his paradigm of wholeness.

Christopher Alexander's (2002a; 2002b) phenomenological research on space and the creation of space is centered on the concept of 'Wholeness.' In this context, Alexander (2002a; 2002b) distinguishes between two types of relationality: analytic and synergistic. Analytic relationality is characterized by a whole consisting of arbitrary connections, primarily based on typologies and relationships between weak or strong parts. On the other hand, synergistic relationality is the integral whole established by intertwined ties with people, context, and the world. He argues that the integrity provided by the vital bonds formed by man and the world will play a role in strengthening architecture, space, and life. Alexander (1979) and Alexander et al. (1975; 1977; 1985; 2012) devoted their academic life to finding patterns in which the integrity of life is achieved. He wrote, 'Wholeness is a global thing – easy to feel, perhaps, but hard to define. You cannot get a person's portrait right unless you see this underlying integrity... As in architecture, the integrity lies beneath the surface in portraiture, and the truth determines everything' (Alexander, 2002a).

The whole, built on analytic relationality, the most common today, is defined as a system of predefined parts and interconnections. Synergistic relationality desirable for community building, on the other hand, relies upon phenomenological explanations concerning:

- A kinship community
- A grouped gathering in belonging;
- The state of coming together as determined by the elements (separate but related parts) and their relationships.

The integrity built on the above characteristics is the synergistic relationality that Alexander (1979) exalts. A whole with synergistic relationality is an integrated, productive space sustained by constituent belonging rather than separated comprehensive parts. The whole and its parts are intrinsic and interrelated. This essentially indescribable, less visible "ambiance" and "presence" marks the essential characteristic of authentic wholeness for Alexander (1979). What he suggested for communities is equally valid for any building: Synergistic relationality.

Based on this foundation, the field research of this study is guided by the insights of Anton Ehrenzweig (1961), a renowned figure in Modern Art. He posited that artistic conception differs significantly from conscious thought's logical and systematic structure. Creative forms are polyphonic, not confined to a single opinion chain, but comprising many overlapping or non-overlapping bands. This 'peripheral unfocused' vision, a product of widespread and scattered thinking, challenges our usual thought processes. It also offers a fresh perspective on architectural concept formation, design, and criticism, which we have adopted in our research.

Space cannot be fully experienced without wandering; the experience creates the haptic space (Cansever, 1996; Düzenli, 2005; Düzenli, 2009; Merleau-Ponty, 2002). The moment of deep thinking calls for an unfocused, undifferentiated, and subconscious mode of vision integrating tactile experiences and embodied identifications (Rushdie, 1990; Pallasmaa, 2012). Hence, a subconscious-peripheral vision was adopted in our critical site-seeing: an unfocused, undifferentiated, and subconscious mode of vision fused with integrating tactile experiences and embodied identifications (Figure 1).

In the following sections, Sancaklar Mosque, mosque ontology and the criticism of Sancaklar Mosque (the building type, design approach, space, and place etc.) are explained in detail.

AN INTERLUDE: THE ONTOLOGY OF THE MOSQUE

Some indexes form a group because of common attributes or characteristics rooted in individuals' subconscious. They are termed 'type' in the discipline of architecture. Theories of type are epistemological and discursive and have guided the organization of buildings and towns together. The precursors such as Antoine-Chrysostome Quatremère de Quincy (1755-1849), Jean-Nicolas-Louis Durand (1760-1834), and Gottfried Semper (1803-1879) paved the way to today's understanding of type as a model. The term comes from the Greek word "typos," which contains the meanings of "figure, image, form, class," and can be interpreted as the general character determined for a particular entity based on historical rightfulness. They may be the whole project, only a specific feature, a method, or principles (Gür, 2017). This repetition - or sometimes transformation – leads to precedents of design rules to follow (Gür & Durmuş, 2012).

The mosque (cami), where Muslims worship collectively, derives from the Arabic root meaning "to reconcile." In the early periods of Islam, no specific building was built for mass worship. However, it is accepted that the first mosque of the Islamic world was the Masjid al-Nabvî, created by Hz. Muhammad in Medina. This earliest example consisted of a courtyard surrounded by mud-brick walls at a human height and rooms along one side where the Prophet and his family would be housed. Initially, a simple pavilion was built on the inside of the northern wall in the direction of Jerusalem, which was converted from Jerusalem to Mecca in 624, and then sat on palm tree poles and consisted of palm branches to protect worshippers from the sun in front of the southern

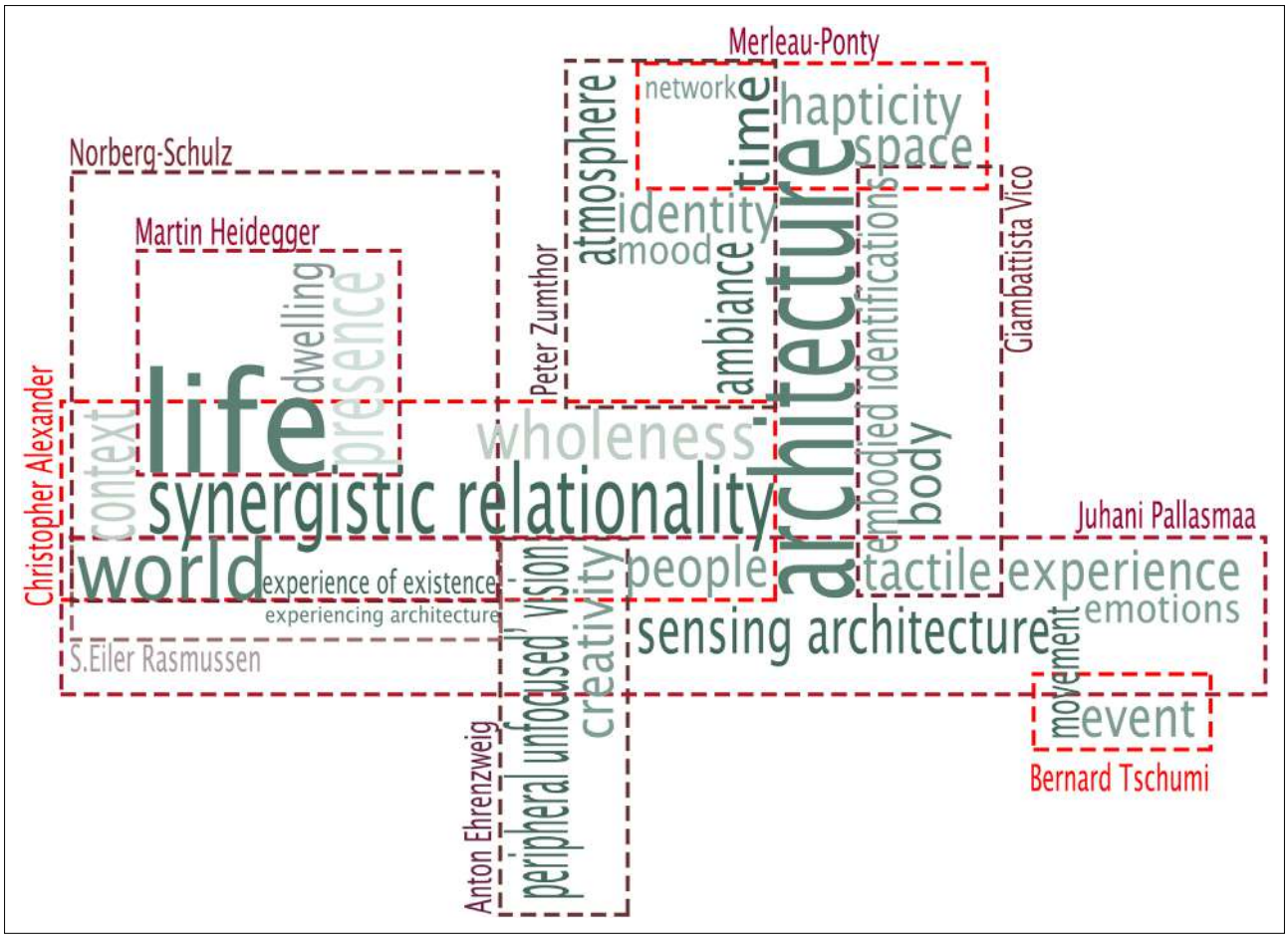

Figure 1. General conceptual map: Terms, relations, architects and philosophers.

wall of the courtyard. Unfortunately, this first mosque lost its original structure due to many repairs and expansions. However, this type, built on purely functional grounds consisting of a mosque with a courtyard in the middle and a cover that sits on the poles, has become a prototype for the mosque architecture that developed after it. The rectangular form was used to keep the first row, considered more sacred in Namaz, as wide as possible (Baltacı, 1985).

The Imperial period (661-749) is full of examples of this type of structure: Umayyad I mosque in Damascus, built in 706, is considered one of the oldest Emevî mosques and has a broad impact on mosque architecture. The typology has also affected later mosques as a characteristic element of the emeritus-era mosque type. Cordoba Grand Mosque (785), Samarra Grand Mosque (846), Ibn Tolun Mosque (879), and Isfahan Masjid Al-Cuma Mosque (1072) are examples of localization of the original typology.

The general typology of Early Anatolia (11th century) mosques is multi-masted and flat-roofed. The thick masonry walls, sparse drain windows, and a single minaret of flat-roofed mosques, supported by wooden poles in some examples and masonry stone feet in others with regional influences, are the most prominent elements that characterize the structure. The leading examples of Anatolia-based versions of this type are Sivas Grand Mosque, Erzurum Grand Mosque, Konya Aladdin Mosque, etc.

The Principality Era, the early Ottoman Period, and most other 11th-century mosques took over this pattern. While the 19th century partially maintained Anatolian Seljuk mosques, in some examples, it attracted attention as a period when a very original but limited developmental typology emerged. Another typology frequently seen in Bursa and its immediate vicinity has also entered the literature as a "Reverse T planned mosque." This typology of iwans scattered around a courtyard covered with a dome can be interpreted as a typological experiment with limited development potential, given the point reached by mosque architecture in Ottoman lands. Green Mosque in Bursa is one of the most important examples of this species.

This era's "single unit" mosques have a typology consisting of a square space and a large dome. They are especially noteworthy because they contain a space design that classical Ottoman architects frequently applied and developed in the following years. The technological and typological peak of

Ottoman Mosque architecture is classical age mosques. The most brilliant examples, such as the Selimiye mosque in Edirne and Süleymaniye Mosque in Istanbul, designed by the renowned Mimar Sinan, showcase a four-, six-, or eight-legged "domed gazebo" that sustains a large central dome and side spaces added to it in two, three or four directions according to the need. In this system, the walls are not carriers but divisive elements; plenty of windows can be opened, and the interior is adequately illuminated.

In Turkey, since the 16th century, mosque practice has been based on principles established by architect Sinan and acquired an image shared by society: a hemispherical dome and at least one minaret. Tuluk (1999) examined the evolutionary development of Ottoman Mosques, which large domed covers can characterize in terms of construction techniques, structure, and space syntax, and traced the precedent of this type to the 13th Century Anatolian indoor madrassas and the Great Mosques (Ulucami). The study, which categorizes six types (the dome, minaret, mihrab, pulpit (minbar), kursî -or sermon platform- and courtyard), clearly shows the origin and how the following spatial syntax and structural systems emerged from the prototype. The transition of types, a fascinating journey influenced by social, cultural, and urban evolutions, is a crucial aspect of Ottoman architectural history.

The dome, minaret, mihrab, pulpit (minbar), kursî and courtyard practiced over centuries are considered obligatory elements of mosque design despite their diversity due to socio-cultural differences. The dome represents the celestial, as the sky reflects the infinity of the universe (Gür & Durmuş, 2012). The curves of the dome inspire a sense of the presence of God, leading to meaningful spiritual sensations in those who pray (Karaesmen, 2012). The minaret is a vertical, often cylindrical element used to call to prayer in the early Islamic period. The minarets have emerged and even towered in time to announce the call further. A typical minaret consists of the body, balcony (sherephe), and the coif. Since regional and cultural influences and traditions influenced the minarets, they became an element reflecting society's construction technology and aesthetic taste. Even the number of minarets has a special meaning since they show how glorious the mosque is.

Mihrab is a prayer niche in the southern wall, usually concave and generally heavily decorated. It indicates the direction of qibla- the direction of Namaz (Grabar, 1973). Mihrab is also where the imam, who leads the congregation, prays. However, more important than all, this indicates the Kaaba, a sacred place for Muslims.

Then there is the pulpit (minbar), a staircase, often narrow and enclosed by handrails. In the first years of Islam, the pulpit also served as a political chair (Baltacı, 1985). According to Burckhardt (2009), a canopy shelters the topmost level, representing the spiritual world since the Seljuk period.

Another elevated element is the kursî- or the sermon platform- where the imam goes to preach to the congregation. There may be more than one in some mosques, and there are examples where the pulpit is a sermon platform from time to time. Sermon platforms can be portable or attached to the wall or a structural unit. They consist of the base, the body, the seat, and the railing and reflect the art style trends of their age (Apa, 2008). All these elements comprise the whole, and any design differentiation determines the whole structure- the total architectonics.

The courtyard isolates the mosque from the surrounding structures and the area and adds autonomy. In Classical Ottoman Mosques, the yard is divided into interior and exterior. The exterior courtyard provides the necessary movement space for the geometry of the mosque to be read more quickly and the details of the façade to be noticed. On the other hand, the inner courtyard has a rectangular plan adjacent to the mosque and is surrounded mainly by a semi-open space with a portico (Oral, 1993).

Notably, after the 20th century, the effects of modernization movements led some architects to re-interpret the elements and components of mosques and the indexical relationships. Some architects have deconstructed the well-established relations between signifier and signified. For example, Özçakı (2018) examined how recent experiments handled the dome differently; Akbulut & Erarslan (2017), Akar & Pilehvarian (2019) also classified these re-interpreted mosque designs based on the plan's geometry, roof construction systems, technology and materials, illumination, and the forms of symbolic elements.

These mosques are unique and undoubtedly deviate from the traditional mosque typology. However, what is common to all these exemplified buildings is the presence of historical-traditional parts in one way or another (Figure 2).

The Case: The Sancaklar Mosque, Istanbul

The Sancaklar Foundation demands a mosque project from Emre Arolat Architecture [EAA] and shows the probable site. Designed by EAA and completed in 2011-2013, Sancaklar Mosque is located at Büyükçekmece, one of the outer districts of Istanbul. The building was granted many national and international awards, including the "Project of the Future" prize at the Barcelona World Architecture Festival 2011. In addition, the world's award in the category of religious buildings was given at the Singapore World Architecture Festival in 2013. It was selected for The Religious Building of the Year Award at the ArchDaily in 2015. It won the Building of the Year Award 2018 from the Royal Institute of British Architects RIBA Award for International Excellence.

The building is located on a road separating it from the surrounding gated communities and is positioned on the gentle slope of the valley, overlooking the rural landscape.

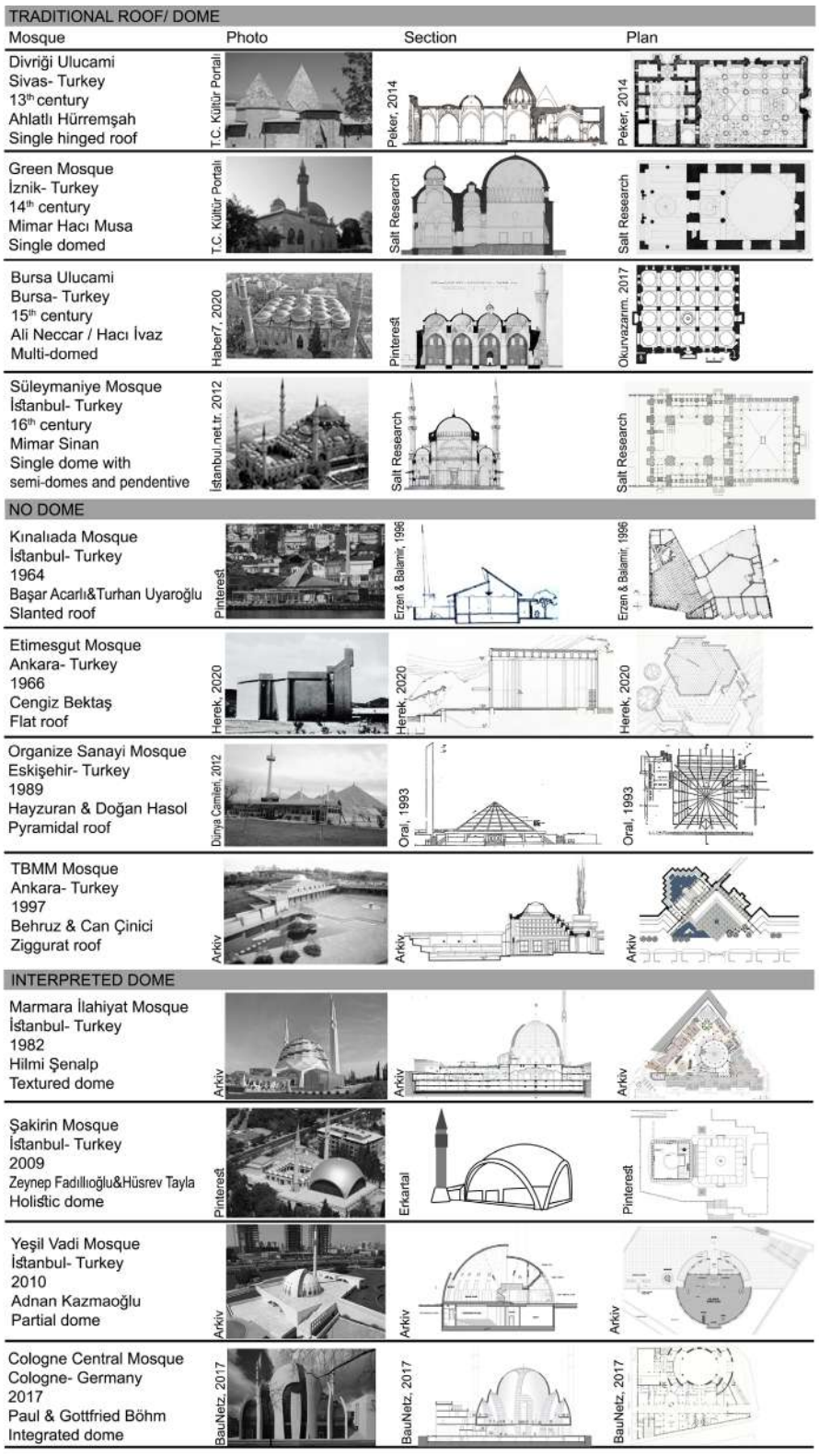

Figure 2. The ontology of the mosque (Arkiv (n.d.a); Arkiv (n.d.b); Arkiv (n.d.c); BauNetz (2017); Dünya Camileri (2012); Erkartal (n.d.); Erzen & Balamir (1996); Haber7 (2020); Herek (2020); Istanbul.net.tr (2012); Okuryazarım (2017); Oral (1993); Peker (2014); Pinterest (n.d.a); Pinterest (n.d.b); Pinterest (n.d.c); Salt Research (n.d.a.); Salt Research (n.d.b.); TC Kültür Portalı (n.d.a); TC Kültür Portalı (n.d.b)).

Its design is modest, reminiscent of a primitive shelter. This mosque is designed to foster a direct connection between the individual and their faith, prioritizing substance over form. Its architecture aims to harmonize with the environment, creating the impression that it has always been a part of the landscape.

THE PERIPHERAL UNFOCUSED VISION OF SANCAKLAR MOSQUE

Ehrenzweig (1965) distinguished 'focused vision' and 'subconscious-peripheral vision' while arguing the importance of peripheral vision in the hierarchy of vision. Subliminal studies have also corroborated the superiority of the subconscious vision in scanning the entire field of view. Furthermore, Ehrenzweig (1965) has proved that under the concept of conscious "hemianopsia," the information processing capacity of the nervous system is 20 bits per second. In contrast, the unconscious information processing capacity is over 100 times this. Freud (1968) had previously noted that the human brain unconsciously grasps 1015 times the knowledge it cannot consciously hold (Augusto, 2010).

In his Scienza Nuova of 1730, Neapolitan philosopher Giambattista Vico had already argued that language, myth, and custom are the metaphorical legacy of the species through self-realization history (Vico, 1968). He emphasized the capacity of the being to experience the environment bodily and the validity of "the notion of corporeal imagination." Vico's concept of the enactment and re-enactment of man through history is corporeal in that the body re-constitutes the world through its tactile appreciation of reality (Frampton, 1995).

Juhani Pallasmaa's 'The Geometry of Feeling: A Look at the Phenomenology of Architecture' (1996) book, The Geometry of Feeling: A Look at the Phenomenology of Architecture' (1996), which criticizes "the reality of how a building is experienced has been overlooked" and proposes a "basic vocabulary" for defining "primary feelings in architecture." By offering a structure for experiences that unfolds through sequences of movement and relational proximity without predetermining the content, Pallasmaa's perspective provides a more intuitive and fluid complement to structured paradigms, offering a structure for emergent experiences through sequences of movement and relational intimacy without predetermining content. This is why the field was physically scanned and experienced through unconscious-peripheral vision.

The findings are structured under eight categories that correspond to distinct aspects of the architectural experience: site, sense of place, morphology, temporal perception, illumination, semiotics, spatial navigation, and atmospheric quality. The Sancaklar Mosque-Specific Map below illustrates how the general conceptual framework are applied to the specific architectural analysis of Sancaklar Mosque (Figure 3). Given that Sancaklar Mosque defies typological classification and challenges conventional representations of mosques, the decision was made to deconstruct these headings and prioritize the phenomenological context.

Site: Topography

Buildings invariably exist out of the interplay of three converging factors: the topos, the typos, and the tectonic. Other than the character, the sound of topography lets one connect with experiences (Frampton, 1995). The moment one gets out of the car on the roadside car parking, one steps on the grass. Unlike those designed later, cobblestone collages take the form of tapestries (Figure 4). They do not create a topographic continuum like Pikionis did in the Acropolis. Instead, the tactile appreciation of reality, sensing the texture by foot and hearing the sound produced by footsteps subconsciously ties one to her stages of life, days in one's childhood walking up narrow paths to the village high on a mountain. Steen Eiler Rasmussen (1962) has a remarkable chapter on Hearing Architecture, where he notes the imperceptible acoustic character of the built form. Spatial reflection of sound immediately affects one's psychological response surfacing from experiences.

A single rectangular prism touches the eye: As Vittorio Gregotti (1966) elocutes, 'placing a stone somewhere marks the moment when changes begin.' There is no icon, sign, or symbol of the minarette. It is an allegory of a threshold!

Unlike historical typologies, Sancaklar Mosque has neither a dome nor a recognizable minaret (Figure 5). They are absent, and their absence is so substantial that they become visible by absence. Two rows of stone walls and a tower are insight, and of course, the sky and trees. There is only one Arabic script on the tower: "Allahu Akbar" (God is the greatest). Nothing on earth is superior to God, meaning there is no need for exaggeration, glamour, or ostentation.

Sense of Place: Anchoring and Emplacement

One blends with nature, slowly moving into almost nothingness in awe and reverence. You remember the tree, the texture of stone, the hissing of grass growing in the commissures; while you move down the steps, you can almost hear the whisper of the ground. The sound of the wind accompanies the adhan (ezan). The mosque is still not visible (Figure 6). Architects preferred to carve the slope rather than putting up an ordinary building on the plain land. The mosque is carved into stone like a cave.

The euphoric memory[1] brings back the anxiety of the earliest believers who hid in caves or cave-like structures to worship. They walk in herds wearing hoods with you,

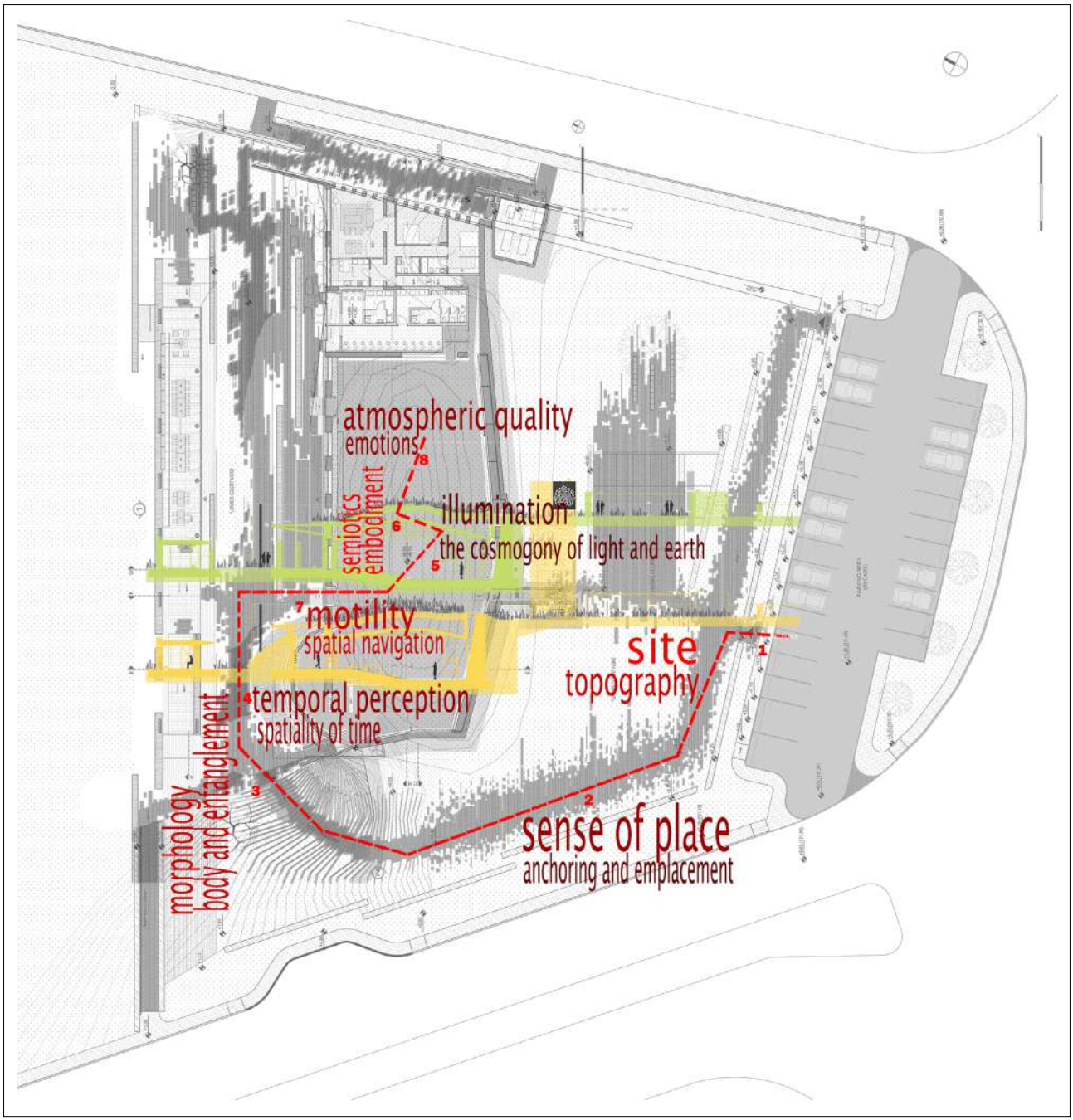

Figure 3. The Sancaklar Mosque-specific map.

as in Rome, Jerusalem, Cappadocia, and even at the Virgin Mary Monastery in Trabzon-Turkey. Silent as stone in astonishment and abstentions, you walk down the stairs ponderously, spellbound.

The mosque is still invisible under the slope. It is anchored into solid rock. The body of the building belongs here. The place and space have become such that it is impossible to separate them anymore. It cannot be moved elsewhere, and it cannot be rooted elsewhere. There is no form, no architecture. There is only one place (Figure 7).

Kengo Kuma (2009)'s words come to mind: My ultimate aim is to "erase" architecture because I believe a building should become one with its surroundings. And "all that I see is within reach of my gaze," says Merleau-Ponty (2006). Peter Zumthor (2010) corroborates, 'Certain buildings' presence has something secret about it. They seem to be there, and we do not pay any particular attention to them. However, it is virtually impossible to imagine where they stand without them. These buildings appear to be anchored firmly in the ground.

Figure 4. The first sight of Sancaklar Mosque (Photo by the authors).

Figure 5. The courtyard of Sancaklar Mosque and the minaret (Photo by the authors).

Figure 6. The courtyard of Sancaklar Mosque (Photo by the authors).

Figure 7. The stone path (Photo by the authors).

The infinite path (Figure 8) runs between two rows of buildings with incomprehensible functions. On the right side is the mosque and other facilities like ablution space, etc. On the left side are the civic buildings, such as the library, seminar rooms, and studios for children. At the end of the path rests the stones of musalla (coffin rest). It stands there like a knot, implying and reminding us that worldly and non-worldly acts should be weighed and judged regarding morality and ethics before the end arrives. Whether a limit or a threshold leaves a question mark in the beholder's brain, a tree between the stones of musalla is visible in the distance, and one cannot help but think: which one is designed?

The eye lingers on the vast horizons of the valley. It is foggy. As Mawlana Jalaluddin Rumi (1959) says: "Everything is an obstacle, a cover, to see the self of God. Because one cannot bear to see God without a cover.

Morphology: Body and Entanglement

It is hidden under the vast canopy (Figure 9). It is quiet, calm, and humble. There is no need to be resplendent; it has no traditional decorations, and there is only the texture and color of the stone. It stands to the right of a long, thin courtyard that reaches the horizon. There is a stone bench and a library under another wide canopy opposite. This

Figure 8. The second courtyard (Photo by the authors).

Figure 9. The mosque and the minaret (Photo by the authors).

Figure 10. The inside of the Sancaklar Mosque (Photo by the authors).

courtyard, similar to life, combines worldly and spiritual matters. It can even be called secular. So can the material and the ecclesiastical co-habit.

It is nothing to be baffled; religious buildings have coexisted with secular buildings since eternity. Between namaz times, people could sit, read, and talk in the courts of mosques; they were social spaces. However, the religious and the secular never seemed so confusingly alike. Sancaklar Mosque equally blesses them by confronting and uniting them in the same narrow court. There is neither forbidding nor prohibition.

Temporal Perception: Temporality and Spatiality of Time

Like its outside, the inside is modest (Figures 10 and Figure 11). The carpet has the same soft tone of color as the walls. There is almost no color. No tiles, no gilding. There is only one inscription on the black granite wall, and the endless light licks the qibla wall (Figure 12a, 12b). This light illuminates the darkness. All bodies turn towards the light

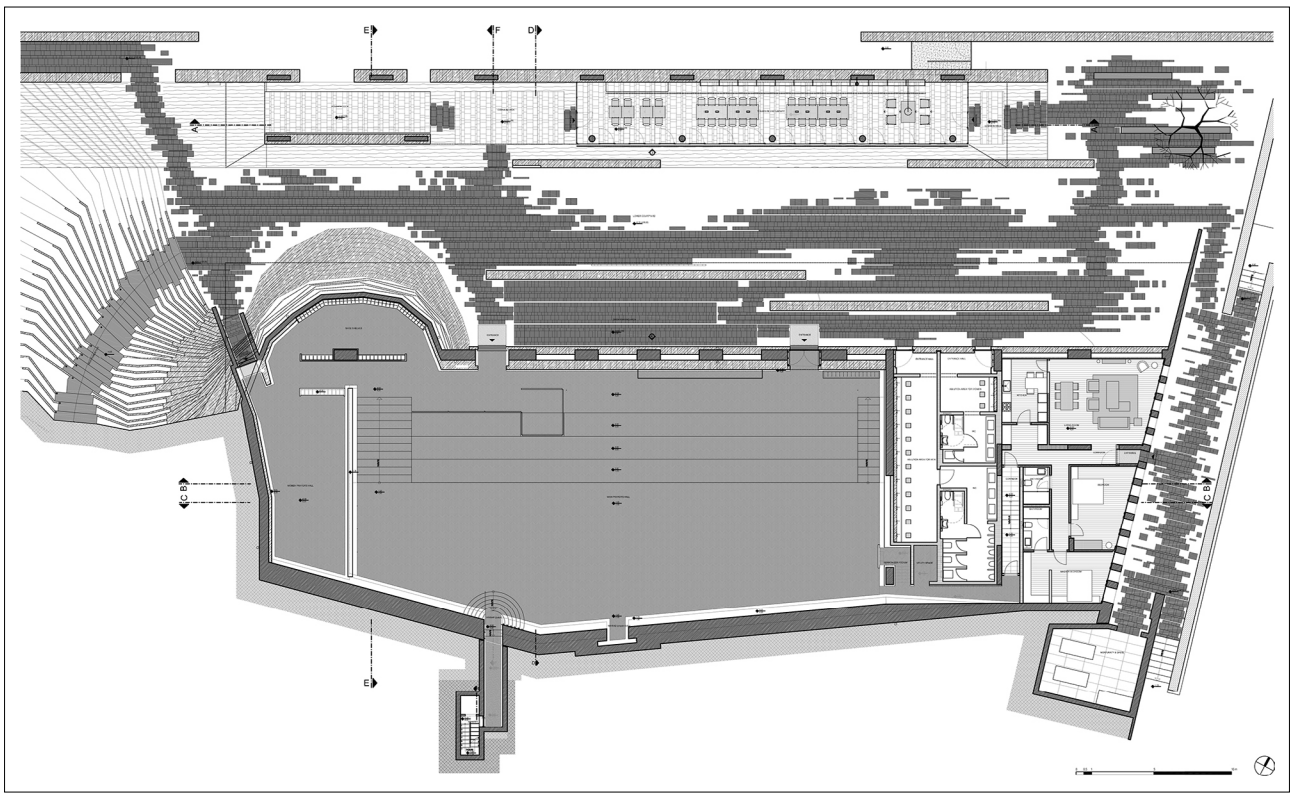

Figure 11. The plan of the Sancaklar Mosque (Copyright: EAA).

Figure 12. **(a, b)** The light from the skylight illuminates the Qibla wall (Photo by the authors).

while preaching. Prostrate there. This light guides the body and quietly calls to it. On the black granite wall shone the calligraphy of Mehmed Özçay. Silhouettes of praying bodies and the light of the qibla wall reflect from the granite.

In Islamic philosophy, Being connects to God through the material, organic, intellectual, and spiritual layers. In this essential sense, establish multi-layered relations with truth, each of which may have multiple meanings. Therefore, the human being is in a constant process of virtual movement-in space/time. Architecture is a discipline that designs a composition to encompass relations between the being and the truth. The flexible, meaningfully lit corporeal space resolves Islam's space/time concepts. The building guide of the Renaissance relies on Brunellechi's perspective based on man standing on a fixed point-unmoving, therefore missing all the other points available to him. Cansever (1996) is holistic and values a moving man's experiences and memories over the static—Cansever allies with living.

Illumination: Light and Earth

The space is so plain and simple. Neither the pulpit nor the mihrab is customary. Here, the mihrab is a simple hollow. The low ceiling, instead of a celestial dome, wraps the body. The top reflects the slope, indicating that the dark, quiet, and peaceful roof is earth. Earth roof cosmogonically refers to the dwelling. According to Pallasmaa (2012), "The timeless task of architecture is to create embodied and lived existential metaphors that concretize and structure our being in the world." 'Historical settings connect us directly with time and the past,' says Pallasmaa (2016b), explaining that the combination of layers such as style, use, and activity has comfortably placed us in the continuity of life for centuries.

This feeling creates the set of references that awaken the memories and experiential knowledge encoded centuries ago into people's subconscious—for example, culture and belief. For example, filtered light gives a sense of peace and solitude (Figure 13) instead of the small windows maintaining privacy on the civic block, cave-like structure, the humble mihrab, and silence slow down the world's experience and create an understanding of the continuum of time. Here, we remember all sacred places, starting with the first place of worship.

Semiotics: Embodiment

Human beings need to know and feel anchored to the world and time. Therefore, they struggle to create spaces that indicate the essence of existence since the beginning. Architecture is an intermediator object at the interphase, as a bridge that connects the inner world of the self with the outer world (Norberg-Schulz, 1980). As Merleau-Ponty (2002) also emphasized, humans realize their standing in these networks. Pallasmaa (2018) underlines this existential sense and conceives architecture as a concrete experience of existence and identity.

The Sancaklar Mosque, with its unique design, encapsulates the individual's essence, evoking a sense of being a part of the universe. The distinctive shape of the ceiling, the tactile floor cover, the smooth, organically formed threads, and

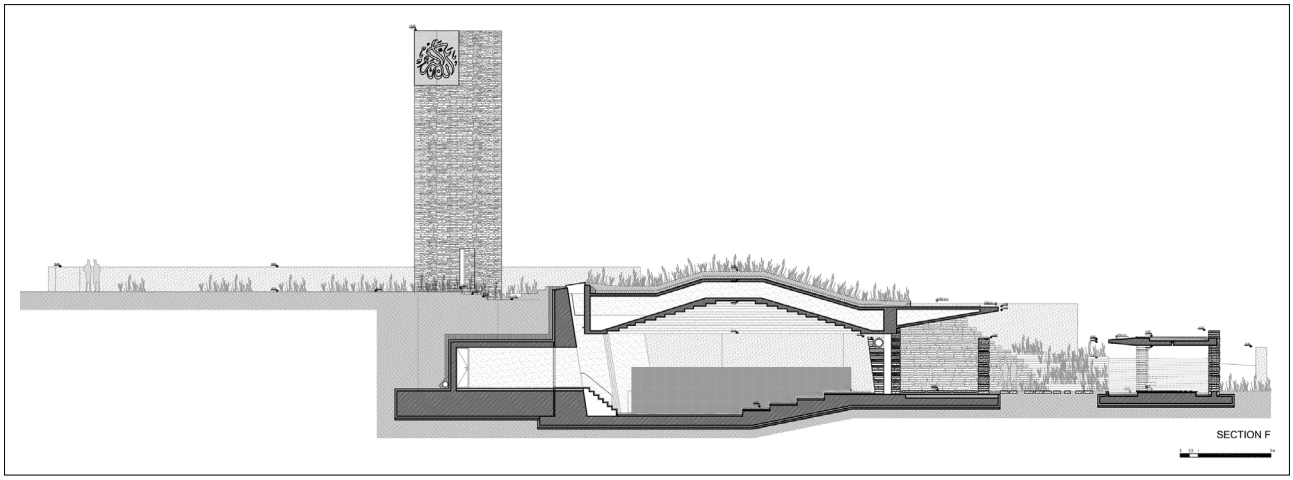

Figure 13. The section of the Sancaklar Mosque (Copyright: EAA).

the bright, narrow light of the top flashing on the pulpit upon entry all contribute to this unique experience.

The Sancaklar Mosque, beyond being a physical structure, is a living testament to the spiritual and existential essence of a place of worship. It offers a sensory journey like no other, where the earth, the landscape, daylight, water, a swallow's nest, and children's laughter blend harmoniously to create an enchanting atmosphere. The architectural elements, such as stonewalls, low ceilings, dimness, achromatic colors, the light illuminating the qibla wall, broad stairs descending towards the qibla, and silence, all resonate with the very essence of existence, beckoning you to immerse yourself in its unique ambiance.

Spatial Navigation: Motility

Through movement, we establish multi-layered connections with truth, each of which may hold multiple meanings. Human-made structures that define a place in space are conceived by looking upward and downward and experiencing the interiors. Any architectural exploration is only possible by tracing the movement and observing people walking in and around. The experience of a moving individual is a sequence of activities, pauses, viewpoints, and his cognitive recall of past interactions with spaces.

Sancaklar Mosque encourages the body to have undreamed flows and excitement. Body and consciousness creatively lead the being towards unexpected and unpredictable behavior and activities. During this process, man perceives form connections and turns toward space. Husserl (1983)'s concept of intentionality comes to the fore. He re-apprehends the space, and vectors aid in disposal. Although Bernard Tschumi (2000) is a distinguished mentor who proposed to foresee possible events, he was unsuccessful in his Columbia University Student Union, where it was impossible to perform a concert. At the mosque, a child bored with the lectures of the hodja may even play football (Figure 14).

Figure 14. A child inside the mosque, bored with the teachings of Hodja, is playing football (Photo by the authors).

Atmospheric Quality: Atmosphere and Emotions

The atmosphere defines the milieu that wraps and caresses the being. It contains invisible but felt moods (Heidegger, 1962) or feelings (Bille et al., 2015) that help to understand and appreciate the place. According to Zumthor (2006), the atmosphere touches the individual's soul and "speaks to the emotional perception." Pallasmaa (2016a) also argues that the atmosphere reaches us through entangled sources. Before describing it, we feel it; "the experience of atmosphere or mood is thus predominantly an emotive, pre-reflective mode of experience" (2016a: 133), meaning that it transmits from space to man and from man to space.

Sancaklar Mosque has a calm and serene atmosphere where the interplay of light, silence and materials enhances a sense of peace and spirituality. Soft light filters through the skylight, emphasizing the direction in which everyone turns. The enveloping height of the ceiling merges with the image of a cave, challenging an overwhelming sacredness. The acoustics amplify the soft murmur of prayers. Whispered speech, slow movements and the reverential gestures of worship add to the solemnity. The simplicity of the space, its intimacy and silence empty the mind, inviting reflection, introspection and a sense of oneness with the sacred purpose of worship. There is an intangible but palpable energy that inspires awe, peace and even catharsis, connecting the prayers to something greater than themselves.

CONCLUSION: BACK TO THE SYNERGISTIC RELATIONALITY

The unfocused perception adopted in this approach prompted a different way of viewing architectural objects and criticism. While the perception of space as a static one since the Renaissance had caused us to see architectural space as a definite Gestalt, the unconscious vision independent from Gestalt enabled us to see other qualities of space such as ontology, topography, anchoring, and emplacement, body and entanglement, temporality and spatiality of time, the cosmogony of earth and light, embodiment, motility, atmosphere, and emotions.

All these discoveries ultimately lead us back to Christopher Alexander and his concept of 'wholeness.' As Alexander (1979; 2002a; 2002b) rightly argued, there are two contrasting ways of understanding wholeness: analytic relationality and synergistic relationality. The synergistic relationality of space, summarized under several headings above, relies not solely upon the analytical relationality of building form and environment but on the intricate interrelatedness of elements and qualities. Alexander (2004; 2005) was concerned with creating communal solid spaces that could transform the space into a place. The synergistic relationality of the aspects of space was his focus. This paper focused on the integral whole

established by intertwined ties with people, context, and the world. Certain phenomenological concepts and specific architectural articulation of the building's site, components, elements, materials, and objects emerged from the peripheral unfocused vision of the Sancaklar Mosque. They are discussed above under semi-arbitrary titles.

In considering architecture's role in human experience, it becomes clear that its essence extends beyond visual aesthetics to embody multi-sensory engagement. The integration of tactile qualities moves architecture from being merely observed to being actively felt, inviting users to connect deeply with the built environment. This tactile emphasis does not stand in isolation but works in harmony with the spatial, material, and environmental dimensions of design, fostering a sense of unity and belonging. Ultimately, architecture achieves wholeness when it resonates with all senses, enabling us to experience its presence as both intimate and encompassing—a true embodiment of human connection and place.

Tactility is being aware of people, bodies, environment, and technology. The phenomena it contains include memory, layers of memory, mental landscapes, empathy, all emotions, all senses, abstraction of nature and geometry (proportions, forms, tension of surfaces), levels of infinity, the energy of the horizon, horizontality, the power of sacred light and shadow, the sublime light and the sense of heaven, cosmic light, dramatic winter light, warm august light, texture and light, hidden existences, imagination, contemplation and imagination, states of being related to water (containment, inhaling, pouring, sharing, tracking); space expressions (such as flexible, accessible, original, rare, unconventional, innovative, dreaming).

Tactility requires superior synthesis and transformation ability, the power to determine society's demands, sensitivity, and inner enlightenment similar to beliefs. As for the materials used, using natural and unnatural together is common. In addition to experimenting with stone and wood, it is possible to evaluate new materials of brankton, steel, and even PVC origin for this purpose. The important thing is not the choice of material but how the material is used.

To comprehend "wholeness through tactility" in architectural criticism, one must probe the relationship among site selection, material appropriateness, structural harmony, and sensory resonance. However, the paradigms proposed in this study, which draw upon Christopher Alexander's prescriptive pattern language, reveal a potential limitation. While the "synergistic relationality of elements of space" provides a structured framework, it appears overly directive compared to Ehrenzweig's intuitive, non-linear peripheral vision. This contrast raises questions about how criticism can balance a systematic approach with intuitive, experiential insights.

Emphasizing the dialogue between architecture and the human being, from the approach to the building to the relationship with the landscape seen through the building's window, this structure is one of many alternatives that demonstrate the impact on human consciousness of the sensory and emotional experience offered by architecture, which is not only a physical structure. For the same purpose, this article seeks the "inner language" of Sancaklar Mosque, as Pallasmaa calls it, and finds it in the building's integration with nature, space, people and even the philosophy of its function.

In essence, the richness of architecture lies in its relationship to human and spatial ontologies. Phenomenological critiques must therefore recognize how architectural wholeness is achieved via the union of its spatial elements—articulating forms, emphasizing tactile interactions, and promoting profound engagement. The success of the Sancaklar Mosque, as explored in this study, lies in its embodiment of "wholeness through tactility"—a principle that envelops physical, sensory, and emotional dimensions while negotiating between structured paradigms and intuitive depths.

In conclusion, phenomenological critics should consider the above paradigms and internalize the synergistic relationality of all these paradigmatic details. One must decipher how these relationships affect integrity and Alexandrian wholeness. This mosque's success is "wholeness through tactility".

NOTES

[1]An automatic memory retrieval process engaged when a specific, proximal cue interacts with information stored in memory. The recovered product of that interaction can either be the result of a strategic memory search, or it could act as fuel for subsequent strategic retrieval processes.

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Article

Thermal comfort in social housing: A case study from Türkiye's hot and dry region

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ABSTRACT

This study examines thermal comfort and satisfaction in TOKI Etiler, a social housing project in Gaziantep constructed by the Turkish Mass Housing Administration (TOKI). Focusing on six high-rise blocks in this project, the research evaluates the current state of social housing in hot and dry climate conditions. Thermal comfort is identified as a critical factor in improving residents' quality of life. Utilizing a mixed-methods approach, the study incorporates in-depth interviews with residents, unit observations, thermal imaging, and statistical analysis using SPSS. The findings underscore significant thermal discomfort, particularly in top-floor units of the 12-story buildings, with dissatisfaction peaking at 45.9% in August. Thermal comfort perceptions also varied based on household size, highlighting the need for tailored solutions. To improve thermal performance, the study proposes strategies such as minimizing excessive heat gain, implementing passive systems like shading devices, and harnessing solar energy. Inspired by the region's vernacular architecture, incorporating water features in outdoor spaces is also recommended to enhance evaporation and cooling. Furthermore, the study identifies thermal bridges in building envelopes and calls for better insulation alongside environmentally friendly alternatives to synthetic and petroleum-based construction materials, which pose risks to both human health and the environment. By analyzing the unique climatic challenges of Gaziantep and residents' adaptive behaviors, this research offers a comprehensive evaluation of indoor environmental conditions in the TOKI Etiler project. The findings contribute valuable insights into climate-responsive housing solutions for hot and dry regions.

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INTRODUCTION

In recent years, there has been a growing interest among researchers in indoor environmental quality and thermal comfort, particularly concerning health and occupant well-being. Enhancing indoor environments to improve these aspects has become a key focus, with numerous studies examining the complex relationship between climate, urban design, and user satisfaction. Research by Erell et al. (2012) highlighted the connection between the outdoor conditions of a settlement and its sustainability performance. Indeed, the microclimates shaped by urban

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design choices influence user satisfaction and behaviors within them. While many studies have addressed the impact of outdoor climate on indoor comfort, the unique contribution of this study lies in its focus on the interaction between local climatic conditions and residential spaces in Gaziantep, Türkiye, particularly in social housing. By examining how traditional passive cooling strategies have been overlooked in modern designs, this research aims to bridge the gap in existing knowledge on the importance of climate-responsive design in Türkiye's hot and dry climate.

A critical component of enhancing indoor environmental quality is thermal comfort, which is a key metric for both building performance and occupant well-being. Defined by ASHRAE Standard 55, thermal comfort refers to the condition of mind that represents satisfaction with the thermal environment and needs subjective evaluation. A thermal environment is considered satisfactory when 80% or more of occupants within a space find it acceptable (ASHRAE, 2013), as the term "acceptability" is used for "satisfaction" in thermal comfort-related research (de Dear & Brager, 2003).

As climate change remains one of the most pressing challenges of the 21st century, numerous studies have focused on evaluating thermal comfort worldwide. In particular, growing awareness of the impact of indoor environmental conditions on well-being has significantly accelerated research aimed at improving thermal quality in residential spaces (Spetic et al., 2008). Thermal comfort studies in multi-unit residential buildings identify several significant parameters affecting comfort. For example, smaller dwelling sizes and lower occupancy levels result in reduced heat gains and less interaction with building control systems (Roetzel et al., 2014; Ioannidis et al., 2016). A thermal performance parametric study on window type, size, orientation, and shadowing presented that north orientation in Portugal has better thermal performance than northwest and northeast orientation (Amaral et al., 2016) Other studies have focused on the effects of building height and the stack effect. During cold periods, the overheated upper levels cause thermal discomfort for occupants, while drafts become a concern for those on lower floors due to the infiltration of cold air (Mijorski & Cammelli, 2016; Jo et al., 2007).

Research conducted in Seville examined the benefits of courtyards, including users' thermal perceptions. Findings revealed that an efficient passive cooling system in Mediterranean social housing could enhance energy efficiency by up to 20.5% (Diz-Mellado et al., 2023). Similarly, Pérez-Fargallo et al. (2018) analyzed improvements in the thermal envelopes of social housing in Chile, evaluating the economic benefits of reducing costs associated with these upgrades using the adaptive thermal comfort model. Another adaptive comfort study in Chile discussed the issue of energy poverty, where homes fail to maintain minimum thermal comfort standards. Results showed that one-third of participants could not maintain a comfortable indoor environment for at least 80% of the time, while over 20% struggled to do so for 65% of the time (Porras-Salazar et al., 2020).

Similarly, research conducted in other regions also explores the effects of thermal comfort in social housing. In Toronto, a year-long study analyzed 70 social housing units across seven buildings, focusing on summer overheating, which led to significant discomfort. The study identified discrepancies between survey responses and monitoring data (Patiño et al., 2018). Another study critically analyzed interventions in social housing in Porto under the Improvement Plan, which enabled the rapid construction of many dwellings. Despite these efforts, challenges persist regarding comfort parameters. This study explored the impact of current measures on interior comfort, existing issues, and alternative approaches to balancing energy efficiency and thermal comfort (Rocha et al., 2023).

Recent research (Ghaddar et al., 2024) has also addressed sustainable cooling technologies, particularly for vulnerable populations facing excessive heat events affecting cities globally, from the south to the north. This study underscores that passive adaptation strategies, including cool and green roofs, radiative coatings, high-R and low-emissivity windows, as well as trees and vegetation, play a crucial role in mitigating extreme heat effects on building surfaces. However, their effectiveness varies depending on building typology and climatic conditions, making a standardized approach unfeasible. Therefore, comprehensive design assessments and impact analyses are essential to develop tailored, climate-responsive solutions for each specific context.

Increasingly frequent extreme climate events and rising global temperatures play a critical role in shaping energy retrofit strategies, highlighting the importance of accounting for future climate scenarios. The study by Iskandar et al. (2025) examined the effectiveness of natural ventilation as a passive cooling strategy for low-thermal-mass buildings in hot-humid climates, assessing its performance under both present and projected weather conditions throughout the century. The results emphasized the necessity of adaptive retrofit solutions, such as optimizing existing systems, modifying operational practices, and incorporating shading devices to minimize heat gain. These findings reinforce the need for integrating passive strategies into building design, particularly in regions with extreme climate conditions (Iskandar et al., 2025).

Traditional vernacular architecture in Türkiye offers valuable insights into passive cooling strategies that are well-adapted to local climatic conditions. In hot and dry regions like Gaziantep, natural ventilation techniques have historically played a significant role in shaping building design, either through spatial configurations such as courtyards or through enclosure elements like solar collectors, shading devices,

and operable architectural features. These design strategies demonstrate how traditional dwellings have effectively filtered extreme climatic forces throughout the year, ensuring indoor comfort. Building surfaces function as a medium for climate regulation, with strategically designed openings facilitating passive cooling. The impact of climatic variables on residential buildings is particularly evident in the widespread use of courtyards and stone construction, both of which serve as defining elements of the region's architectural identity. While many of these low-rise courtyard houses have been demolished or repurposed into hotels, they once dominated the residential landscape in Gaziantep.

Courtyards provide naturally ventilated, habitable open spaces, while the thermal mass of locally sourced stone helps maintain indoor temperatures during the hot season. Additionally, landscape features such as gardens and water ponds contribute to microclimate regulation while enhancing the visual and environmental quality of the built environment. As Taleghani (2014) highlights, courtyards function as natural cooling systems by storing cool air at night, which is absorbed by surrounding surfaces and released gradually throughout the day. As temperatures rise, thick walls slow heat penetration, while convection-driven ventilation helps maintain thermal balance indoors (Taleghani, 2014).

Despite these traditional strategies, modern social housing developments in Türkiye often fail to integrate climate-responsive design, leading to significant thermal comfort challenges. While passive systems have been widely studied in warm climates, there remains a gap in research on their application in social housing projects, particularly regarding microclimatic influences and resident perceptions. For instance, Şuta & Zencirkan (2024) evaluated user satisfaction in social housing in Edirne, Türkiye during the COVID-19 era, emphasizing that thermal comfort positively influences overall satisfaction. Despite these studies covering various climate zones, the lack of experimental research and data on thermal comfort in arid and hyper-arid regions complicates decisions between passive or active heating and cooling systems (Sakhri et al., 2022).

While the energy efficiency of passive systems in warm climates has been extensively analyzed, research addressing the conditions in social housing projects, including the influence of their microclimates and residents' perceptions, remains insufficient. Additionally, the limited number of thermal comfort studies in Turkish social housing underscores the need for further research in this area. This research contributes to understanding the local climatic conditions of Gaziantep, their impact on residents, and the behavioral patterns adopted to adapt to the complexities of Türkiye's hot and dry climate. It offers a scientific assessment of indoor environmental conditions in TOKI residential projects, emphasizing the importance of appropriate orientation and layout in optimizing natural ventilation for energy efficiency and improved thermal comfort.

This study aims to highlight the importance of passive cooling and thermal comfort in identifying pathways for sustainable development in hot and dry regions. By experimenting with a social housing typology in Türkiye, the study will address the following questions related to the thermal comfort of residents living in the selected social housing:

- Does the thermal comfort and satisfaction of occupants in social housing in Gaziantep fall within acceptable ranges as defined by established standards?
- Are there any thermal-related differences that residents experience in different units? If yes, what are the reasons for discomfort?

Studies into human thermal comfort have generated comfort models that predict a statistical population averaging neutral temperature. These include the Physiological Comfort Model and Adaptive Comfort Model. It is important to understand the heat balance mechanism in the human body and also the factors affecting thermal comfort. Personal and environmental variables are used when defining conditions of thermal comfort: metabolic rate and clothing insulation as personal factors and air temperature, radiant temperature, air velocity, and humidity as environmental factors (ASHRAE, 2010).

There is a strong connection between thermal comfort sensation and heat balance. The human body needs to maintain the heat balance to operate properly. Being warm-blooded, it tries to maintain a core body temperature of about 37°C and a skin temperature of about 33°C. If the body heats up or cools down too much, it can impair its functionality. For instance, at approximately 42°C, individuals may experience fainting due to potential brain damage, and at about 44°C, severe consequences like passing out can occur. Similarly, shaking begins at 35°C, while serious damage that is irrecoverable starts to occur at 15°C (La Roche, 2012). So, our body employs several regulatory mechanisms to maintain optimum operating conditions.

To prevent overheating, subcutaneous blood vessels expand and increase the amount of blood to the skin and skin temperature. Thus, it enhances heat dissipation. If this is insufficient, the body initiates sweating for evaporative cooling. However, if evaporative heat loss fails to restore equilibrium, hyperthermia ensues. On the other hand, the human body reduces blood circulation to the skin to prevent excessive cooling. This process lowers skin temperature and decreases the rate of heat dissipation and surface evaporation. The metabolic rate increases through shivering. If heat loss cannot be sufficiently mitigated, this condition progresses, inevitably leading to hypothermia. Our body employs several regulatory mechanisms to maintain optimum operating conditions.

Variables Affecting Thermal Comfort

Fanger (1970) combined four environmental variables; air temperature, humidity, radiation, and airspeed, and two personal variables; metabolic rate and clothing level, into a deterministic model that can be used to determine a predicted mean vote and predicted percentage dissatisfied(Spagnolo & de Dear, 2003).

- Among two personal variables, metabolic rate refers to the heat produced by the human body. It is associated with two kinds of activities: Basal metabolism which are continuous or nonconscious biological process and muscular metabolism.
- The clothing insulation unit is clo which ranges from 0 (for a body without clothes) to 3 or 4 (for clothing for very cold temperatures like in polar regions). In this regard, 1clo=0.155°C/W. Also, it can be measured in the same units of thermal transmittance (U-value) W/m²K.
- Air temperature is one of the most important environmental factors that affect thermal comfort. With air movement, air temperature affects the rate of convective dissipation.
- Radiant temperature exchanges between the body and the surfaces that surround it affect thermal comfort. Also, the view angle between the body and the surface has an impact. For instance, a larger angle of exposure increases radiant exchange. This parameter is indicated by the mean radiant temperature (MRT).
- Air movement affects the evaporation of moisture from the skin. Especially in hot climates, air movement is a useful method to cool the body. It is measured in meters per second (m/s) or feet per minute (ft/min).
- Relative humidity affects the evaporation rate from the skin. A humidity level between 30% and 60% is considered acceptable since it does not have a great effect on thermal comfort.

Thermal Comfort Model

To assess indoor thermal comfort, Fanger's model was used as the most commonly used method (Fanger, 1970). This heat balance model is a mathematical representation of the thermodynamic equilibrium of the human body. It states that all individuals are alike physiologically, and their comfort can be explained through a physiological perspective. Furthermore, it acknowledges that the comfort zone remains consistent for individuals regardless of location and adaptation (La Roche, 2012). Establishing a numerical system, Fanger introduced two metrics for assessing thermal comfort. First, the Predicted Mean Vote (PMV) is an index that calculates the average value of thermal sensation options on a 7-point scale. This system is based on the heat balance of the human body.

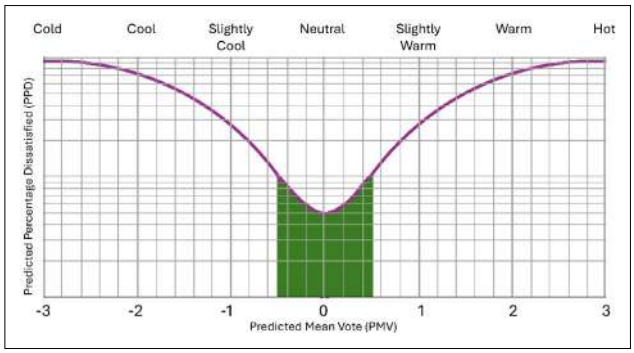

Figure 1. Predicted Mean Vote (IES, 2018).

The predicted mean vote is defined as an index that predicts the mean value of the thermal sensation votes of people on a sensation scale (ASHRA, 2013). This scale ranges between -3 to +3 where 0 symbolizes ideal thermal comfort. PMV Scale is expressed via a seven-point thermal scale representing the categories "cold", "cool", "slightly cool", "neutral", "slightly warm", "warm", and "hot". Acceptability is associated with thermal sensations of "slightly warm", "neutral", and "slightly cool" (de Dear & Brager 2002). The PMV value between -0.5 and +0.5 is for typical metrics for thermal comfort (Figure 1). It corresponds to a Percentage of people dissatisfied of <10% (IES, 2018).

Additionally, Fanger introduced the concept of the Predicted Percentage of Dissatisfied (PPD), which forecasts the average thermal sensation opinions of a large group of people exposed to the same environment. The adaptive method, on the other hand, suggests that occupants can adjust to varying temperatures by interacting with their surroundings, such as by adjusting insulating (clothing) or opening windows. These methodologies for evaluating thermal comfort have become the basis for contemporary international standards, including the ASHRAE Standard 55 (ASHRAE, 2013), ISO 7730 ISO 7730 (ISO, 2005), and EN 15,251 (CEN, 2007). PPD offers a quantitative estimate of the percentage of individuals dissatisfied with their thermal environment, derived from PMV (ASHRAE, 2013). PPD is influenced by various environmental conditions including the average air temperature and the mean radiant temperature (Hacker & Holmes, 2007).

Outdoor Conditions for Thermal Comfort

Studies indicate that outdoor human comfort in urban climates is influenced by a diverse array of human and weather-related factors. Factors such as air velocity, air temperature, relative humidity, and solar radiation play significant roles in determining human preference and overall comfort. Nikolopoulou et al. (2001) discuss how characteristics of microclimates impact outdoor urban spaces and influence user behavior regarding comfort. Especially the emphasis on the psychological adjustment of users, identified as a significant aspect.

Stathopoulos (2009) explains the profound correlation between temperature, humidity, and wind conditions. Temperature and relative humidity impact on human comfort is explained through the connection between the heat balance of the human body and sensation. This equilibrium is shaped by metabolic processes and mechanisms of heat dissipation such as conduction, convection, radiation, and evaporation. Heat losses by convection and evaporation are linked to wind conditions which affect temperature and humidity. In hot regions, the human body requires increased heat losses to maintain thermal comfort. Adjusting the insulation value of clothing and sweating facilitates heat losses associated with the latent heat of evaporation. Since wind speed increases the efficiency of evaporation, wind is a significant parameter in hot climates. Conversely, increased relative humidity diminishes this efficiency (Stathopoulos, 2009).

The effectiveness of cooling via natural ventilation depends on various factors such as peak interior temperatures, humidity, solar radiation, and wind directions. Typically, air temperatures are below the human body's average temperature of 36.5°C. Cooling occurs in different ways according to wind patterns. If air is still, the heat loss occurs via convection from exposed body parts like the hands and head. Conversely, in breezy conditions, heat loss occurs through conduction, and evaporation also contributes to cooling. The intensity of the wind influences the rate of cooling (Krautheim, 2014). Occupant satisfaction rises when they have control over their surroundings, particularly through operable windows in naturally cooled and ventilated environments (Jones & West, 2001).

A simulation study by Yucekaya & Uslu (2020) examined meteorological parameters in Gaziantep, including air temperature, wind speed, relative humidity, and mean radiant temperature. The findings indicate that during the overheated period, relative humidity remains relatively stable, with no significant differences between the hottest and coldest hours, fluctuating between 45–55%. Furthermore, urban planning decisions directly influence wind dynamics; construction aligned with optimal wind directions can enhance airflow, whereas multi-story buildings reduce wind speed and intensify temperature stress due to the canyon effect (Yucekaya & Uslu, 2020). As stated by several studies (Perini & Magliocco, 2014; Song & Park, 2015; Ali-Toudert & Mayer, 2007; Wania et al., 2012), multi-storey buildings reduce wind speed and increase temperature stress by increasing the canyon effect. It is seen that the hardscapes such as roads, carparks, and walkways etc. have negative effects on bioclimatic comfort.

METHODS

The methodology employed in this study is depicted in Figure 2 and schematically described as follows. A case study approach was adopted to examine a social housing project

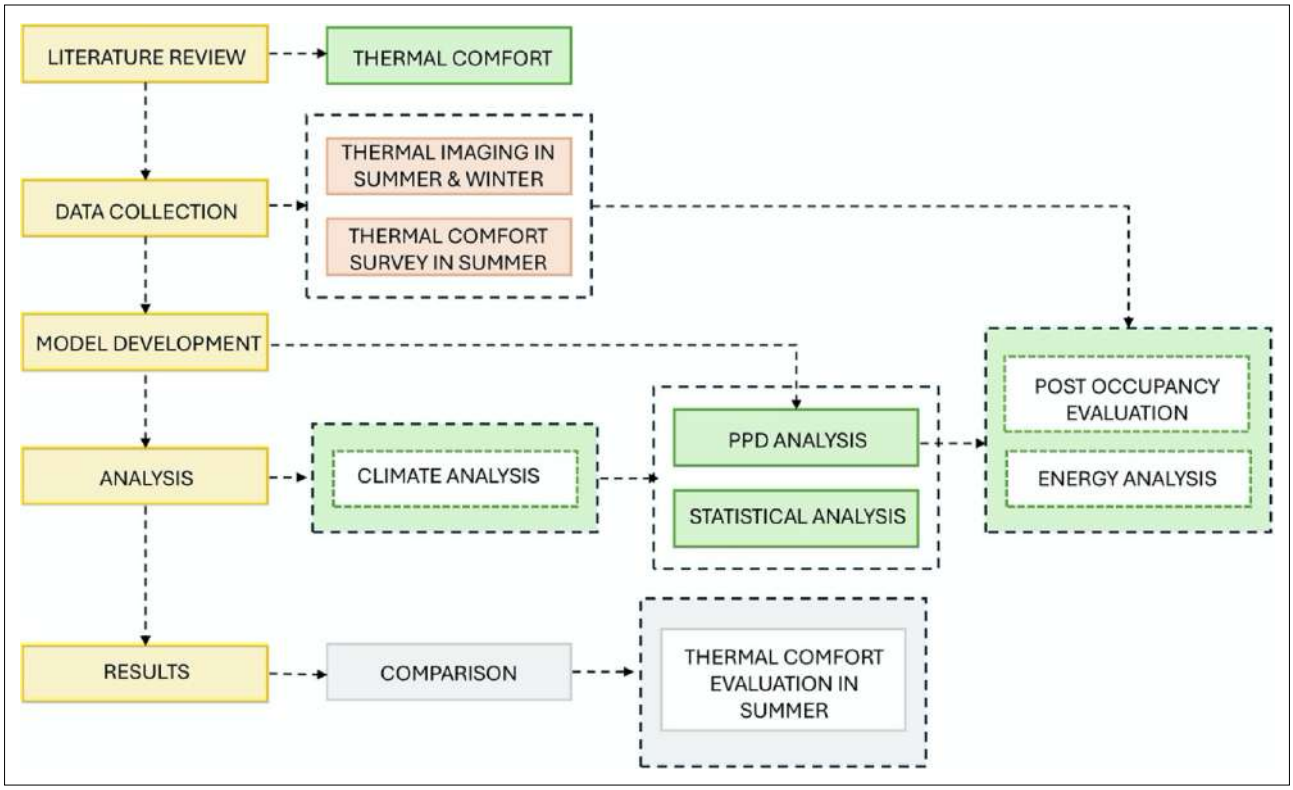

Figure 2. Applied methodology.

located in a hot and dry climate region of Türkiye. Following a literature review on thermal comfort, indicators for the research were identified. Subsequently, a thermal comfort analysis was conducted to gain insights into the real-world conditions of the selected project in the city of Gaziantep. To comprehensively evaluate thermal comfort in the TOKI Etiler housing project, a mixed-methods approach was employed, combining resident surveys, thermal imaging, and energy analysis. The responses collected from 143 residents through detailed questionnaires provided insights into their behavioural patterns and thermal comfort perceptions during the cooling period. These behavioural characteristics were instrumental in understanding how residents adapted to seasonal temperature fluctuations.

Thermal imaging was conducted during representative summer and winter months to capture temperature variations across the building envelope and identify areas of missing or inadequate insulation. This step was crucial in pinpointing thermal bridges and evaluating the overall effectiveness of the building's insulation systems. Furthermore, energy simulations were performed using the IESVE software, focusing on the thermal performance of individual floors over six months. This analysis quantified the dissatisfaction levels experienced by residents based on Predicted Percentage of Dissatisfied (PPD) metrics, revealing significant variations in comfort levels across different floors. For instance, upper floors demonstrated higher thermal discomfort during peak summer months due to excessive heat gain.

The integration of survey responses, thermal imaging results, and energy analysis allowed for a comprehensive and realistic evaluation of thermal comfort. The combined use of statistical and energy modelling approaches ensured a robust comparison of resident feedback with simulated data, validating the accuracy of the findings. This methodology not only highlights key thermal comfort challenges within the case study but also offers actionable insights for improving the design and performance of social housing projects in similar climatic contexts.

Case Study

Location and Climate

Situated in the South-Eastern Anatolia region of Türkiye, Gaziantep serves as a typical representation of the challenges associated with cooling in hot and dry climatic conditions. The city's topography within a 3-kilometer radius exhibits various elevations, with a maximum difference of 135 meters and an average elevation above sea level of 860 meters. Approximately 52% of Gaziantep's total area comprises mountains, while 27% consists of plains. This topographical diversity engenders a blend of continental climate effects in the north and Mediterranean climate characteristics in the south.

Summers are characterized by heat and dryness, whereas winters are marked by cold and rainfall. Gaziantep has a hot-summer Mediterranean climate with influences of a continental climate. This entails hot, dry summers and cool, wet winters, occasionally accompanied by snowfall (The Köppen-Geiger Climate Classification). Despite low relative humidity levels in the region, the evaporation rate is high during the summer months. Figure 3 illustrates the variation in dry-bulb temperature, external relative humidity, and wind speeds across different seasons. Values increase from blue color to red color on the key for all parameters. While the highest relative humidity values are observed during the winter months, wind speeds peak in the summer period, particularly in July. A prevailing southwest wind dominates the city's wind conditions. During the summer, the high temperatures are mitigated by breezes that provide a cooling effect. These breezes are of moderate intensity, with an average wind speed of 3 m/s.

Based on five-year real-time weather observations from Gaziantep weather stations spanning 2013 to 2018 (Figure 4), this climate is characterized by hot and dry summers

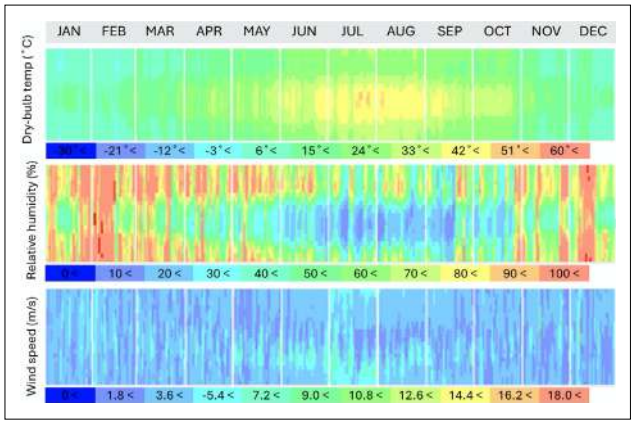

Figure 3. Diagrams for three climate variables in Gaziantep (IES, 2018).

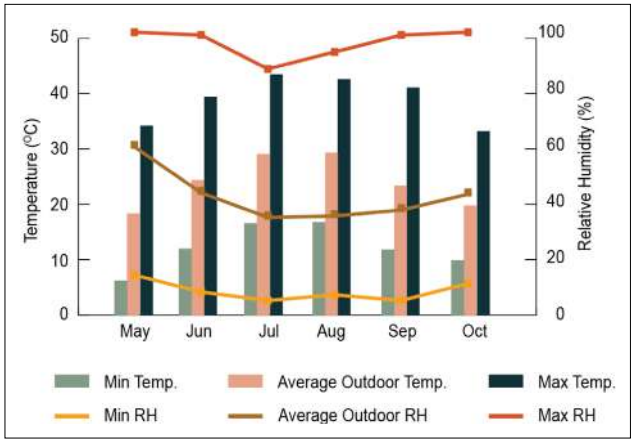

Figure 4. Minimum, maximum, and mean outdoor values during the warmer period in Gaziantep.

with average temperatures exceeding 30°C and lasting up to six months. Conversely, January marks the coldest month with an average temperature of 3.7 °C (Turkish State Meteorological Service). The annual average temperature is 16.4°C. Although May and October are considered 'comfortable' in terms of thermal conditions in the city, daytime temperatures can still climb to 28°C and 24°C, respectively. The temperature differences between day and nighttime bring a cooler and more pleasant sensation during the summer nights. However, heat stress remains a significant thermal issue.

Population and Social Housing in Gaziantep

The TOKI Etiler project was considered a typical model of TOKI mass housing initiatives for low-income groups in Gaziantep. This city has experienced rapid urbanization and significant population growth over the past decades. In the 1970s, its population stood at around 120,000 people. However, by 2018, the population had surged to over 2.02 million, with an annual growth rate of 4.25% (TUIK, n.d.). This urbanization has occurred in a largely unplanned manner, leading to haphazard development. Projections indicate that the population will grow to an estimated 3 million in the next 20 years. By 2000, Istanbul had become the largest city with over 10 million inhabitants, followed by Ankara, Izmir, Bursa, Adana, and Gaziantep. Today, these numbers show an increment in these cities between 20-40% and just with Gaziantep reaching 56% growth in the last two decades (Table 1).

Despite this substantial growth, urban planning measures in Gaziantep have been limited. The most recent city growth plan dates back to 1974. As a result, local municipalities have relied primarily on zonal plans as a means of controlling urban expansion (ECA Sustainable Cities Report, 2013).

The rapid expansion of Gaziantep places considerable strain on land markets, housing markets, and public service infrastructure. This unplanned growth also contributes to energy efficiency shortcomings, particularly due to the emergence of new developments without proper planning. Like many other major Turkish cities, Gaziantep has witnessed the rise of informal settlements on available land to accommodate both domestic and incoming populations. Additionally, high gasoline prices in Türkiye discourage outward expansion and suburban-type developments (Figure 5). Consequently, the city's developed area has reached a population density of approximately 3,750 people per square kilometer (ECA Sustainable Cities Report, 2013).

Considering the European Commission's (Florczyk et al., 2019) description of high-density urban centers worldwide as areas characterized by at least 1,500 inhabitants per km² of land or a built-up surface covering at least 50% per km² (including roads and infrastructure), with a total population of at least 50,000, Gaziantep's population density is relatively high. By 2017, the number of these residences in Gaziantep has reached 25,000 due to the need for accommodation for former informal housing residents (TOKI, n.d.). Since the great numbers of the same housing typology produced by the Mass Housing Administration in Türkiye, the Etiler Project in Figure 6, serves as a representative model of the multifamily buildings TOKI produces.

Figure 5. Growth along the Southern border of Gaziantep, 2009 (top) -2019 (bottom) (GoogleEarth).

Table 1. Gaziantep Population 1990-2018 (Turkish Statistical Institute 2019)

Name	Population 2000	Population 2010	Population 2018	Growth 2000-2018 %
Istanbul	11.076.840	13.255.685	15.067.724	36
Ankara	3.889.199	4.771.716	5.503.985	41
Izmir	3.431.204	3.948.848	4.320.519	25
Bursa	2.150.571	2.605.495	2.994.521	39
Adana	1.879.695	2.085.225	2.220.125	18
Gaziantep	1.292.817	1.700.763	2.028.563	56

Figure 6. TOKI Etiler project during and after construction. (Photos by Aydın Insaat, n.d (top) and Bay- Şahin, 2019 (bottom)).

Building Description

The selected TOKI Project, constructed in 2012, aimed to accommodate low-income families displaced during the 'gecekondu (informal housing in Turkish) clearance' phase of an urban renewal program. (Gaziantep 27, 2011). The selection of residents was conducted jointly by the TOKI agency and local municipalities, based on criteria such as economic status and demographic details of the families. The Etiler project comprises six residential blocks distributed randomly on an irregular plot (Figure 7). The project consists of 12 story blocks with a total of 48 identical units. Like many social housing projects in Türkiye, it prioritizes less dense land utilization and offers larger outdoor spaces. However, concerns regarding pedestrian discomfort because of the harsh summer conditions resulted in limited usage of these outdoor areas.

The Etiler Project, within a site spanning 18.506,63 m^2, features two different block types that have 296 identical housing units. Two blocks, each with twelve stories and a basement, were complemented by an additional basement floor in the other four blocks, accommodating two extra units. Each floor has a plate area of 346m^2 with the ground floor slightly larger (359.2 m^2) due to the entrance. The building follows a residential unit prototype with a central core developed by TOKI. Each apartment unit, with a volume of 232 m^3, has an average of 67 m^2 enclosure area facing the exterior (Table 2). These units incorporate naturally conditioned spaces, allowing residents to regulate thermal conditions. The window-to-wall ratio is obtained as 0.14. The units in the Etiler project include side-hung and fixed windows. Since each opening is divided into flow and non-flow regions, the openable area is 80% after accounting for the removal of the window frame. Each floor comprises eight thermal zones including four residential units along with a staircase, an elevator, a corridor, and emergency stairs. The floor-to-floor height is 2.9 m.

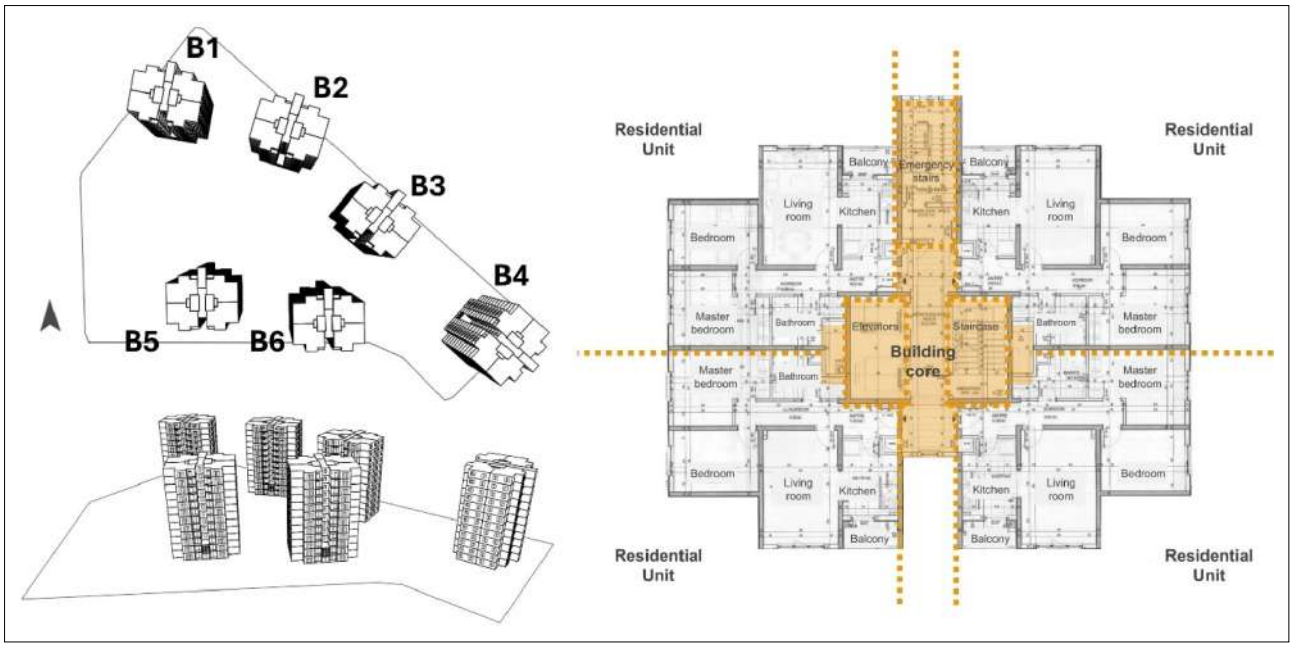

Figure 7. TOKI Etiler project and a typical floor plan.

Table 2. TOKI Etiler Building specifications

a) Unit dimensions		b) Specifications of windows	
Floor area (m^2)	80.32		Openable area (%)
Volume (m^3)	232	Side hung window	80
Ext wall area (m^2)	67		
WWR	0.14	Fixed window	0
c) Specification of the building envelope			
Building components	Material	Thickness (m)	U-value (W/m^2K)
Exterior walls	Cast concrete (C30/37)	0.28	0.433
Interior walls	Cast concrete	0.10	1.099
Floor	Concrete	0.2	0.453
Roof	Concrete	0.1	0.263
d) Specification of the building openings			
Windows (Double- glazed, clear float with air-filled cavity)	SHGC	Visible light normal transmittancea	U-value (W/m^2K)
	0.75	0.8	3

WWR: Window-to-wall ratio; SHGC: Solar Heat Gain Coefficient.

In contrast to most mass housing examples, these blocks lack a centralized area designated for communal services (Givoni, 1991). However, the project features limited collective spaces concentrated at the center of the project except a playground for children and benches for socializing. There are 148 parking spaces located along the perimeter streets and within the inner part of the site. This allocation translated to one parking space per two dwellings within the 296-unit project.

Access to the units is provided through the core on each floor. Within the core, two elevators are centrally positioned while the main staircase and emergency staircase are situated on opposite edges of the floor. The project does not offer various types of housing; instead, each unit is uniform, featuring two bedrooms, one living room, one kitchen, and one bathroom. Additionally, units have a balcony. Although the first level mirrors the layout of other floors, except the building entrance, four units on this floor do not have direct access to the street level.

Thermal Comfort Survey and Statistical Analysis

To comprehend the factors influencing residents' thermal preferences, a survey was conducted in August 2019 within the TOKI Etiler Project. The sample surveyed was obtained through voluntary participation during the field study. The demographic characteristics of the interviewed residents were assessed for correlation with information related to thermal related questions and opinions on natural ventilation. Therefore, data on gender, age, first occupancy, and ownership status were collected. At the time the questionnaires were administered, the majority of participants were adult women with over half being 'first occupants' and 'owners' of their units.

In the data analysis aimed at understanding the dynamics of thermal comfort, the proportion between women (125) and men (18) and the 'age range' were taken into account (Figure 8). Additionally, information related to 'clothing values' and 'metabolic activities' was also observed. Within the sample, the predominant group falls within the age range of 18 to 50 years old.

The questionnaire was designed according to the socioeconomic level of residents. It was translated into Turkish, as it is the primary language spoken by the residents of the TOKI Etiler project. To ensure clarity and avoid any issues related to natural ventilation and thermal comfort conditions, the questionnaires were distributed exclusively to adults aged 18 years and above. Respondents completed the questionnaires either at the central core of their floor or within their apartment unit if they permitted the researcher to enter.

Interviews were carried out between 10 am to 5 pm over two months (July and August 2019). A total of 143 respondents out of the 288 residents participated, representing their households during the study period. The questions aimed to gather comprehensive information about occupants' opinions on thermal comfort, behavioral patterns related to natural ventilation, and overall satisfaction with their living environment during the survey period. The questionnaire covered the following topics:

- Age (Also, bands arranged as 18-30, 31-40, 41-50, 51-60, 61-70, and 71+.) and family size.
- Block (B1, B2, B3, B4, B5 or B6), unit level (1 to 12), and unit orientation (N, NE, E, SE, S, SW, W, NW, N)
- Residents' information (whether the resident owns the unit and whether he/she is the first occupant of the unit)
- Type of previous dwelling (apartment unit/house) and residents' future expectation
- Indoor and outdoor Thermal Sensation Vote (TSV) according to ASHRAE 55's seven-point sensation scale (-3, -2, -1, 0, +1, +2, +3) from very dissatisfied to very satisfied
- Existing clothing preference based on ASHRAE 55 (including choices in the answer options)
- Having air conditioning in residential units or not

Following the survey, the collected data, consisting of categorical and ordinal variables, was tabulated and analyzed using the SPSS 21 software package. Findings about user profile, block location, unit level, and unit orientation were presented by calculating the frequency and percentage distribution of the coded data. A one-way analysis of variance (ANOVA) was employed to examine whether the mean values of thermal sensation, unit level, family size, and summer clothing differed significantly from each other. Furthermore, correlation analysis was conducted to assess the relationship between two normally distributed interval variables, namely airflow performance and thermal sensation.

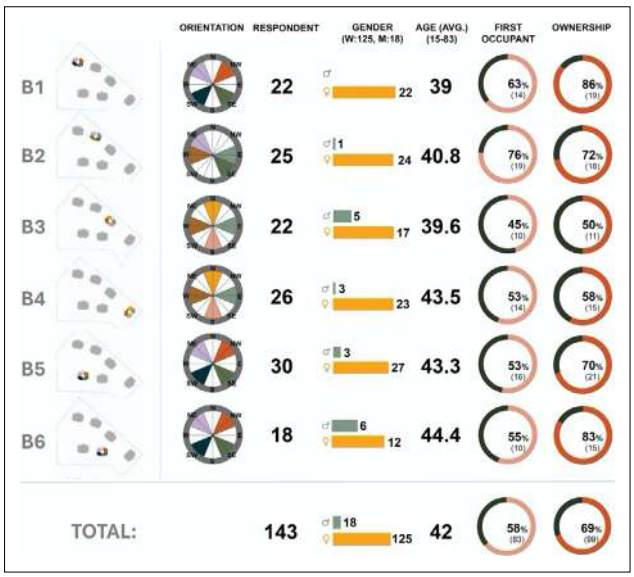

Figure 8. Residents' demographic and unit information.

FINDINGS AND DISCUSSION

Infrared Thermography Images in TOKI Etiler Buildings

Thermal imaging was utilized as a method to observe thermal insulation within the studied residential blocks. A thermal imaging camera connected to a smartphone was used to capture surface and window temperatures both in the winter and summer seasons. The iron (FLIR) color palette was used to visualize the images. This setting displays the purples and blacks as cold areas and uses warm colors such as yellow and white to show warm areas. Thermal images taken during both the summer and winter periods were transferred to a computer and analyzed to identify significant thermal bridges and surface temperature differences.

During the thermal imaging phase of the study, a representative unit in Block 3 was selected to analyze the

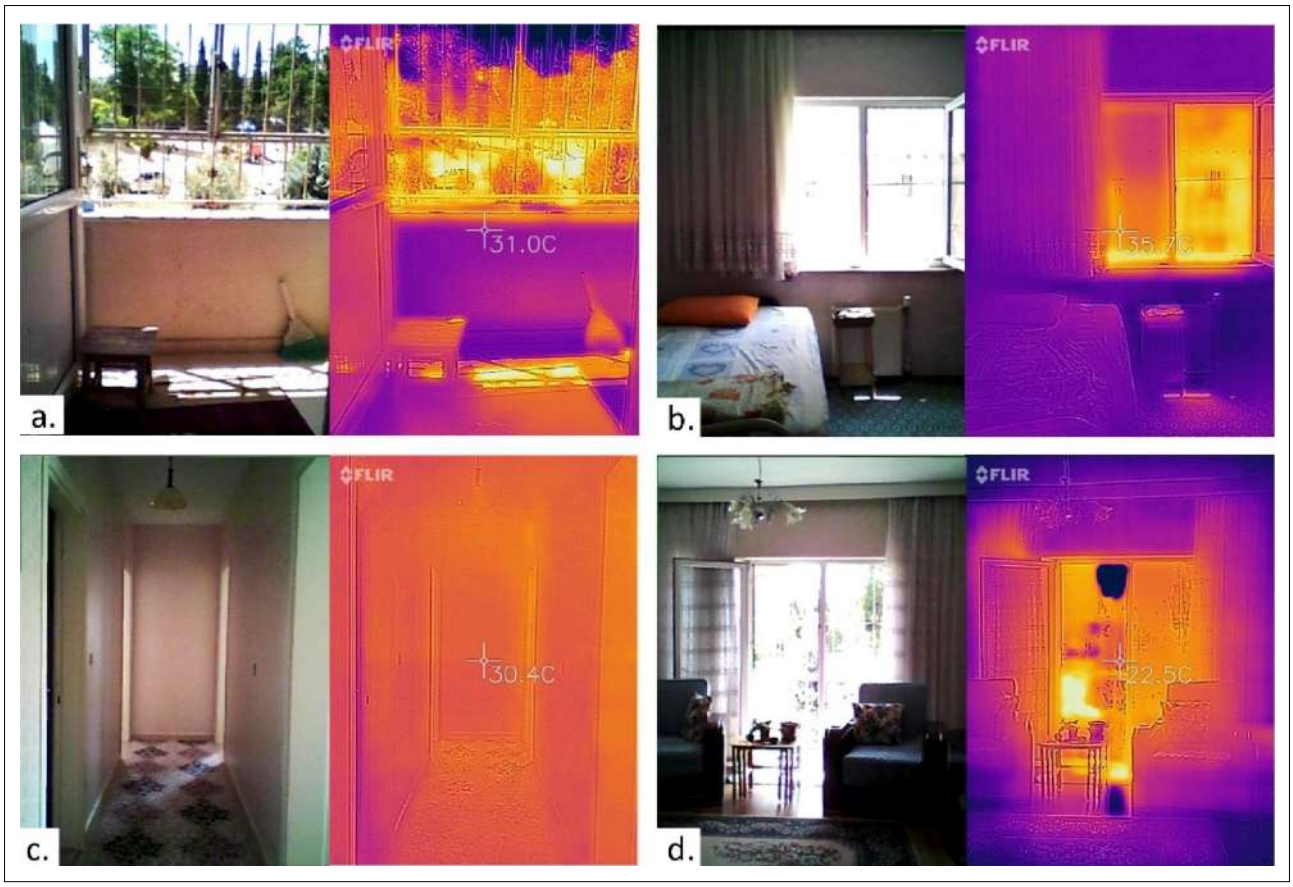

Figure 9. Surface and glazing temperatures in Block 3 units in July, **(a)** Kitchen (South West), **(b)** Bedroom (North West), **(c)** Corridor, **(d)** Living room (North West) (Photo by Bay-Şahin, 2019).

worst-case scenario during the summer. The availability of airflow is a key factor in the performance of natural ventilation. Given that Block 3 is centrally located among the six surrounding blocks, it experiences the most significant airflow restrictions, making it the least advantageous in terms of natural ventilation. Figure 9 shows the surface temperatures at 3:30 pm in Block 3. The selected unit has facades oriented southwest and northwest. The surface temperature of the southwest wall in the unit's balcony was recorded at 31°C, while the window temperature was approximately 35°C (Figure 9a). In the apartment layout, each bedroom and the living room are equipped with one operable window, while the kitchen lacks any windows. However, the kitchen has a glazed balcony door as the sole opening. As shown in Figure 9, it's worth highlighting that during the daytime, over 95% of families utilize the balcony door, making it the primary opening for ventilation both during the day and at night. As anticipated, bedroom windows are predominantly open during nighttime. Interestingly, they are also utilized in the mornings and afternoons by more than 65% of families (Figure 9b).

Figure 10 displays the thermal image of the southeast façade of Block 3 bedrooms which was taken from a residential unit in Block 4. This data related to exterior wall surface temperatures was recorded during the early afternoon. Since July is the warmest month when the highest outdoor temperatures and lowest humidity levels are seen during the cooling period in the city. As seen in Figure 10, the wall surface temperature was recorded as 41.6°C at 1 pm.

Figure 10. Exterior wall temperature on the southeast façade of Block 3 in TOKI Etiler in July(Photo by Bay-Şahin, 2019).

The thermal image taken in December at 5 pm shows temperature variations of the walls in Figure 11 that might be the result of gaps in insulation or insulation bridged by other building materials. Thermal bridging is a significant problem that typically occurs in the insulation area of the external construction layer. In these two thermal images taken during the winter, the brighter yellow areas at the center of the façade indicate a higher surface temperature in these places, suggesting higher local heat loss. This inconsistency in insulation installation could be attributed to gaps between the insulation batts in certain areas of the cavity or the accumulation of mortar debris (NHBC Foundation, 2020).

SPSS Statistical Analysis for Thermal Comfort Evaluation

To investigate the relationship between unit orientation and users' thermal perception, respondents were queried about whether they observed minor thermal-related issues (cooler conditions during warm periods) in other apartment units within six TOKI blocks of the Etiler Project. The sample of the survey comprised 143 participants from various households across different blocks, unit levels, and unit orientations within the residential project. The feedback collected was analyzed according to these variables. Also, open-ended questions encouraged residents to provide deeper, more detailed responses during one-on-one discussions.

Overall, the distribution of respondents was consistent across all six blocks of this residential project. Additionally, a similar number of households were interviewed per level. When researchers asked whether they were satisfied with their unit's orientation compared to their neighbors' units, 28% of respondents drew comparisons and complained about excessive heat gain during the warm period. They reported that other apartments were cooler than their units during the summer season. These 40 respondents included 13 residents living in southwest-facing units in Blocks 1 and 5, 9 residents living in southeast-facing units in Blocks 1, 2, and 6, and 18 residents living in south-facing units in Blocks 3 and 4.

Inside their units, it is observed that some residents undertake modifications that are related to passive strategies to adapt their living spaces to achieve thermal comfort, particularly during the hot summer months. They rely on natural ventilation methods to deal with the high temperatures during the summer months in Gaziantep.

To understand user behaviors regarding thermal adaptation during warm periods inside their units, residents were presented with multiple options for cooling methods and asked to select their preferred choices. The options included 'opening windows,' 'opening their apartment door,' 'using fans,' 'using air conditioning units,' and 'keeping windows closed.' The survey revealed that the most commonly utilized method for cooling was the operation of windows and the apartment door to enhance cross ventilation through the units. However, occupants prefer spending time in building hallways when cross ventilation is not enough to enhance their thermal comfort (Figure 12).

Our previous work (2019) showed that with a central heating system (a hot water boiler with radiators in each unit), a significant proportion of residents report a 'warm' thermal sensation during cold periods, even when wearing light clothing. During the summer months, over 60 percent of residents experience a thermal sensation above neutrality, despite also wearing light clothing. Also, a 'Likert-type' scale is used to measure the attitudes of surveyed occupants (Figure 13). Through this assessment, the thermal satisfaction level of interviewed residents was recorded with only 13.9% expressing an 'acceptable satisfaction' (above neutral) with their indoor thermal conditions. Conversely, 68.6% of residents indicated dissatisfaction/below neutral with indoor areas (13.4% very dissatisfied, 7.7% dissatisfied, 47.6% slightly dissatisfied, 17.5% neutral, 7.7% slightly

Figure 11. Exterior wall temperature on the southwest (left) and southeast (right) façades of Block 3 in TOKI Etiler in December (Photo by Bay-Şahin, 2019).

Figure 12. Occupants when cross ventilation is insufficient, July 2019 (Photo by Bay-Şahin, 2019).

satisfied, 5.6 % satisfied, and 0.6% very satisfied). Similarly, residents were asked about their overall satisfaction levels regarding their units and the outdoor environment within the TOKI Etiler Project. The results revealed that 68.6% of the total residents reported a unit satisfaction level below 'neutral.' Additionally, 57.3% of the population expressed being 'very dissatisfied' with outdoor areas in the Etiler project while 17.4% and 5.5% expressed 'dissatisfied' and 'slightly dissatisfied', respectively (Bay, 2019).

Following the surveying process, the collected data (categorical and ordinal) was tabulated and analyzed using the SPSS 21 software package. In the SPSS output, the model summary section typically includes several key data points. This data includes:

- Demographic information such as age, gender, and family size;
- Homeownership details such as whether the respondent is the first occupant of the unit, previously lived in a low-rise building, or previously had a garden;
- Unit features such as the block name, unit orientation, floor, etc. Findings related to user information and unit features were derived through the calculation of frequency and percentage distributions of the coded data.

The correlation coefficient (R) indicates the strength and direction of the linear relationship between the observed and predicted values of the dependent variable. The R-square value represents the proportion of variance in the dependent variable that can be explained by the independent variables. Adjusted R-square is a modified version of R-square that adjusts for the number of predictors in the model and

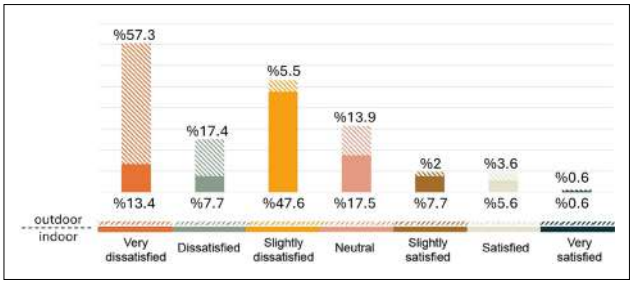

Figure 13. Likert-type scale for thermal comfort survey.

provides a more accurate estimate of the proportion of variance explained by the model in the population. Lastly, the standard error of the estimate quantifies the average distance between the observed and predicted values of the dependent variable.

The linear regression analysis in Figure 14 was used to interpret the relationship between air flow performance and thermal sensation. The R-square value indicates that 12.8% of the variance in the thermal sensation can be predicted from the independent variable "airflow performance". However, the adjusted R-square provides a more reliable estimate of the R-square for the population, accounting for potential overfitting or underfitting issues in the model (UCLA, n.d.).

In the Anova table, the sources of variance include Regression, Residual, and Total. Regression represents the variance that can be explained by the independent variables included in the model, while Residual represents the unexplained variance that remains after accounting for the independent variables. Total variance encompasses all variances in the independent variable. As shown in Figure 14, "Sig." The column in the Anova table represents the p-value associated with the F statistics (IBM, 2012). This p-value indicates the probability of observing the obtained F value (or a more extreme value) if the null hypothesis is true or if the independent variables do not have any effect on the dependent variable. If this value is smaller than the alpha level which is typically 0.05, it can be concluded that the independent variables reliably predict the dependent variable. If not, it means that the selected independent variables do not reliably predict the dependent variable.

Gürbüz & Şahin (2014) explain the correlation relationship levels as weak between 0 – 0.30, medium between 0.30 – 0.70, and strong between 0.70 – 1. Since R is between 0.30 – 0.70, the correlation coefficient (0.357) indicates a moderate positive relationship between air flow performance (independent variable) and thermal comfort (dependent variable). The coefficient of determination (0.128) shows that approximately 12.8% of the variation in thermal comfort is explained by air flow performance. Adjusted for the number of predictors, it is 0.122, meaning 12.2% of the variance is explained when accounting for model complexity. The F-value of 20.658 indicates that the

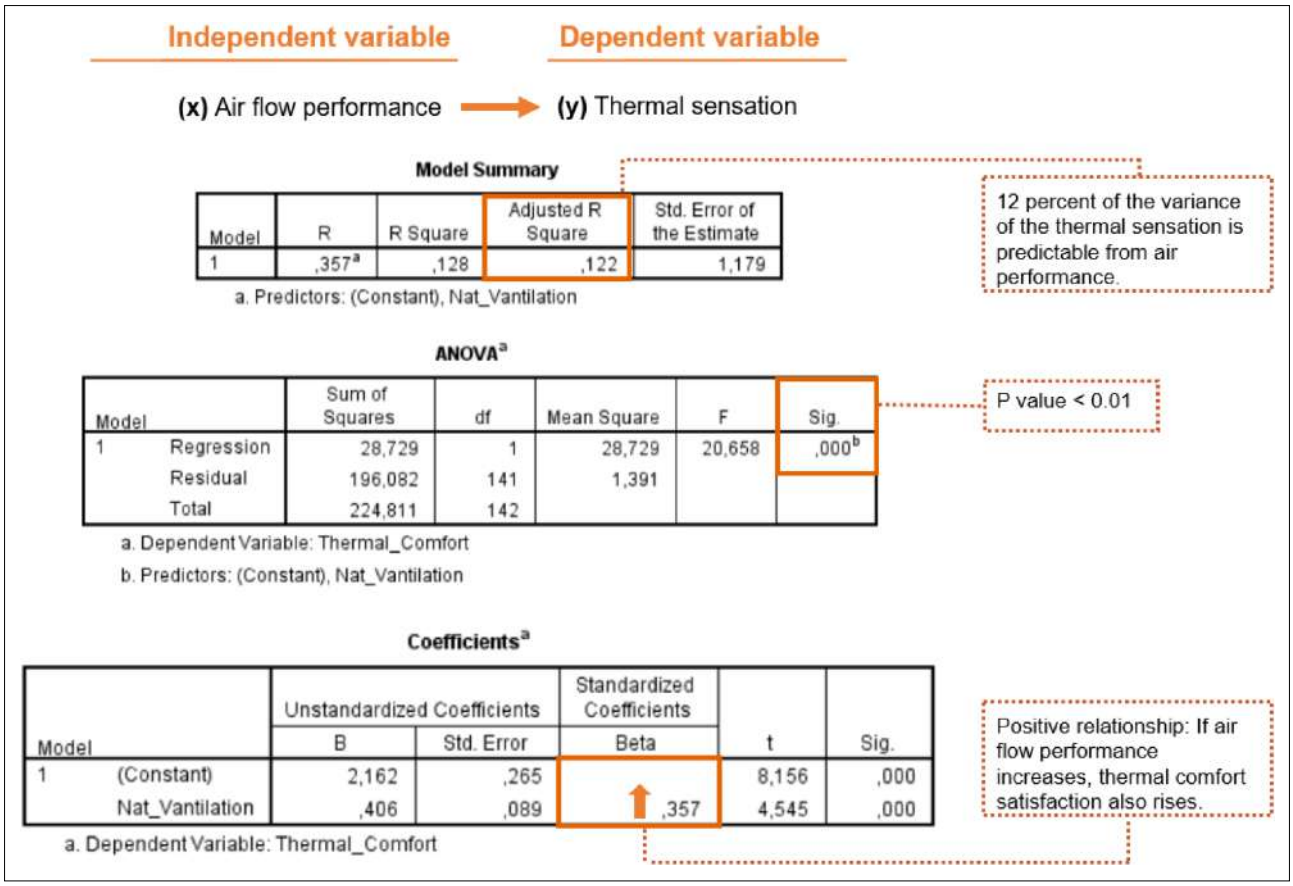

Figure 14. Linear regression analysis.

model significantly predicts thermal comfort.The standard coefficients, or Beta, suggest that as airflow performance increases, there is a corresponding rise in thermal comfort satisfaction within this climate region (Figure 14). This can be interpreted that if air flow performance increases, the thermal comfort satisfaction level rises. The p-value (0.000) indicates that the air flow performance significantly impacts thermal comfort. Overall, the model is reliable, as indicated by the low p-value and moderate F-statistic.

ANOVA test was used to determine if the mean values of thermal sensation, unit level, family size, and summer clothing value are statistically different from each other. Although there was no environmental monitoring in the units, this statistical analysis helped to understand whether unit level, family size, or clothing value of residents in summer influences users' thermal sensation. For instance, upper floors typically experience more heat due to greater exposure to sunlight, while lower floors might be cooler due to shades. Variations in airflow can impact thermal comfort differently depending on the unit level. The second hypothesis indicates a statistical difference between thermal sensation and family size. It means that the perception of thermal comfort significantly varies depending on the size of the household. Larger families lead to more internal heat generation which could elevate thermal sensation levels and people feel warmer. The last hypothesis in Figure 15, suggests that the thermal sensation varies significantly based on the type or amount of clothing worn during summer since clothing plays a key role in thermal regulation. Lighter or thinner clothing allows the body to cool more efficiently, which could lead to a lower perception of heat. On the other hand, people who wear less clothing are likely to experience less thermal discomfort than those wearing more covering clothing.

Overall, the ANOVA test confirmed the hypothesis that all groups of variables are indeed statistically different from each other (Figure 15). Furthermore, both the linear regression analysis and the Anova test confirmed that the current airflow conditions in the project effectively explain the issue of overheated indoor environments.

PPD Analysis

To comprehend residents' satisfaction levels under these climatic conditions, the Predicted Percentage of Dissatisfied (PPD) values for each of the six blocks were documented over one year using energy simulations. Through a visual comparison, PPD values obtained in each block were similar, despite the varying orientations and spatial configurations across the studied plot.

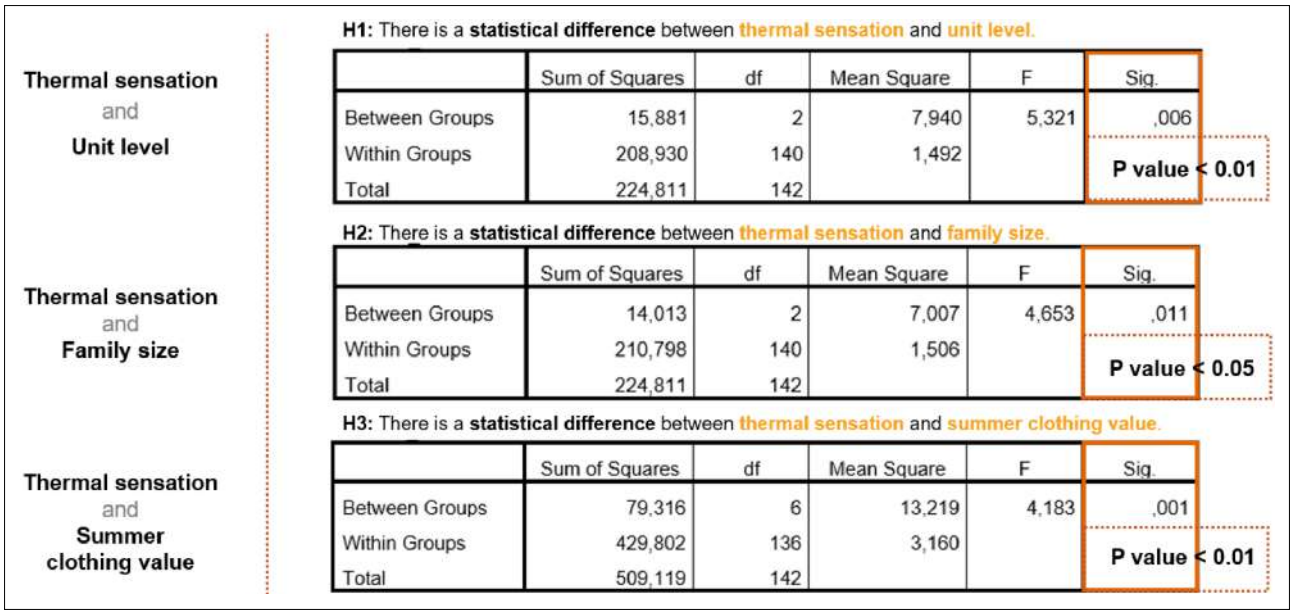

Figure 15. Anova test.

For the whole-year energy analysis model, a simplified geometry was modeled following the original drawings of this residential project using IES VE simulation software. It was used in many scientific publications to conduct building performance analysis (Iskandar, et al., 2024; Bay, et al. 2022; Elzeyadi & Batool, 2017; Lau, et al., 2016). After building the model in IES VE, different modules of the software were used to perform an energy simulation. The Apache as a Dynamic Simulation Module (DSM) allowed to evaluate thermal comfort performance. The required weather data for the energy simulations was obtained from the Gaziantep Airport weather station (TMY3 weather file) by IES VE.

During the cold period, the 'heating setpoint' was maintained at 21 °C, resulting in PPD values of less than 10%. On the other hand, during the hot period, no mechanical cooling systems were utilized. In this scenario, the highest levels of dissatisfaction were observed for more than 50% of the time, particularly in July and August. The PPD values were obtained from May to October for each floor level. It was observed that the top-floor units exhibit higher dissatisfaction levels compared to the other eleven floors in the twelve-story building. The highest level of 'dissatisfaction' reaching 45.9 %, was recorded in August. The PPD values fluctuated between 5.9% to 7.1% during May and October. However, this range increases significantly from 11.7 % in September and 18.8 % in June. As the 'heat stress' rises during the two warmest months of 'July and August', the minimum number of people experiencing dissatisfaction rises to 36.7% (Table 3).

The majority of units in the Etiler Project face northwest and southeast, similar to the units in Blocks 1, 2, 5, and 6. Consequently, representative units located on the northwest and southeast orientations were selected for the PPD analysis. Furthermore, PPD is exemplified by two typical units located on the northwest (NW) and southeast (SE) sides on the third level on which there are thermally advantageous units between upper and lower-level apartments. During May, July, and August, residents in both NW and SE units have higher satisfaction levels during May. SE units consistently display higher PPD values across May, June, and July, primarily due to increased 'solar gains' and lack of 'shading'. Also, 'dissatisfaction' values in the SE unit peaked at 60 % in June.

Table 3. Percentage of People Dissatisfied (PPD) values per floor (mean)

Floor	May	Jun	Jul	Aug	Sep	Oct
12	6.5	18.8	42.2	45.9	13.9	7.1
11	6.0	15.8	37.4	41.0	12.1	6.7
10	5.9	15.4	36.7	40.3	11.8	6.6
9	5.9	15.5	36.7	40.3	11.8	6.6
8	6.0	15.8	37.3	41.0	12.2	6.6
7	6.1	16.2	38.0	41.5	12.4	6.5
6	6.0	15.9	37.5	41.3	12.1	6.4
5	5.9	15.7	37.3	41.1	11.9	6.3
4	5.9	15.7	37.3	41.1	11.8	6.2
3	5.9	15.7	37.5	41.3	11.7	6.2
2	6.1	16.4	38.2	42.0	12.1	6.3
1	6.3	17.5	39.9	43.5	12.8	6.5

DISCUSSION AND CONCLUSION

This study examines the contemporary urban dynamics of Gaziantep, a southeastern city in Türkiye, where recent migrations have led to an unprecedented demand for housing. The research employed a Thermal Comfort survey to assess the level of comfort perceived by individuals in low-income housing. The findings of the Post-Occupancy Evaluation (POE) presented in this study were derived from a high-rise residential project in Gaziantep, encompassing a total sample of 288 apartment units. The findings provided insights into the current thermal environment within these residential units. This information was gleaned from users' detailed responses regarding indoor and outdoor microclimate conditions.

The spatial and thermal needs/preferences expressed by the TOKI residents in the POE were identified as key 'environmental' objectives. Findings related to air velocity, indoor temperature, and predicted percentage of dissatisfied (PPD) were aimed at addressing the technical aspects required in a naturally ventilated building. Passive cooling strategies help alleviate thermal stress and reduce electricity consumption. Olgyay (2015) mentions that the possibility of better living conditions and improved thermal environments can be achieved at lower costs by minimizing reliance on mechanical conditioning systems. This can be accomplished by designing structures that effectively harness natural resources to mitigate undesirable stresses and create environments conducive to human comfort.

The findings highlight the significant influence of outdoor climatic conditions on residents' reported thermal sensation. During the cooling season, residents reported higher dissatisfaction with indoor temperatures, primarily due to the absence of mechanical ventilation or cooling systems. Consequently, residents rely on natural ventilation strategies, such as operable windows and doors, to regulate indoor temperatures. Incorporating resident feedback on thermal preferences and clothing values into simulation models provides a more comprehensive understanding of thermal dynamics in social housing. This holistic approach integrates outdoor conditions, occupant behaviour, their preferences, clothing choices, and adaptive strategies contributing to provide a more detailed analysis of indoor comfort.

To enhance sustainability in social housing design, architectural strategies should prioritize minimizing environmental impact while fostering a high-quality living environment. This can be achieved by incorporating collective and multifunctional spaces with diverse programs, which foster community integration with the urban fabric. A balanced approach between private dwellings and communal areas is essential, facilitated by flexible living spaces that adapt to residents' evolving needs. Additionally, building shapes and compactness should be carefully considered in response to the climatic context. By achieving climate balance - through optimized air movement, shading strategies, and material selection - buildings can be designed to enhance occupant satisfaction across diverse climatic regions in Türkiye.

This research contributes to understanding the local climatic conditions in Gaziantep and their influence on resident behavior and adaptation strategies. The field study provided an effective methodological approach to investigate and understand issues or challenges in real-world settings. The findings offer practical insights into the impact of spatial configurations on indoor microclimates and resident satisfaction levels. By providing a scientific diagnosis of indoor environmental conditions in TOKİ residential projects, this study contributes to evidence-based decision-making for social housing design. In particular, it highlights the advantages of natural ventilation as a cost-effective and sustainable passive cooling strategy for thermal comfort.

Considering the climatic characteristics of Gaziantep, including hot and dry summers, cold winters, and high diurnal temperature variations, housing design should aim to minimize excessive heat gain and reduce thermal losses. Implementing shading devices and solar energy solutions can significantly reduce cooling demands, while evaporative cooling techniques, such as incorporating water features in outdoor spaces, align with the region's traditional vernacular principles. A major challenge in existing housing stock is thermal inefficiency due to poorly insulated envelope designs and thermal bridges. Improved insulation strategies should be prioritized to enhance building performance. The widespread use of concrete and petroleum-based products raises environmental and health-related concerns, emphasizing the need for eco-friendly materials.

Furthermore, building typology and urban form significantly impact thermal comfort. Instead of adopting a "one-size-fits-all" approach, housing developments should be tailored to local environmental conditions to optimize indoor climate regulation. This raises critical questions regarding alternative low-rise or mid-rise housing, which may offer better thermal performance than conventional high-rise developments.

The study acknowledges limitations in its data collection methodology. As stated in Standard 55, thermal comfort is a condition of mind that reflects satisfaction with the thermal environment. Due to its subjective nature, thermal comfort can vary for each individual, influenced by factors such as age, gender, metabolic rate, clothing preferences, and adaptation. Data collection for this study was conducted during the daytime, resulting in a non-homogeneous gender distribution among participants. Specifically, 87.4% of respondents were women due to the selected survey

timing. This imbalance may limit the generalizability of findings concerning gender-related variations in clothing insulation, thermal adaptation, and comfort perception.

For future investigation into natural ventilation and thermal comfort in social housing in Türkiye, research could be expanded by incorporating indoor and outdoor environmental monitoring to enhance data accuracy. Expanding this methodology to different climate regions in Türkiye would provide broader insights into climate-responsive social housing. Additionally, integrating computational modeling with field measurements can further validate findings and refine passive cooling strategies.

In addition, given the county's diverse climate conditions, various passive strategies can be effectively implemented to enhance thermal comfort in social housing. For instance, optimizing building orientation by aligning facades perpendicular to prevailing winds can significantly improve natural ventilation. In addition, incorporating courtyard configurations in dense urban areas can create shaded and ventilated microclimates. The use of high-thermal mass materials is beneficial in hot and dry regions like Gaziantep, as these materials regulate indoor temperatures by mitigating diurnal temperature variations. Moreover, passive solar control through deep overhangs, adjustable louvers, and green facades can effectively reduce solar heat gain, which is especially critical in humid regions. Enhancing airflow through double-skin facades, ventilated atriums, and windcatchers can further improve natural ventilation. Additionally, cool roofs and reflective surfaces like whitewashed buildings minimize heat absorption. By integrating these passive design strategies into social housing projects, a more climate-responsive and cost-effective approach can be achieved, ultimately improving occupant comfort while reducing energy consumption.

Overall, this study reinforces the importance of passive cooling strategies in improving indoor thermal comfort while reducing energy demand. In cities like Gaziantep, where urban heat mitigation is a priority, integrating bioclimatic principles into social housing and urban planning can enhance liveability, sustainability, and occupant well-being.

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Article

A comprehensive performance evaluation of the cement mortar and sulfur mortar

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Sulfur-modified concrete; sulfur mortar; sustainable concrete; waterless concrete.

ABSTRACT

Concrete, one of the most important construction materials used in the building industry in Türkiye, is not a sustainable material because it relies on non-renewable natural resources. However, by replacing a certain percentage of the cement in the concrete mixture with industrial by-products and binders, the material's sustainability-related properties can be improved, resulting in more durable materials. Sulfur mortar is a type of waterless mortar obtained by melting sulfur and mixing it with aggregate, it is known to have a different structure than traditional cement-bound mortars and concrete. Studies have shown that sulfur concrete demonstrates superior durability in aggressive environments, maintaining its structural integrity while Portland cement concrete undergoes significant deterioration. It has a similar feature to polymer concrete, and since it does not contain cement, it does not have the hydration products of cement-bound mortars. The reason why sulfur concrete does not absorb water is that it is produced by melting and therefore has no voids.

As part of the study, a literature review was conducted to examine the sustainability of sulfur and evaluate previous studies on sulfur-modified concrete and mortar. Following this, three different types of mortar samples were produced in the laboratory based on the literature: Sulfur mortar, standard cement mortar, and a cement mortar with the same mix proportions as the sulfur mortar. When determining the mix proportions, the EN 196-1 standard was used as a reference for the standard cement mortar. Since there is no specific standard for sulfur mortar production, literature data were used during the preparation of both the sulfur mortar and the cement mortar with the same mix proportions. After all samples were subjected to curing under standard conditions, they were tested on the 28th day for flexural strength and compressive strength to determine their mechanical properties. In addition, ultrasound pulse velocity was taken to compare the void content of different mortars, providing insights into material strength and void structure. In addition to mechanical tests, the dry weights of the produced mortars were measured before being saturated in water. Physical parameters such as unit weight, water absorption by weight, and water absorption by volume were determined through measurements in air and water. Capillary water absorption tests were also conducted to compare the capillarity coefficients of the mortars. The results of the study showed that sulfur mortar had lower mechanical strength than cement mortars, but it exhibited significantly higher permeability compared to cement mortars.

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INTRODUCTION

Concrete is one of the most important construction materials used in the building industry in Türkiye. It is a brittle material created by mixing cement, aggregate, and water (and chemical additives if necessary), which gains its required properties through the hydration of cement (Ararat, 2015). Concrete is not a sustainable material because it relies on non-renewable natural resources. However, by partially replacing the cement in its composition with secondary binders (mineral additives) such as ground granulated blast furnace slag or fly ash, which are industrial by-products, the material can be made more sustainable (or less unsustainable) (Justnes & Martius-Hammer, 2016). Studies on the sustainability of cement-based mortars have demonstrated that optimizing their performance is possible through the incorporation of different binders and aggregates (Yi et al., 2023). In this regard, research on the use of expanded perlite and other lightweight aggregates has yielded significant findings in terms of water permeability and durability.

The aim of this study is to observe the contribution of naturally occurring organic structures to the permeability of concrete, based on key characteristics of good concrete, such as being dense, hard, impermeable, wear-resistant, and durable against external effects. Additionally, it aims to provide insight into the performance of additives to be used in concrete or mortar production under the fundamental principles of sustainability. The research question of this study is whether such materials can be produced solely through the use of local resources and whether they can be manufactured in a laboratory setting. In this context, a literature review was conducted to determine whether substances found in ant nests could contribute to the permeability of concrete products. It was found that ant nests have a consistent effect on the chemical properties of soil, with higher levels of carbon, nitrogen, sulfur, phosphorus, and electrical conductivity compared to the surrounding soil. Studies in this field show that the elements found in ant nests alter the macroporosity of the soil and, consequently, its water conductivity (James et.al., 2008). The water absorption and permeability of concrete depend on the total number of voids within the hardened concrete and whether these voids are interconnected. The durability of concrete is also affected by its water absorption properties (Ilıca, 2008). As a result of the literature review, it was determined that the factor responsible for the water permeability in ant nests is the high sulfur content in their chemical composition.

Sulfur differs from other minerals in terms of mining issues and supply concerns. Due to the depletion of sulfur resources, sulfur mining has come to a near halt; however, sufficient sulfur can still be obtained as a by-product in oil refineries and natural gas processing plants. Today, the amount of sulfur produced far exceeds global demand for sulfur.

Various studies have been conducted to date on the contribution of sulfur, which is found in higher concentrations in ant nests compared to other soil products, to concrete impermeability. Research that began in the 1930s showed that products obtained by combining sulfur and aggregate gained strength quickly and were more resistant to acid and chemical effects. During these years, improvements were made to sulfur-based cement formulations by adding various components to cement formulations. In the late 1960s, Dale & Ludwig (1968) pioneered studies on sulfur and emphasized the importance of aggregate ratios in achieving the best durability (Dale & Ludwig, 1968). This study was followed by the research of Crow & Bates (1970) on the development of high-strength sulfur-basalt concretes (Crow & Bates, 1970). In the early 1970s, various projects were undertaken where sulfur concrete was used as a construction material. In 1971, the U.S. Department of the Interior's Bureau of Mines and the Sulphur Institute (Washington, D.C.) established a cooperative program to research and develop new uses for sulfur. At the same time, the Canada Centre for Mineral and Energy Technology (CANMET) and the National Research Council of Canada (NRC) launched a research program to develop sulfur concrete (Malhotra, 1974). In 1973, the Canada Sulfur Development Institute (SUDIC) was jointly established by the Canadian federal government, the Alberta provincial government, and Canadian sulfur producers to develop new markets for the increasing sulfur stock in Canada. In 1978, CANMET and SUDIC organized an international conference on sulfur in construction, where many researchers published papers and presentations exploring various aspects of sulfur concrete. Mc Bee and other researchers have published a series of articles and reports on various aspects of sulfur and sulfur concrete. All these activities have raised awareness regarding the potential use of sulfur as a construction material. Recent studies aim to develop a new technology that enhances the performance of sulfur concrete products by adding bitumen as an additive to sulfur concrete (Mohamed & El Gamal, 2010).

Sulfur concretes have many positive properties from various perspectives:

- They can be used as a construction material in industrial facilities exposed to highly corrosive acids or in other structures where acid and salt environments cause early deterioration.
- They achieve high mechanical strength rapidly during setting (approximately 80% of the ultimate strength is achieved within just a few hours, and full strength is reached within one day).
- Their low permeability and porosity contribute to the water impermeability of the material.

- Mechanical properties, including flextural, compressive, and flexural strengths, as well as fatigue life, can be enhanced with additives used in sulfur concrete.
- They have comparable density and radiation protection properties to hydrated Portland cement.
- They can be protected throughout the year at temperatures below freezing.
- The materials in the mixture are recyclable and reusable.
- Impurities in the materials used do not affect the final strength properties.
- No water is needed for production.

It has been observed that sulfur, which provides the water impermeability characteristic of ant nests and is one of its chemical components, has also been used in studies related to the production of waterless concrete on Mars. The abrasion resistance of sulfur concrete, its rapid setting and strength gain, and its lack of water requirement during production make it a suitable construction material for creating habitable environments for permanent human settlement on Mars. Furthermore, with NASA's renewed interest in manned missions to the Moon and the idea of establishing a permanent base in the lunar environment, research on waterless concrete has gained importance. In this context, the experimental studies conducted by Toutanji and colleagues in 2010 demonstrated that sulfur concrete could be used as an alternative construction material in lunar applications (Toutanji & Grugel, (2009)).

EXPERIMENTAL STUDIES

Since the concrete of the load-bearing system is permeable, it is affected by water. These effects can be physical, such as swelling and shrinkage, or they can be corrosive with salts and harmful chemicals in the water. Damages and defects that may occur in the carrier system will affect the durability of the structure. Making concrete less permeable. It is known that the presence of sulphur in ant hills provides impermeability to protect the nest from the effects of water. With the research, some impermeability can be provided with the addition of sulphur to be used in concrete mortar. In this study, the aim was to determine the effects of sulfur found in the chemical composition of ant nests, which provides water impermeability to the nest on concrete, with the goal of contributing to the production of new building products by increasing concrete's water impermeability and durability against chemical effects.

Materials

In the experimental part of the study aggregate, cement and sulphur were used as materials. The aggregates used in the mortar are granular materials of mineral origin and constitute the dispersed phase of the mortar. The most important factors in the workability and strength of the mortar are the particle size, shape, and distribution. In mortars, silica or limestone-based sand or fired clay aggregates are used, with the maximum particle size being 2-4 mm. (Ekşi & Yüzer, 2013; Gökyiğit, 2016). In this study, silica-based CEN Standard Sand conforming to EN 196-1 was used in all types of mortars produced.The particle size distribution of the CEN Standard Sand described in EN 196-1 is presented in Table 1.

In the cement mortars produced in this study, PC 42.5 Portland cement was used. The physical properties of PC 42.5 Portland cement according to EN 197-1 are provided in Table 2 (BSI, 2011).

The physical properties of the sulfur (sulphur) element used in the produced sulfur mortar were created in accordance with the data from the General Directorate of Mineral Research and Exploration (MTA) and are presented in Table 3. During the literature review, it was noted that the impurities in the sulfur element do not affect the final strength of the material; therefore, impurities were not sought in the sulfur obtained during the experimental study.

Table 1. Particle Size Distribution of CEN Standard Sand (BSI, 2016)

Square Mesh Opening (mm)	**2.00**	**1.60**	**1.00**	**0.50**	**0.16**	**0.08**
Retained on Sieve (%)	0	7±5	33±5	67±5	87±5	99±1

Table 2. Physical properties of PC 42.5 Portland cement

Physical Properties	**Desired Values**
Fineness - Blaine (cm^2/g)	Min. 2800 cm^2/g
2-Day Compressive Strength (N/mm^2)	Min. 20 N/mm^2
7-Day Compressive Strength (N/mm^2)	Min. 31.5 N/mm^2
28-Day Compressive Strength (N/mm^2)	Min. 42.5 N/mm^2
Initial Setting Time (hour-minute)	Min. 1 hour
Final Setting Time (hour-minute)	Max. 10 hours
Volume Expansion (mm)	Max. 10 mm

Table 3. Physical properties of the sulfur element

Physical Properties	**Values**
Color	Yellow
Melting Temperature	119°C
Ignition Temperature	270°C
Boiling Temperature	444°C
Hardness	1.5 - 2.5
Density	2.03 - 2.06 g/cm^3
Thermal Conductivity	Low
Electrical Conductivity	None
Solubility in Water	None

Table 4. Codes assigned to the produced samples

SAMPLE CODE	SAMPLE CONTENT	AGGREGATE (CEN standard SAND)	CEMENT	SULFUR	WATER
A	Standard Cement Mortar	3 (1350g)	1 (450g)	-	0,5 (225g)
B	Cement Mortar with Same Mix Ratio as Sulfur Mortar	4,6 (1855g)	1(400g)	-	0,5 (200g)
C	Sulfur Mortar	3.1 (1855g)	-	1 (600g)	-

In this study, three different types of samples were produced: Standard cement mortar (EN 196-1), cement mortar with the same mix ratio as sulfur mortar, and sulfur mortar. This approach allowed for the comparison of all mortar types with each other. The produced samples were designated as A, B, and C codes, respectively (Table 4).

The production methods and curing conditions of all the types of mortars produced and compared in this study are explained in detail. Experimental studies on the water resistance and durability of mortars have shown that no-cure mortars can exhibit comparable performance to conventional counterparts (Gul et al., 2024). However, for non-water-based binders such as sulfur mortar, specific considerations regarding high-temperature requirements and different hardening mechanisms must be taken into account.

Production and Curing Conditions of Standard Cement Mortar (A):

According to the EN 196-1 the standard cement mortar with sample code "A" consists of 1 part cement, 3 parts aggregate (sand), and 0.5 parts water were used; specifically, 450g of cement, 1350g of CEN standard sand, and 225g of water (Figure 1).

The prepared mortar was filled into previously oiled triple prismatic molds with dimensions 40×40×160 mm. Following the EN 196-1 standard, the molds were first filled halfway and then completely, followed by compaction on a vibration table. The molded samples were kept covered in an environment of 20±2 °C temperature and 90% relative humidity for 24 hours. After this period, the samples were removed from the molds and stored in lime-saturated water at a temperature of 20±2 °C until the testing day (28th day).

Production and Curing Conditions of Cement Mortar with the Same Mixture Ratio as Sulfur Mortar (B):

In this study, since there is no standard to produce cement mortar with the same mixture ratio as sulfur mortar, the ratios specified in the literature for sulfur mortar have been utilized. Accordingly, the produced mortar consists of 400g of cement, 1855g of CEN standard sand, and 200g of water, with a mixture ratio of 1 part cement, 4.6 parts aggregate (sand), and 0.5 parts water by weight.

To apply the same mixing procedure as for sulfur mortar, a mechanical mixer was not used; instead, mixing was carried out manually with a trowel (Figure 2). Initially, water and cement were added to the mixing container and mixed for 30 seconds, followed by the addition of sand during the next 30 seconds. Afterward, all materials were mixed with a trowel at a higher speed for an additional 90 seconds.

The cast samples were kept covered in an environment with a temperature of 20±2°C and relative humidity of 90% for 24 hours. After this period, the samples were removed from the molds and stored in lime-saturated water at a temperature of 20±2°C until the testing day (28th day).

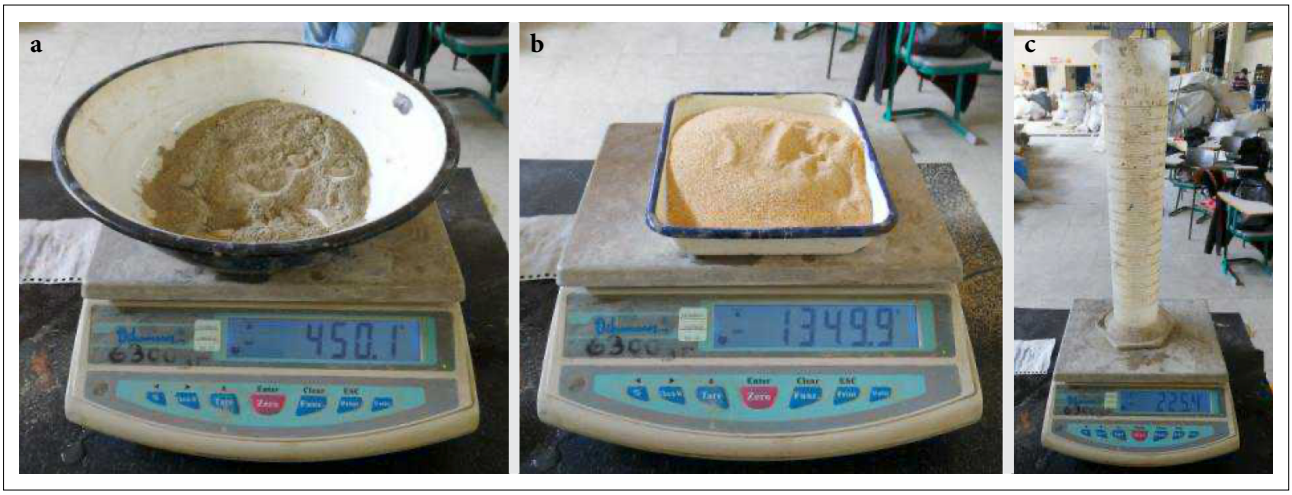

Figure 1. Materials and their weights used during the production of standard cement mortar: **(a)** PC 42.5 Portland cement **(b)** CEN standard sand **(c)** Water.

Figure 2. **(a)** Mixing with a trowel **(b)** Compacting mortar B.

Production and Curing Conditions of Sulfur Mortar (C): According to literature research (Vroom, 1977) the sulfur mortar with sample code "C" consists of 1 part sulfur and 3.1 parts aggregate (sand) by weight. To investigate the effect of the sulfur element, the cement mortar with sample code "B," which has the same mixing ratio as the sulfur mortar which consists of 1 part cement, 4.6 parts aggregate (sand), and 0.5 parts water by weight; 600g of sulfur and 1855g of CEN standard sand were used. The production of the standard cement mortar was carried out using a mechanical mixer in accordance with the standard.

Figure 3. Electric stove used during the production of sulfur mortar.

Methods

However, due to the high temperature required for producing sulfur mortar (ranging from 132°C to 141°C), an electric stove was used during the mixing process, and the mixing was done with the help of a trowel. The mixing procedure for the cement mortar with the same mixing ratio as the sulfur mortar was determined based on the mixing procedure of the sulfur mortar.

Sulfur mortar is a type of mortar produced without the use of water, which is crucial for its binding properties, as can be inferred from its composition. Therefore, it is also referred to as dry mortar. In this type of mortar, the binding properties that arise from the combination of cement and water are provided by the sulfur element. However, unlike cement mortars, the production of sulfur mortar involves a thermal process. Sulfur melts at 119°C and rapidly loses its viscosity above 149°C. For this reason, many literature sources indicate that the suitable working range for transporting, placing, and finishing the mixture is between 132°C and 141°C (ACI, 1998).

The temperature required for the production of sulfur mortar was achieved using an electric stove during the mixing process (Figure 3). The mixing was done with the help of a trowel. The mixing container and trowel, along with the sulfur and aggregates to be included in the mixture, were kept in an oven heated to 140°C for 1 hour. The melted sulfur poured into the mixing container was then mixed with the CEN standard sand, which had been heated to 140°C, for 30 seconds. After that, the mixture continued to be stirred with the trowel on the electric stove for an additional 90 seconds.

The 40×40×160 mm tripartite prismatic molds were greased with mold oil and kept in a 140°C heated oven until the time of production. Then, they were filled and compacted with the prepared sulfur mortar (Figure 4). The molded samples were kept covered in an environment of 20±2°C temperature and 90% relative humidity for 24 hours. After this period, the samples were removed from the molds and placed in lime-saturated water at 20±2°C until the testing day (28th day).

The high temperature requirement for the production of sulfur mortar made the process difficult. Due to the material's rapid heat loss, vibration could not be performed on the vibration table; instead, the vibration process was carried out by striking the mold against the workbench. After production, crystalline shimmering was observed on the dark, yellow-colored sample produced, and it was noted that the material began to set rapidly due to heat loss.

Figure 4. Molded sulfur mortar.

Experimental Studies

In order to determine the physical and mechanical properties of sulfur mortar, the experimental study conducted in this work was limited to density, water absorption by weight and volume, capillary water absorption, compressive and flexural strength, and ultrasound pulse velocity.

Physical Tests

Physical tests provide information about the material's pore structure, such as water and gas permeability, freeze-thaw resistance, and pore size. In this study, the samples prepared for physical tests were weighed in air and water, and capillary water absorption tests were conducted. From the test results, density, weight-based water absorption (as, %), volume-based water absorption (hs, %), and capillarity coefficients (Kk, cm^2/s) were determined.

Density, Weight and Volume Water Absorption:

According to EN 1015-10, the samples were kept in an oven at 60±5°C for 24 hours to allow the evaporation of free water (BSI, 1999). To calculate the density, the dry weights of all samples were first recorded. In this study, the samples were placed in a deep container and initially filled with water to a height equal to one-fourth of their height. After waiting for 1 hour, water was added until it reached half the height of the samples. After another hour, the same procedure was repeated until the water level reached three-fourths of the sample height, and finally, the samples were completely submerged. After 24 hours, the samples were removed from the water and weighed in both air and water.

Capillary Water Absorption:

In the study, mortar samples prepared in accordance with the standard (EN 1015-18) were kept in a drying oven at a temperature of (60±2)°C until they reached a constant weight (BSI, 2002). Measurements were taken at 64 seconds, 144 seconds, 256 seconds, 576 seconds, 1024 seconds, and 1600 seconds (t_i, s), and their weights (W_i, g) were determined. All measurements were performed at an ambient temperature of 20±2°C and a relative humidity of 40±5%. (Figure 5).

Capillary water absorption tests were conducted on three test samples from each of the three different mortars. To determine the capillary coefficient, the averages of the measurements taken during the first 26 minutes were used to plot the graph of Qi/A - √t nd the slope of the line was utilized (Figure 6). The capillary water absorption coefficient (K, cm^2/s); has been determined as specified in Equation 2.

$$K = \frac{m^2}{60} = \frac{Q^2}{A^2.t.60}\ cm^2/s \qquad (2)$$

The capillarity coefficient of A mortar (Standard Cement Mortar) has been found to be 1,5.10-7 cm^2/s, and the capillarity coefficient of B mortar (Cement Mortar with the Same Mixture Ratio as Sulfur Mortar) has also been found to be 1,5.10-7 cm^2/s. However, the capillarity coefficient of C mortar (Sulfur Mortar) has been found to be 0 cm^2/s due to the linear appearance of the value in the graph and the fact that the mortar absorbs almost no water.

Figure 5. The capillary water absorption test.

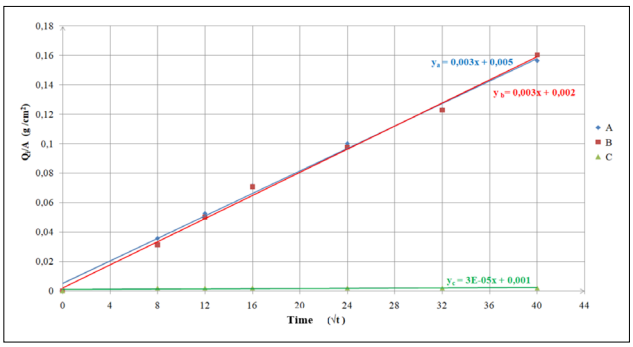

Figure 6. Qi/A - √t Graph of three different mortar samples.

Mechanical Tests
Mechanical tests provide information about the material's strength under vertical loads (fracture strength) and indirectly about its flexural strength. The compressive strength (fb, MPa) and flexural strength (fe, MPa) of the samples prepared for mechanical tests are tested in a laboratory environment. In this study, the ultrasound pulse velocity, which is considered a non-destructive in-situ test, is also examined within the scope of mechanical tests, as it helps determine the voids within the material and indirectly provides information about the material's strength.

Flexural Strength
Within the scope of the study, the flexural test was performed on 40x40x160 mm specimens on the 28th day, according to EN 1015-11 (BSI, 2019). The aim is to determine the flexural strength of hardened mortars on the 28th day. The flexural test was applied to three prismatic samples of each of the three different types of mortar (Figure 7).

Compressive Strength:
In this study, compressive tests were conducted according to EN 1015-11 (BSI, 2019) on the 28th day using steel plates measuring 40x40 mm placed above and below the two separated pieces from the flexural test results. The compressive strengths were determined by dividing the maximum load identified after the sample broke by the area over which the load was applied (Figure 8). The compressive test was applied to three prismatic samples of each of the three different types of mortar.

Ultrasonic Measurement:
It is known that there is a direct proportional relationship between the speed of sound transmission and strength. Knowing the speed of sound in a porous material provides information about the number of voids contained in the material. The voids present within the material negatively affect its strength. If the density of the object is low and/or if there are cracks within it, the propagation of sound waves and, consequently, the speed of ultrasound pulse velocity will be low. Conversely, if the object has few voids and high strength, the speed of ultrasound pulse velocity will be high. However, while this test provides information about the strength of the object, it is not sufficient on its own to determine strength; a comprehensive assessment should be made in conjunction with other measurements (Aköz et al., 2005; Ekşi, 2006; Gökyiğit, 2016).

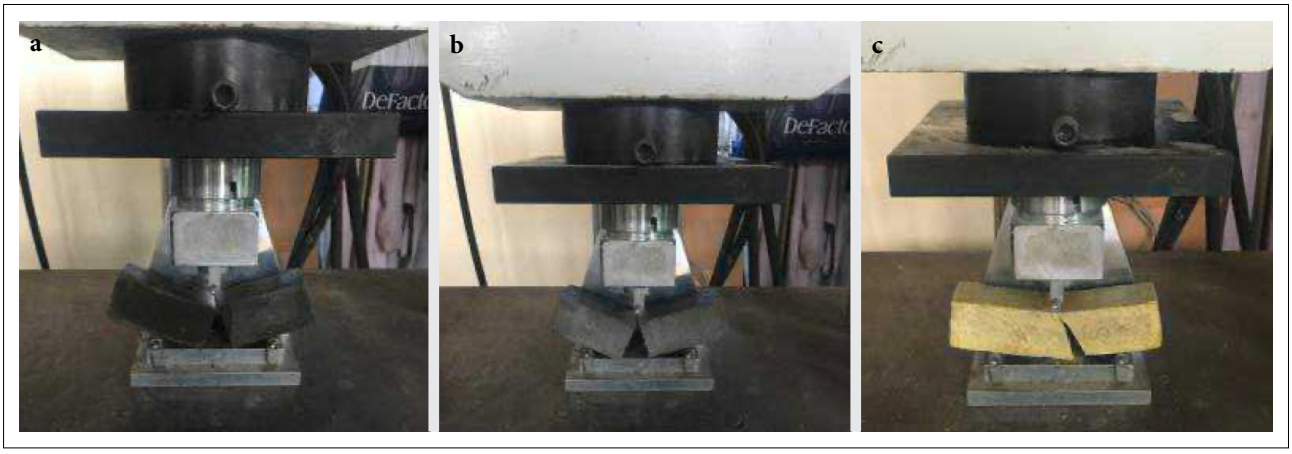

Figure 7. Flexural test of three different mortar samples **(a)** A mortar **(b)** B mortar **(c)** C mortar.

Figure 8. Compressive test of three different mortar samples **(a)** A mortar **(b)** B mortar **(c)** C mortar.

To obtain information about the number of voids in the samples produced during the study, an ultrasound pulse velocity was performed as specified in the EN 12504-4 standard (European Committee for Standardization, 2021). During ultrasonic pulse velocity tests, signal processing techniques based on frequency-modulated waveforms can be utilized to detect voids within the material structure. Particularly, phase noise compensation techniques have been shown to enhance the accuracy of experimental data analysis (Vardarlı & Aldoğan, 2018) (Figure 9).

Using the ultrasonic measurement device, as shown in Figure 9, the ultrasound pulse velocity time and the measurement distance were measured directly, and the ultrasound pulse velocity speed was calculated using equation 3.

$$V_{sound} = L/t \ (mm/\mu s) \quad (3)$$

L (mm) = The measurement distance

t (μs) = The ultrasound pulse velocity time

V_{sound} (mm/μs) = The ultrasound pulse velocity speed

RESULTS AND EVALUATION/DISCUSSION

In this study, the aim was to evaluate the physical and mechanical properties of sulfur mortar to contribute to the production of building materials that can be used in the future. In this context, three different types of mortar samples were produced: Sulfur mortar, standard cement mortar, and cement mortar with the same mixing ratio as sulfur mortar. Density of all types of mortars were determined, and water absorption tests by weight and volume, as well as capillary water absorption tests, were conducted. Additionally, the mechanical performances were evaluated through flexural and compressive strength tests. Finally, an ultrasound pulse velocity was performed to obtain information about the void structure of the material (Table 5).

After determining the density parameter for all mortars, it was observed that the density of standard cement mortar was 1.97±0.01 g/cm³, the density of the cement mortar with the same mixing ratio as sulfur mortar was 1.96±0.01 g/

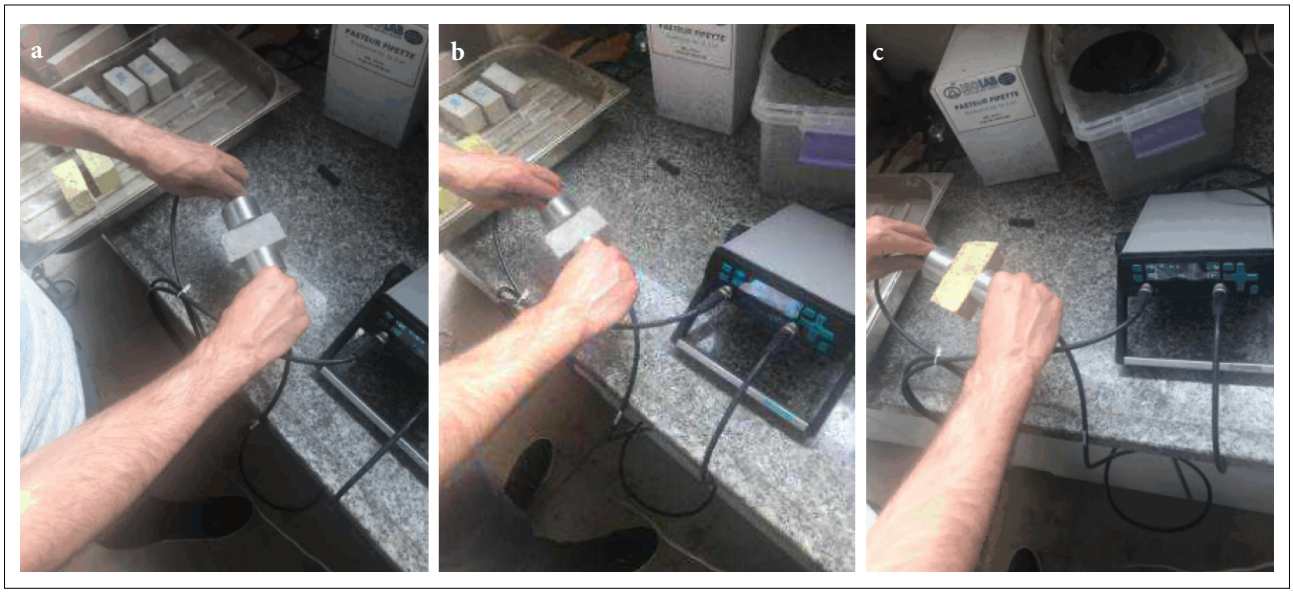

Figure 9. Ultrasonic measurement of three different mortar samples **(a)** A mortar **(b)** B mortar **(c)** C mortar.

Table 5. Physical and mechanical properties of the samples

Mortar Type	Density (β, g/cm³)	Weight Water Absorption Rate (%)	Volume Water Absorption Rate (%)	Capillarity Coefficient, Kk (cm²/s)	Flexural Strength (MPa)	Compressive Strength (MPa)	Ultrasound pulse velocity (V, mm/μs)
Standard Cement Mortar (A)	1.97±0.01	7.74±0.02	15.23±0.06	1,5.10-7	8.54±0.15	34.72±1.20	2,84
Cement Mortar (same ratio as Sulfur Mortar) (B)	1.96±0.01	8.42±0.05	16.53±0.10	1,5.10-7	6.97±0.07	33.68±1.94	2,88
Sulfur Mortar (C)	2.10±0.03	1.00±0.03	2.02±0.60	It has almost not absorbed any water.	3.98±0.47	14.75±0.06	1,94

cm^3, and the density of sulfur mortar was 2.10±0.03 g/cm^3. It was understood that the densities of all types of mortar were like each other, but the density of sulfur mortar was slightly higher than that of the cement mortars.

As a result of the water absorption tests by weight and volume, the water absorption ratio by weight for standard cement mortar was found to be 7.74±0.02%, and the water absorption ratio by volume was 15.23±0.06%; the water absorption ratio by weight for the cement mortar with the same mixing ratio as sulfur mortar was 8.42±0.05%, and the water absorption ratio by volume was 16.53±0.10%; the water absorption ratio by weight for sulfur mortar was 1.00±0.03%, and the water absorption ratio by volume was 2.02±0.60. Lin et al. (2025) demonstrated that modifications such as alkali treatment and silica fume incorporation reduced water absorption in sulfur concrete by 50%, while also enhancing its mechanical performance. The results of this study confirm that increased density in sulfur concrete leads to improved durability and reduced microcracking (Lin et al., 2025). It has been observed that the water absorption by weight and volume of sulfur mortar remained very low compared to cement mortars. In this context, it can be said that the open voids in sulfur mortar are significantly fewer compared to cement mortar.

As a result of the capillary water absorption test, the capillarity coefficient of standard cement mortar and the cement mortar with the same mixing ratio as sulfur mortar was found to be 1.5×10^{-7} cm^2/s. However, it was observed that the capillarity coefficient of sulfur mortar was 0 cm^2/s due to its almost negligible water absorption. Similarly, Vlahovic et al. (2011) reported that sulfur concrete exhibited minimal mass loss when exposed to NaCl and acidic solutions, while Portland cement-based concrete lost up to 20% of its mass within two months. The findings of this study align with these results, confirming the superior durability of sulfur concrete in corrosive environments (Vlahovic et al., 2011).

In this context, when the capillary water absorption test is evaluated together with the water absorption tests by weight and volume, it can be stated that the water absorption of the material is very low and slow, and that sulfur mortar is significantly less permeable compared to cement mortar.

As a result of the flexural test conducted on the 28th day, the flexural strength of standard cement mortar was found to be 8.54±0.15 MPa, the flexural strength of the cement mortar with the same mixing ratio as sulfur mortar was 6.97±0.07 MPa, and the flexural strength of sulfur mortar was 3.98±0.47 MPa. Amanova et al. (2024) reported that modified sulfur concrete exhibited 40% faster setting time and 25% greater chemical resistance compared to traditional sulfur concrete. The results obtained in this study align with these findings, indicating that modifications to sulfur concrete significantly improve its durability and applicability in construction (Amanova et al., 2024). In this context, it was observed that the flexural strength of sulfur mortar is lower than that of the cement mortars. However, considering that the flexural strengths of lime mortars range between 0.5 MPa and 0.9 MPa, it can be stated that sulfur mortar possesses sufficient flexural strength for use in construction.

As a result of the compressive test conducted on the 28th day, the compressive strength of standard cement mortar was found to be 34.72±1.20 MPa, the compressive strength of the cement mortar with the same mixing ratio as sulfur mortar was 33.68±1.94 MPa, and the compressive strength of sulfur mortar was 14.75±0.06 MPa. It was observed that the compressive strength of sulfur mortar is lower than that of cement mortars. However, considering that the compressive strengths of lime mortars range between 0.4 MPa and 1.5 MPa, and that the concrete used in lean concrete production is classified as C16 (with a compressive strength of 16 MPa), it can be stated that sulfur mortar possesses sufficient compressive strength for use in construction.

As a result of the ultrasound test, the ultrasound pulse velocity speed in standard cement mortar was found to be 2.84 mm/μs, in the cement mortar with the same mixing ratio as sulfur mortar it was 2.88 mm/μs, and in sulfur mortar, the ultrasound pulse velocity was 1.94 mm/μs. In this context, it was observed that the ultrasound pulse velocitys in cement mortars were higher than those in sulfur mortar. Since ultrasound pulse velocitys are slower in porous materials, it can be suggested that sulfur mortar is a more porous material, or that while there are no visible cracks on the exterior, there are more micro-cracks within it compared to cement mortars. Given that the void ratio is known to be directly related to the material's strength, it can be expected that the strength of sulfur mortar is also lower than that of cement mortars based on the results of the ultrasound pulse velocity. The flexural and compressive strength tests conducted so far also show similar results to those of the ultrasound pulse velocity. Physical experiments have demonstrated that the open voids in sulfur mortar are significantly fewer compared to cement mortars. In this context, when all experiments are evaluated, it is understood that the voids observed as a result of the ultrasound pulse velocity are closed voids within the material.

CONCLUSION

In conclusion, it has been observed that while the mechanical properties of sulfur mortars are lower than those of cement mortars, they are still at a sufficient level for use in construction. Considering that literature studies indicate that the mechanical strength of sulfur concrete is directly affected by the aggregates used, it is thought that improvements can be made in the mechanical strength

of sulfur mortars produced with different aggregates (such as basalt, etc.) (Crow & Bates, 1970). The material has significantly lower permeability compared to cement mortars, which can be regarded as a positive feature in terms of water insulation.

The use of waste materials in the construction industry is of great importance for sustainability. Incorporating alternative materials such as wood fibers in mortars enhances their mechanical properties while reducing environmental impact (Lin et al., 2025). When employing special binders like sulfur mortar, investigating their compatibility with alternative sustainable materials remains a critical area for future research. However, the requirement for high temperatures during the production of the material complicates its application in the field and also increases energy consumption. Additionally, the harmful gases emitted by the sulfur element during the material production can be considered among the difficulties of application.

The literature review and experimental study conducted in this work aim to contribute to future research, and in this context, the experiments were limited to unit volume weight, weight-based and volume-based water absorption, capillary water absorption, flexural strength, compressive strength, and ultrasound pulse velocitys. However, to better understand the pore structure of sulfur mortars, it is suggested that parameters such as specific weight, compactness, and porosity should also be investigated. Additionally, to analyse more detailed applications in construction, it is proposed to examine their permeability under pressurized water conditions and to carry out permeability measurements as a subject for future studies.

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Article

Evaluating architectural appeal in Turkish shopping mall investments: Insights from investors and consumers

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ABSTRACT

In modern society, shopping malls are key elements of daily consumer activity. Even though some studies indicate that spatially "architectural appeal" is considered as one of the supportive factors on commercial performance and also an attractiveness component to visit mall, it is open to be proven this aspect by comparing from perspective of investors and consumers in Türkiye among other influencing factors. To address this gap, surveys were conducted with purposeful sample of institutional investors to ascertain their rankings of investment success factors based on the existing literature and consumers' preference of shopping malls. The data analysis commenced with an assessment of normality, which was followed by measuring importance level of the variables was evaluated using the Friedman test. Mann-Whitney U test was utilized to compare the priority variables for both investors and consumers groups. The findings suggest that decision-makers in Türkiye, deemed *the presence of anchors, location of the investment, and tenant mix structure* more critical than architectural appeal. For consumers, factors such as *product/price variety, entertainment opportunities, food and beverage services* are primary reasons to frequent a mall. Based on the comparison results, *location* was considered most important by investors, while consumers found product/price diversity more attractive. This study makes a unique contribution to the literature by offering a comparative analysis of shopping mall investments' performance from the perspectives of entrepreneurs and consumers alike, providing insights for entrepreneurs, developers, designers, and retailers.

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INTRODUCTION

In the contemporary era, shopping malls have become an integral part of consumers' daily lives. These malls go beyond the simple act of shopping and provide users with quality leisure time and browsing activities that characterize their hedonic experiences by taking advantage of the architectural appeal of the mall itself (Bäckström, 2011; Lucia-Palacios et al., 2016). The concept of these social centers can be attributed to the architect Victor Gruen, who designed them in the 1950s (Derya Arslan & Ergener, 2023). The malls operated during this period became popular everyday spaces where people could gather, engage in various activities, and purchase products from different brands. Furthermore, to attract consumers, new design strategies were developed based on architectural appeal (Derya Arslan & Ergener, 2023). Within this context, a range of design elements were employed to enhance aesthetics, safety, comfort, and hygiene.

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At the present time, these design components remain an important motivating factor for consumers to visit shopping centers regularly (Çavka, 2023a).Moreover, Teller & Elms (2010) argue that the architectural appeal of a shopping mall still has a positive impact on the commercial and financial performance of the investment, thereby gaining an edge in an intensely competitive market. But, for a shopping center investment to be commercially successful and perform consistently, it is not enough to have only architectural appeal elements. Various factors influence the consumer's motivation to visit and the investor's decision to invest. To achieve comprehensive commercial and financial success from an investment, it is essential that the expectations of both consumers and investors are aligned.

Based on the relevant literature, several key factors come to the fore for a mall's success such as the presence of anchor brands (Damian et al, 2011), location selection, tenant mix structure (Teller & Reutterer, 2008), the role of mall management, the availability of entertainment and dining options (Zacharias & Schinazi, 2003), and consumer shopping behavior (Bloch et al., 1994). In addition, architectural appeal is also a supportive factor influencing a mall's commercial performance during the operational period (Gilboa & Vilnai-Yavetz, 2013; Tozzi et al., 2022; El-Adly, 2007). However, previous scholarly research has tended to examine these success factors of shopping mall investments, including architectural appeal, from either the consumer or the investor perspective discretely. On the other hand, while previous studies have comprehensively investigated the role of architectural appeal from the consumer perspective (Teller & Reutterer, 2008; Damian et al., 2011; Mittal & Jhamb, 2016; El-Adly, 2007; Zacharias & Schinazi, 2003; Singh & Sahay, 2012; Anselmsson, 2016; Wee, 1986), only a limited number of studies—such as those by Ahmadi et al. (2020), Brettmo & Sanchez-Diaz (2022), Çavka (2023a), and Oztaysi et al. (2016) — have explored this factor from the investor perspective. Although all these researches have highlighted architectural appeal as an effective factor in the commercial success of a mall, there is a lack of research comparing its relative importance among other factors from investor and visit's preferences from consumer perspectives. This study seeks to address this gap in the literature by analyzing and comparing the primary expectations of investors and consumers within the context of architectural appeal. However, the data of this study is limited to the opinions of consumers and experts in shopping mall investments in Istanbul, Türkiye. In line with the aim of the study, the research questions were structured as follows.

- What is the importance level of architectural appeal among the other success factors affecting the commercial success of a mall investment for investors in Türkiye?
- To what extent architectural appeal is important among consumers' preferences for visiting shopping malls in Türkiye?
- Which characteristics stand out when comparing the factors influencing commercial stability for mall's investors and the preference variables of visitors in Türkiye?

This research contributes to the literature by uniquely discussing the impact of architectural appeal on shopping mall investment success from both investor and consumer perspectives. It also emphasizes the need for a holistic understanding of architectural appeal as a strategic factor and identifies key success factors for mall investments in Türkiye, offering valuable insights for retail sector investors.

LITERATURE REVIEW

Investors of shopping malls compete to attract consumers, aiming for long-term returns through design, development, and management that draws interest (de Castro et al., 2020). On the other hand, Nasim & Shamshir (2018) argue that shoppers, in turn, assess malls based on spatial, functional, and experiential qualities. To engage consumers, investors offer diverse stores, entertainment, events, new sales channels, and leverage architectural appeal as part of mall attractiveness (Teller & Elms, 2012; Warnaby et al., 2005).

Although architectural appeal is considered beneficial for the commercial success of shopping malls (Oteng-Ababio & Arthur, 2015; Anselmsson, 2016; Vilnai-Yavetz et al., 2021) and linked to overall attractiveness (Dębek, 2015), its academic conceptualization remains fragmented. Factors such as orientation and ambience shape mall attractiveness (Teller & Reutterer, 2008), through atmosphere often being central focal point (Wakefield & Baker, 1998). In some cases, atmosphere—closely tied to architectural appeal—is the most influential element (Turley & Milliman, 2000), and one of the strongest contributors to retail investment success (Teller & Elms, 2010). Furthermore, Dębek (2015) claimed that architectural appeal directly impacts consumer satisfaction and loyalty.

As Finn & Louviere (1996) noted, most previous studies evaluating architectural appeal focused on consumer opinions related to a mall's image, design, or atmosphere. Similarly, Çavka, (2023b) found that spatial openness—defined by the balance of open and enclosed areas—is a top priority for consumers. Additionally, the study highlights that design features fostering social interaction, such as communal zones and fluid circulation, are key aspect in modern mall development. This aligns with retail architecture trends that emphasize experiential over purely transactional aspects (Teller & Reutterer, 2008). Moreover, Mittal & Jhamb (2016), El-Adly (2007), Zacharias & Schinazi (2003),and Singh & Sahay (2012) emphasize that architectural features enhancing comfort, orientation, and emotional connection—such as natural lighting and human-scale proportions—are increasingly valued by consumers. Yuan et al. (2021) identified four dimensions of shaping mall experiences: Visual atmosphere, physical comfort, spatial configuration, and operational management. These reflect the sensory and functional facets of architectural appeal influencing users' perceptions and behaviors in retail spaces. Rather than being

merely aesthetic, architectural appeal is shaped by sensory, emotional, and cognitive engagement (Baker et al., 2002; Kwon et al., 2016; Olonade et al., 2021; Gomes & Paula, 2017; Normie, 2004). However, Aliagha et al. (2015) argues that this influence on consumer loyalty is limited, compared to factors such as cleanliness, amenities, and accessibility.

Although the essence of architectural appeal has frequently been explored from the consumer perspective in the shopping mall literature, it has received limited attention from the investor standpoint. Teller et al. (2016) claimed that the main reason behind this approach is that investors prioritize marketable attributes during production period. Only few investor-focused studies, undertake factors influencing mall success include location, tenant mix, and architectural design, with appeal as a sub dimension (Ahmadi et al., 2020; Çavka, 2023a). Yet, Oztaysi et al. (2016) demonstrated that managers focus more on brand mix, consumer behavior, and market structure—indicating architectural appeal is not seen as central to marketing strategies. However, evolving user expectations and market trends necessitate that investor must consider flexible spatial planning, user comfort, efficient circulation, and maintenance-friendly design strategies to enhance architectural appeal (Çavka, 2023a).

In conclusion, the concept of architectural appeal in shopping malls has been addressed in a fragmented manner within the existing literature, primarily under the themes of "attractiveness" and "investment success factors." Within the scope of this study, architectural appeal is defined as an investment success factor from the perspective of investors, and as a visit preference from the perspective of consumers. Furthermore, there appears to be a gap of studies that rank the importance of architectural appeal among other influential factors from both investor and consumer viewpoints. Therefore, by comparatively examining the extent to which the expectations of these two groups align within the framework of architectural appeal in the context of investment success. This study aims to contribute original value to the field and offer an innovative perspective to the existing body of shopping mall literature.

METHODOLOGY AND DATA

The research methodology is portrayed in Figure 1. Initial stage entailed the identification of pertinent data sources within the related literature through a comprehensive literature review. In the subsequent phase, the sources were subjected to content analysis, resulting in the formation of a pool of potential variables. Then, Pareto analysis was used to reduce the number of variables. Following, these variables were converted to surveys to collect data from

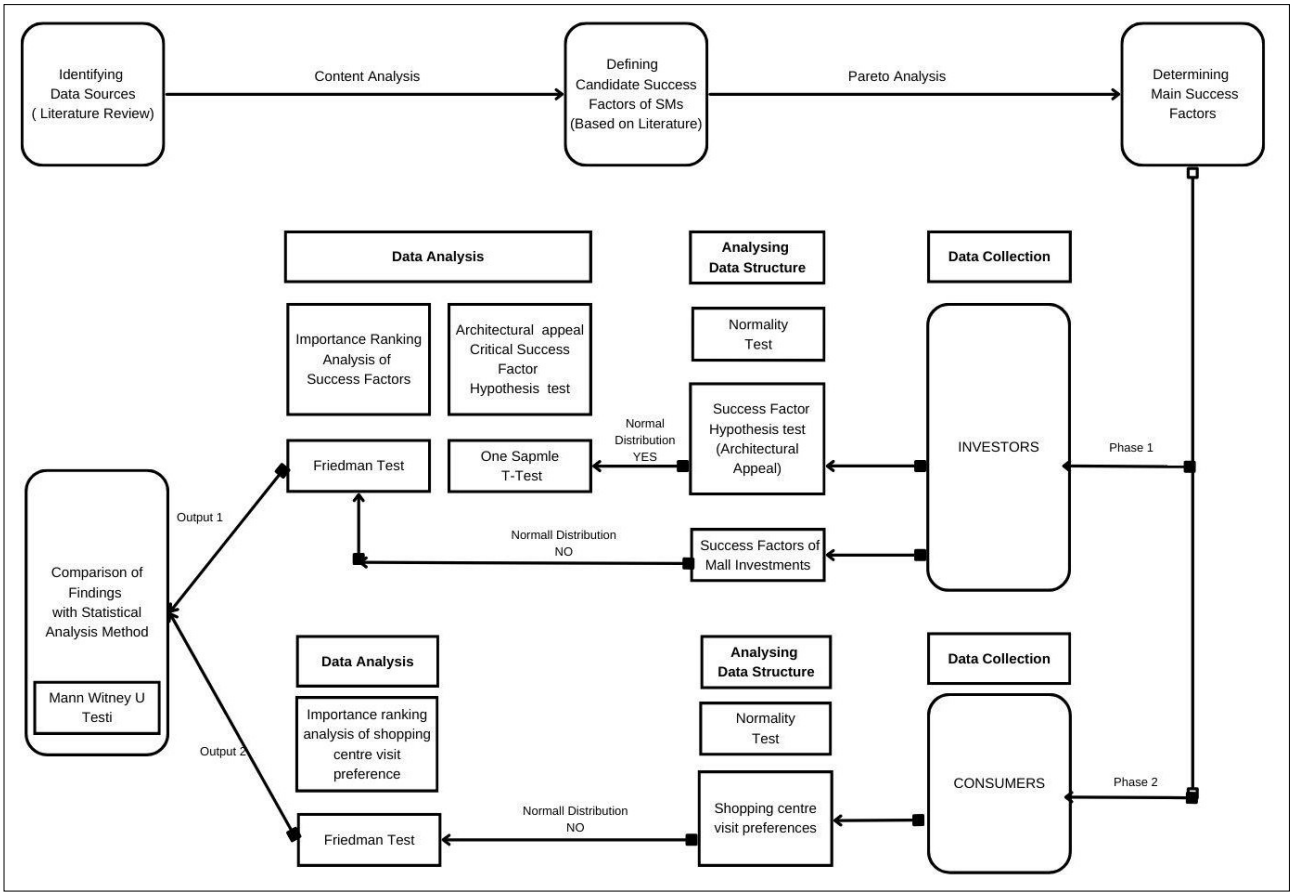

Figure 1. Research methodology flow chart.

investors and consumers. A variety of analyses were applied to present investors and consumers' dimensions.

Data

In the first part, to define the data, a comprehensive literature review was conducted using databases such as Scopus, WOS, ProQuest, and Türkiye's Dissertation Centre, with keywords such as "shopping mall development", "investment success factors," and "architectural appeal". The review included journal articles, conference papers, and postgraduate dissertations. In the second phase, a content analysis was applied to identify the data factors, based on a total of 210 scientific publications. This analysis resulted in a candidate pool of 28 variables, including the architectural appeal. In the subsequent stage, the Pareto analysis was employed to ascertain the key success factors that have a broad impact on the shopping malls' commercial success (Haughey, 2010). Thus, Table 1 illustrates 13 key success factors based on the related literature. Sampling was composed after examination of similar studies conducted by researchers such as Pantano et al. (2021), Martin & Turley (2004), and Bloch et al. (1994) in the shopping mall literature reveals that a "purposive sampling" approach was employed for each group. This method not only allows for the identification of knowledgeable and experienced individuals or groups but is also one of the commonly used techniques in qualitative research for selecting and identifying information-rich cases, ensuring the most efficient use of limited resources (Yağar & Dökme, 2018).

During data collection phase, for investor group, an online survey was conducted with a total of 17 experts who have worked or are currently working in various departments of shopping mall investment sector in Türkiye such as portfolio management, business development and rental unit, project development, facility management. Most of these experts possess considerable experience during the feasibility and operational phase of mall development.

As was stated previously, to score the key factors, including the architectural appeal, a "ranking scale" was utilized. Ranking scale is advantageous to facilitate a direct comparison between factors and enables the determination of their relative importance (Arıkan, 2018). In this regard, the 13 factors, based on the literature, were ranked by the experts on a scale of 1 to 13 according to their level of importance.

In the second phase of the study, data were collected through face-to-face surveys from 96 consumer who visit shopping centers regularly. Same factors were aligned for consumers, and similar ranking scale was applied. However, the factor pertaining to the utilization of software technology in the context of innovation during the feasibility phase was excluded from the survey as it was deemed to be irrelevant for consumers. Consequently, importance ranking questions were prepared for nine literature-based success factors, allowing consumers to rate them on a scale from 1 to 9. Participants were also asked to provide demographic information regarding their age, education level, monthly income, and frequency of visits to shopping malls.

Table 1. Literature-based success factors in shopping mall investments

Factor Code	Shopping Mall Investments Success Factors	Resources in the Shopping Mall Literature
X-1	Age distribution of the population residing within a five-kilometer	(D'Arcy et al., 1997; White & Gray, 1996)
X-2	Education level of population living within 5 km	(El-Adly, 2007; Des Rosiers et al., 2005)
X-3	Household income level population living within 5 km	(Beddington, 1990; White & Gray, 1996)
X-4	Carpark capacity	(El-Adly, 2007; Said et al., 2020)
X-5	Tenant mix	(Beddington, 1990; Krugell, 2010; Teller & Reutterer, 2008; Brown, 1992; Xu et al., 2022)
X-6	Presence of Anchors	(Brown, 1992; de Bruwer, 1997; Abratt et al., 1985; Finn & Louviere, 1996)
X-7	Entertainment and food and beverage opportunities	(Zacharias & Schinazi, 2003; Feldmann, 2004)
X-8	Physical size of the shopping mall	(Tay et al., 1999; Martin & Turley, 2004)
X-9	Shopping mall's architectural appeal	(Murphy et al., 2013; Anselmsson, 2016; Mittal & Jhamb, 2016; Wee, 1986; Howell & Rogers, 1981)
X-10	Location and easy accessibility	(Krugell, 2010; Des Rosiers et al., 2005; Hoyt & Nelson, 1960; Cheng et al., 2007; Cheng et al., 2005)
X-11	Product and price diversity depending on tenant mix	(Yavas, 2001; Glaeser et al., 2001; Yiu & Xu, 2012)
X-12	Open to sustainable development in commercial, social and environmental contexts of the investment	(Križan et al., 2022; Ferman & İlhan, 2019; İlhan, 2020)
X-13	Use of software technology in an innovative context during the feasibility stage	(Masebe et al., 2020; Pupentsova et al., 2022)

Analysis of Data Structures

In the study, all data collected from the investor and consumer sample groups through surveys were subjected to a structural examination using normality assumption tests. This preliminary evaluation serves the purpose of determining the appropriate data analysis technique that can provide robust results (Uysal & Kılıç, 2022). The normality test results were examined using three different methods. The initial method entailed the interpretation of Skewness and Kurtosis values, which represent the Skewness and Kurtosis of the data, respectively. If these values fell between -1.5 and +1.5, the data were deemed to exhibit a normal distribution (Tabachnick et al., 2018). The second method entailed dividing the Skewness and Kurtosis values by their respective standard error values. If the resulting values fell between -1.96 and +1.96, the data were deemed to be normally distributed (Büyüköztürk, 2018). The third method entailed an examination of the significance (Sig) values associated with the Shapiro-Wilk and Kolmogorov tests. If the p-value was less than 0.05, the data were deemed to deviate from a normal distribution. In assessing normality, if the sample size (n) was below 50, the significance value of the Shapiro-Wilk test was employed, whereas if n exceeded 50, the significance value of the Kolmogorov-Smirnov test was utilized to evaluate the results (Büyüköztürk, 2018).

The data reliability of each survey was analyzed Kendall's W test and hierarchical clustering analysis and K-means clustering analysis methods to reinterpret each group's data (Ikotun et al., 2023). The findings are discussed in comparative analysis of investors and consumers.

RESULTS AND DISCUSSION

Investor Dimension

As previously mentioned, a dataset was compiled to determine the ranking of the architectural appeal factor among other key parameters of mall investment from the investors' perspective in Türkiye. This dataset was sourced from the related literature review and contains ratings from 17 professionals experienced for Türkiye in both operational and feasibility periods. These experts ranked 13 investment variables on a scale from 1 to 13. A normality test was applied each factor using the SPSS program. As illustrated in Table 2, "The utilization of software technology in the feasibility phase within an innovative context" (X13) did not demonstrate a normal distribution among all three methods. Moreover, factors such as the age distribution of the population residing in the surrounding area (X1), the presence of anchors (X6), location and easy accessibility (X10), and open to sustainability of investment projects in commercial, social, and environmental contexts (X12) also did not exhibit a normal distribution when analyzed through to the Shapiro-Wilk (Sig) significance values.

As the data did not demonstrate normal distribution, the Friedman test method was employed. This non-parametric test was preferred due to the nature of the data as it facilitates the determination of the ranking of the variables' relative importance based on their mean rankings (Sheldon et al., 1996) and it yields robust outcomes even when working with datasets that do not adhere to a normal distribution (Zimmerman & Zumbo, 1993). In this context, the findings of the Friedman test, which illustrate the importance ranking of the success factors from the investor dimension of the shopping mall, are presented in Table 3.

In terms of the relative importance of the factors, architectural appeal (X9) ranked seventh (μ=6.64) among 13 investment factors from the perspective of Turkish investors, indicating its relatively limited perceived influence on success. Investors may probably prioritize more measurable elements such as tenant diversity, location, accessibility, tenant capacity, market demand, operational costs as marketing strategy.

Other finding of this study indicates that the presence of anchor brands (X6) is the most critical factor for shopping mall investment success in Türkiye, with an average score of 9.71. This aligns with previous research Sirmans C.F. & Guidry K. (1993), Gatzlaff et al. (1994), and Anderson (1985)., highlighting that anchor attract customers and increase the value of smaller stores. However, if anchors face financial issues or bankruptcy, customer traffic may drop sharply, potentially leading to mall closure (Glennen & Peterson, 2017) Thus, close monitoring during operations is essential for mall managers.

Furthermore, the other two critical success factors (Table 3), are the location of the investment (X10) and the tenant mix structure (X5). These findings align with previous studies by Zhou et al. (2024), Zhu & Chung (2023), Wu et al. (2023), and Leung et al. (2024), who emphasize location selection and tenant distribution as key contributors to investment success. Moreover, based on the findings, location (μ=9.41) is considered more important than tenant mix (μ=8.94) because a prime location can appreciate in value over time, whereas a poor location increases the risk of depreciation.

A key finding of this study is that factors such as household income level (X3), entertainment and food/beverage opportunities (X7), and parking facilities (X4) rank higher than architectural appeal (X9) (μ=6.64) from the investor perspective, with scores of μ=8.82, μ=7.76, and μ=7.29, respectively. Although architectural appeal is one of the important factors, it alone cannot guarantee the commercial success of a mall. Fundamentally, household income level directly affects the economic sustainability of the mall (Xu et al., 2022). In high-income areas, consumers tend to spend more, which increases the profitability and return on investment (ROI) of mall stores (Zhang et al., 2023). Food

Table 2. Normality test results of success factors data

Factor Description	Method 1			Method 2					Method 3	
	Skew. Value	Kurtosis Value	Normal Distr.	Skew. Error Value	Kurt. Error Value	Skew. Value/ Standard Error Value	Kurt. Value/ Standard Error Value	Normal Distr.	Shapiro-Wilk (sig) Value	Normal Distr.
X1- Age distribution	0.980	0.249	Yes	0.550	1.063	1.782	0.234	Yes	0.021	No
X2- Education level	0.149	-1.234	Yes	0.550	1.063	0.271	-1.161	Yes	0.275	Yes
X3- Household Income	-0.164	-1.420	Yes	0.550	1.063	-0.298	-1.336	Yes	0.095	Yes
X4- Carpark capacity	0.053	-1.027	Yes	0.550	1.063	0.096	-0.966	Yes	0.100	Yes
X5- Tenant mix	-1.058	0.895	Yes	0.550	1.063	-1.924	0.842	Yes	0.080	Yes
X6- Presence of Anchors	-0.888	-0.103	Yes	0.550	1.063	-1.615	-0.097	Yes	0.040	No
X7- Entertainment and food and beverage opportunities	-0.580	-0.730	Yes	0.550	1.063	-1.055	-0.687	Yes	0.190	Yes
X8- Physical size of the SM	-0.027	-1.237	Yes	0.550	1.063	-0.049	-1.164	Yes	0.136	Yes
X9 Architectural appeal	0.108	-0.882	Yes	0.550	1.063	0.196	-0.830	Yes	0.269	Yes
X10- Location and easy accessibility	-0.889	-0.728	Yes	0.550	1.063	-1.616	-0.685	Yes	0.001	No
X11- Product and price diversity	0.453	-1.136	Yes	0.550	1.063	0.824	-1.069	Yes	0,103	Yes
X12-Open to Sustainable development in commercial, social, and environmental contexts	0.509	-1.403	Yes	0.550	1.063	0.925	-1.320	Yes	0.017	No
X13- Use of software technology in an innovative context during the feasibility	1.714	2.227	No	0.550	1.063	3.116	2.095	No	0.000	No

Table 3. Importance ranking of shopping mall success factors from investor perspective

Importance Ranking	Success Factor Description	Factor Code	Ranking of Averages
1	Presence of Anchors	X6	9.71
2	Location and easy accessibility	X10	9.41
3	Tenant mix	X5	8.94
4	Household Income level population living within 5 km	X3	8.82
5	Entertainment and food and beverage opportunities	X7	7.76
6	Carpark capacity	X4	7.29
7	Architectural appeal	X9	6.65
8	Physical size of the shopping mall	X8	6.47
9	Product and price diversity	X11	6.12
10	Open to Sustainable development in commercial. social and environmental contexts of the investment	X12	5.94
11	Education level of population living within 5 km	X2	5.88
12	Age distribution of the population residing within a five-kilometer	X1	4.41
13	Use of software technology in an innovative context during the feasibility stage	X13	3.59

and beverage, entertainment areas also allow consumers to spend more time in the shopping center. Thus, store sales increases and tenants may pay higher rents (Zacharias & Schinazi, 2003). However, at this point, architectural appeal can still influence people, and the entertainment and gastronomy experience can keep them in the mall longer and encourage them repeatedly (Çavka, 2023a). As a result, easy accessibility, income level and entertainment opportunities including food and beverage services rank higher than architectural appeal for investors to attract more customers to the mall.

Consumer Dimension

This study also investigates the significance of architectural appeal from the consumer perspective. In this phase a survey was conducted, and data collected from 96 respondents to explore the ranking of variables. According to the demographics of the participants, 79% were in the 18-25 age range, 9% were in the 26-35 age range, and 11% were 36 years or older. In regard to the education level of the respondents, 82% of them have an associate degree, while 18% have bachelor's degree or higher. The participants of consumers stated their visiting frequency to shopping malls are in the following order: 22% visit weekly, 22% visit monthly, 30% visit more than once a month, and 22% visit every few months.

To explore the structure of the data and determine the importance ranking method for the visit preference factors, the normality test was applied using the SPSS program. The results, as illustrated in Table 4, indicated that the data set did not exhibit a normal distribution, as evidenced by the Skewness and Kurtosis values, the ratio of these values to the standard error, and the Shapiro-Wilk (Sig) significance value. Therefore, a non-parametric test of the Friedman test, was applied to reveal the rankings of the importance of the variables (Sheldon et al., 1996).

So far, architectural appeal factor has been investigated from the investors' perspective and found that this factor is not a critical issue among the other factors such as anchors, tenant mix, and location. However, it is essential to portray the consumer preferences as well. In line with the objective, the Friedman test method was used to analyze the factors according to importance ranking that increase the frequency of shopping mall visits by consumers. This method is a non-parametric test, frequently preferred when data structures do not follow a normal distribution (Zimmerman & Zumbo, 1993).

The results of the Friedman test are presented in Table 5. According to data analysis in this section indicate that the product and price diversity (μ=6.40) offered in a shopping mall is the most influential factor in consumers' decision to visit such a venue. In this regard, an evaluation of the findings pertaining to the consumer dimension of the study reveals that product-price diversity and the availability of entertainment, food and beverage options, and other services within the malls are the primary

Table 4. Results of normality tests (Consumer dimension)

Factor Description	Method 1			Method 2					Method 3	
	Skew. Value	Kurt. Value	Normal Distr.	Skew. Error Value	Kurt. Error Value	Skew. Value/ Standard Error Value	Kurtosis Value/ Standard Error Value	Normal Distr.	Kolmogorov (sig)	Normal Distr.
Presence of Anchors	-0.523	-0.834	Yes	0.246	0.488	-2.126	-1.710	No	0.000	No
Carpark capacity	0.444	-1.013	Yes	0.246	0.488	1.807	-2.075	No	0.000	No
Entertainment and food and beverage opportunities	-0.648	-0.529	Yes	0.246	0.488	-2.633	-1.083	No	0.000	No
Physical size of the shopping mall	0.375	-0.813	Yes	0.246	0.488	1.525	-1.666	Yes	0.000	No
Location and easy accessibility	-0.077	-0.985	Yes	0.246	0.488	-0.315	-2.018	No	0.007	No
Product and price diversity	-0.861	0.430	Yes	0.246	0.488	-3.498	0.880	No	0.000	No
Tenant mix	-0.375	-0.868	Yes	0.246	0.488	-1.523	-1.778	Yes	0.001	No
Architectural appeal of mall	0.775	-0.527	Yes	0.246	0.488	3.150	-1.081	No	0.000	No
Open to Sustainable development	0.922	-0.217	Yes	0.246	0.488	3.750	-0.444	No	0.000	No

Table 5. Importance ranking of shopping mall visiting factors at consumer perspective

Importance Ranking	Factor Description	Factor Code	Ranking of Averages
1	Product and price diversity	X11	6.40
2	Entertainment and food and beverage opportunities	X7	6.17
3	Presence of Anchors	X6	6.10
4	Tenant mix	X5	5.93
5	Location and easy accessibility	X10	5.33
6	Carpark capacity	X4	4.10
7	Architectural appeal	X9	3.98
8	Physical size of the shopping mall	X8	3.69
9	Open to Sustainable development in commercial, social and environmental contexts	X12	3.29

factors influencing consumer visits to the centers. This finding aligns with the results of previous research by Topçu (2011), Mert & Altunışık (2000), Cengiz & Ozden (2002). Besides, Tuncer et al. (2008), and Arslan & Bakır (2010) focused also on user-centered decision-making mechanisms for shopping mall visits. This suggests a relationship between product-price diversity and the distribution of tenant mix. An ideal tenant mix within a shopping mall can offer consumers different product and price segments, enhancing the consumer experience.

Another significant outcome of the Friedman test is that architectural appeal is not one of the critical factors for consumers to increase the frequency of visits to a shopping mall. The lower prioritization of architectural appeal in consumer's visit preferences can be explained by several factors. Fundamentally, consumers may perceive the architectural appeal of a mall as merely one component of the shopping experience, or they may focus primarily on their functional and social needs. As a result, functional factors such as price advantages (μ=6.40), entertainment and food and beverage opportunities (μ=6.17), store variety (anchors (μ=6.10); tenant mix (μ=5.93)), easy accessibility (location (μ=5.33); parking facility (μ=4.10) may take precedence respectively over architectural appeal (μ=3.98).

The findings from this part of the study are highly valuable for investors in shaping an innovative design strategy prior to construction. Consumers primarily choose to visit shopping malls due to the availability of diverse product and price options, as well as a variety of food and beverage offerings. In this context, investors can identify the optimal tenant mix during the feasibility phase, incorporating anchor brands and entertainment venues. Additionally, architects can develop effective spatial planning strategies during the design process by carefully organizing tenant placement, integrating large-scale entertainment zones, and designing efficient parking systems to enhance the mall's overall appeal and attract a higher number of visitors.

Comparative Analysis of The Success Factors Between Consumers and Investors

So far, critical success factors from the investor's perception and the driving factors for the consumers to increase their visit to shopping malls are analyzed separately, it is also important to determine whether there is a significant difference among these factors between the two groups. Therefore, this section compares the average importance rankings the investors and consumers.

Kendall's W test was initially used to assess the level of agreement among multiple experts and participants, but due to a low concordance value (0.238), hierarchical clustering and K-means clustering were employed for further analysis. In the investor group, 15 out of 17 participants clustered factors such as anchor brands (10.20), location and tenant mix (9.80), and entertainment & food services (8.00) together. The remaining participants grouped household income (10.00), product price diversity (10.00), sustainable growth potential (11.00), and use of software technology (12.00) in a second cluster. In the consumer group, 63 participants prioritized anchor brands (6.89), price diversity (6.86), tenant mix (6.51), and entertainment & food services (6.44) in one cluster, while 36 focused on architectural attractiveness (6.06). Despite varying opinions, these results suggest a strong convergence of factors under consistent categories.

Hence, there is a significant disparity between the sample size of the expert group (n=17) and the sample size of the consumer group (n=96), a non-parametric Mann-Whitney U Test applied for statistical comparison (Mann & Whitney, 1947). As illustrated the results of Mann-Whitney U test in Table 6, the variables with a p-significance value below 0.05 were identified as product-price diversity (0.003) and location and easy accessibility (0.03).

Furthermore, upon re-examination of these two variables in terms of the average ranking as indicated in Table 7, location and easy accessibility is the highest critical factor for investors where, product and price diversity play a significant role in consumer preferences in Türkiye.

Architectural appeal was not prioritized by either group. Ostensibly investors focus on selecting the best location to minimize future risks, while consumers prioritize access to diverse products and competitive prices. This finding coincides with Feldmann's (2004) study, so that shopping malls must be located within the main transportation arteries with a visible and distinctive design. Additionally, effective tenant mix placement, with product-price diversity and brand distribution across floors, can increase visit frequency and duration (Krugell, 2010). When examining the differences between the rankings of investors and consumers, it can be observed that shopping malls with high visitor volumes are generally located along the main arteries of the city. From a logical standpoint, if consumer survey participants have prior experience with such malls, it is plausible that the factor of accessibility and ease of transportation may rank lower in their preference hierarchy.

CONCLUSION

Shopping malls are high-capital investments with strong long-term return potential. Their success depends on factors such as anchor brands, tenant mix, location, entertainment, food and beverage services, parking, and architectural appeal. While architectural appeal may not be the main factor, it enhances the consumer experience, increases visit frequency, and supports profitability. For overall success, consumer and investor expectations must align. Therefore, within the scope of this study, to assess the importance level of architectural appeal in Türkiye, data was collected via surveys from investors and consumers to compare. The Friedman test ranked the importance within each group, while the Mann-Whitney U test identified key variables across both groups.

The findings indicate that factors such as anchor presence, location of the investment, tenant mix structure, household income levels in the surrounding area, the entertainment, food, and beverage services offered by the mall, and parking capacity exert a more profound influence on the commercial performance of the investment than the architectural appeal. However, architectural appeal supports consumer preferences by enhancing spatial quality through aesthetics, comfort, lighting, cleanliness, and security, which can strengthen emotional connections and increase visit frequency, ultimately boosting mall performance frequency.

Conversely, the findings obtained from the consumer perspective, though limited in scope, offer partial support for this view. While factors such as the diversity of products and prices offered by the mall, the presence of entertainment and dining facilities, the availability of anchor brand stores, the fulfilment of expectations and needs through an appropriate tenant mix, ease of accessibility to the mall's location, and sufficient parking capacity are the primary reasons for consumers to visit a shopping mall, they also consider the attractiveness of the architectural appeal as a contributing factor. It can therefore be posited that an

Table 6. Results of Mann-Whitney U Test for comparison

	Anchors	Location accessibility	Tenant Mix	Entertainment and food and beverage	Carpark	Appeal of SM	Physical size	Product and price diversity	Open to Sustainable development
Mann-Whitney U	607.00	547.50	667.00	735.00	593.00	690.50	631.00	455.00	717.50
Wilcoxon W	5263.00	5203.50	5323.00	888.00	5249.00	5346.50	5287.00	608.00	5373.50
Z	-1.70	-2.17	-1.21	-0.66	-1.80	-1.02	-1.51	-2.93	-0.81
Asymp. Sig. (2-tailed)	0.089	0.030	0.227	0.511	0.071	0.307	0.132	0.003	0.420

Table 7. Comparison of location and product price diversity based on two dimensions

Factor Description	Group Variable	N (sample size)	Ranking of Averages
Location and easy accessibility	Investor Group	17	72.79
	Consumer Group	96	54.20
	Total	113	
Product and price diversity	Investor Group	17	35.76
	Consumer Group	96	60.76
	Total	113	

investment in the appeal of the architectural appeal will positively impact the future success of the investment by increasing user visit frequency.

Finally, a comparison of the prominent factors between the investor and consumer perspectives reveals that the "location and easy accessibility" of the investment holds strategic importance for investors, while consumers emphasize "product and price diversity".

This study provides a comprehensive analysis on the significance of architectural appeal among other success factors in shopping mall investments from investors view and visit motivation element from consumers' perspective in Türkiye. Moreover, this research not only examines the extent to which the spatial appeal of a shopping mall is a key factor in the context of architectural design, but also outlines the other success components of such commercial investments from both the entrepreneurial and user perspectives. This is done to provide a general framework for future research. It is anticipated that this framework will prove a valuable resource for future empirical studies in the field of shopping mall design and investment planning. Furthermore, the study's findings may inform the development of predictive models to forecast the future success of shopping mall investments.

Although architectural appeal is not the primary determinant for investors and consumers in the context of shopping malls, it nonetheless plays a noteworthy role in shaping both investment and consumption decisions. A distinguishing feature of this study lies in its integrative approach, wherein the perspectives of both key stakeholder groups are concurrently examined. Future research should aim to conduct more comprehensive analyses of architectural attractiveness by incorporating the demographic and psychographic attributes of the involved actors.

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Article

Use of artificial intelligence in interior architecture education and case study an example of using Vizcom artificial intelligence tool in Kocaeli University interior architecture education

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ABSTRACT

The aim of this study is to determine the necessary conditions for the inclusion of artificial intelligence in design education in interior architecture and to evaluate the use of artificial intelligence technology that creates renderings from sketches in this context. Literature review, and "experimental model" method, one of the quantitative research types, were used in the study. The experimental study was carried out with thirty-eight students studying in the Department of Interior Architecture, Faculty of Architecture and Design, Kocaeli University. As a result of the study, it was determined that students express their thoughts more easily in their designs and produce three-dimensional presentation works faster with the artificial intelligence tool that creates renderings from sketches. In addition, when the visual that emerged as a result of editing with artificial intelligence was evaluated according to the determined design criteria, it was observed that the visual content was directly proportional to the student's professional competence and the success of hand drawing. It has been revealed that the inclusion of artificial intelligence tools in interior design courses will be useful in developing creative thinking skills in terms of working with more than one proposal and producing different alternatives with the help of various visuals.

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INTRODUCTION

The use of artificial intelligence technology for design and visualisation in the interior architecture profession, as in every professional field, has recently increased considerably and continues to increase. Those who are indifferent to this development will find it very difficult to remain competitive in the sector and to stay current in the profession. It is therefore essential to train interior designers who can filter and use artificial intelligence effectively, and to investigate ways to include these innovations in education.

The human brain is likened to a computer in terms of its working structure. This view can be explained by various (D. Adrian, 1913; H. Berger, 1929; W. Penfield and T. Rasmussen, 1957; A. Turing, 1950) developments in science

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(Tarlacı, 2022). In this context, it can be said that artificial intelligence studies are directly related to the functioning and imitation of the human brain (Yıldırım & Demirarslan, 2020). Even if artificial intelligence is assumed to think like humans, creativity plays a role in design. More than intelligence, is needed for creativity. As Hawkins & Blakeslee (2007) say, "A human being is more than an intelligent machine". Cognitive skills such as intelligence, knowledge, and affective skills come to the fore in creativity. Not only being aware of one's own emotions, but also being aware of the emotions of others, establishing interpersonal relationships, cooperating with the team, developing others, communication and persuasion skills can serve as a useful component in the development of the creative product. In addition, people can use technology as a tool in the development of creative products.

Design can be defined as a problem-solving process in which creativity is at the forefront. While interior architecture education, a design-oriented discipline, expects a creative product as an output, it also supports the development of students' creative thinking skills. The inclusion of technology in the development process of interior architecture students' creativity has been the subject of recent discussion. In this context, there is a need for studies investigating the impact of the inclusion of artificial intelligence technologies in interior architecture education.

Review of the Literature

Due to the development of large-scale artificial intelligence models and the acceleration of artificial intelligence studies, the study took into consideration literature that was expected to emerge between 2022 and 2024. Especially in Türkiye it has been observed that there are many studies examining the relationship between artificial intelligence and interior architecture education. As of now, there are 3603 records in the Higher Education Institute Thesis Centre in the field of artificial intelligence. While 58 of these are in the field of architecture, eight of them are in the field of interior architecture (YÖK, 2024). The study titled "Evaluation of the Interaction of Artificial Intelligence and Space Design in Today's Design Education," conducted by Ekin Bayrak in 2022, is the closest to this study in terms of its subject. In Bayrak's (2022) study, the aim was to determine the views of students studying interior architecture and environmental design on the integration of interior design and artificial intelligence. Unlike Bayrak's study, this article includes the measurement of students' competences in the use of artificial intelligence and the experiments with artificial intelligence conducted by the author.

It is also necessary to briefly mention other studies in the field of 'Artificial Intelligence and Design' in the literature that support this study. Özdemir (2022) conducted a study titled "The Effect of Artificial Intelligence on Graphic Design and Designer", which clearly argues that artificial intelligence is in the role of an assistant supporting the designer (Özdemir, 2022). Deveci (2022) emphasised in the study titled "Reflection of Artificial Intelligence Applications on Art and Design Fields" that designers save time with the use of artificial intelligence and that it contributes to the development of their creativity (Deveci, 2022). Jaruga-Rozdolska's (2022) study "Artificial Intelligence as Part of Future Practices in the Architect's Work: MidJourney Generative Tool as Part of a Process of Creating an Architectural Form" proves that Artificial Intelligence (AI) is a valuable tool for architects and supports creative thinking when used appropriately (Jaruga-Rozdolska, 2022).

Pamuklu & Fındıkcı (2023), "The Future of Graphic Design: Artificial Intelligence and Human", they conducted a survey with graphic designers and concluded that artificial intelligence is an important assistant for the field of graphic design (Pamuklu & Fındıkcı, 2023). Arisha's (2023) study "Transforming Interior Design Education through Generative Artificial Intelligence (AI) Trend" proves this point. It definitively shows that the use of artificial intelligence technologies in interior architecture education will produce different design alternatives (Arisha, 2023). Taluğ & Eken's (2023) study titled "The Intersection of Human Creativity and Artificial Intelligence in Visual Design" emphasises that while artificial intelligence can contribute to the visual design sector, it can also have negative consequences in terms of the creativity of the artist and therefore should be used carefully (Taluğ & Eken, 2023). The study "Is Midjourney-AI a New Anti-Hero of Architectural Imagery and Creativity?: An Atypical Era of AI-Based Representation & its Effect on Creativity in the Architectural Design Process" claims that artificial intelligence has some advantages such as creativity, speed and diversity in architectural imagery, as well as disadvantages such as being limited to images in memory and not being able to transfer human experience to the work of art (Radhakrishnan, 2023). "Using Text-to-Image Generation for Architectural Design Ideation" definitively demonstrates how text-to-image generation tools can support human discrete creativity in the early-stage concept design process (Paananen et al., 2023) "Robotecture and Artificial Intelligence (AI) Technology and its Impact on the Creativity", which argues that artificial intelligence technology can revolutionise the interior design industry by accelerating the creative process and increasing productivity (Gbr, 2023).

Çeken & Akgöz (2024) conducted studies in the field of visual design and as a result, they agreed on the data visualisation success of artificial intelligence, but argued that the resulting product was automated in the artistic context (Çeken & Akgöz, 2024). Coşkun's (2024)'s study titled "Productive Artificial Intelligence Systems in the Field of Art and Design" in which he stated that artificial intelligence supports the creative process in terms of obtaining content in direct proportion to the user's artistic competence (Coşkun,

2024). Sivri's (2024) study titled "The Future of Visual Arts in the Framework of Artificial Intelligence" in which he argues that the use of artificial intelligence in the fields of art and design will reduce the need for manual skills and that people who can use these tools effectively with the right inputs will come to the fore and that artificial intelligence should be used effectively in education while all this is happening (Sivri, 2024). In their 2024 study, Kahraman et al., (2024) explored the integration of AI in interior design education, emphasising its role as an auxiliary tool for designers in the creation of conceptual images based on keywords (prompt). The study underscores the significance of designers' interpretation and adaptation skills, emphasising that these cannot be replaced by AI in this context. This study aligns with the research themes of this article, as do other studies in this field (Kahraman et al., 2024).

A review of the literature on the role of artificial intelligence in design education was conducted. This revealed both the advantages and disadvantages of using artificial intelligence in this field. However, no study had previously been conducted that involved direct questioning in the field of education. In this context, it is hypothesised that the present study will contribute to future research in this field, specifically examining the use of artificial intelligence in design education in interior architecture and investigating its effect on students' creativity skills.

Artificial Intelligence and Interior Architecture Education

Artificial intelligence is the imitation, by computer programs controlling machines, of behaviours that are called intelligent, when performed by humans, (Pirim, 2006). The concept of artificial intelligence officially emerged as the name of a new research discipline during a workshop at Dartmouth College in 1955 or 1956, according to different sources. John McCarthy named this discipline for further study using the term "Artificial Intelligence (AI)" in a project application on 31 August 1955 (Aydın & Değirmenci, 2018).

Designing with AI has a significant impact on the interiors of various environments, including homes, workplaces, and public spaces. With the rapid development of digital technology, the integration of AI into these spaces is becoming increasingly common. The effects of AI on interior design are as follows:

- AI technology can make a great contribution to interior design by accelerating the creative process and increasing efficiency,
- With the help of AI, designers can create work in a shorter time than they would using traditional methods. Furthermore, AI can help designers to optimise their designs in terms of functionality, sustainability and cost,
- With the help of AI, the design process has the potential to be more efficient and effective, but it is extremely important to preserve the personal touch that constitutes the artistic value of interior design. The human touch is vital in interior design and cannot be completely replaced by technology,
- AI can help designers quickly create and explore a wide range of design options, enabling them to test and develop their ideas more efficiently (Gbr, 2023).

The current quality of AI and the lack of readiness of computers to perform the complex tasks associated with both design itself and relating the designed buildings to the surrounding context make many people sceptical; they doubt that AI can be developed to replace humans in particularly complex fields such as architecture. According to Kolata & Zierke (2021), "AI itself cannot exist without the creativity of the people who create it. Artificial intelligence facilitates the development and implementation of innovative ideas and solutions. It makes the idea possible. It does not create the idea in the first place" (Kolata & Zierke, 2021).

Creativity is the focus of education and learning outcomes in interior architecture (Williams et al., 2010). Interior architecture education is an education model in which the student is offered the opportunity to comprehend problem-solving methods. In this education model, the course instructor directs the students and the students are involved in the design creation process with their creativity (Güzelci et al., 2012). In this context, creativity is among the criteria for evaluating the designer and the final product (Christiaans & Venselaar, 2005).

Interior architecture education is a model that includes theoretical courses as well as applied basic vocational courses, company-site visits and workshops that support students to create a designer identity. The aim of the workshops is to strengthen hand-eye-brain coordination, assimilate the information learnt from theoretical courses and develop creativity (Zorlu et al., 2012). According to Aydınlı (2015), architectural education should not be limited to the transfer of knowledge, but should be such that students are encouraged to think inquisitively and creatively, and their imagination is nurtured. In this context, the use of AI in the interior design process was examined in this study. Furthermore, it was aimed to investigate how AI would contribute to students' creativity.

In the literature, it is observed that the interior design process consists of various parts such as definition, integration, analysis, decision and implementation stages. Although this classification differs from source to source, it is commonly used in applications (Özker, 2014). In Choa & Suhb's (2020) study, the interior design process is segmented as follows; definition of the problem (analysis of user needs), concept development (analysis of precedent studies), schematic design (presentation of the design with visual expression techniques) and implementation (Figure 1) (Choa & Suhb, 2020).

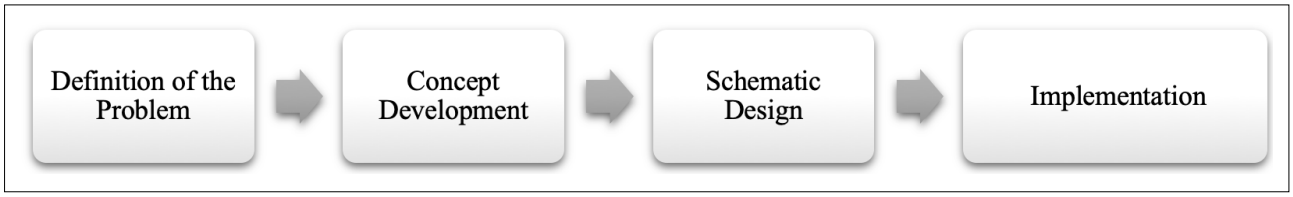

Figure 1. Stages of the interior design process (Choa & Suhb, 2020).

According to the above-mentioned interior design stages of Chao & Suhb (2020), a classification study of artificial intelligence technologies used in interior design was carried out on the AI technologies active as of this study's date (Figure 2) (Choa & Suhb, 2020).

Within the scope of the study, "Artificial Intelligence Technologies for Creating Renderings from Sketches" have been examined in the experimental field. A sketch is draft data suitable for development; it is the expression of the first thought of the design. The sketch, which is a stage of the design process, defines the outlines of the design and leads to the result step by step. Sketching in architecture, which is the language of expression of the line, creates the opportunity to produce fast and numerous ideas (Özker, 2014). Computerised presentation techniques are frequently used in the visualisation phase, which is one of the interior design stages. At this stage, a space or product is modelled in three dimensions based on two-dimensional drawings. A realistic image of the modelled product is created by assigning coating materials and lighting with the help of a camera. This image is called rendering (Özgel Felek, 2019). AI tools, in which sketches are quickly converted into renderings, are frequently preferred in interior design today. In this study, the "Vizcom" artificial intelligence tool was selected for its free usage right, user control of the similarity rate decision to the draft drawing, fast and high quality, image creation, prompts (keywords) entered in addition to the sketch, and the ability to upload reference images where prompts are insufficient.

Vizcom is an AI-supported rendering software that can transform sketches into photorealistic images in a short time. Its main features are as follows;

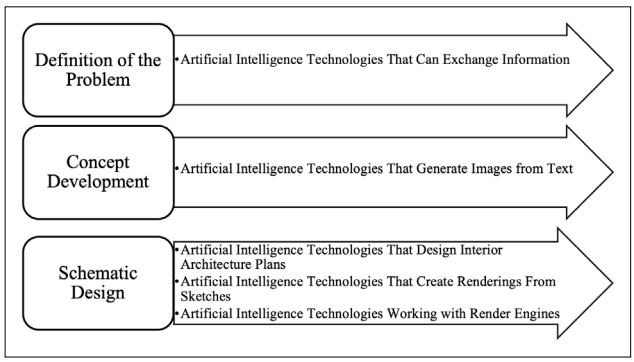

Figure 2. Classification of artificial intelligence technologies used according to the stages of interior design (Figure by [Elif Küçük], 2025).

- Direct input of sketches or uploading of various artwork images to the platform,
- Fast artificial intelligence processing for photorealistic image transformation,
- High-resolution 4K output for quality visuals,
- A suite of creative tools including Prompts, Live Render, 3D Painting and Drawing Tools,
- Enterprise-level security with compliance standards for data protection,
- Cross-platform compatibility for accessibility on a variety of devices,
- Collaboration features such as Teams, Projects and Folders for shared workspaces,
- It is designed to save up to 80% of the time by automating repetitive design tasks (McFarland, 2024).

METHOD

The study, which evaluates the use of artificial intelligence technology that creates renderings from sketches in interior design courses according to the determined design criteria, aims to test the professional competencies of interior architecture students. For this purpose, "Interior Design Criteria" were created using Choa & Suhb's (2020) interior design process stages and the Professional Standards (CIDA, 2023) used by the Interior Design Accreditation Council to evaluate interior design programmes. The criteria are summarised below.

Adequacy of User Profile: Demographic characteristics and behavioural tendencies are discussed under the sub-headings.

- Determination of Demographic Characteristics: Demographic characteristics are the innate physical, social, economic and geographical characteristics of the individual that explain the individual and his/her position in the society (Tekvar, 2016). The study evaluated the relationship between the physical, social, economic, and geographical characteristics of the user profiles determined by the student and the designed project.
- Determination of Behavioural Tendencies: In the analysis phase of an interior design, it should be calculated how the user will behave in the face of

which event. The behaviour of a person in the face of a situation depends on factors such as personality structure, environmental factors, interests, habits, etc. (Özkalp, 1981). In this context, the relationship between the behavioural characteristics of the user profiles determined by the student and the designed project was evaluated.

Adequacy of the Function Diagram: Adequacy of the list of requirements and adequacy of the schematic representation are discussed under the sub-headings.

- Adequacy of the Needs List: For a correct design; space needs should be determined completely, the equipment to be used should be classified functionally positioned in appropriate places in the later stages of the design (Sümer, 2011). In the study, the needs list created in line with user profiles and space needs was evaluated.
- Sufficiency of Schematic Representation: Drawing is the healthiest way to share information with the user in the discipline of interior architecture. Schematic representations are tools that help the designer in thinking and problem solving (Yi-Luen Do & Gross, 2001). In the study, the function diagram created in line with the list of needs was evaluated.

Adequacy of the Concept Study: The adequacy of the research section and the adequacy of the design of the project in line with the determined concept were discussed under the sub-headings.

- Adequacy of the Research Department: The way in which the concept determined as the starting point will be reflected in the space is directly proportional to the adequacy of the preliminary preparation. Kaya & Fitöz (2020) stated in their study that the prerequisite for creativity is knowledge. As the width of the knowledge treasure increases, the limits of thought increase (Kaya & Fitöz, 2020). In this context, the adequacy of the research conducted by the students before the idea generation phase was evaluated in the study.
- Adequacy of the Design of the Project in line with the Determined Concept: At this stage, two-dimensional and three-dimensional drawings of the project created by the designer were evaluated along with research data.

Sufficiency of Interior Architecture Expression Techniques: Compliance with technical drawing rules and adequacy of the presentation sheet are discussed under the subheadings.

- Compliance with Technical Drawing Rules: The correct transfer of the design is possible by drawing basic drawing types such as plan, section, perspective as they should be (Cho & Suhb, 2019). The conformity of the drawings made by the students to the rules of technical drawing standards was evaluated at this stage.
- Adequacy of the Presentation Sheet: Visual presentation sheets describing the design should be able to stand alone without verbal expression (Dodsworth, 2012). At this stage, the adequacy of the presentation sheets prepared by the students was evaluated.

Ergonomic Competence: It is handled under the sub-headings of space organizational, physical compatibility, and environmental compatibility.

- Space Organisation: It is evaluated under the category of the functionality.

Functionality: All elements in the space should provide cues and open possibilities to help users determine the right sequence of interactions to achieve their goals. Proper space organisation allows individuals to perceive and navigate through the primary cues in the environment (Nehme et al., 2020). The space designs drawn by the students were evaluated in line with user needs and the relationship between the spaces.

- Physical Compatibility: It was evaluated under the headings of compliance with anthropometric measurements and accessibility.

Compliance with anthropometric measurements: Anthropometry is an ergonomic study discipline related to human body measurements and physical characteristics. Anthropometric data are used in product and space design at the stage of sizing in accordance with the user (Shamaileh, 2022). In the study, the suitability of the designed spaces with anthropometric dimensions was evaluated.

Accessibility: According to the Dictionary of Architecture and Construction, accessibility is "a building, facility or area that can be approached, entered and used by a physically disabled person" (Acırlı & Kandemir, 2021). In this context, this study evaluates whether the spaces can be designed for everyone.

- Environmental Compatibility: It was assessed under the headings of lighting, acoustics and air conditioning.

Illumination: It has some effects on human physiology and psychology. Proper lighting helps to protect eye health and provide an efficient working environment. The user exposed to a poorly lit environment may experience negative effects such as fatigue, distraction, and irritable mood (Gürel, 2001). The study evaluated whether the spaces designed have lighting comfort suitable for the function.

Acoustic: Acoustic design is the design process for providing acoustic comfort that aligns with the space's function. In some cases, the lack of acoustic comfort does not even allow the realization of the main purpose of the space (Çalışkan, 2014). The study evaluated that the designed spaces provide acoustic comfort suitable for their function.

Air Conditioning: In order to create healthy and comfortable living conditions, thermal comfort, humidity, ventilation, and natural lighting conditions must be designed correctly. In this context, air conditioning has an important place in interior design (Ali & Say Özer, 2012). The study evaluated whether the spaces designed are suitable for providing air-conditioning comfort.

Structural Competence: Structural competence in space and structural competence in reinforcement were handled under the sub-headings.

- Structural Competence in Space: The concept of structure refers to the holism formed by the combination of parts and is primarily used in the sense of a building. In the right design, the parts that ensure integrity and functionality must be constructed correctly. In general, the structure, which is the system used to sustain the form, is one of the main components of architecture (Akçaova & Sungur, 2022). In this context, the structural adequacy of the designed spaces was evaluated.
- Structural Competence in Reinforcement: Fittings are objects with functional and aesthetic features that give meaning to the interior space and define it (Güremen, 2011). Design should be developed within the framework from form-space-structure components. The inclusion of the structure, which constitutes the basic fiction of the design, in the design process also increases creativity (Akçaova & Sungur, 2022). In this context, the structural adequacy of the designed reinforcement elements was evaluated.

The visualisation component of the interior design process enables designers to transfer visuals from their minds to graphic images on paper, then analyse, refine and finally present them to customers as a successful solution. In this context, it can be observed that visualisation ability is important in interior design. Images are an important part of visualisation. There are three types of visual images. These are perceptual, which is to see or experience the physical world through our senses, mental, which is to create an image by rotating the perceptual image in our mind, and graphic image, in which the mental image is recorded (Nussbaumer & Guerin, 2000). The perceptual image mentioned is the use of visual perception elements within the scope of the study, and the mental image is organized to perceive realism. "Three-Dimensional Interior Architecture Visual Creation Criteria" were created to evaluate the design competence of the images produced with artificial intelligence. These criteria are summarised as follows.

Use of Visual Perception Elements:

- Adequacy of the Use of Light and Colour: The correct combination of light and colour contributes to the user's perception and provides a positive spatial experience (Podma, 2009). The evaluation showed that the visuals created in the study were selected in light levels and colours appropriate to the function and concept.
- Adequacy of the Use of Form: Form is the first and most important design element. Form, which is the external appearance of objects, creates a boundary with the environment through its surfaces. The form used have a great role in the perception of space (Kaptan, 2004). The visuals created in the study were evaluated to determine if they were designed in accordance with the function, concept, and structure.
- Adequacy of Material and Texture Use: The choice of material and texture is an important aspect of design in terms of its effect on the user (Ataoğlu, 2015). The visuals created in the study were evaluated as being designed with materials suitable for the function, concept, and structure.

Perception of Reality:

- Correct Use of Ratio and Proportion: The way to ensure the authenticity of the created image is through the correct use of ratio and proportion in drawings (Civcir, 2015). In the study, the design elements in proportions appropriate to the perception of reality were evaluated.
- Reflection Gloss and Shadow Representation: Reflected brightness and shadow provide a three-dimensional perception of the drawing and are very important in terms of adding meaning to the space (Coles & House, 2012). The study evaluated whether the design elements had brightness and saturation values suitable for the perception of reality.

The experimental study was conducted with thirty-eight students enrolled in the "ICM 305 Interior Space Design 3" course at Kocaeli University, Faculty of Architecture and Design, Department of Interior Architecture, in the 2023-2024 autumn and spring semesters. Since the students should have competence in visual presentation and technical knowledge, students taking 'ICM 305 Interior Design 3' course were selected for the study. The study carried out with thirty-eight participants, was based on volunteerism. In order to carry out the experiment, permission was received from the Ethics Committee with document date and number "19.10.2023-E.487611". In addition to the project designed in the interior design course, each student designed a seating-recreation area to be created by the researcher with artificial intelligence. In order to test the functionality of artificial intelligence, students designed in 5 different interior design styles (Art Deco, Bauhaus, Japanese, Country and Neo Classical) determined by lottery method. In this study, the students' sketches of the seating-recreation area constitute the

control group, and the visuals created by the researcher with artificial intelligence constitute the experimental group. The evaluation of whether the students who prepared the sketches constituting the control group were competent in the use of artificial intelligence was made according to the 'Interior Design Criteria'. The experimental study is not only focussed on the final product. Students' work was followed from the first sketches to the final submission, taking into account their creative thinking skills throughout the process. The adequacy of the product produced with artificial intelligence was evaluated according to the 'Three-Dimensional Interior Design Visual Creation Criteria'.

FINDINGS AND EVALUATION

The Interior Design Criteria, which are explained in detail in the Experimental Study Section, were prepared according to a 5-point Likert scale. The results obtained were graphed with SPSS (IBM SPSS Statistics 27) (Figure 3).

As a result of the evaluation of the student interior design projects according to the "Interior Design Criteria," it was determined that the average of the total scores of 38 students was 3.37. In the study where full grade was considered to be five, and accordingly passing grade was considered to be 3, the average of the total scores of 8 students for 16 criteria was below 3, while the remaining 30 students scored above 3. The most successful topic in the students' projects was "Determination of Demographic Characteristics" with a score of 3.73, while the most unsuccessful topic was "Functionality" with a score of 2.92. The only criterion that did not receive a passing grade was "Functionality". In line with the results obtained, it can be said that interior architecture third-year students, are competent to use AI in their educational life, considering the general success of their projects.

In the visualisation stage, the last step of the interior design, alternative hand-drawn drawings of the sitting

Figure 3. SPSS generated graphs of the evaluation results of student projects within the scope of "Interior Design Criteria" (Figure by [Elif Küçük], 2025).

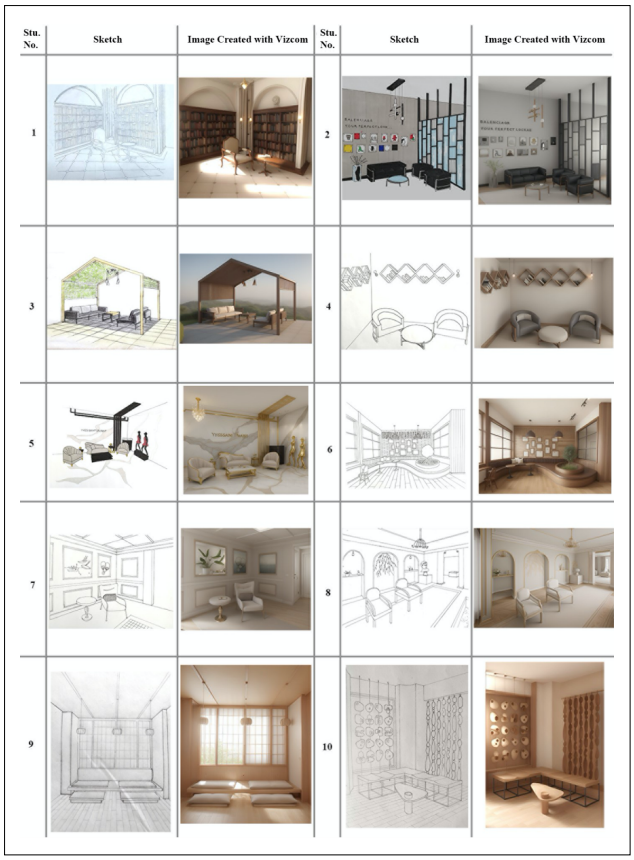

Figure 4. Student sketches and visuals created with Vizcom-Part 1 (Sketches created by students, Vizcom visuals by [Elif Küçük], 2025).

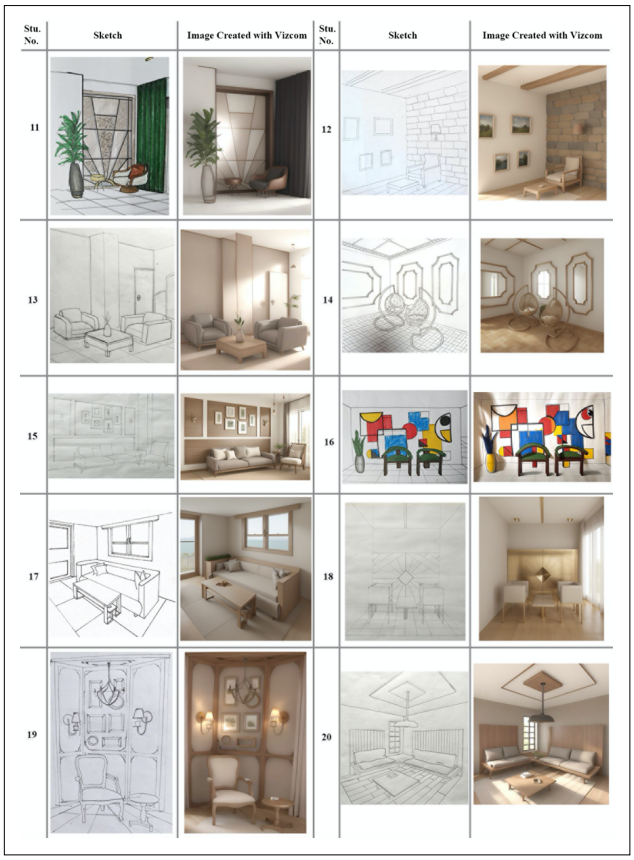

Figure 5. Student sketches and visuals created with Vizcom-Part 2 (Sketches created by students, Vizcom visuals by [Elif Küçük], 2025).

and relaxation corner by the students were created with artificial intelligence by the researcher. Thirty of the sketches were visualised by the researcher with the help of artificial intelligence by entering only prompt information (Figure 4; Figure 5; Figure 6), and eight of them were visualised by using additional reference images in addition to prompt (Figure 7; Figure 8). To ensure consistency in each visual created with Vizcom, the drawing influence section was set to 60%. Prompts included the project concept of each student and the words "sitting-rest corner". Prompt language is English. Within the working system of Vizcom, by entering the same prompts and influence values, each rendering of a sketch recreated using these inputs produces different results. The researcher created an option for each student sketch within the scope of the study.

The design adequacy of the created visuals was evaluated using a 5-point Likert scale according to the "Three-Dimensional Interior Design Visual Creation Criteria," and the results were graphed with the SPSS program (Figure 9).

As a result of the evaluation of the visuals created with Vizcom according to the "Criteria for Creating Three-Dimensional Interior Design Visuals", the average of the total scores of 38 visuals is 3.02. The criterion with the highest visual success is "Adequacy of Light and Colour Use" with a score of 3.21, while the lowest is "Reflection, Brightness and Shadow Representation" with a score of 2.63. The average of the visuals evaluated according to the criteria of "Reflection, Brightness and Shadow Representation" and "Correct Use of Proportion" did not receive a passing grade. The criteria by which student sketches were more effective in the formation of visuals were "Adequacy of the Use of Form-Form" and "Correct Use of Proportion-Proportion", while the criteria by which AI was more effective were "Adequacy of the Use of Light and Colour", "Adequacy of the Use of Material-Texture" and "Reflection, Brightness and Shadow Representation". Student drawings are less prominent, and the visuals created by Vizcom technology are more successful.

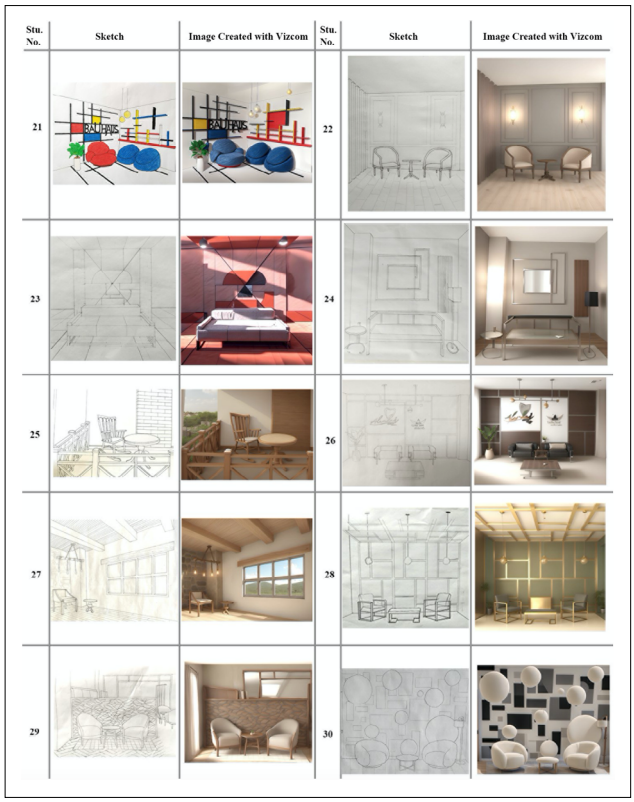

Figure 6. Student sketches and visuals created with Vizcom-Part 3 (Sketches created by students, Vizcom visuals by [Elif Küçük], 2025).

Figure 7. Student sketches, visuals created with Vizcom, reference visuals and final products created using Vizcom and reference visuals Part 1 (Sketches were created by the students, Vizcom visuals were by [Elif Küçük], 2025. Reference images are taken from (Gassmann (2019); Big See (2022); Pinterest (n.d.a); Ramos (n.d.)).

CONCLUSION

The ongoing development phase of the databases to which AI tools are connected means that they may contain incomplete, inaccurate or outdated information, thus leading to potential issues regarding the reliability of the outputs produced by AI. It is therefore recommended that designers and users exercise caution and verify the outputs of AI tools. This study posits that interior architecture students possess sufficient professional knowledge to apply artificial intelligence at an adequate level in the 3rd year of their undergraduate education.

The quality of the end product, which is the result of students' work with artificial intelligence, is directly proportional to the quality of their hand drawing and the adequacy of their professional knowledge. In particular, the criteria of "Adequacy of the Use of Form-Form" and "Correct Use of Proportion-Proportion" include the visual results in the hand drawing stage. The AI produced visuals with 60% similarity to the hand drawing presented as data. As the majority of the drawings were uncoloured, the remaining criteria were determined autonomously by the AI. Kurak Açıcı & Sönmez (2014) emphasised in their study with third-year interior architecture students that a fundamental understanding of hand drawing is paramount for achieving the most accurate computer-aided design. In this context, it can be posited that hand drawing should be emphasised in the 1st and 2nd year interior architecture education in order to facilitate the creation of successful designs with AI starting from the third year.

The integration of artificial intelligence in interior architecture education enables students to articulate their ideas with greater ease by providing the capability to swiftly transform freehand drawings into realistic images. This increased efficiency affords students the opportunity to engage with a broader range of design content. The potential of this approach to develop students' creative thinking skills is notable because theoretical research has shown that there are studies that support that the use of AI in design enhances creativity.

The experimental field of study incorporated the "Vizcom" artificial intelligence tool, which facilitated

Figure 8. Student sketches, images created with Vizcom, reference image and final products created using Vizcom and reference image Part 2 (Sketches were created by students, Vizcom images were by [Elif Küçük], 2025. (Erdoğan (2022); Pinterest (n.d.b); AliExpress (n.d.); Pinterest (n.d.c)).

the transformation of freehand drawings into realistic images, offering students a more efficient means of expressing themselves. The tool's free usage, the selection of the similarity ratio to the draft drawing, and its fast and high-quality image generation contributed to the study. However, the efficacy of the prompt command, which conveys changes to be made on the sketch verbally, was found to be inadequate in achieving the desired outcomes. It is noteworthy that the adequacy of the images produced for different prompts in the experimental studies conducted in August 2023 and the adequacy of the images produced for the experimental study in April 2024 are not equivalent. This observation underscores the dynamic nature of AI, which is subject to continuous updates, enhancements, or deterioration on a daily basis. Vizcom, which can obtain clearer information with visual scans, has produced superior results with the processing of reference images in addition to the prompts. This feature assists students in the learning process by inspiring them to create their own design language and adapt it to their projects.

Each interior design student develops their skills by following the path shown by the course instructors. Due to the rapid pace of technological progress, it is impractical to teach all the intricacies of a computer programme in a school environment. Vizcom is only an example used in the limited time available for this study. It is the students' duty to keep abreast of the latest developments in the field of artificial intelligence. As with other artificial intelligence tools, Vizcom has positive and negative aspects. As new technologies emerge over time, it will be easier for each student to choose a more appropriate tool.

Although the number of students participating in the experiment, time and the choice of the artificial intelligence tool used as the only tool are seen as limitations of this study, it is valuable in terms of the data it provides in integrating artificial intelligence into interior design education.

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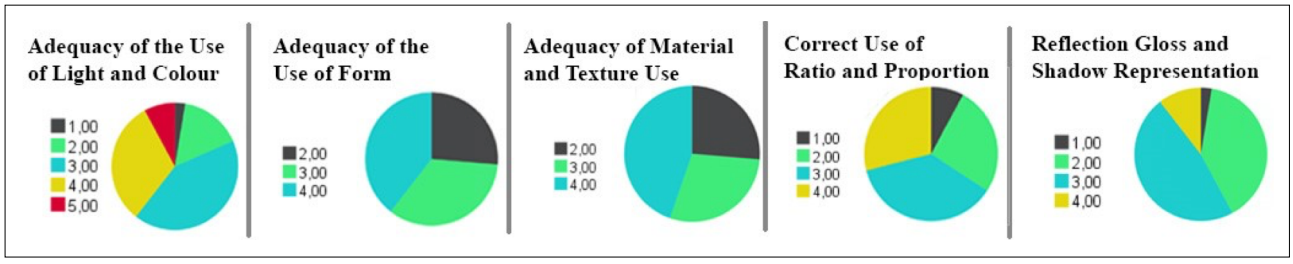

Figure 9. SPSS Graphs of the evaluation results of the visuals created with Vizcom within the scope of "Three-Dimensional Interior Architecture Visual Creation Criteria" (Figure by [Elif Küçük], 2025).

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Article

Effects of absorption and scattering values of liquids on global illumination

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ABSTRACT

In Global Illumination, calculating absorption and scattering values of transparent or semi-transparent materials is one of the most difficult phenomena. Absorption and scattering values affect indirect illumination. This phenomenon is often overlooked in realistic image processing software. When an absorption or scattering coefficient is not input for transparent or semi-transparent materials, the global illumination values do not change. In this study, an experiment was planned to see the effects of absorption and scattering values of liquids on spherical illumination. In the experiment, different liquids were placed in a 55 cm Cornell box, and the illuminance values on the surfaces of the Cornell box were measured for each liquid. The same scene was created with digital image synthesis software. Afterward, the luminance values in the real model and the virtual image were compared. This study proposes adding an absorption and scattering parameter to realistic image synthesis software for transparent and semi-transparent materials. This parameter was prepared with the Open Shading Language (OSL) developed by Sony Imageworks. In this way, the luminance values of the Cornell box in real and digital images are very close to each other.

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INTRODUCTION

Realistic image synthesis is the process of creating images that are indistinguishable from real photographs using computational methods and advanced techniques. Realistic image synthesis has important applications in many fields such as the film and video industry, virtual (VR) and augmented reality (AR), architecture and urban planning, industrial design, educational simulations, and medical imaging systems. Realistic image synthesis plays an important role in architecture and is not limited to visualization. Beyond determining how a building will look, it is an efficient tool for building information modeling, building physics, and materials analysis. By simulating the interaction of materials with light, this technology is used to measure their physical properties such as reflectivity, transmittance, and refraction. In addition, when integrated with virtual and augmented reality (VR - AR) technologies, realistic image synthesis has the potential for high-level interaction in the fields of architecture and design. As can be seen, the techniques used in realistic image synthesis, when used correctly and effectively, contribute to the improvement of projects both aesthetically and functionally.

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The main goal of realistic image synthesis is to simulate the natural behavior of light and improve the visual fidelity of objects and scenes. Direct illumination, indirect illumination, reflection and refraction, shadows, caustic effects, and global illumination are the basic principles for modeling the behavior of light. Algorithms used to model these principles include ray tracing, radiosity, photon mapping, and path tracing. All these algorithms are different methods for calculating global illumination. Each method, which samples the behavior of light, has advantages and disadvantages over the others. Ray tracing is a point sampling technique that traces infinitesimal light beams through a model (Whitted, 1980). Basic ray tracing, which started in 1980, is based on the principle of tracing light rays from the observer to the light sources. This approach deals only with mirror reflections, refractions, and direct illumination and cannot account for effects such as depth of field, motion blur, caustic, and bright reflections. Radiosity was developed to calculate indirect lighting effects (Cohen & Wallace, 1993). This technique is based on the idea that each surface on the stage can both receive light and act as a light source. It was developed as an alternative to light tracing methods, where the balance of light exchange between surfaces in the scene is calculated. The propagation algorithm is limited to simulating light effects such as the reflection of light from surfaces and its passage through transparent objects. Propagation is mainly designed to calculate the indirect light transfer between surfaces and how this light is scattered. It is often used in combination with other methods, such as ray tracing, to accurately simulate interactions such as reflection and refraction. The strength of the propagation method comes from its ability to calculate the overall illumination of the scene, indirect lighting effects, and the distribution of light between surfaces. Photon mapping shows very successful results in material and surface conditions where ray tracing and diffusion methods are inadequate (Jensen, 2001). This method is a two-step method used in global illumination calculations. The first stage is to record the scattering of photons from light sources and their interactions with surfaces. The second stage is the light calculations that use this information to produce visually accurate images. Photon mapping is suitable for modeling indirect illumination, caustics, and other complex light interactions. It is especially efficient in simulating transparent and semi-transparent objects compared to methods such as light tracing and diffusion. Path tracing is a powerful, realistic image synthesis method that simulates the complex interactions of light in a scene (Kajiya, 1986). By tracing the progression of light paths through the scene, it is able to model phenomena such as reflection, refraction, shadows, and indirect lighting in a natural way. This method works based on the physical laws of the real world. This makes it easy to create challenging effects such as indirect lighting, complex reflections, and caustics (bright light patterns caused by the refraction of light). In addition to these basic methods, complementary algorithms such as bidirectional ray tracing, Metropolis light transport, and Monte Carlo ray tracing are also used in conjunction with the basic methods.

In global illumination, the most complex situation to compute is the passage of light through transparent and semi-transparent objects. Light exhibits unique interactions, especially as it passes through liquids, being absorbed and scattered depending on the density and components of the liquid. These interactions affect the appearance of the liquid, its depth of color, and how objects in it appear. Absorption is the partial or complete absorption and retention of the energy of light as it travels through a medium. Liquids absorb certain wavelengths of light, causing the liquid to acquire a distinctive color. Accurately simulating absorption values allows liquids to gain a realistic sense of color and depth. Scattering is the change in direction of light as it travels through a medium. This feature causes the light to spread over a wider area in the liquid, creating a soft lighting effect in the process. Accurate modeling of scattering in a liquid affects the opacity of the liquid and the visibility of objects in it. Accurate calculation of absorption and scattering values ensures that the colors of liquids and the objects in them are seen realistically, which contributes to the overall atmosphere of the scene. Absorption rates, which vary depending on the depth of the liquids, create a perception of depth in the scene. Scattering creates soft lighting effects in and around the liquid and makes the shadows on the liquid surface and on the objects in it appear more realistic. Absorption and scattering determine how clear objects in the liquid appear. This is important for the degree of blur in the liquid and the visibility of details behind objects.

Accurate modeling of the absorption and scattering values of liquids, as part of global illumination algorithms, plays a critical role in producing photorealistic images. This is especially important in scenes involving transparent materials such as water, glass and different liquids to enhance visual realism.

BACKGROUND

Global Illumination

Global Illumination (GI) is a lighting model in computer graphics and rendering technologies that provides a realistic calculation of the light in a scene. GI takes into account not only the light coming directly from the light source but also the light that is reflected between surfaces and objects in the scene and reaches other surfaces indirectly (Angel & Shreiner, 2020). This approach allows for more natural and detailed lighting and shadows to be created in scenes. For example, thanks to GI, light reflected from one surface carries its color to other surfaces, adding

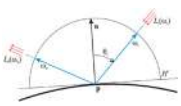
a color-bleeding effect to the scene. Based on the principle of energy conservation, this model is compatible with physically based rendering (PBR) and ensures that the total energy of light remains constant in the scene (Peddie, 2019). GI simulates direct and indirect light calculations with ray tracing and path tracing, while techniques such as radiosity and photon mapping are used to model complex light distribution. In addition, volumetric lighting adds depth to scenes by accounting for the transport of light in participating environments (e.g. fog and smoke). GI is indispensable for providing lifelike and dynamic lighting in areas such as film, animation, architectural visualization, and modern game development.

Basic Radiometric Quantities

Radiometry is the field that deals with the entire electromagnetic spectrum, including visible light, and studies the measurement of radiation. In this context, three fundamental quantities are considered: flux, irradiance, and radiance (Kurachi, 2007).

- Radiant Flux (Φ) is the total electromagnetic energy emitted from a source in a given time interval. Its unit is expressed in Watts (W) (Table 1).
- Irradiance (E) is the energy flux falling on a surface. It is defined as the amount of energy incident on a surface area and is expressed in watts/square meter (W/m^2). It is often used when analyzing sunlight or other light sources (Table 1).
- Radiance (L) is the flux of energy emitted or reflected from a unit area in a given direction. This quantity provides information about both the direction of light and the amount of light leaving the source. It is expressed in watts/(square meter-steradian) [$W/(m^2$-sr)] (Table 1).

Table 1. Radiometric quantities and expressions

Reference	Quantity	Formula Expression
	Radiant Flux (Φ)	$\Phi = \frac{dQ}{dt}$
	Irradiance (E)	$E(p) = \frac{d\Phi(p)}{dA}$
	Radiance (L)	$L(\mathrm{p},\omega) = \frac{\mathrm{d}^2\Phi(\mathrm{p},\omega)}{\mathrm{dA}\,\mathrm{d}\omega\,\cos\theta} = \frac{\mathrm{dE}(\mathrm{p},\omega)}{\mathrm{d}\omega\,\cos\theta}$

Radiometric units cover the entire electromagnetic spectrum, while photometric units are organized according to the visible light spectrum, which only the human eye can detect. Therefore, radiometric and photometric units differ from each other (Table 2).

BRDF-Based Lighting Models

BRDF (Bidirectional Reflectance Distribution Function) is a mathematical function that defines the angle and intensity at which light coming to a surface is reflected from this surface. It determines the scattering of light in different directions by reflecting from the point where it hits the surface and thus analyzes the optical properties of the surface (Zhou, 2023). BRDF models the interaction of light with the surface, simulating the physical properties of the material such as matte, glossy, metallic or translucent. This function is used in computer graphics and rendering processes to obtain realistic visualizations. It helps calculate both the direct and indirect lighting. BRDF-based lighting models increase the realism of reflections in scenes by also taking into account the interactions of light with the texture and microstructures of the surface (Guarnera et al., 2016).

The image of objects in the real world is formed when ambient light is reflected from the surface of the object and reaches our eyes. BRDF is a function that describes the relationship between light incident on a surface and reflected light (Figure 1). Its mathematical expression is as follows:

$$f_r(p,\omega_i,\omega_0) = \frac{\mathrm{d}L_0(p,\omega_0)}{\mathrm{d}E_i(p,\omega_i)} = \frac{dL_0(p,\omega_0)}{L_i(p,\omega_i)\cos\theta_i d\omega_i}$$

In this equation,

- $f_r\,(p,\omega_i,\omega_0)$ represents the BRDF
- p is a point on the surface
- ω_i is incoming light directional
- ω_0 is the direction of the observer or reflected light
- $\mathrm{d}L_0\,(p,\omega_0)$ is the differential reflected radiance of the surface in the direction ω_0
- $\mathrm{d}E_i\,(p,\omega_i)$ is the differential illuminance of the surface from the incoming light direction ω_i
- θ is the angle between the incoming light direction ωi and the surface normal at the shading point p.

Integrating over the entire semi-spherical surface:

$$L_0(p,\omega_0) = \int_{\Omega} f_r\,(p,\omega_i,\omega_0)L_i(p,\omega_i)\cos\theta_i d\omega_i$$

Table 2. Radiometric and photometric units

Quantity	Radiometric Unit	Photometric Unit
Radiant Flux (Φ)	Watt (W)	Lumen (lm)
Irradiance (E)	Watt per square meter (W/m^2)	Lux (lx)
Radiance (L)	Watt per square meter per steradian ($W/(m^2{\cdot}sr)$)	Candela per square meter (cd/m^2)
Radiant Intensity (I)	Watt per steradian (W/sr)	Candela (cd)

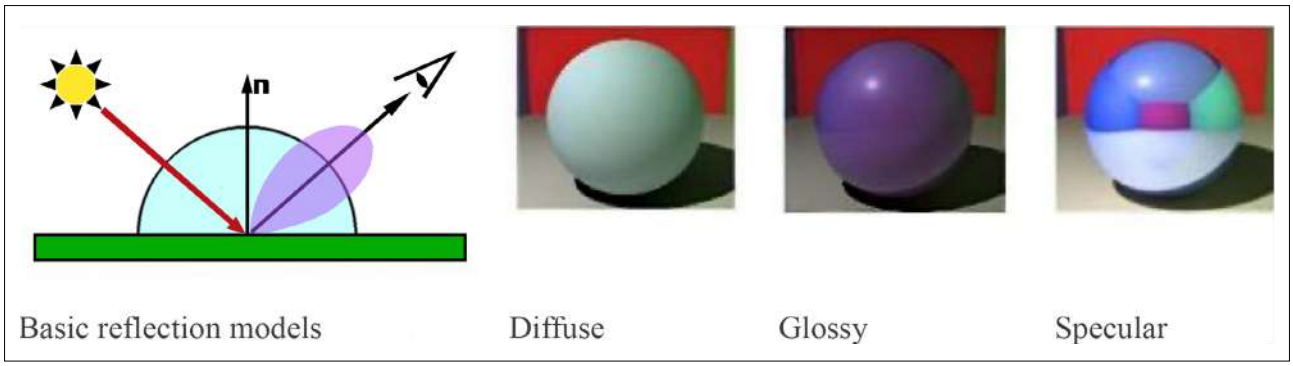


Figure 1. Basic reflection models for incident light (Goral et al., 1984).

In general, BRDF describes the distribution of outgoing light after it reflects from a point on the object's surface with the direction of the incoming light. In computer graphics, the BRDF is represented as a three-component RGB vector. BRDF has basic properties such as reversibility, energy conservation, and linearity.

The reversibility of the BRDF is based on the Helmholtz Reciprocity Principle, which states that changing the incident and reflected light will not change the BRDF value:

$$L_0(p, \omega_i, \omega_0) = L_0(p, \omega_0, \omega_i)$$

BRDF is also subject to the principle of energy conservation. The energy conservation equation is as follows (Q represents the corresponding energy):

$$Q_{incoming} = Q_{reflected} + Q_{absorb} + Q_{transmitted}$$

Therefore, it can be concluded that:

$$Q_{reflected} \leq Q_{incoming}$$

Therefore, the BRDF must satisfy the following integral inequality for the energy conservation property:

$$\forall \omega_i, \int_{\Omega} f_r(p, \omega_i, \omega_0) \cos\theta_i d\omega_i \leq 1$$

The linearity property of BRDF requires multiple BRDF calculations for the correct reflection description. The total reflected radiance of a point on a surface can be simply represented as the sum of the individual BRDF reflected radiances. For example, bright diffuse reflectance can be obtained by calculating multiple BRDFs.

To make BRDF data easier to process and more efficient, the researchers translated them into numerical models. These models were categorized as empirical and physically based. In addition, data-driven models were developed to directly obtain measured BRDF data and use it in the processing process.

Empirical Models

Empirical models are generally focused on the calculation of reflected light. They produce simple formulas for fast calculations on this subject. Empirical models include parameters based on observation of the behavior of light and provide results close to physical reality. However, they may not fully meet the laws of physics such as reversibility and conservation of energy.

In 1975, Bui Tuong Phong (Phong, 1975) introduced the Phong Reflection Model to simulate specular reflections. Considered one of the earliest BRDF models, it described the light reflected by a point on a surface towards an observer as the sum of various light intensities. The Phong Reflectance Model is one of the most basic and common reflectance distribution functions used to model how surfaces reflect light and provides a simple yet effective approach to making surfaces appear matte or shiny. For this reason, it is still used today as a basic reference in many computer graphics applications.

The Phong model describes the behavior of light on a surface with two main components. Diffuse accounts for the dispersion of light on the surface, and specular accounts for the reflection of light back to the observer. Thus, the Phong BRDF combines these two components to calculate the reflection behavior of a surface. However, the Phong model fails to simulate more complex surface properties and micro-surface details.

In 1977, Jim Blinn (Blinn, 1977) developed the Blinn-Phong reflection model as an improvement to the Phong model. The Blinn-Phong model simplifies some of the calculations of specular reflections in the Phong model and provides a more efficient computational process while providing similar visual results. For this reason, it has become widely used in computer graphics. Although the Phong model uses the angle between the ideal reflection vector and the view vector to calculate the specular component, the Blinn-Phong model uses a different vector called the half-vector. The half-vector represents the direction halfway between the light source vector and the line-of-sight vector, so the calculation is performed with this half-vector instead of the ideal reflection vector. This method is particularly computationally efficient and provides a more stable result.

The Blinn-Phong model produces more realistic specular highlights, especially on surfaces with high specular exponential values. Highlights appear more diffuse or more focused depending on the smoothness of the surface and

the light source. This increases realism by making surfaces look more natural. In addition, the half-vector calculation reduces visual errors due to changes in the angle between the light source and the observer. However, the Blinn-Phong model, like the Phong model, does not take into account the orientation of the observer relative to the surface. This can lead to inaccurate reflections at some angles.

In 1992, Ward (Ward, 1992) proposed the Ward BRDF model, an empirical model developed by measuring and fitting reflection data of objects. This model was an important step forward, especially for photorealistic imaging and the simulation of light reflection properties. In particular, he aimed to more accurately model the reflection properties of metallic surfaces. Ward's BDRF model takes into account the effects of surface roughness and micro-geometric properties on reflections in areas where traditional Lambertian surfaces are inadequate in reflection modeling. Based on the assumption that the micro-roughnesses on the surface are randomly distributed, the Ward BDRF model determines the different reflectance amounts of these roughnesses according to the directions. Therefore, the Ward model more accurately describes the reflection behavior of anisotropic surfaces (i.e., surfaces with different properties in different directions).

However, the original Ward BRDF model has energy loss when light is scattered. In 2006, Arne Dür (Dür, 2006) made some additions to Ward's model and introduced a more accurate and flexible reflection model. The Ward-Dür model ensured that surface reflections conform to the principles of energy conservation. In 2010, Geisler-Moroder and Dür (Geisler-Moroder & Dür, 2010) developed the Ward-Dür BRDF model to conserve energy at all angles. This version of the model addresses the problem of energy conservation by introducing a finite albedo parameter that helps to ensure that the model remains physically plausible at all angles. However, Ward's 1992 BDRF model is considered a revolutionary development, especially for computer graphics and rendering engines.

In 2000, Ashikhmin & Shirley (Ashikhmin & Shirley, 2000) proposed a new BRDF model inspired by the models of Ward (Ward, 1992), Schlick (1994), and Neumann et al., (1999). The Ashikhmin-Shirley model was a new experimental model with many desirable properties, such as energy conservation and reciprocity. It allows anisotropic reflection to create effects such as the striped appearance of brushed metal. The parameters of the model are intuitive and take into account the Fresnel effect, which causes the specular reflection to increase as the angle of incidence decreases. In addition, the diffuse term is not constant, so the diffuse component decreases as the angle of incidence decreases. This model is well suited for Monte Carlo processing techniques.

Physically-Based Models

Physically based models are models that calculate surface reflectance in more detail based on physical principles and produce more accurate results. Because they are physically accurate, they are particularly suitable for realistic rendering and simulations. These models more accurately describe the microstructure of surfaces and the direction of light reflection. Physically based BRDF models are based on physics concepts such as energy conservation and Helmholtz reciprocity.

In 1967, Torrance & Sparrow (1967) used radiation and microfacet theory to produce a rough surface specular reflection model. In 1981, Cook & Torrance (1981) introduced the Cook-Torrance model, an improved version of the Torrance-Sparrow model. The Cook-Torrance model is based on the microsurface theory. According to this theory, the irregular structure of the surface consists of tiny bends and ridges at the micro level and light interacts with these micro surfaces and reflects at different angles depending on the degree of roughness of the surface. This reflection model takes into account not only the reflection properties of the surface, but also the effects of roughness, shadowing, and light refraction.

The Cook-Torrance model is a microfacet model widely used in computer graphics. It is used to simulate the appearance of metal and glass materials and has many advantages, notably the Fresnel effect. In this model, the Fresnel effect, the reflection of light at tangential angles from surfaces, is more accurately calculated, and the anisotropic reflection used to achieve the appearance of brushed metal is also obtained. In addition, the Cook-Torrance model is used to model a wide range of materials, from dull to shiny surfaces.

In 1991, He et al., (1991) published a paper proposing a more complex and purely physical BRDF model based on wave optics. This model takes into account the polarization of smaller scattering angles of light, diffraction, interference, surface conductivity, and roughness, and can simulate more optical phenomena than microfacet models. However, the computational cost is much higher.

The Oren-Nayar model was introduced by Oren & Nayar (1994) in 1994. This model was developed for rough surfaces and establishes a relationship between surface roughness and reflection pattern. One of the main advantages of the Oren-Nayar model is that it simulates the surface roughness of real objects to a certain extent, giving them a more textured appearance. However, it may not be suitable for real-time applications as the computation times are too long.

Data-Driven Models

Data-driven models are a type of general model that provides a way to quantify anisotropic BRDFs based on measured

data. These save a large set of BRDF materials as high-dimensional vectors and then use dimension reduction to compute a low-dimensional model from this data. This allows a lookup table-based approach to directly find processing results and saves a lot of real-time computation. Matusik et al., (2003) described in their 2003 paper how they implemented a series of studies and obtained a data-driven reflectance model. In addition, many laboratories have used a variety of tools to measure reflectance data of various real-world materials under different light angles and observation angles and recorded them in public databases such as the MERL BRDF Database.

Since data-driven models are based on measurements of real-world materials, the resulting renders are very realistic, and this is one of the main advantages of these models. However, a major drawback is the lack of parameters for adjusting effects, so it is not possible to manipulate the data to achieve the desired results. In addition, data collection for some extreme angles is difficult due to instrument limitations. These models also require large amounts of data and are computationally expensive, making them less suitable for real-time applications such as video games, but suitable for offline renders such as movies. They can also be used in graphics research to evaluate the realism of other BRDF models.

Participating Media-Based Lighting Models

Participating media-based lighting models are lighting models that simulate how light interacts not only with surfaces but also with particles within a medium. These media can be transparent or translucent substances such as air, fog, smoke, water. Participating environments take into account the absorption, scattering and redirection of light, resulting in a more realistic and immersive visual experience in scenes (Cerezo et al., 2005).

Participating media are volumes filled with particles that affect the light passing through them by scattering or absorption. This term refers to media that actively participate in the transmission of light. In computer graphics, low-density media such as water, fog, steam, and air, in addition to solid surfaces, are also important for modeling their interactions with light. The composition and particle density of a medium determine the behavior of light in the medium. In homogeneous media (e.g., air or water), the density is constant, while in heterogeneous media (e.g., clouds or steam), the density is variable. Some dense materials, such as skin or candle wax, exhibit high levels of light scattering, and such interactions form the basis of diffuse surface shading models. As a result, all media scatter or absorb light to some extent, depending on their density and composition (Deng et al., 2020).

In recent years, various algorithms have been introduced to handle participatory media, such as many light-based methods (virtual ray lights, VRL) (Novák et al., 2012), various extensions to photon mapping resulting in unified points, rays and paths (UPBP) (Křivánek et al., 2014), Monte Carlo-based methods (Herholz et al., 2019) and point-based methods (Wang & Holzschuch, 2017). All these methods have greatly improved the simulation of participating media.

Features of Participating Media

In a participating medium, three different phenomena affect the amount of radiation emitted along the beam (Siegel & Howell, 1992).

- Absorption: The medium absorbs some of the light, and the light energy is converted into heat or other energy. The intensity of light absorbed determines the degree of opacity of the medium.
- Scattering: Light changes direction when it hits particles in the medium. This process scatters some of the light in other directions. In Single Scattering, light is scattered only once and then either hits the observer or another surface. In Multiple Scattering, light is scattered more than once in many directions. This is more pronounced in dense environments.
- Light Extinction: Light loses intensity due to both absorption and scattering.

Participating media-based lighting models are usually based on the Radiative Transfer Equation (RTE). This equation mathematically describes the absorption, scattering, and propagation of light in a medium (Table 3):

$$L(x,\omega) = L_e(x,\omega) + \int_V \sigma_s(x,\omega') \cdot L(x,\omega') \cdot p(\omega',\omega) d\omega'$$

In this equation,

- $L(x,\omega)$ is the light intensity at a given point (x) and direction (ω).
- $L_e(x,\omega)$ is the light emitted from a light source.
- $\sigma_s(x,\omega')$ is the scattering coefficient.
- $p(\omega',\omega)$ a is the phase function (determines which direction the light is scattered).

Table 3. Features and units used in participating media (Akenine-Möller et al., 2018)

Symbol	Feature	Unit
σ_a	Absorption coefficient	m^{-1}
σ_s	Scattering coefficient	m^{-1}
σ_t	Extinction coefficient	m^{-1}
ρ	Albedo	unitless
p	Phase function	sr^{-1}

Types of Participating Media-Based Lighting Models

- Volumetric Lighting: A lighting method in computer graphics and visualization that simulates how light propagates, absorbs, and scatters through a medium. It is used to model the interactions of light with participating media such as smoke, fog, vapor, or water instead of solid surfaces. This technique is particularly important for adding depth, atmosphere, and dramatic visualization to scenes (Novák et al., 2018).
- Ray Marching: Although it works on a similar principle to ray tracing, ray marching calculates the density of the medium or its distance from the surface at each step the light travels, which is a great advantage, especially for complex volumetric media.
- Single Scattering: This model simulates situations where light is scattered only once. It is less complex and gives fast results in low-density environments (e.g. light fog). However, it does not provide realism in dense environments such as multiple scattering (Jönsson et al., 2014; Yan et al., 2013).
- Multiple Scattering: Simulates the complex interactions that occur when light is scattered more than once. It can produce more realistic results for environments such as dense fog, smoke, or water. Computational cost is high, but the results are highly detailed (Jönsson et al., 2014; Yan et al., 2013).
- Subsurface Scattering: Simulates light penetrating translucent materials (such as skin, wax, milk), propagating through them and then exiting. This model is especially used for realistic visualization of organic materials such as skin (Dutré at al., 2006; Kurachi, 2007).

Comparison of BRDF and Participating Media-Based Lighting Models

These models are the two main approaches used to model the interaction of light with different physical media. BRDF-based models deal with the interactions of light with surfaces while participating media-based models simulate how light propagates, absorbs, and scatters within a volume (participating media) (Table 4).

BRDF (Bidirectional Reflectance Distribution Function) is a model that describes the light reflection of surfaces. It calculates the reflection of light from a surface depending on the incoming and outgoing light angles. It is often used for opaque surfaces and simple lighting situations. BRDF models are fast, so they are common in real-time rendering engines, but focus only on surface effects.

Participating media-based models simulate the propagation, scattering, and absorption of light in a medium. These models are ideal for handling volumetric effects such as fog, smoke, or water. Participating ambient models focus on physical accuracy but are computationally expensive and are often favored in cinematic rendering engines.

As a result, BRDF is simpler and faster, suitable for surface reflections. Participating environment models, on the other hand, are more complex but are required for effects that aim for volumetric and physical accuracy. The two are often used together to optimize both surface and volumetric lighting effects.

METHOD

In this study, an experiment was planned to determine the effects of absorption and scattering values of liquids on global illumination. In this experiment, a glass filled with different liquids was placed in a 55cm Cornell box and the luminance values on the surfaces of the Cornell box were measured for each different liquid. The same scene was created digitally with V-Ray 6 and Corona software for image synthesis. As a result, the surface luminance values of the real model and the virtual image were compared.

- Color Contrast: The colors red and green are opposite each other in the color spectrum. This contrast makes it easier to observe the reflection and propagation of light on different surfaces. Thus, the behavior of light on different colors can be analyzed more clearly.
- Light Reflection and Diffusion: Different colors reflect and diffuse light in different ways. Strong colors such as

Table 4. Comparison of BRDF and participating media-based models

Feature	BRDF-Based Models	Participating Media-Based Models
Focus	Surface-Oriented	Volume-Oriented
Type of Interaction	Reflection, Refraction	Absorption, Scattering, Multiple Scattering
Physical Theories	Fresnel Reflection, Micro-face Distribution, Conservation of Energy	Radiative Transfer Equation
Physical Accuracy	High Accuracy for Surface Materials	
	High Accuracy in Volumetric Environments	
Calculation Cost	Lower	Higher
Areas of Usage	Metal, Glass, Plastic Surfaces	Fog, Smoke, Liquid, Atmospheric Effects

red and green make the behavior of light on these surfaces apparent. In this way, the reflection and propagation properties of light can be studied in more detail.

- Realism and Accuracy: The use of red and green colors is used to test the accuracy of calculations made to create realistic scenes in computer graphics and visual effects. These colors are ideal for testing light and shadow interactions and how the human eye perceives these interactions.
- Psychological Impact: The colors red and green are easily distinguishable to the human eye. This allows observers to analyze light and color interactions more easily.

The experiment was conducted with a 55 cm Cornell box, a surface-mounted luminaire and a measuring device (Figure 2). The interior surfaces of a 55 cm box were painted with RAL code-defined colors (Table 5) (Figure 3).

The equivalents of the three colors on the experiment box surfaces in all other color systems have been calculated (Table 6). These values will be the reference in the virtual experiment to be conducted later.

The luminaire is a surface-mounted model used for indoor lighting (Table 7). Luminaire, supplied by İkizler Lighting, has been tested again in the company's laboratory. The technical data of the products manufactured in industrial design are very close to each other. However, due to production conditions, the values are not exactly the same. All technical features of the luminaire have been re-measured in order to simulate the virtual scene very close to reality. In addition, the IES Map has been prepared to be used in the 3D scene.

Figure 2. Experiment box, luminaire, spectroradiometer, and liquids.

Table 5. RAL codes for the Cornell box

Surface	RAL Codes
Red Surface	RAL 3020
Green Surface	RAL 6001
White Surface	RAL 9003

Konica Minolta CS-2000 Spectroradiometer was used for the measurements (Figure 4).

In the Cornell Box, the luminance values on the box surfaces were measured for an empty glass and 8 different liquids. The value changes in different liquids were compared in tables. In this experiment, an empty glass, water, milk, olive oil, white wine, red wine, beer, honey, and grape vinegar were used (Figure 5). Measurement values are (cd/m^2).

For each liquid, luminance values were measured at 16 different points on the Cornell box surface (Figure 6). In addition, an identification number is defined for the points defined on the colored surfaces (Table 8).

In this experiment, the change in luminance values of points determined on the Cornell box surfaces under the influence of different liquids was investigated. The luminance value at each point is the sum of the direct light, reflected light, and indirect light reaching after being absorbed by the liquid (Figure 7).

The luminance values of three different surfaces in the Cornell Box were measured. Each surface was divided into three equal parts horizontally and vertically after leaving a 2 cm gap from the edges. Thus, 4 axes intersecting each other horizontally and vertically were formed. The intersection points of these axes are the 16 points to be measured. The luminaire located in the middle of the upper surface of the Cornell box emits light in all directions at 180 degrees. In this case, each point on the surface to be measured is at a different position and angle from the light source. In this sense, measuring from 16 different points for each surface is an important factor in understanding the distribution and reflection of light (Table 8).

Experiment Results

In the measurements, it is seen that the red and green surface values are close to each other (Table 9; Table 10; Figure 8; Figure 9). However, it was determined that the white surface values are different from the red and green values (Table 11) (Figure 10). While the red and green surfaces have the same angle and position as the light source, the angle and position of the white surface are different. The luminance value on the surfaces is the sum of four different light values (Figure 7). These are the direct light coming from the luminaire, the indirect light coming by bouncing off other surfaces, the indirect light coming by reflecting off the glass surface, and the indirect light coming after being absorbed in the glass. In this case, the only element that will affect the values in measurements made with different liquids is the liquid in the glass. The values are affected by the different color and absorption coefficients of these liquids. The purpose of this study is to determine whether these experimental findings made with a real model give the same results in software that performs realistic image synthesis.

Figure 3. Experiment box and RAL codes.

Table 6. Color code equivalents in other color systems

RAL 6001			
RGB	54, 103, 53	CSS	rgb (54, 103, 53);
HSL	119, 32, 31	CSS	hsl (119, 32%, 31%);
HSB	119, 49, 40	Hex	#366735
CMYK	80, 30, 100, 10	Websafe	#336633
RAL 3020			
RGB	187, 30, 16	CSS	rgb (187, 30, 16);
HSL	5, 84, 40	CSS	hsl (5, 84%, 40%);
HSB	5, 91, 73	Hex	#bb1e10
CMYK	0, 100, 100, 10	Websafe	#cc3300
RAL 9003			
RGB	236, 236, 231	CSS	rgb (236, 236, 231);
HSL	60, 12, 92	CSS	hsl (60, 12%, 92%);
HSB	60, 2, 93	Hex	#ecece7
CMYK	0, 0, 0, 0	Websafe	#ffffff

Virtual Scene Experiment

The experiment, the technical details of which are described above, was simulated in 3D environment. Cornell box, luminaire, and glass were modeled with the same dimensions and material properties were defined. The luminaire used was re-measured in the manufacturer's laboratory and an IES map was taken by these values. The RAL color codes of the surfaces were converted to RGB values and this value was processed into the material properties. V-ray 6.0 and Corona 11 were used as image-processing software. Surface luminance values were measured as (cd/m^2) with the VrayLightingAnalysis render element module in V-Ray software. Since Corona software does not have a Light Analysis module, indirect illuminance values on the surfaces were measured with the Indirect Light render element module.

Table 7. Technical Specifications of the Luminaire

Luminaire Photometric Test Report					
Test: U:224.20V I:0.0873A P:18,674W PF: 0.9544 Freq:50.03Hz UTHDi:0.00%					
Lamp Flux:983,472x1 lm					
Name	Canvas-T	Type	Su	Weight	0.6 kg
Spec.	4000K	Dim.	175x175x115mm	Serial No.	05250.22.40.022.N000
Mfr.	İkizler Lighting	Sur.		Shielding Angle	
Data of Lamp		**Photometric Data**	**Eff: 52,66 lm/W**		
Model	Led	Imax (cd)	338.1	S/MH (C0 / 180)	1.25
Nominal Power (W)	18.67	LOR (%)	100.0	S/MH (C90 / 270)	1.26
Rated Voltage (V)	220	Total Flux (lm)	983.47	η UP, DN (C0 - 180)	0.9 – 49.2
Nominal Flux (lm)	983,472	CIE Class	Direct	η UP, DN (C180 - 360)	0.6 – 49.2
Lamps Inside	1	η up (%)	1.6	CIBSE SHR NOM	1.25
Test Voltage (V)	220	η down (%)	98.4	CIBSE SHR MAX	1.35

Figure 4. CS-2000 Spectroradiometer.

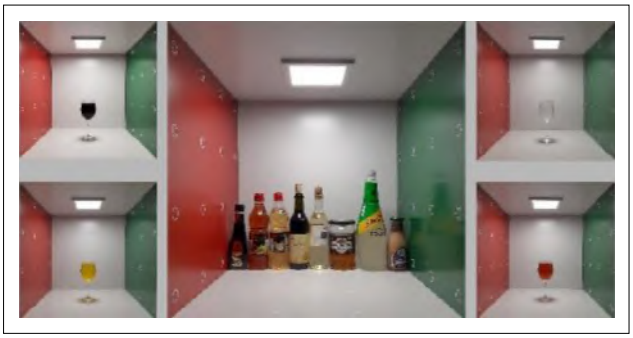


Figure 5. Empty glass and 8 different liquids.

Figure 6. Experiment box and measuring points.

Virtual Scene Material Properties

The materials of the red, green, and white surfaces are defined by Diffuse - Roughness, Reflection - Glossiness, and Fresnel Reflection parameters. VRayIES light was used for the light value in the luminaire illumination. The material properties of the glass and all liquids are defined by the parameters Diffuse - Roughness, Reflection - Glossiness, Fresnel Reflection, Refraction - Glossiness - IOR, and Translucency - Fog Color - Depth(cm).

Table 8. Measurement points inside the Cornell box

Surface	Measurement Points
Red Surface	L01, L02, L03, L04, L05, L06, L07, L08, L09, L10, L11, L12, L13, L14, L15, L16
Green Surface	L17, L18, L19, L20, L21, L22, L23, L24, L25, L26, L27, L28, L29, L30, L31, L32
White Surface	L33, L34, L35, L36, L37, L38, L39, L40, L41, L42, L43, L44, L45, L46, L47, L48

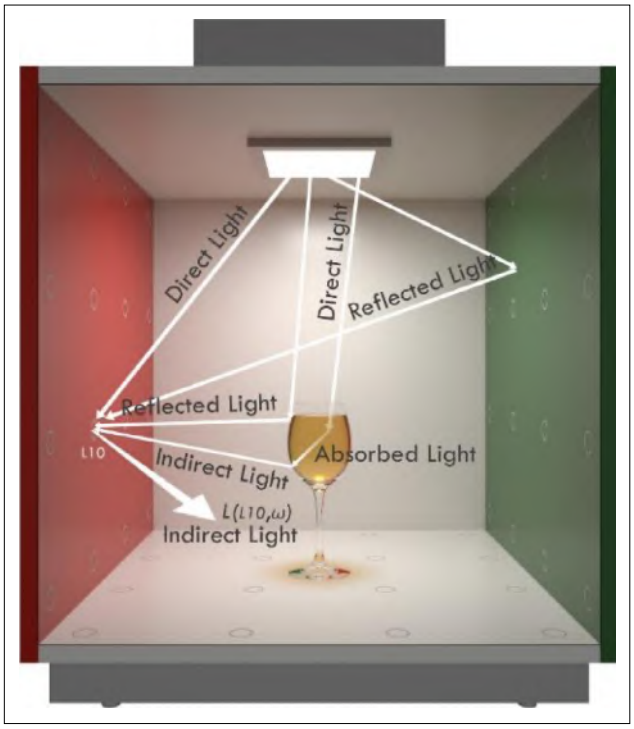


Figure 7. Example light scheme at point L10.

Virtual Experiment Results

Realistic renders of the Cornell box and liquids created with V-ray 6 software (Figure 11; Figure 12; Figure 13):

Light analysis renders of the Cornell box and liquids created with V-ray 6 software (Figure 14; Figure 15; Figure 16):

Realistic renders of the Cornell box and liquids created with Corona 11 software (Figure 17; Figure 18; Figure 19):

Indirect light renders of the Cornell box and liquids created with Corona 11 software (Figure 20; Figure 21; Figure 22):

The measurement values taken from the surfaces in the real model experiment do not match the surface measurement values in the images created in V-ray and Corona software. The reason for this is that the software generally does not define an absorption coefficient for liquid materials. Each transparent and semi-transparent material has its own absorption coefficient. Open Shading Language (OSL) was preferred to add this feature to the software. Open Shading

Table 9. Measurement values on the red surface of the Cornell box (cd/m²)

Liquids	L01	L05	L09	L13	L02	L06	L10	L14	L03	L07	L11	L15	L04	L08	L12	L16
Empty Glass	32.68	86.69	66.96	67.11	43.98	121.5	91.86	98.54	42.53	120.1	99.59	106.1	36.35	104.1	91.74	79.04
Water	34.24	90.5	71.48	75.1	44.79	123.8	96.42	107.6	44.39	124.3	103.2	113.8	37.66	105.3	96.67	98.34
Milk	33.39	89.28	70.71	73.92	47.81	123.8	95.97	107.3	46.96	121.1	104.4	115.1	38.54	105.7	115.9	94.22
Olive Oil	32.58	88.97	70.42	73.42	43.54	124	96.55	107	42.33	132.8	111.9	113.8	38.2	110.3	110.1	85.89
White Wine	31.61	87.83	70.23	72.66	43.84	122.9	96.18	105.2	43.3	120.8	104.2	112.9	38.3	100.9	98.3	82.78
Red Wine	33.31	87.49	69.09	73.53	44.31	121.5	94.9	104.2	40.89	132.2	101.5	111.6	37.91	117.7	93.84	86.25
Beer	31.65	88.53	69.91	72.68	42.82	123	95.05	105.4	45.78	120.5	101.9	112.9	34.14	106.3	96.41	92.96
Honey	32.95	90.92	71.45	73.89	43.99	123.7	95.76	106.6	42.35	124.7	103.3	112.8	39.61	105.5	94.99	88.45
Grape Vinegar	34.35	91.49	71.89	108.2	44.37	127.6	97.97	107.8	44.32	149.5	113.1	115.3	37.98	120.9	107.8	94.52

Table 10. Measurement values on the green surface of the Cornell box (cd/m²)

Liquids	L33	L37	L41	L45	L34	L38	L42	L46	L35	L39	L43	L47	L36	L40	L44	L48
Empty Glass	71.8	68.2	91	31.8	104	91.7	119	44	113	99.1	116	42.2	84.4	98.4	126	39.4
Water	72.3	68.4	91	31.5	104	91.7	119	43.7	113	99	117	42.5	84.8	105	115	36.8
Milk	70.7	66.3	88.6	31.5	103	90.8	119	44.5	113	98.3	115	39.7	83	104	105	43.1
Olive Oil	73.4	68.9	91.5	29.5	106	92.5	120	42.4	116	100	116	47.9	91.8	122	125	45.5
White Wine	72.1	67.4	89.8	30.1	104	90.9	119	43.6	113	98	115	40.7	85.8	106	99.6	36.1
Red Wine	71.3	66.4	88.1	28.7	103	90.3	117	39.6	112	96.9	113	48	91.7	96.7	114	44.2
Beer	72.1	67.1	89.9	30.4	104	90.7	119	41.6	114	98.1	115	40.4	100	94.1	122	42
Honey	72.4	66.9	90.1	30.4	104	90.2	118	42.6	113	97.8	119	40.2	85.2	101	111	36.2
Grape Vinegar	72.3	67.6	90.3	29.4	105	91	119	41.1	114	102	122	40.7	108	129	116	42.4

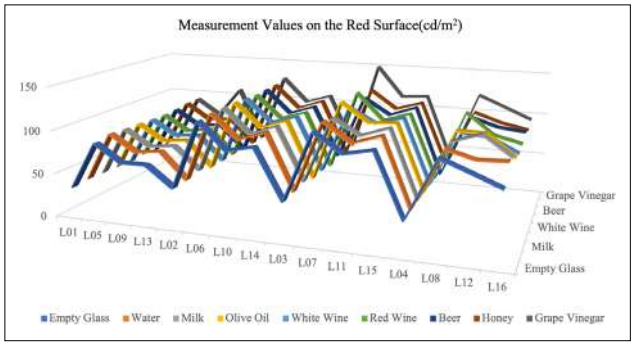


Figure 8. Radiance change graph on the red surface.

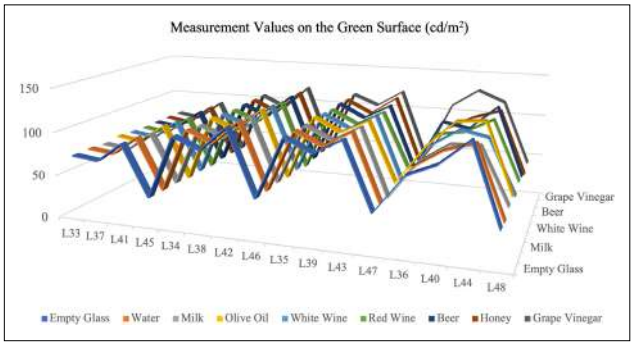


Figure 9. Radiance change graph on the green surface.

Language (OSL) was preferred because it works integrated with rendering software such as Arnold, Blender/Cycles, Pixar/Renderman, Chaos/V-ray, Chaos/Corona.

Adding Parameters with Open Shading Language

This work continues in terms of analyzing other realistic image processing software and preparing the code infrastructure of the proposed parameters. Software such as Arnold Renderer and Renderman are being analyzed. In addition, it is planned to add the proposed parameters to the materials with the Open Shading Language (OSL) language developed by Sony ImageWorks.

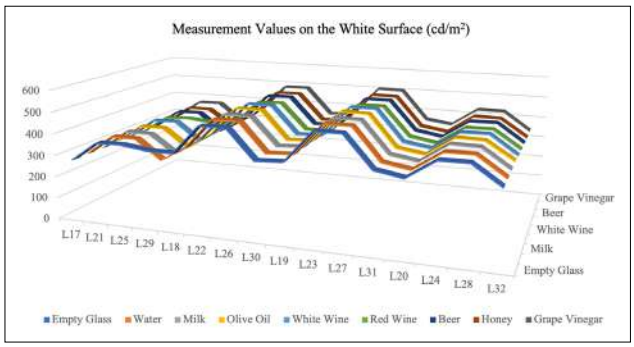


Figure 10. Radiance change graph on the white surface.

Table 11. Measurement values on the white surface of the Cornell box (cd/m²)

Liquids	L17	L21	L25	L29	L18	L22	L26	L30	L19	L23	L27	L31	L20	L24	L28	L32
Empty Glass	275	363	366	350	349	480	482	350	356	497	497	357	335	420	421	336
Water	276	365	365	276	351	482	485	351	358	502	501	357	336	423	423	337
Milk	274	362	359	275	353	481	481	354	361	502	501	360	340	427	424	339
Olive Oil	279	361	361	275	354	485	486	353	362	506	502	359	340	425	423	344
White Wine	277	364	368	279	352	483	484	354	357	501	501	358	338	422	424	338
Red Wine	273	355	360	348	347	469	472	349	352	489	490	355	333	416	418	335
Beer	276	360	365	278	350	478	480	352	355	496	495	357	336	420	422	336
Honey	274	359	358	274	347	474	475	348	356	493	492	353	333	420	417	335
Grape Vinegar	282	368	370	280	357	484	485	355	363	503	502	361	344	430	428	341

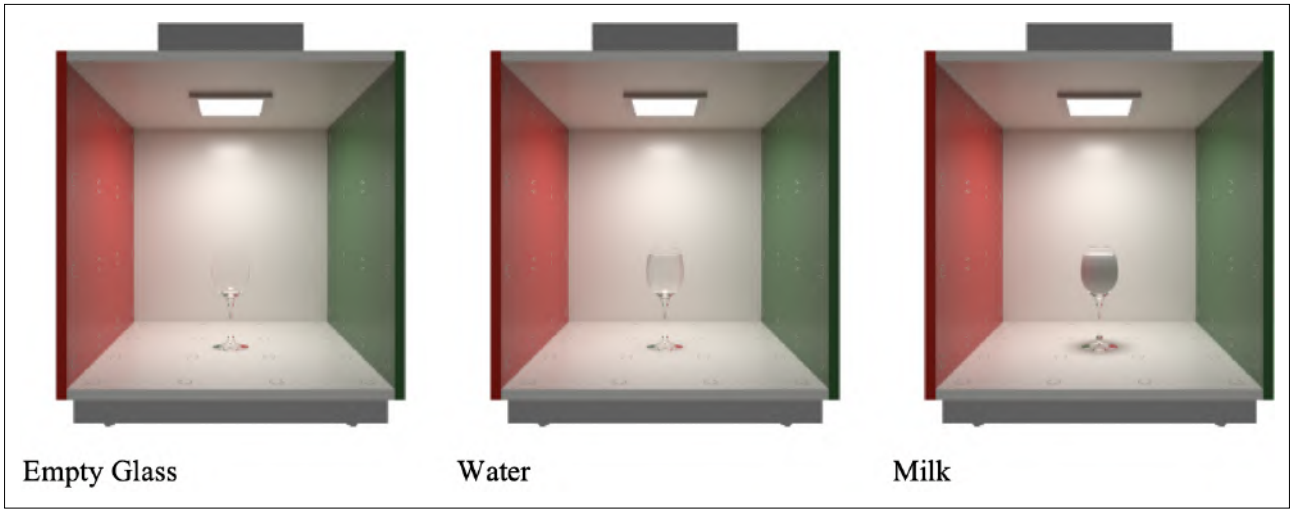


Figure 11. V-ray realistic renders of empty glass, water, and milk.

Figure 12. V-ray realistic renders of olive oil, white wine, and red wine.

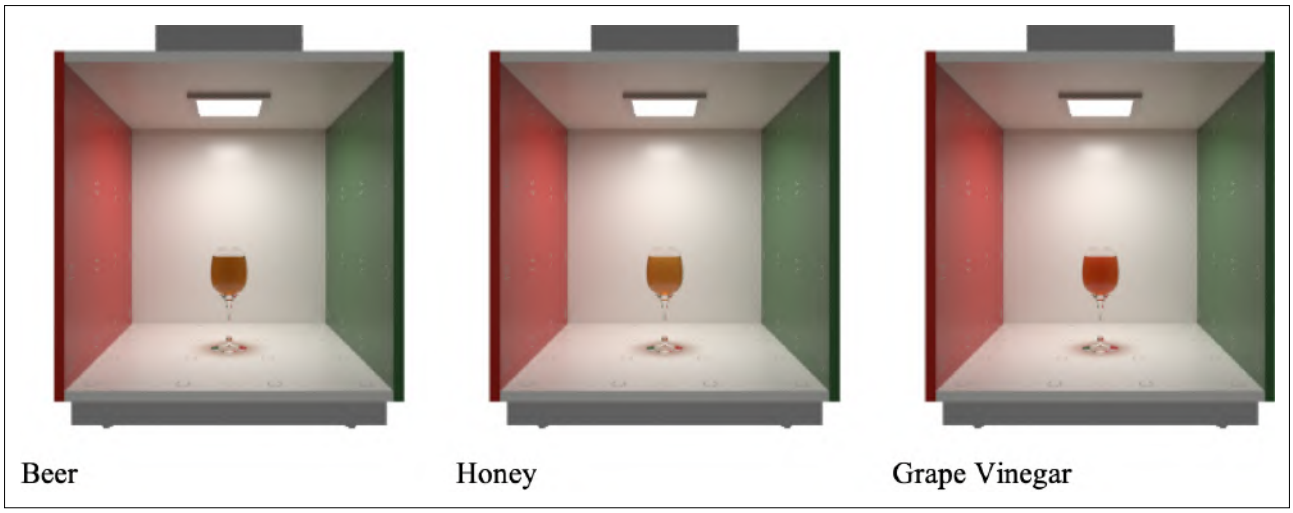


Figure 13. V-ray realistic renders of beer, honey, and grape vinegar.

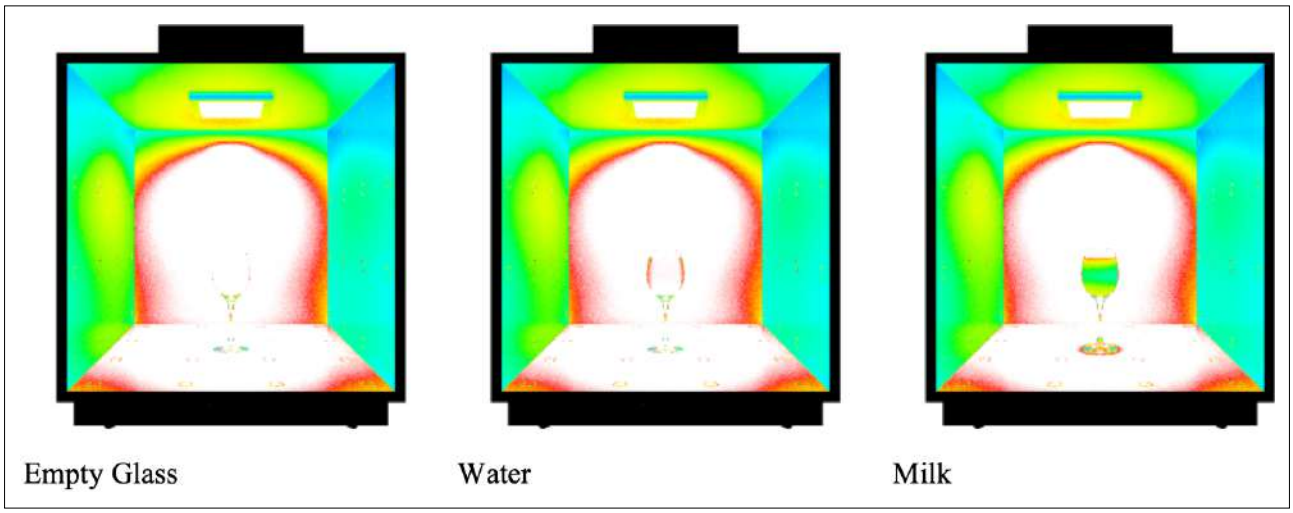


Figure 14. V-ray light analysis renders of empty glass, water, and milk.

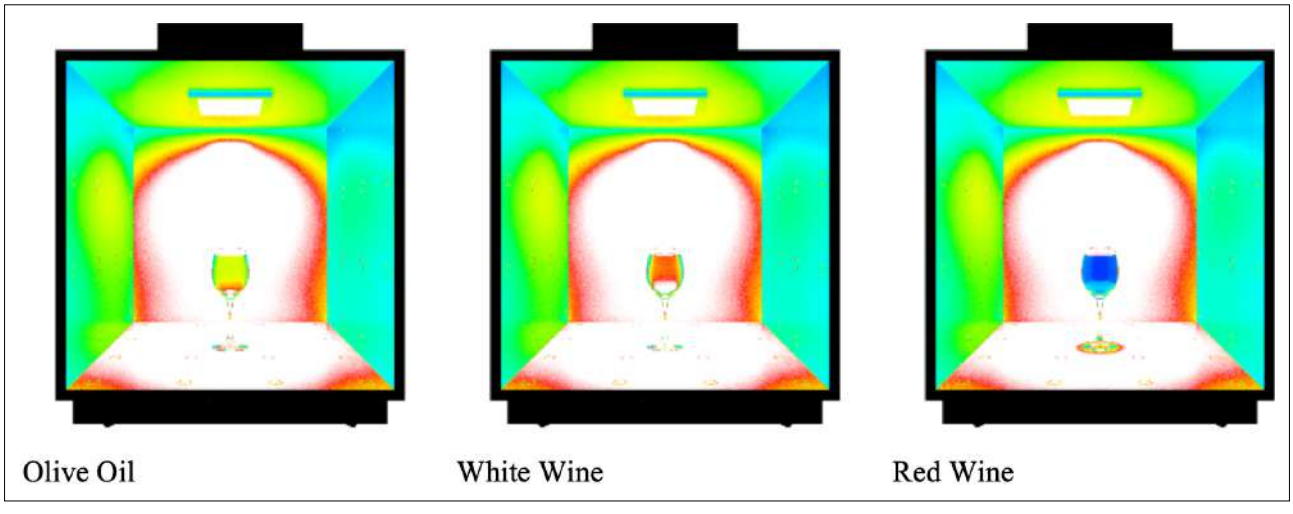


Figure 15. V-ray light analysis renders of olive oil, white wine, and red wine.

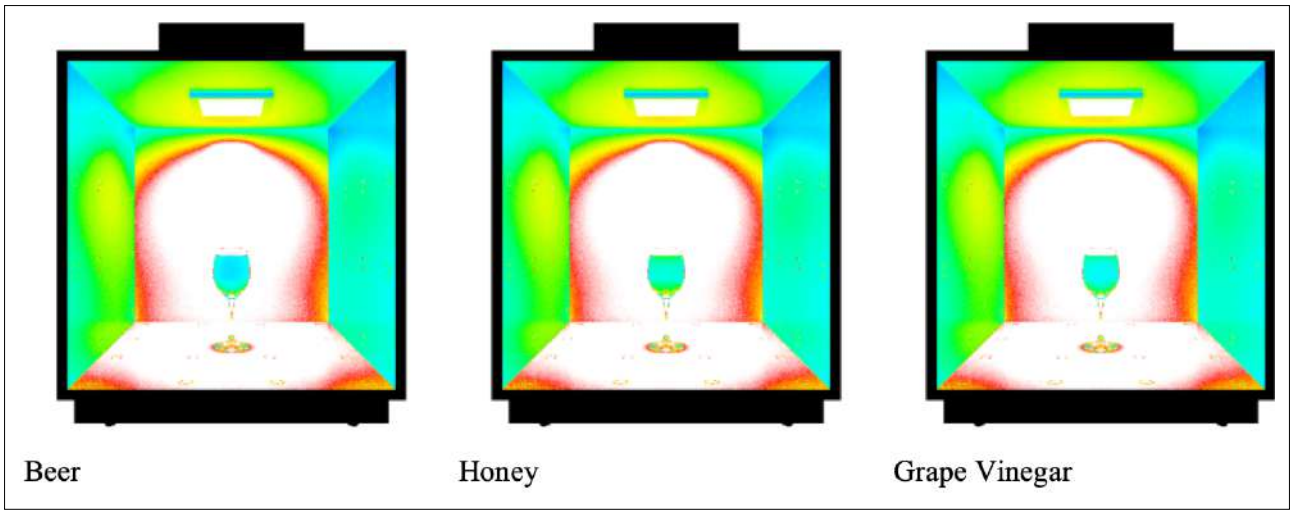


Figure 16. V-ray light analysis renders of beer, honey, and grape vinegar.

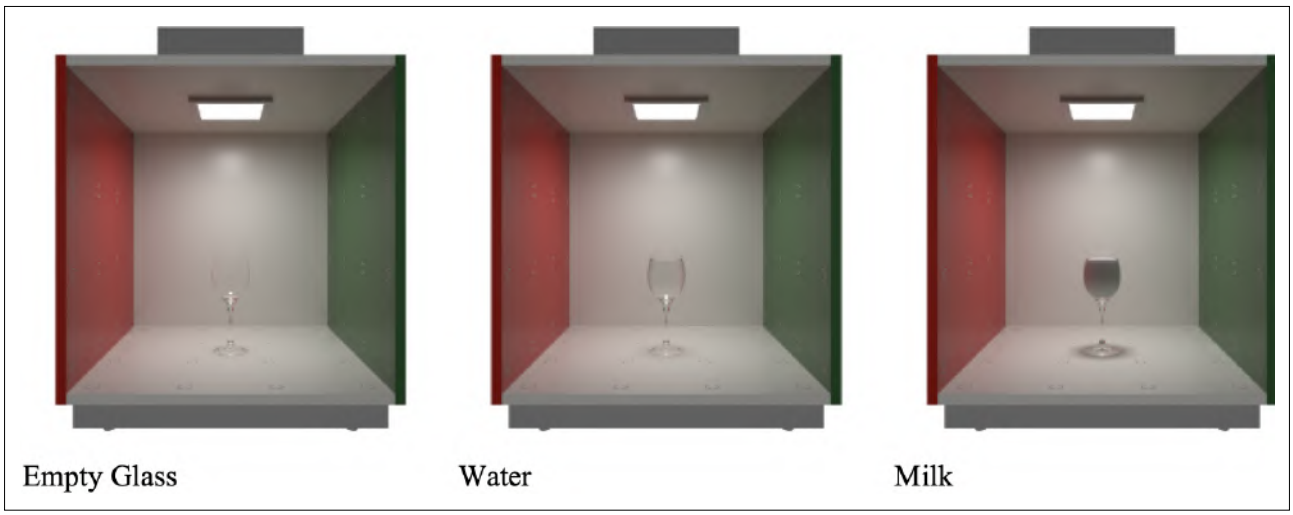


Figure 17. Corona realistic renders of empty glass, water, and milk.

Figure 18. Corona realistic renders of olive oil, white wine, and red wine.

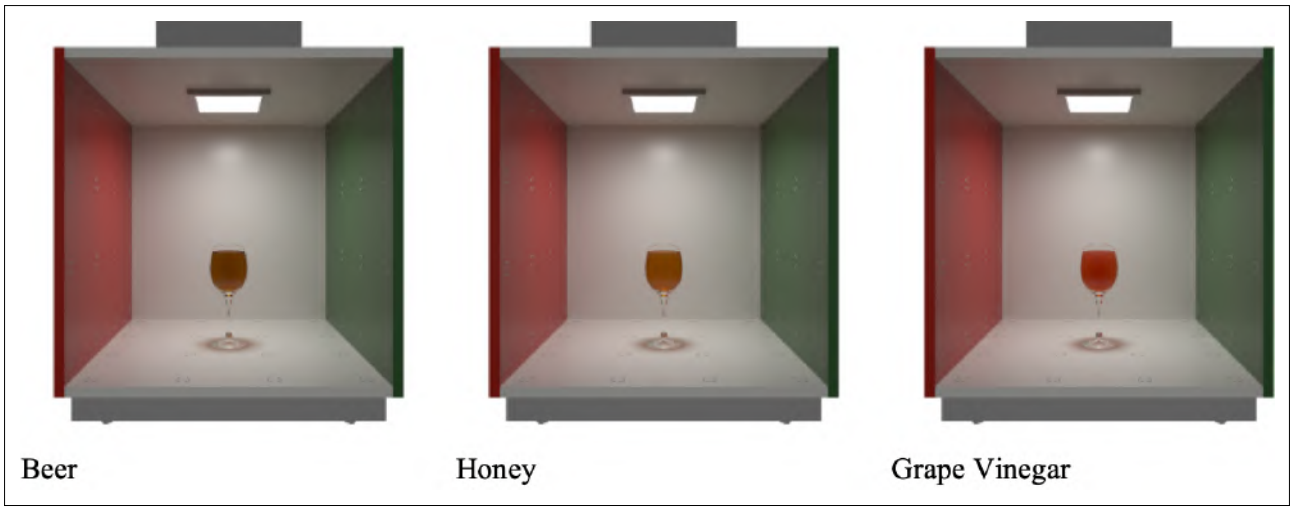


Figure 19. Corona realistic renders of beer, honey, and grape vinegar.

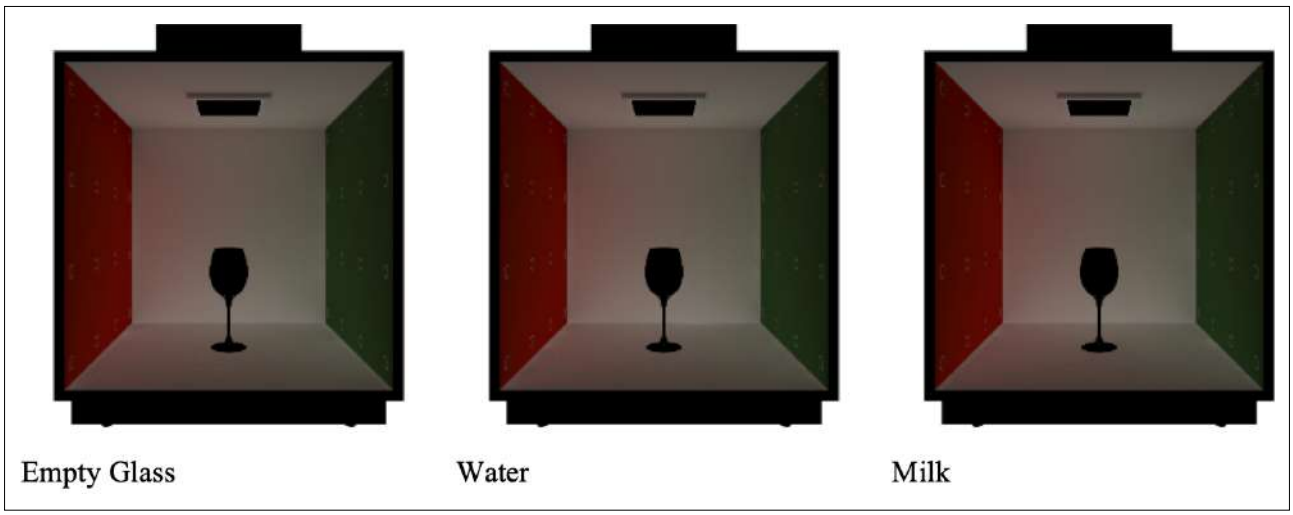


Figure 20. Corona indirect light renders of empty glass, water, and milk.

Figure 21. Corona indirect light renders of olive oil, white wine, and red wine.

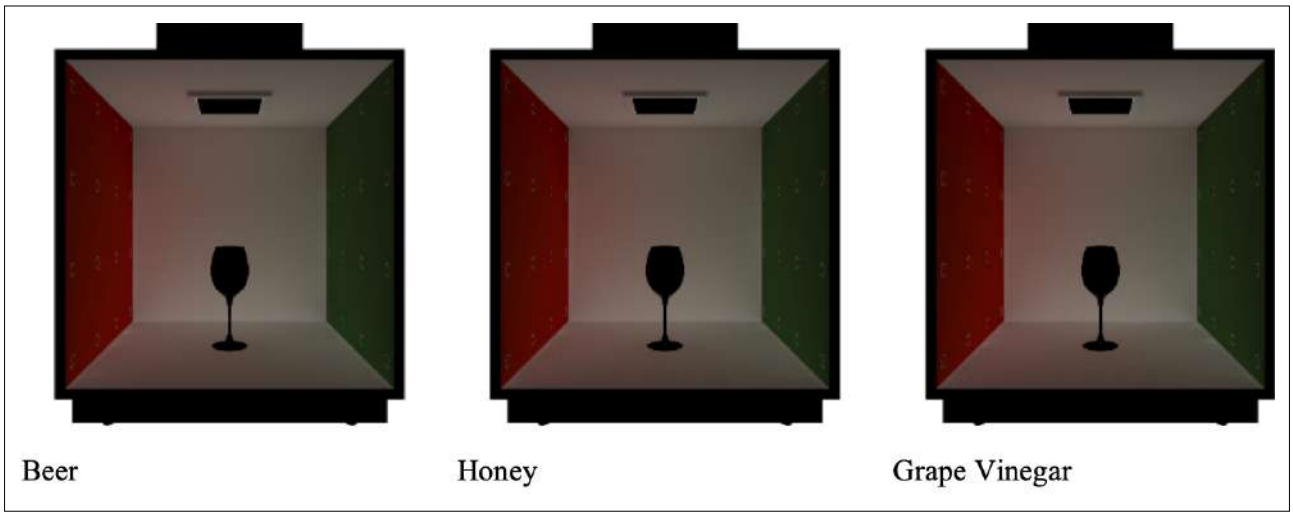


Figure 22. Corona indirect light renders of beer, honey, and grape vinegar.

Shader Variables

- base_color: A variable of type "color" that represents the base color of the material. Color(1.0, 1.0, 1.0) : Default white color
- liquid_name: A variable of type "string" representing the name of the liquid. The user can specify this value in the interface.

string liquid_name = "Custom Liquid";

- absorption_value: A "float" variable representing the absorption value of the selected liquid. The user can specify this value in the interface.

float absorption_value = 0.1;

0.1 : Default absorption value

min = 0.0, max = 1.0 : Minimum and maximum values

- custom_absorption: A "float" variable representing the absorption value for a user-specified type of liquid.

float custom_ absorption = 0.1;

0.1 : Default absorption value

min = 0.0, max = 1.0 : Minimum and maximum values

- absorption_influence: A variable of type "float" representing the local absorption effect.

float absorption_influence = 1.0;

1.0 : Default absorption value

- influence_radius: A variable of type "float" representing the radius of influence of regional effects.float influence_ radius = 1.0;

1.0 : Default radius of influence

- result: A variable of type "output color" representing the final calculated color.

output color result = color(0.1, 0.1, 0.1);

- transform: A function that performs the transformation of the current point.

point Pobj = transform ("object" , P);

"object" : Transform type

" P" = Valid point

- getattribute: A function to get the value of the specified attribute.

if (getattribute(("occlusion" , dirt_value)) { …. }

" occlusion" : The attribute name to retrieve.

" dirt_value" = Variable to store the value in.

The OSL code prepared according to the variables explained above is connected to the diffuse channel of the base material (Figure 23). Therefore, the light entering the material is defined to affect the environment and itself after being absorbed. In addition, an easy interface is provided to enter data (Figure 24).

Shader Code

```
shader AbsorptionProximity(
  color base_color = color(1.0, 1.0, 1.0), // Base color of the material
  int liquid_type = 0 // Type of liquid
    [[ string widget = "mapper",
string options = "Water:0| Milk:1| Beer:2| OliveOil:3| Honey:4| GrapeVinegar:5| WhiteWine:6| RedWine:7| Other:8",
      string label = "Liquid Type",
        string description = "Select the type of liquid for absorption properties" ]],
    float custom_absorption = 0.1 // Custom absorption value for "Other" liquid type
```

Figure 24. OSL code interface.

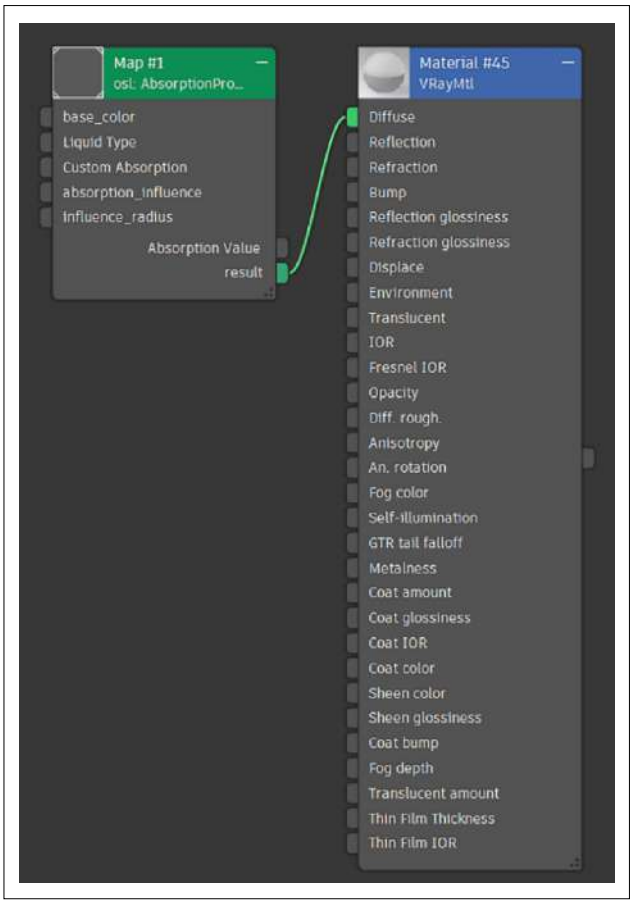


Figure 23. OSL shading network.

```
[[ string label = "Custom Absorption",
        string description = "Custom absorption value for 'Other' liquid type",
        float min = 0.0, float max = 1.0, string visible_when = "liquid_type == 8" ]],
    output float absorption_value = 0.1 // Absorption value for the selected liquid
        [[ string label = "Absorption Value",
        string description = "Absorption value for the selected liquid",
        float min = 0.0, float max = 1.0, string visible_when = "liquid_type != 8" ]],
    float absorption_influence = 1.0, // Influence factor for surrounding absorption
    float influence_radius = 1.0, // Radius of influence for surrounding objects
    output color result = color(1.0, 1.0, 1.0) // Output color
)
{
    // Local variable to store the absorption value based on the selected liquid type
    float base_absorption;
    // Set the base_absorption based on the selected liquid type
    if (liquid_type == 0) {
        base_absorption = 0.1; // Water
    } else if (liquid_type == 1) {
        base_absorption = 0.5; // Milk
    } else if (liquid_type == 2) {
        base_absorption = 0.3; // Beer
    } else if (liquid_type == 3) {
        base_absorption = 0.7; // Olive Oil
    } else if (liquid_type == 4) {
        base_absorption = 0.8; // Honey
    } else if (liquid_type == 5) {
        base_absorption = 0.6; // Grape Vinegar
    } else if (liquid_type == 6) {
        base_absorption = 0.2; // White Wine
    } else if (liquid_type == 7) {
        base_absorption = 0.4; // Red Wine
    } else if (liquid_type == 8) {
        base_absorption = custom_absorption; // Custom value for Other
    }
```

```
    // If the selected liquid is not "Other", update the absorption_value for the UI
  if (liquid_type != 8) {
    absorption_value = base_absorption;
  }
  // Get the current point in object space
  point Pobj = transform("object", P);
  // Calculate a simple dirt value based on proximity
  float dirt_value = 0.0;
  if (getattribute("occlusion", dirt_value)) {
    // Calculate adjusted absorption value
    float adjusted_absorption = base_absorption;
    if (dirt_value > 0.0) {
      float influence_factor = 1.0 - dirt_value;
    adjusted_absorption += influence_factor * absorption_influence;
    }
    // Calculate the final color based on absorption
    result = base_color * (1.0 - adjusted_absorption);
  } else {
    result = base_color;
  }
}
```

CONCLUSION

In the Cornell box experiment, as a result of precise measurements, the luminance values on the box surfaces were different for each different liquid. The luminance value on the box surface is the sum of direct and indirect light energy. Indirect light energy is affected by light reflected from surfaces and absorbed and scattered within the liquid. The difference in the measurements here is due to the different absorption and scattering values of each liquid. However, in the experiment with realistic image processing software, the results on the Cornell box surfaces are almost identical. The reason for this is that there is no absorption parameter in the material definitions in the software. From a physical perspective, in the real world, all materials except dielectric materials have a light absorption rate. The missing parameters in the liquid materials were added with the Open Shading Language, and an experimental study was put forward. Open Shading Language is an open-source software and has been preferred because it has support for many software. Different software languages can also be preferred instead. The important factor here is to be aware of the absorption parameter. This work continues to be developed.

As a result, it is necessary to use participating media models together with BRDF illumination models in realistic image processing software. Using participating media means that absorption and scattering coefficients are included in the calculations. Thus, the light energy that bounces off objects and incidents on surfaces in global illumination can be more accurately described. In addition, a pre-measured preliminary absorption and scattering value of each liquid can be defined. This method will reduce the computational cost as in the Data-Driven BRDF model. This approach will contribute to more accurate results in all areas of realistic image synthesis. In addition to realistic image synthesis, surface and volume calculation image processing algorithms will also be necessary in areas such as building information modeling, structural physics, and material analysis. Finally, the absorption coefficient must be taken into account in all simulation models related to light.

ETHICS: There are no ethical issues with the publication of this manuscript.

PEER-REVIEW: Externally peer-reviewed.

CONFLICT OF INTEREST: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Article

A critical discourse on phenomenological reflexes of liveability in architectural design

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ABSTRACT

The Cartesian approach draws a sharp distinction between mind and body, adopting a rational and quantifiable understanding of the world. The phenomenological critique of the Cartesian approach emphasizes that it neglects the subject's perceptions, emotions, and experiences; instead, it argues that the mind and body perform in unity. The concept of liveability (livability), which gained significant momentum in the 20th century alongside phenomenology, encompasses notions such as well-being, happiness, and satisfaction, in addition to objective indicators focused on the quality of the physical environment. These notions demonstrate that liveability possesses a subjective dimension that is perceptual, sensory, and experiential in nature. However, liveability assessments predominantly focus on objective indicators and quantitative data, overlooking the multidimensional and complex nature of liveability that pertains to both the object and the subject. This study aims to highlight the theoretical and methodological potentials of liveability from a Cartesian-critical perspective by analyzing its phenomenological dimensions through theoretical and discursive analysis. Phenomenology offers an alternative understanding of liveability and insights for place-making by defining the subject's lived experience and bodily perception within the context of place-time. Based on thinkers such as Husserl, Heidegger, Merleau-Ponty, and Norberg-Schulz, and architects like Pallasmaa, Tschumi, Zumthor, Holl, and Aalto, phenomenologically, liveable places are environments that support human existence through multisensory experiences, emotional resonance, and embodied perception. Rather than aiming for urban perfection, liveability focuses on enhancing well-being by enriching the identity and experiential quality of places, ultimately contributing to a higher quality of life.

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INTRODUCTION

The origins of liveability debates date back to the 1950s, a period marked by observations of disappearing open spaces, the loss of urban identity, and the declining quality of urban living environments (Pressman, 1981). Following these concerns, the liveability of cities began to be discussed from various perspectives. While there is no precise date for the term's first usage, Ley (1980) notes that in the 1960s, an

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urban reform party in Vancouver advocated for liveability as a strategy against growth-oriented approaches, adopting a planning perspective centered on people rather than the economy.

In the 1980s, Donald Appleyard's book Livable Streets associated the concept of liveability with traffic management and mobility, leading to its frequent inclusion in the literature (Yassin, 2019). By 2009, the concept gained significant attention through a set of principles introduced by the Partnership for Sustainable Communities. During the 1990s, researchers—particularly in the U.S. and Europe—focused increasingly on liveability studies. This trend became visible in Eastern regions, especially Asian countries, in the early 2000s (Paul & Sen, 2020).

In recent decades, with accelerating urbanization on a global scale, liveability and its societal welfare implications have grown increasingly critical, forming the core motivation for studies aimed at understanding liveability (Kyttä et al., 2015).

Today, numerous national and international institutions measure the liveability of a place using objective indicators such as education, career and employment opportunities, housing and cost of living, diversity of cultural activities, and local health and safety conditions. These quantitative assessments are used to select the "world's most liveable cities" (EIU, 2024; OECD, n.d.).

On the other hand, liveability represents a qualitative construct that embodies the characteristics making a place an attractive and desirable living environment (Vuchic, 1999). Vienna, Austria which was ranked as the "world's most liveable city" in 2024 and previous years (EIU, 2024), uses the German term *lebenswert*—meaning "liveable"—to convey the notion of "worth living in" (Langenscheidt, n.d.).

Liveability is closely linked to numerous concepts, including well-being, quality of life, life satisfaction, welfare, utility, positive and negative emotions, biodiversity, and ecosystems (Ruth & Franklin, 2014; Papachristou & Rosas-Casals, 2015).

The incorporation of liveability into people's daily lives and experiences demonstrates that the concept possesses not only objective indicators pertaining to the physical environment but also a subjective evaluative dimension encompassing human perception, senses, and emotions. Researchers adhering to purely objective approaches argue that a subjective assessment of liveability is unfeasible due to variations in individual preferences. Consequently, some scholars in the literature contend that focusing on a balanced set of indicators—integrating both objective measures and subjective perceptions of environmental quality and resident experiences—would yield more meaningful results in the context of liveability (Ruth & Franklin, 2014; Kashef, 2016; Namazi-Rad et al., 2016).

This situation highlights the challenges in defining and measuring indicators of liveability, a complex and multifaceted concept. The literature contains relatively few studies that address overcoming these challenges or unlocking their potential. Figure 1 presents a synthesis of existing studies in the field, highlighting gaps in the literature and delineating the focus of this research.

Liveability studies focusing on subjective indicators and the complex nature of these indicators (Hortulanus, 2000; Boeing, 2018; Dsouza et al., 2023; El-Didy et al., 2023) appear to intersect with concepts and topics associated with phenomenology. While Cartesian critical liveability studies emerging from this relationship reveal some overlapping concepts and themes between theoretical and experimental research, they predominantly address distinct concepts and topics. Conceptualizations in the field largely stem from theoretical studies. Concepts such as meaning of life, quality of life, well-being, and happiness (Veenhoven, 2000) presented in these studies have yet to be reflected in experimental research. This underscores the challenges in translating these concepts into testable hypotheses for experimental studies and the difficulties in measuring such data.

Experimental studies far outnumber theoretical ones and cover a broad research scope. Notably, although experimental studies focus on subjective indicators, they often predominantly employ quantitative assessments and statistical methods (Salehi et al., 2017; Baig et al., 2019; Amin et al., 2020; Ho et al., 2020; Mahanta & Borgohain, 2022; Sultana et al., 2022; van Dinter et al., 2022; Zhan et al., 2023). Moreover, as illustrated in Figure 1, the expansion of experimental research to encompass concepts and topics such as rural living, sustainability, and technology (Graham & Lora, 2009; Macke et al., 2018; Zhong et al., 2020; Johnson-Woods & Feldpausch-Parker, 2022; Alshammari, 2023; Chen et al., 2023; O'Sullivan et al., 2023; Pang et al., 2024) contributes to a more nuanced understanding of the theoretical constructs introduced in scholarly work.

The differences between theoretical and experimental research reveal both significant potential and various challenges in the field of liveability studies, demonstrating the need for broader investigation of conceptual dimensions. In this context, it can be argued that the literature requires more studies focusing on the subjective dimensions of liveability.

METHODOLOGY

The study aims to highlight recent developments in liveability research and make the theoretical and methodological potentials of liveability more visible from a phenomenological perspective. The study employs

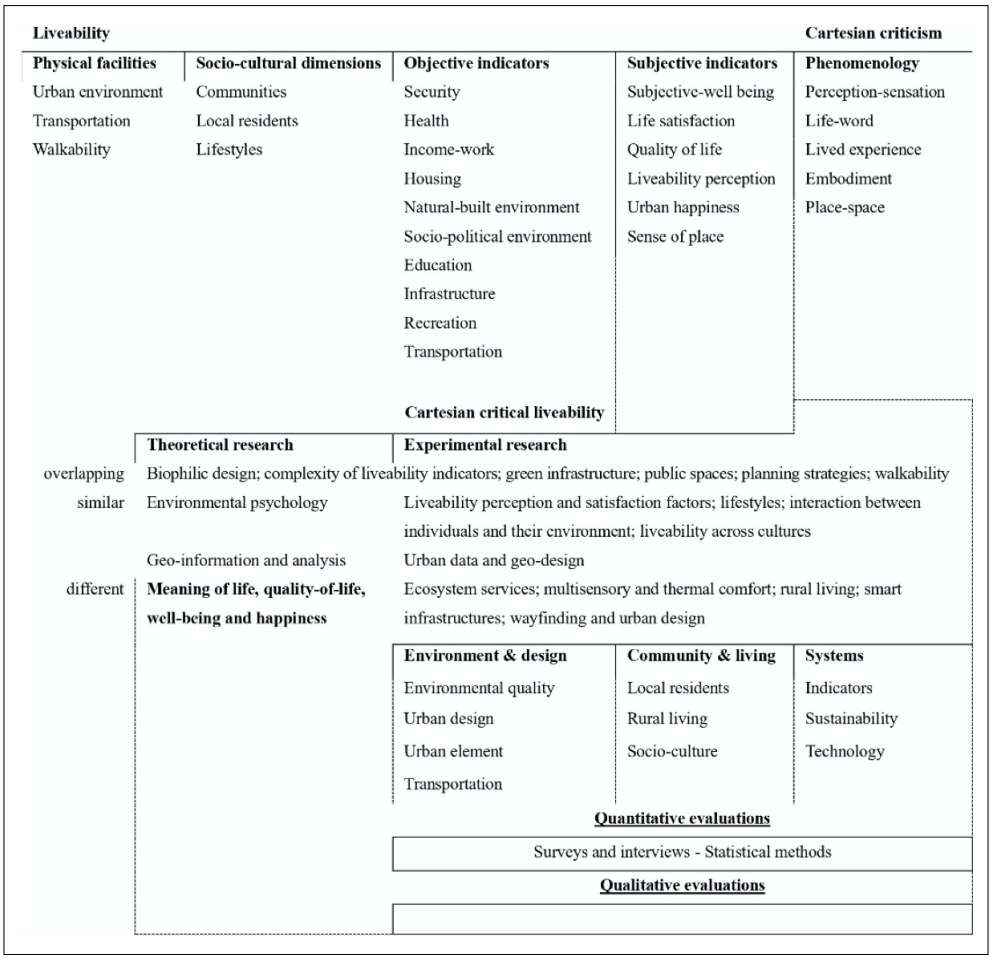

Figure 1. Cartesian critical liveability studies.

theoretical analysis and discursive analysis to provide a comprehensive examination of the liveability concept.

The theoretical analysis employs the philosophical perspective of Cartesian critique (Cartesian dualism and critical approach to the human-nature dichotomy) to reveal the phenomenological dimensions of liveability. This analysis evaluates the concept's historical evolution, inherent contradictions, and aspects open to alternative theoretical interpretations, while providing depth to understanding how liveability can be defined relationally. Discourse analysis, a widely used method in qualitative research, examines how language and narratives shape social and professional practices (Fairclough, 1995). It enables understanding of what power dynamics liveability approaches reflect and how they construct social reality.

The review has two research questions:

1. How does phenomenological perspective challenge or expand the Cartesian (objectivist/quantitative) foundations of liveability research?
2. How does phenomenological perspective reveal the theoretical and methodological potentials of liveability?

First, the study identifies pioneering approaches that lay the groundwork for a phenomenological examination of liveability. Subsequently, it traces the interactions between Cartesian critique and liveability and presents the phenomenological dimensions of liveability. Thereby, it reveals the evolving and developing dimensions of liveability within a phenomenological framework. The outcome of this study includes: (1) A discussion of the potential meanings of liveability and the characteristics of liveable places from a phenomenological perspective, and (2) an examination of their prospective capacity to generate place-making insights.

Figure 2 compiles the events, agents, actors, and discourses that reveal the phenomenological aspects of liveability. The philosophers listed in Figure 2 are not only the pioneers of phenomenology (Husserl, 2015; Heidegger, 1996; Merleau-Ponty, 1962), but also thinkers who have engaged with the concept of place (Bachelard, 2018; Gadamer, 2009; Heidegger, 1971; Norberg-Schulz, 1980). Their ideas provide the theoretical foundation for studies positioned at the intersection of architecture and phenomenology. The architects included in Figure 2 are those who have either

			Key Discourses
Events	**Eras**	1950s: Rapid Urbanization	Loss of urban identity/place attachment
		1960s: Election Campaigns	Critique of growth-oriented urbanism
		1980s: Academic Adoption	Link to traffic/mobility paradigms
		1990s: Indicator Proliferation	Quantification of livability
		2009: Sustainability Policy	Livability as sustainable principle
Agents	**Organizations**	EIU	Revise subjective assessment ranges according to current conditions
		OECD	Integrate demographic dimensions into standardized assessment models
		AARP	Develop livability metrics that account for individual-level preferences
Actors	**Philosophers**	Edmund Husserl	Lifeworld as basis of experience
		Martin Heidegger	Dwelling as fundamental human existence
		Maurice Merleau-Ponty	Embodied perception and spatiality
		Gaston Bachelard	Poetics of space and memory
		Hans-Georg Gadamer	Hermeneutics of built environment
		Christian Norberg-Schulz	Place identity conservation
	Architects	Juhani Pallasmaa	Sensory architecture beyond visual primacy
		Bernard Tschumi	Architecture of events and movements
		Peter Zumthor	Material memory and atmospheric spaces
		Steven Holl	Phenomenological anchoring to site
		Alvar Aalto	Human-centered modernism and regionalism

Figure 2. Events, agents, actors, and discourses.

directly (Holl, 1989; Pallasmaa, 1996; Pallasmaa, 2005; Zumthor, 1998) or indirectly (Tschumi, 1994; Aalto, 1998) referenced phenomenology in their work. They focus on the perceptual, emotional, and experiential dimensions of architecture, emphasizing subjective experience in the architectural practice. The discourses compiled in Figure 2 are analyzed in the following sections to elucidate the phenomenological dimensions of liveability.

APPROACHES THAT LAY THE GROUNDWORK FOR A PHENOMENOLOGICAL EXAMINATION OF LIVEABILITY

The mind-body dualism of the Cartesian tradition separates the subject from the object, treating the body as an independent entity. It prioritizes mathematics over perception, reason over the senses, and establishes a mechanistic understanding of nature. The reduction of human existence to mere thought and the consideration of cognitive faculties as the sole, true, and reliable source of knowledge leads to alienation from the natural world, detaching humans both from their environment and their own bodies (Evernden, 1993). This perspective underscores how Cartesian thought reduces the richness of human-environment interaction to a purely cognitive model.

The Cartesian tradition limits the scope of human understanding and the capacity to interact with the world through a cognitive and rationalist approach in the pursuit of truth. Orr (2004) states that while human cognitive abilities distinguish humans from other species, this leads to the neglect of other forms of knowledge, such as relational knowledge of the world. Furthermore, he explains that this approach prioritizes theories over values, abstraction over consciousness, definitive answers over questioning, and technical efficiency over ethical concerns. In this context, modern philosophy has distanced humanity from consciousness and severed its connection with the world. Orr (2004) proposes reflecting on the consequences of an approach that fails to consider different forms of knowledge alongside reason.

Building on Orr's critique of abstraction and neglect of values, Buckley expands the argument by focusing on how epistemological priorities affect environmental outcomes. According to Buckley (2013), as reason becomes the primary method for acquiring knowledge, humanity moves away from a more nuanced understanding that involves learning from the world itself. The modern epistemological orientation views the world as something to be controlled or overcome. In this context, while reason-based methods meet needs such as fuel, industry, and technology—thereby increasing humanity's capacity for survival—they simultaneously generate numerous environmental problems, including waste and pollution. This duality reveals a critical tension between technological advancement and ecological responsibility.

The belief that the outcomes of reason-based rational decisions cannot be wrong weakens humanity's capacity to question and evaluate the consequences of its own actions. Buckley (2013) argues that these actions represent signs of participation in contemporary society, which is characterized less by decision-making and more by accepted modes of existence. However, globally debated environmental issues now demonstrate that rational participation has lost its validity. In daily choices, humanity must act with awareness of the long-term consequences on both the physical environment and human life. It must observe and recognize that living in the world means being connected to it and coexisting with it. Such a recognition marks a potential shift from detached knowledge systems to more engaged and responsible ways of being-in-the-world.

Abram (1996) argues that humanity disregards nature and its necessities, a tendency reinforced by the rationalist approach that devalues sensory reality. This approach interprets the world as an infinite, and absolute resource while diminishing the significance of the embodied subject and perception. Abram's interpretation echoes a broader phenomenological emphasis on the body's primacy in shaping experience. In this sense, perception is not merely passive but participatory. Abram (1994) notes that Merleau-Ponty dedicated himself to demonstrating how perception occurs as a reciprocal interaction between the living body and the living world that surrounds it. The perception of the embodied subject constitutes the fundamental basis enabling its interaction with the environment. Through this perception, humanity gains direct experience of the world and acquires a form of intuitive understanding. Orr (2004) conceptualizes this awareness of the physical environment and living existence through the notion of "earth in mind." According to Berry (2002a), this means "reinstating the world in our awareness."

Particularly in the 20th century, the notion that philosophy essentially concerns thinking about life gained prominence; philosophy turned toward unfolding lived experience within the simultaneity of space, time, and life (Sahakian, 1990). This transformation reflects the increasing urgency to make philosophy relevant to real-world conditions and lived human experience.

In this context, phenomenology serves as a fundamental method for critiquing Cartesian knowledge.

Functioning as a general doctrine of essences, phenomenology aims to reach the essence of phenomena. It maintains that humans and the world form an inseparable whole, asserting that the subject's mind and body perform together in an active role within the world (Husserl, 1973). Given the limitations of Cartesian rationalism in addressing the experiential and embodied aspects of human existence, phenomenology provides a valuable counter-framework that positions perception as foundational to our understanding of knowledge.

PHENOMENOLOGICAL REFLEXES OF LIVEABILITY

Within the scope of Cartesian criticism, this section identifies four core phenomenological dimensions, namely the phenomenological reflexes of liveability, which redefine it as a multidimensional concept grounded in human experience. First, it necessitates a re-examination of the concept's etymology, which challenges traditional subject-object dichotomies and underscores the inseparable relationship between humanity and the earth. This reflex invites us to reconsider the Cartesian separation of human consciousness from the natural world. Second, liveability encompasses both objective and subjective indicators, acknowledging that true understanding of lived environments requires engagement with human perception, sensory experience, and emotional responses alongside measurable physical factors. This dual nature bridges the gap between quantitative assessments and qualitative experiences.

Third, liveability is inherently place-specific, engaging with the unique character, spirit, and identity of particular locations. This reflex moves beyond universal standards to recognize how local contexts shape the meaning and experience of liveable spaces. Finally, the concept calls for holistic participation, inviting individuals to engage with their environments through integrated mind-body-soul awareness. This fourth reflex synthesizes experiential knowledge with researched information, offering an alternative to Cartesian fragmentation by valuing embodied ways of knowing alongside rational analysis. Together, these reflexes provide a framework for understanding liveability that challenges reductionist approaches while maintaining critical rigor.

Etymological Roots of Liveability: Human-World Unity, and the Role of the Subject

The term "liveability" (Oxford Learner's Dictionaries, n.d.; also spelled "livability") originates from the adjective "liveable," which itself derives from the verb "to live" (Online Etymology Dictionary, n.d.). The root meaning of "live" encompasses both biological existence ("to be alive") and spatial inhabitation ("to dwell"), tracing back to the Proto-Indo-European leip-, suggesting permanence and connection (Merriam-Webster, n.d.; Oxford Learner's Dictionaries, n.d.). This linguistic heritage reveals liveability's dual nature: it requires both a living subject and a lived environment, framing human existence as an active, situated phenomenon.

At its core, liveability presupposes existence—a subject inhabiting and experiencing the world. Merleau-Ponty (1962) contends that the world is not merely thought but lived through embodied engagement, an inexhaustible

reality that precedes human conceptualization. This perspective challenges Cartesian dualism by asserting that human-world relations are fundamentally phenomenological. Heidegger (1996) extends this view, arguing that space is neither external object nor internal construct but an inseparable dimension of Dasein (being-in-the-world.) His concept of dwelling (1971) transcends mere occupancy, proposing that "humans are ontologically of the world" (Moran, 2000), with Earth as our primordial home that provides a common space, a place for food and community, connects all humanity (Buckley, 2013).

This unity demands recognizing humanity's reciprocal relationship with the environment—not as dominators but as mindful participants. Husserl's (1970) lifeworld theory further radicalizes this stance: the pregiven world of lived experience precedes and grounds scientific abstraction. The lifeworld, shaped by perception and culture, resists reduction to idealized formulas, positioning subjective experience as the foundation for all knowledge, including scientific inquiry (Føllesdal, 2010).

Liveability is intertwined with the essence of human existence and spatial habitation. It reflects both the biological aspect of living and the act of dwelling in a specific environment. Philosophically, it draws upon Merleau-Ponty's (1962) concept of the embodied experience of the world, where the subject's connection with its surroundings is not abstract but directly lived. While Merleau-Ponty focuses on embodied perception as the foundation of spatial experience, Heidegger deepens this view by grounding human existence ontologically in the act of dwelling. Heidegger's (1971) notion of "dwelling" further emphasizes this relationship, wherein the human subject is inseparable from the world, co-creating the experience of place. This unity of the subject and environment is crucial for understanding liveability as a fundamental, situated experience, rather than as an abstract, disconnected concept.

In architectural practice, this understanding of liveability manifests in the design of spaces that foster a profound connection between the inhabitants and their environments. Juhani Pallasmaa (2005) advocates for a multi-sensory architecture that goes beyond visual dominance, emphasizing touch, sound, and embodied experience; spaces should invite not only visual appreciation but also bodily engagement to establish a connection with their users. In his *Rovaniemi Art Museum* project (Rovaniemi, Finland, 2000), Pallasmaa refunctions a disused post office while preserving the building's historical layers. By reflecting the memory of the place through architecture, he enables visitors to form a bodily and sensory connection with the space, thus materializing phenomenological principles of liveability.

Indicators of Liveability: Based on Human Experiences, Perceptions, and Sensations

Although liveability is defined as a specific and qualitative component of the sustainability concept, its fundamental distinction lies in its greater emphasis on human experience and social factors (Szibbo, 2016). The primary reason for this is that each society—and even each individual—exhibits different expectations, demands, and conditions due to cultural background and socioeconomic status, consequently resulting in variations in liveability criteria. In this context, while the prevailing understanding of sustainability today is largely based on technical, measurable, and standardized indicators, the concept of liveability distinguishes itself by advocating for a subjective, contextual, and experience-based approach.

The Economist Intelligence Unit (EIU) stated that its Global Liveability Index required revisions and the inclusion of subjective assessments during situations like the COVID-19 pandemic in 2021. The organization explained that restrictive living conditions causing stress among populations affected liveability, necessitating a scoring system ranging from "intolerable" to "ideal" to evaluate stress and restriction levels (EIU, 2021).

The Organisation for Economic Co-operation and Development (OECD) conducts assessments across 15 member countries to examine levels of depression and anxiety risks, measuring feelings of loneliness, fragmentation, and social disconnection. The OECD reports that these experiences, along with economic conditions, show significant variations depending on age, gender, race, ethnicity, and subjective qualities, emphasizing the importance of subjective attributes for "sustainable well-being" (OECD, n.d.). The American Association of Retired Persons (AARP) employs an online tool to measure liveability, allowing individuals to personalize the index according to their own liveability criteria (AARP, n.d.).

Liveability discourses often associate "liveable cities" with subjective ideals, as reflected in terms like suitability (EIU, 2024), desirability (Vuchic, 1999), and attractiveness (Lennard, 1997). This suggests a conceptual shift wherein liveability transcends measurable criteria, becoming an experiential construct shaped by human perception, sensory engagement, and emotional resonance. In this context, certain researchers argue that assessing liveability through an objective approach is impossible, asserting instead that perception and sensory experiences play a pivotal role in the liveability experience (Porteous, 1971; Van Kamp et al., 2003; Namazi-Rad et al., 2016). The authentic assessment of liveability fundamentally depends on residents' environmental perceptions and satisfaction levels (Szalai, 1980; Cummins, 2000; Hur et al., 2010).

According to Merleau-Ponty (1962), perception is not the intentional behaviors and actions of human consciousness. The world constitutes the natural milieu of all human thoughts and perceptions. The world is what we perceive. Perception presents us with the unity of subject and world as a field of experience. This experiential field reveals the world's reality to the subject. Carman (2005) maintains that perception, memory, judgment, and expectations are neither states nor properties of the mind, but rather elements that directly orient us toward, unite us with, and bind us to the world. This account strengthens the phenomenological position that consciousness is always situated and relational. Şan (2017) explains that perception serves as a foundational source accompanying all other phenomena. In this context, perception is not only the starting point of knowledge but also the existential ground upon which human-world relations are constituted. The philosophy of perception constitutes not merely a philosophy about the perceiving subject, but equally a philosophy that teaches us about perception itself. Consequently, Merleau-Ponty's approach involves not only thinking about perception but also structuring thought in accordance with perception. Perception describes an experience where active qualities emerge, demonstrating that humans are not passive recipients of external qualities but rather embodied perceiving subjects.

Prioritizing human perception and senses in liveability assessments does not negate the necessity of scientific research. In this context, phenomenology's role is to demonstrate that science cannot depict a world devoid of unanswered questions. It unsettles scientific dogmatism, which regards rational knowledge as absolute and complete, and instead creates space within the scientific domain for life-world, lived experience, and, particularly, perception. Merleau-Ponty (1962) asserts that phenomenology demands we continually relearn from the world—a realm of direct, immediate experiences and intertwined relations—and expects meaning to be grasped through awareness and existence. Thus, rather than engaging in theoretical inquiries, phenomenology proposes narrating the story of all our relationships and experiences in the perceived world (Bognar, 1985).

Architectural phenomenology places humans at its core, moving beyond analytical processes, methodological frameworks, or physical environments. It advocates for a conscious and attentive engagement with the built environment, emphasizing the significance of perception and emotions. In doing so, it seeks to define phenomena through "pure looking at" or "viewing its essence," distinguishing them from mere sculptural objects, without reducing the environment to its physical qualities alone (Pallasmaa, 1996).

The experience of liveability cannot be reduced to mere quantitative measures, as it hinges on subjective human perceptions and emotional responses to the environment. This aligns with Merleau-Ponty's (1962) philosophy of perception, where liveability is not just a condition but a sensory, lived reality. The human perception of space—shaped by individual and collective experiences—forms the essence of what constitutes a liveable place. This perspective challenges the purely objective measurements often used in urban planning, asserting that the true measure of liveability lies in how spaces are experienced by their inhabitants.

In architectural practice, Tschumi (1994) explores architecture as a dynamic field shaped by events, sequences, and user interactions, challenging static spatial norms. In designs like the *Parc de la Villette* (Paris, France, 1982-1998), Tschumi transforms architecture into a medium for the unfolding of human experiences, where the environment becomes an active participant in daily life. The spatial dynamics, events, and movements within these spaces are integral to the liveability of the place, enhancing human interaction and engagement. Similarly, Steven Holl employs phenomenological strategies to ground architectural form and experience in the specific qualities of place. The *Chapel of St. Ignatius* (Seattle, USA, 1994) explores the relationship between light, space, and time in a sensory and experiential manner, imbuing the spaces with distinct atmospheric qualities. By using light as a fundamental element that shapes perception, Holl embodies phenomenological principles that contribute to the creation of liveable environments.

Description of Liveable Place: The Unique Character and Spirit of Place

Girardet (2004) defines a liveable city as one with well-defined neighborhoods where basic facilities are within walking distance, featuring attractive public spaces, a vibrant street culture, good connectivity, affordability, and cleanliness. Lennard (1997) identifies the primary factors that enhance well-being as: a central neighborhood square, urban spaces designed at a human scale, a safe and comfortable pedestrian network, visual enclosure that strengthens a sense of belonging, diversity and complexity that encourage exploration, natural elements that enhance sensory pleasure, clear spatial relationships between familiar personal spaces and significant structures, meaningful experiences, and appropriately designed seating arrangements. Vuchic (1999) describes liveable places as comfortable, efficient, and conducive to recreation. Gehl (2011) adds that liveable places facilitate encounters, ease movement, and ensure human presence. Jacobs (1961) also emphasizes the importance of creating mixed-use urban areas to promote urban diversity and support human presence in the urban fabric, which is crucial for safety. Bentley et al., (1985) aimed to identify the social, psychological, and physical factors that contribute to the quality of life in an urban community and concluded that the character of a place is a key indicator of its liveability.

In summary, the liveability of a place is related to the local qualities that distinguish it, make it stand out, or relegate it to the background (EIU, 2024).

While there are numerous definitions of a liveable place in the literature, the common thread among them is that liveability emerges as a place-based concept, encompassing aspects related to a place's character, meaning, and distinctiveness (Ley & Newton, 2010). According to Giap et al., 2014, although liveability is considered an umbrella concept covering many interrelated issues, its dominant focus appears to center on place character and the local environment.

According to Norberg-Schulz (1980), phenomenology serves as a means to understand and analyze the concept of place—where analytical and scientific methods fall short—by revealing its unique character and potential meaning. Places possess a distinctive spirit, Genius Loci, which accompanies individuals from birth to death. This spirit refers to the qualities that define a place—its environmental character and overall atmosphere—encompassing descriptive elements such as materiality, form, texture, and color. Since the dawn of human existence, people have sought to create places that reflect the essence of being. In this context, the purpose of architecture is to provide an existential foothold, and its task is to create meaningful places (Norberg-Schulz, 1980). This understanding of place aligns closely with Heidegger's ontological approach, which emphasizes the deep connection between being and spatial existence. Heidegger (1971) describes this as the moment when a place is brought into being through construction—a process of dwelling. Similarly, Sharr (2013), summarizing Unwin's view, refers to this as the "definition of place."

On the other hand, architecture must respond to the multiplicity of human life modes. According to (Norberg-Schulz, 1971), humans seek to express and enact their intentions in daily life, and in this context, their actions are neither homogeneous nor uniform in character. Consequently, they require places of differing characters to accommodate diverse activities.

Thus, a place may be "protective, practical, festive, and solemn"; a landscape may be "natural, barren, fertile, smiling and threatening (Norberg-Schulz, 1980). While such descriptors may sometimes fall short in capturing complex interrelationships, they invariably convey essential qualities of a place's essence. Within this framework, conceptual categories such as artificial-natural, interior-exterior, and horizontal-vertical can be established.

The approach proposed by Norberg-Schulz (1971; Norberg-Schulz, 1980) shifts focus from abstract or mathematical representations to the sensory character and perceptible atmosphere of a place, enabling the revelation of its essence and the comprehension of place's realities. Phenomenology achieves this not through explanation or analysis, but through description (Merleau-Ponty, 1962).

A liveable place is not only defined by functional aspects but by its unique character, which shapes the human experience of space. According to Norberg-Schulz (1980), architecture must embody the spirit of the place, or Genius Loci, which ties the environment to human experiences and cultural memory. This conceptualization of place emphasizes the importance of context, materials, and atmosphere—elements that help create a meaningful, lived experience within architecture.

In architectural practice, Alvar Aalto's (1998) works —such as the *Saynatsalo Town Hall* (Saynatsalo, Finland, 1952)—blend modernist principles with human-centered design and regional sensitivity, emphasizing empathy, nature, and cultural context. Aalto's designs interact with their local settings, employing natural materials and textures to harmonize with human scale and cultural background. His buildings are not only functional but also imbued with a sense of place that strengthens the bond between the space and its occupants. Aalto's architecture exemplifies how liveability can emerge through the integration of environmental and cultural factors, creating spaces that feel both intimate and universal.

The Practice of Liveability: Synthesizing Experiential Knowledge with Investigated Knowledge

Liveability demands more than theoretical understanding—it requires an embodied, participatory engagement with the world that bridges the gap between abstract knowledge and lived experience. This holistic approach recognizes that truly liveable environments emerge from the synthesis of investigated (Cartesian) knowledge and experiential (phenomenological) wisdom.

The path to liveability involves cultivating what Berry (2002a; 2004) describes as a radical reorientation—from assuming human benefit drives environmental health to recognizing that planetary wellbeing fundamentally sustains human flourishing. This shift requires moving beyond what Moran (2000) describes alienation to earth toward what Buckley (2013) frames as conscious reconnection through sensory immersion in natural processes: smelling rain-drenched soil, feeling the texture of terrain underfoot, or witnessing seasonal transformations. These embodied encounters ground abstract ecological principles in tangible reality, fostering what Merleau-Ponty (1962) identifies as the indispensable dialogue between scientific understanding and first-person experience. Our fundamental connection with the world cannot be fully grasped through objective analysis alone; it must be experienced and felt through bodily participation.

Urban spaces aiming for liveability, should balance measurable factors like infrastructure quality with less tangible but equally vital elements—the play of light through tree canopies, the acoustic texture of public squares, or the

tacit social rhythms that animate neighborhood streets. As Buckley (2013) notes, this synthesis operates reciprocally: just as research should inform how we live, lived experience must continually refine our research priorities.

Engaging with liveability means embracing what Berry (2002b) calls the great work of our era—cultivating modes of existence that honor our profound entanglement with the more-than-human world. This involves neither rejecting scientific knowledge nor privileging raw experience, but rather sustaining the creative tension between them. In doing so, we move toward what Heidegger (1971) envisioned as dwelling—not merely occupying space, but participating meaningfully in the ongoing story of place. The measure of true liveability lies in this capacity to weave knowledge into lived practice, creating environments that don't just sustain life, but make being alive a continually unfolding discovery.

The practice of liveability requires an integration of both subjective, experiential knowledge and objective, scientific knowledge. This synthesis reflects a deeper understanding of how humans interact with their environment, moving beyond theoretical abstractions toward lived experiences that are grounded in sensory engagement and ecological awareness. The idea of "dwelling" proposed by Heidegger (1971) emphasizes this participatory relationship with the world, where liveability is not merely an outcome but an ongoing, embodied process.

In architectural practice, Zumthor (2006) interprets architecture as an art of space and time. Zumthor focuses on materiality and sensory atmosphere, creating emotionally resonant spaces rooted in memory and tactile experience. His *Therme Vals* (Vals, Switzerland, 1996) is an example of place-making where both intellectual and sensory experiences, such as light, sound, and tactility, resonate. Zumthor invites not only visual observation but full bodily engagement with the space. At this point, liveability transcends the physical, encompassing emotional and sensory responses to create living spaces in resonance with human experience. Zumthor creates a liveable place by interpreting his environmental research to add experiential qualities to the building.

DISCUSSION AND CONCLUSION

The Cartesian tradition reduces the world to a calculable, measurable object—a technical realm stripped of its worldhood. As Polt (2005) underscores in his reading of Heidegger, this tradition's subject-object dichotomy severs humans from the lived fabric of daily existence. Heidegger's critique, reclaims the world as a liveable place through the concept of *Erlebnis* (lived experience), where life is not biological survival but a trajectory of meaning, failures, and successes embedded in place (Polt, 2005). Here, the world emerges not as an abstracted "object" but as a contextual structure. This relational ontology rejects Cartesian dualism—the subject-object dichotomy—asserting that lived experience only becomes real within the holistic structure of place, where humans dwell.

In Cartesian approach, understanding is solely achievable through reason, whereas in phenomenological approach, experiences constitute the fundamental source of knowledge. Phenomenology, entirely eschewing objectifying sciences, is a philosophical method, a mode of thought, and a teaching endeavor seeking to describe the purposeless experiences of the subject in relation to the world and the subjective orientations of our consciousness. It is an inquiry into how the subject experiences and constructs the world. Phenomenology allows to access the essences of phenomena questioning existing knowledge and without benefiting from ready-made knowledge (Husserl, 1973). Phenomenology achieves this without theorizing or mathematizing - by comparing, distinguishing, connecting, relating, dividing into parts, and breaking down into elements. It makes no explanations in the sense of deductive theory (Husserl, 2015).

Phenomenology integrates the subjective realm into the natural world: it engages with multiple domains of knowledge to better comprehend human-world connectedness and lived experience (Moran, 2000). By addressing not only rational cognition but also perceptual knowing, phenomenology facilitates both the disclosure of potential meanings tied to liveability's subjective dimensions and the exploration of the subject's role in constituting a liveable environment.

The phenomenological approach demonstrates the possibility of an experiential understanding of place—one grounded in human bodily perception and focused on the "here and now" (Moles, 2012). Phenomenology's examination of human existence across temporal and spatial dimensions unveils the multilayered and holistic nature of liveability - a structure intrinsic to both the experiencing subject and the experienced world.

Phenomenology is fundamental methodological framework for comprehending human nature and elucidating individual behaviors and distinct perceptions (Seamon, 2000). As posited by Nickerson (2002), human actions and behaviors, wield significant influence over the prospective of planet Earth's future. As scientific research on the environmental impacts of human actions expands, a paradigm shift is occurring - from models asserting human dominion over Earth to what Dunlap (2008) terms the "New Ecological Paradigm", which conceptualizes humanity as fundamentally interconnected with and integral to the world system. According to Buckley (2013), phenomenology enables a transition to a new paradigm that conceptualizes humanity as the recipient

of all consequences of its actions. The phenomenological approach enables the understanding and maintenance of liveability's essential conditions, integrates liveability into daily actions and behaviors, and frames liveability as both a way of life and a subject of inquiry. Liveability necessitates listening to and comprehending the messages the world seeks to convey, while cultivating consciousness and awareness toward our environment. The phenomenological approach conceptualizes liveability not merely as a notion interwoven with the objective qualities of one's lived environment, but also as an expression of poetic sensitivity toward the world.

Based on thinkers such as Husserl, Heidegger, Merleau-Ponty, and Norberg-Schulz, and architects like Pallasmaa, Tschumi, Zumthor, Holl, and Aalto, phenomenologically, liveable places are those that confer meaning upon human existence through embodied experiences, generate perceptual-sensory pleasures and affective resonance, orchestrate the multisensory interplay of lived place, support both human and life itself, and actively sustain the very possibility of human flourishing. In this context, liveability does not pursue comprehensive perfection in the urban environment; rather, it focuses on evaluating and enhancing the fundamental factors that influence a community's well-being and happiness, revealing the identity and character of places while making them more desirable to experience - thereby improving overall quality of life. Figure 3 presents the potential meanings of liveability and the characteristics of liveable places from a phenomenological perspective.

Figure 3 reveals that liveability from a phenomenological perspective includes concepts such as "meaning of life," "quality of life," "well-being," and "happiness." These concepts have emerged as exemplary potential concepts in Cartesian critical liveability studies, highlighting that theoretical and experimental research focus on different concepts (Figure 1). In this context, the study demonstrates that the theoretical and methodological potentials of liveability are more visible from a phenomenological perspective, and that liveability potentially includes these concepts.

This study's phenomenological critique of Cartesian rationalism reframes liveability as a dynamic, relational phenomenon rooted in embodied experience, temporal-spatial situatedness, and emotional connection—rather than static metrics. By exposing the limitations of dualistic, calculative paradigms, the research reveals that truly liveable places: Prioritize sensory richness and bodily engagement, foster a sense of belonging and place through historical/contextual continuity, and focus on enhancing quality of life and subjective well-being alongside the qualities and functionality of the physical environment. Ultimately, they are places that evoke a sense of being worth living. For place-making, these insights demand a shift from abstract standards to lived experience-centered design. Rather than merely deconstructing Cartesian worldview, the study also offers phenomenological dimensions of liveability as constructive directions for creating more humane and meaningful environments.

Philosophers / Architects	Expanded Key Discourses	Potential meanings of liveability and characteristics of liveable places from a phenomenological perspective
Edmund Husserl	Scientifically lived experience	Prioritizing subjective lived experience through the exploration of everyday life • ***Focusing on liveability perception***
Martin Heidegger	Existential unity of human and world	Supporting humans and life; sustaining the possibility of human flourishing • ***Contributing to personal fulfillment***
Maurice Merleau-Ponty	Sensory experience, body-space interaction	Conferring meaning upon human existence through embodied experiences • ***Revealing the meaning of life; creating desirable experiences***
Gaston Bachelard	Place-memory relation and emotion	Generating resonance and emotional depth; revealing lived character of place • ***Fostering a sense of belonging***
Hans-Georg Gadamer	Meaning revealed through hermeneutics	Interpreting spatial tradition and meaning; enhancing continuity and memory • ***Maintaining subjective well-being***
Christian Norberg-Schulz	Embodiment of *genius loci* (the spirit of place)	Revealing the identity and character of places; reinforcing contextual meaning • ***Creating a sense of place***
Juhani Pallasmaa	Polyphony of sensory experience	Orchestrating multisensory interplay; evoking perceptual-sensory pleasures • ***Providing spatial joy, happiness***
Bernard Tschumi	Space as a field of interaction	Fostering dynamic space use; supporting personal engagement • ***Reinforcing spatial interaction and social cohesion***
Peter Zumthor	Atmospheric effect of material	Creating atmospheres; evoking intimacy; encouraging tactile experience • ***Creating a sense of satisfaction and a place worth living in***
Steven Holl	Human-space-time relationship	Enhancing spatial-temporal experience; supporting human-place symbiosis • ***Harmonizing with place and time***
Alvar Aalto	Local settings, cultural background	Focusing on local, human-centered factors instead of idealized environments • ***Improving quality of life***

Figure 3. Potential meanings of liveability and characteristics of liveable places from a phenomenological perspective.

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Article

Empathy theory as an early trace of experience in architecture

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Architectural design; einfühlung; empathy; experience of space; phenomenology.

ABSTRACT

This study claims that the concentration on the spatial experience in Modern architecture is related to the "einfühlung/empathy theory." The empathy theory emerged in Germany as an attempt to explain the psychological mechanism of identification with visual phenomena during the second half of the nineteenth century. Later on, Worringer introduced the concept of abstraction as the opposite of empathy. According to him, the need to overcome feelings of distrust and fear toward the world resulted in art removing the naturalistic/figurative, i.e., empathic, elements from the object. This paper aims to show the early connections between empathy and abstraction in Modern architecture.

It is claimed here that "abstraction," an indispensable property of Modern art and architecture, facilitated the modern spatial experience by emphasizing movement within the boundaries of volumes. In other words, abstraction became the new means to empathize with the object, thus eroding the opposition created by Wittkower. The erosion between the boundaries of empathy and abstraction became part of the phenomenal and literal “transparency” in twentieth-century architecture due to its reliance on the experience of engagement with forms, either physically or mentally.

Finally, the study intends to contribute to the field of Modern architecture aesthetics by starting a discussion on how the modern emphatic experience of space might be at the root of the latent phenomenological approaches in architecture, which surfaced during the second half of the century as a reaction to both the copy-paste productions of Modernism and the superficiality of Postmodern currents.

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INTRODUCTION

When the early traces of "experience" in architecture are questioned, it is seen that this concept is closely related to art. As is well known, classical art is based on beauty and is subject to specific measures such as ratio-proportion and symmetry. In the early 18th century, changes began in the classical understanding of art. In his essay "A Treatise of Human Nature", Hume (1739), Hume (2007) makes statements that challenge the existing understanding of the art of his time. According to him, the distinctive feature of beauty is that it gives "pleasure and satisfaction to the soul. “In another essay entitled "Of the Standard of Taste" (1757), Hume presents ideas that do not conform to the classical

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understanding of art. Hume's understanding of art is based on "emotion," "the common feelings of human nature," and "experience" rather than the qualities inherent in the object of art object of art (Hume, 1985).

Similarly, Burke (1757) distinguishes beauty from the classical understanding of proportion in his text "Inquiry into the Origin of our Ideas of the Sublime and Beautiful". He claims that beauty has no connection with calculation and geometry. Instead, the sensory and emotional approach and the idea of sublimity are elements of the new approach to art. According to Wittkover (1949), this new understanding of art frees the architect from the limitations of mathematical proportions.

By the 19th century, with the influence of the establishment of modern psychology and psychophysics, art became linked to the "subject" and was read through the subject's impulse. Fechner, considered the founder of psychophysics, questioned “Why is something pleasing or unpleasant? And to what extent is it pleasing or displeasing?" (Tunalı, 1975). Fechner’s interrogation reveals that aesthetics and philosophy of art began to be included in psychology in the mentioned period. As a matter of fact, in this period, the beauty of the art object is tied to the subject's taste.

Theodor Lipps, one of the principal founders of modern psychological aesthetics and art theory, used the term "*Einfühlung* theory" to explain the evaluation of the object through the subject's taste. Lipps's definition of aesthetics signifies a change in the concept of beauty which becomes a subjective judgment: "Aesthetics is the science of the beautiful. An object is called beautiful because it evokes or can evoke a special feeling in me. Accordingly, beauty is the ability of an object to evoke a certain effect in me." (Tunalı, 1975). In other words, *Einfühlung* means the subject's pleasure through the object by projecting itself onto it.

The term "*Einfühlung* theory," which is translated into English as empathy theory, first appeared in the book "Über das Optische Formgefühl" written by Robert Vischer in 1873 (Otero-Pailos, 2010). With the term *Einfühlung* theory, which literally means "feeling oneself" or "stimulating" something, Vischer suggests that we neurologically stimulate our physical environment during our perceptual activity. In Vischer's definition, in the case of visual arts, while the eye perceives the artwork, the body's perceptual response to form and content constitutes the first step of empathy theory; then, as these sensations deepen into emotions and empathy, our self, in modern terms, merges with this "phenomenal" object. In other words, according to Vischer, empathy theory means the individual's reflection of himself in artistic form. In Vischer's words: "We thus have the wonderful ability to project and incorporate our physical form into an objective form, in much the same way as wild fowlers gain access to their quarry by concealing themselves in a blind" (Mallgrave & Ikonomou, 1994).

According to Mallgrave & Ikonomou (1994), Vischer's conception of empathy theory is that the individual retains his or her appearance and identity only out of habit. Although there is a separation between the individual and the object, the mental representation of the object and the individual merge. If the object is considered as tiny as a pebble, the representational feeling shrinks, the self is weakened, and contractive feeling occurs; if the object is considered as significant as a sea, the self is strengthened and liberated, and expansive feeling occurs (Mallgrave & Ikonomou, 1994).

Theodor Lipps, another empathy theorist, adopts the empathy theory as a kind of inner stimulation. In Lipps' view, as in Vischer's, there is a state of integration with the object, reflection on the object, and leaving one's own "bodily and sensory" awareness behind. For example, according to Lipps, when we watch a dancer, we feel as if we are making the movements she makes; we become one with her movements, and we evaluate this experience as a reflection of our power. "In a large hall, for instance, we "expand" our chest with the room's dimension and breathe more easily. A Doric column, the parts and fluting of which compose a complex and lively structure, makes us happy because it allows us to stand tall and revel in our strength” (Mallgrave, 2013).

Heinrich Wölfflin, another empathy theorist who explored how architecture affects emotions and moods, in his essay "Prolegomena to a Psychology of Architecture", does not, like other aesthetic theorists, embrace the idea that our selves are reflected in architectural forms but the reverse (Mallgrave, 2013). Instead, he advocates experiencing form through the body as architectural objects: "The optic nerve directly stimulates the motor nerves and thereby sympathetically works on our internal organs.” According to him, while we perceive the narrow houses of Northern European cities as oppressive, we perceive Italian Gothic forms as "restful because they are horizontal and wider" (Mallgrave, 2013).

August Schmarsow, on the other hand, opposes Wölfflin's prioritization of form and rejects the formalist aspect of architecture. As Mallgrave (2013) puts it, Schmarsow defines architecture "as a "spatial construct" built around the phenomenological human axis." (Mallgrave, 2013). In other words, he considers the sense of space surrounding the subject as a more important phenomenon than form.

Among the empathy theorists, Schmarsow is the one who most clearly applies the theory to architecture. According to Panin (2003), although the idea of space has been around since antiquity, it has only started to be included in architecture since the late 19th century with Schmarsow. This concept first passed through aesthetics and then was added to architecture. Therefore, the idea of space emerged as a concept produced by aesthetics while trying to define

emphatic experience in art forms. Moreover, the idea of space led to the search for the aesthetic in the successive effects rather than the static envelope. Again, in Panin's words, "space was accepted as the embodiment of human activities within the stylistic shell." (Panin, 2003).

These shifts in aesthetic theory—from Hume's emphasis on subjective pleasure, to Burke's notion of the sublime and affect, and Fechner's psychophysical explorations—collectively reveal a gradual transition from object-centered beauty to subject-oriented affective experience. Each of these positions shapes aesthetic judgment increasingly through the lens of sensation, perception, and emotion. As such, the idea of "experience" becomes internalized, setting the stage for *Einfühlung* theory (empathy theory), in which the perceiving subject is no longer separate from the object but projects itself into it. This empathic merger of subject and object constitutes the defining moment of a century-long shift from rationalist aesthetics toward embodied, psychological participation in art.

Therefore, this study assumes that the conceptualization of experience in architecture begins with the emergence of empathy theory. This theory laid the groundwork for understanding space not as a static form, but as a phenomenon shaped by the subject's embodied perception and emotional engagement.

To summarize, the idea of the sublime, the first trace of the aestheticization of "experience" in art, developed into empathy theories around the turn of the twentieth century. This article explores how empathy theory (*Einfühlung* theory), originally developed in psychological aesthetics, laid the conceptual foundation for the spatial experience of modern architecture, particularly through its connection to abstraction and bodily experience. It can now be argued that these theories resulted in the perception of architecture as abstract volumes around flowing spaces to be experienced emphatically by the subject.

EMPATHY THEORY AND MODERN ARCHITECTURE

Reflections of Empathy Theories in Modern Architecture

To trace the reflections of empathy theories on the plane of architecture, it is helpful to examine first the idea of spatial movement in the thought of Adolf von Hildebrand, a sculptor influenced by the theories of Robert Vischer and Theodor Lipps. Hildebrand, who first built his theory on painting and sculpture, says the following about space in his book "Das Problem der Form in der bildenden Kunst" written in 1893: The main task of the artist is to design layered planes that create the effect of depth, where spatial values can be perceived from front to back. According to him, for the eye to develop the effect of volume, the whole must carry spatial clues that require a two-dimensional effect. In this formation, which he refers to as relief, art consists of the combined effect of two-dimensional images and a series of three-dimensional movements that give the effect of depth. The sculptor and the painter must consider the dynamic relationship between two-dimensional values and kinesthetic ideas that evoke depth and volume (Figure 1) (Mallgrave & Ikonomou, 1994).

Hildebrand then extends this idea of relief to painting, architecture, and furniture. In architecture, according to him, the idea of relief effects combined with form was achieved in the Greek temple (Figure 2): "What we perceive is not a spatial body fronted by columns: the columns form part of the spatial body and our ideal movement into depth passes between them." (Mallgrave & Ikonomou, 1994).

According to Mallgrave & Ikonomou (1994), Hildebrand's incorporation of visual perception and movement into the conception of space reappears as a central idea in Schmarsow (Mallgrave & Ikonomou, 1994).

It would be helpful to revisit Schmarsow's idea of space in terms of these parameters. Schmarsow summarizes his ideas about body and movement in the following words:

Figure 1. "Hunt of the Amazons" is an example of relief from 1887/88, Adolf von Hildebrand, Neue Pinakothek, Munich (Gwyneth Thompson Briggs, 2019).

Figure 2. Temple of Hera (Oliver-Bonjoch, 2010).

"The less we are willing to behave like exclusively visual beings and be satisfied with only one viewpoint, the more freely will we make use of the change of position to grasp the material individuality of the object from as many sides as possible" (Mallgrave & Ikonomou, 1994).

These statements show that Schmarsow treats movement as an essential factor constituting the third dimension. Schmarsow's position can be better understood through his critique of the ideas of Alois Riegl, who, like Schmarsow, considered the "creation of space" as a constitutive element of architecture. Riegl argues that from early antiquity to the late Roman period, there was a shift in architecture from tactile to optical vision. This claim implies that the individual has tactile or "near vision" in the Egyptian pyramid, "normal vision" in the Greek temple, and "distance vision" in the Roman Pantheon. Schmarsow criticizes this idea regarding how Riegl deals with human perception in space. According to him, Riegl imprisons the human being an observer in a fixed point of view. Moreover, he deprives the perceiving subject of the freedom of movement that enables it to experience space through its sensation of objects (Mallgrave & Ikonomou, 1994).

In his book "Grundbegriffe der Kunstwissenschaft: am Übergang vom Altertum zum Mittelalter," Schmarsow considers art as a creative reconciliation of man with the world in which he has been placed. The elements of human anatomy that enable this mediation are "our upright posture, our eyes, arms, legs, and frontal orientation." He says we achieve our three-dimensional experience of space and psychic awareness through these. Another parameter related to the movement and the body involved in the experience of space is direction. While relating the "human subject, which constitutes the center of the phenomenal world" to space, Schmarsow considers the human being as an "upright body." However, the emphasis on space is not on the vertical axis. Since Schmarsow's understanding of space creation is based on enclosure, depth is more important than height in directional movement through space. According to him, we shape space with the orientation of our body and limbs. This situation, defined as forward movement, is the factor that transforms the spatial enclosure into a living space (Mallgrave & Ikonomou, 1994). In other words, the moving body is one of the primary elements that establish space.

A similar thought can be seen in Henry David Thoreau's text "Walking". Thoreau emphasizes that walking is not merely a physical movement, but a holistic experience where body and soul are aligned: "The thought of some work will run in my head and I am not where my body is, -I am out of my senses. In my walks I would fain return to my senses (Thoreau, 1862). In this context, walking is not just a physical displacement, but a way for the body and self to reorient towards space and existence. Such a body–space relationship forms the basis of empathy theories in architecture.

The idea of the moving body, which emerged from empathy theories in architecture, has had different direct and indirect reflections in modern architecture. Its direct reflections are the making of the idea of volume felt while constructing the space. Indirect reflections arise due to the evolution of the concept of empathy theory into abstraction. The direct impact of empathy theory in architecture can be seen through Adolf Loos' raumplan principle.

From Empathy Theory to Raumplan

Adolf Loos's raumplan principle reflects the result of the 19th-century tradition of spatial thinking in architecture from Semper to Schmarsow (Panin, 2003). In a Loos building with the raumplan, the body goes through an empathic experience as it travels through volumes of different dimensions and character.

In the Four Elements of Architecture, Gottfried Semper correlates the two types of wall construction – wooden framework (*die Wand*) and massive blocks of earth or stone (*der Mauer*) - for the birth of an extended-lasting spatial paradigm of architecture. Semper claims that the wooden framework functioned as the support for the textile clothing (*bekleidung*) for protection, of which the effects were imitated on surfaces of masonry constructions as ornamentation. Therefore, for Semper, the representation of the warm and homely envelope (the mat, the carpet) on durable walls dominated the spatial configuration in architecture. In his text, The Cladding Principle, which shows the influence of Semper's *bekleidungstheorie*, Loos describes a situation in the beginnings of architecture in which the architect aims to create a warm and livable space. He claims that some architects chose to respond to this problem by laying carpets - a warm element - on the floor and the walls. So, the architect needed to construct a structure to hang the carpets on the walls. Therefore, Loos says that the first purpose of construction in this method is to produce the cover, which is necessary for protection, and then the walls (Loos, 2017). Loos states that there is another style of construction, which is building the walls first, so the space inside the walls becomes the room. Then, they cover the interior surfaces of the room with a suitable material. However, Loos supports the idea that the architect/artist should design first the effect he wants to evoke and then decide on the materials and the forms of the space to produce that effect (Loos, 2017). However, his well-known article "Ornament and Crime," as well as his built works, prove that Loos accepts Semper's thesis as historical facts but disregards- even confronts - them for the sake of a new spatial paradigm suitable for the modern, civilized people. There is more than a reasonable doubt that Loos' *raumplan* (Figure 3) is related to Schmarsow's attempt to associate empathy theory with psychological stimuli produced by architectural space (*raumgefühl*) and its intentional reapplication in design (*raumgestaltung*).

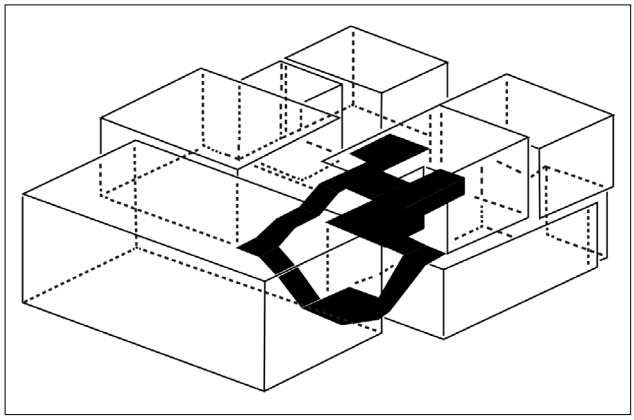

Figure 3. Raumplan diagram. Redrawn by the author based on a drawing of Adolf Loos's Villa Müller (Villa Muller, n.d.).

Another similarity between Schmarsow and Loos is their search for the meaning of the building within the space. According to Schmarsow, seeing a building does not only mean seeing its form; his theory is about an "aesthetic from within." When looking at a building, one projects one's body onto it and takes one's bodily meridian as the central axis of the projected center. Therefore, Schmarsow states that we understand a building better by observing it from the inside (Mallgrave & Ikonomou, 1994). Loos is also known to have shaped his spatial fiction through the interior space.

In short, the direct impact of empathy theories in architecture can be understood through the raumplan principle, which means designing the space. This principle, rooted in the psychological and spatial empathy theories, signifies a shift from decorative or symbolic approaches in architecture toward an experience-centered spatial organization. In Loos's *Raumplan*, the body is not a passive observer but an active participant navigating through differentiated volumes. The sequence of movement through space becomes an architectural narrative, reflecting the core idea of empathy theory: the subject's psychological engagement and projection into spatial form. Therefore, *Raumplan* can be seen as a built expression of the empathic bond between body and space.

THE EFFECT OF EMPATHY THEORY ON MODERN ARCHITECTURE THROUGH ABSTRACTION AND MODERN ART

Empathy Theory and Abstraction

Empathy theory is a concept that has influenced modern art, primarily through its peculiar intermingling with its alleged opposite, abstraction. Worringer has a significant role in making abstraction the basis of modern art by bringing abstraction against the empathy theory. In Worringer's view, empathy theory is a condition within naturalist styles. The happy union of man with nature is represented in art as naturalism. Just as the subject derives pleasure from nature, it also derives pleasure from an art object representing the harmonious union of human beings with nature. At this point, Worringer questions the encompassing and inclusive nature of empathy theory (Tunalı, 1975) and finds the objectified self-enjoyment (*Objektivierter Selbstgenuss*), which is the essence of theory. Worringer defines "objectified self-enjoyment" as enjoying ourselves through an object (Worringer, 1907). However, while empathy theory can explain "Greco-Roman and modern Western art," it is not possible to understand, in other words, to empathize with other artistic traditions. Therefore, alongside one's "self-enjoyment" with the object, Worringer also sees in the work of art a mental process based on the principle of abstraction. Contrary to widespread ideas that see the origin of art in a mimetic impulse and ornamentation, Worringer attributes the origin of art to human psychological needs (Helg, 2015). Eventually, the primeval origin of art traced in non-European art and the means to recuperate its essence become frequent themes connected with Worringer's theory.

According to Vallier, Worringerian abstraction aims to transcend reality, which is only possible through abstraction. Therefore, abstraction is a starting point for modern artists (Bonfand, 2015). Cézanne, one of the first artists to mention abstraction, considered abstraction in his late age as the absence of the contours of objects, but instead as "sensations of color that give light" (Chipp, 1968). The object is now expressed in color without contours, and the result is "the impression of massiveness and material substance" (Merleau-Ponty, 2019). According to Kandinsky, abstraction can be said to be an inner experience. Indeed, the relativity of the act of seeing, the impossibility of reliving the same experience of seeing, forms the basis of the idea of abstraction. Accordingly, an object is represented in color as we see it as a new object each time. Eliminating the relativity of our gaze and seeing the object as color is a method of abstractionist attitude (Bonfand, 2015).

It can be said that the theories about empathy and abstraction emerged from investigations on the relationship between the senses and psychology vis-à-vis visual phenomena as two critical concepts in the quest to revitalize European art at the beginning of the twentieth century. These interacting theorizations facilitated the remolding of various influences from non-European art in European art, like those that had appeared prematurely in the works of artists like Van Gogh, Cezanne, and Gaugin.

Even though Worringer constructed an opposition between empathy theory and abstraction, his theory suggests that empathy, as self-enjoyment with the object, is possible not only in natural but also in abstract forms. The psychological themes in non-figurative paintings prove the existence of empathic impulses in Modern Art, such as those found in Kandinsky and Klee.

For Worringer, abstraction is the "first artistic impulse." He thinks that the primitive man, fearing the complex and ambiguous structure of the world, resorted to abstraction. However, despite its resemblance to the archaic one, modern abstraction differs from it in terms of forms and methods of manifestation. Because modern man is no longer helpless in the face of the world, he uses abstraction to express his reason, not his instinct. Moreover, the abstraction that modern man produces becomes a form of artistic production that emerges not from the collective instinct of a population but from an individual's world of thought. Ultimately, modern abstraction emerges not out of fear of nature but from an understanding of being liberated from the world (Helg, 2015).

Abstraction in Modern Art

It is vital to reveal the dynamics that led artists to abstraction in the formation of Modern Art to elaborate on the role of empathy theory/abstraction in Modern Architecture. The main idea behind using abstraction in Modern Art is to handle reality differently. The first reflection of the idea of abstraction in Modern Art is in the impressionist attitude. According to Tunalı (1970), every art movement is based on how the subject, the artist, reflects the object in the work of art. The pre-modern artist (subject) establishes a thought-based relationship with his object and creates his work based on what he sees and thinks. However, in Impressionism, which is the beginning of Modern Art, the subject establishes a relationship with his object through his senses. The subject reflects the impressions left on him by the objects and nature in his work. Therefore, the reality of Impressionism is "a mixture of impressions and sensations." (Tunalı, 1970).

In modern art, abstraction emerged as a deliberate stance against figuration, either by gradually abstracting forms found in nature or by directly employing fundamental shapes. The primary tools of abstraction are geometric form and pure color (Bonfand, 2015). In the process of the dissolution of figurative representation, objects are fragmented and reassembled, depth is reduced, the hidden grid comes to the fore, and the painting becomes geometric with straight instead of curved lines (Rowe & Slutzky, 1963). According to Tunalı (1970), the artists' searches in abstraction are similar to the subjects of the philosophy of their period, namely phenomenology. Phenomenology is expressed as grasping the essence by bracketing "the accidental and the individual" and therefore shares abstract art's goal of searching for "the essence, truth, and the universal." (Tunalı, 1970)

In ontological interpretations of modern art, abstraction is not a rupture from being, but rather a mode of expressing it on a different plane. Even in non-figurative paintings, Being reveals itself. Moreover, everything that is visible carries a trace of Being (Merleau-Ponty, 2019). In other words, in this new conception of art, reality is sought not on the visible surface of nature but beyond it. The new understanding of reality means searching for the depiction of the "pure reality" beyond the visible. Thus, the essence of phenomena is sought in abstraction (Tunalı, 1970). Similarly, the transition from Cézanne to Cubism, which marks the beginning of abstract art, demonstrates that abstraction in Modern Art was not a severance from reality, but a reconstruction of it through a new spatial logic. Artists like Picasso and Braque fragmented the volume of objects using small surface planes (facet-planes), aiming both to define the object's volume and to preserve the flat integrity of the canvas. In doing so, they distanced themselves from traditional representational techniques and developed a new abstract visual language that redefined depth and form (Greenberg, 1989).

Another critical parameter in the transition to abstraction in art is the disappearance of "perspective" in painting, which enables the perception of space without the limitations of depth, width, and height of the Euclidean geometry (Yılmaz & Ödekan, 2009). With the introduction of non-Euclidean geometry comes the fourth-dimension theory, which, in contrast to the current linear perception of time, allows a new spatial perception of time in which the past, present, and future coexist (Yılmaz & Ödekan, 2009). According to Yılmaz & Ödekan (2009), the non-perspectival representation is the main connection within the avant-garde circles leading up to the emergence of suprematism in abstract art.

Florenski's text "Die Umgekehrte Perspektive" is essential in understanding this change. He defines reverse perspective as a multidirectional mode of representation, contrasting it with perspective, which he associates with "subjectivism and illusionism." According to him, the perspectival structure reflects the individual's subjective experience of seeing. Rather than expressing objective or metaphysical views rooted in religious traditions, perspective reduces vision to individual observation. Therefore, rejecting perspective aligns with a preference for "religious objectivity and a transpersonal metaphysics". Florenski argues that perspective is restrictive because it is grounded in Euclidean geometry and Kantian thinking. It forces the artist to adopt a fixed, absolute viewpoint—typically the optical center of the right eye. As the observing eye does not move, the world is rendered from a single static point, like a camera obscura, producing a "still and unchanging" reality (Florenski, 2021).

Furthermore, vision in this system becomes mechanical, excluding psychological and spiritual dimensions. Thus, perspective does not offer an accurate representation of reality, but rather a limited, subjective interpretation. He also suggests that although perspective and Euclidean principles were known in the Middle Ages, they were

consciously adopted only after the secularization of the Christian worldview. The Renaissance shift from divine to naturalistic representation would not be challenged until the late 19th century, when abstraction began to reject perspective, depth, and naturalism. Florenski's position, while metaphysically grounded, is part of a broader critical discourse on representation, which is expanded by Merleau-Ponty's phenomenological reading and Panofsky's historical-symbolic analysis (Florenski, 2021).

Merleau-Ponty states that perspective is not merely a visual system, but also a conceptual construct that governs how thought perceives the world. According to him, perspective organizes appearance around a fixed viewpoint; thus, being is no longer a multiple and layered phenomenon but is reduced to a singular visual object. This critique aligns with Florensky's view of perspective as a system that replaces the divine with the individual observer. According to Merleau-Ponty, the pursuit of accurate representation often distances things from their reality, because perspective operates in a space shaped by thought's intentions. In this context, the represented world is no longer experienced, but becomes a plane mentally constructed (Merleau-Ponty, 2019).

While Florensky opposes the representational system of perspective by advocating a multidimensional and metaphysical perception that opens toward the immanence of being, Panofsky conceptualizes this structure as a secular and mental representational order (Panofsky, 2021). In this context, although approaching from different angles, both Florensky and Panofsky acknowledge that representation is a limited and conceptually constructed structure.

Tunalı, claims that these changes in art resulted from the changes in the artist's perception of man, the world, and God (Tunalı, 1970). As stated before, abstract art was formed to reach "pure reality" beyond the sensible reality. The abstraction, which is considered to have started with Cezanne, influenced the later avant-garde artistic movements such as Cubism, De Stijl, and suprematism. The concept of abstraction became more visible at the Bauhaus School, where the aesthetics of modern design was directly based on Modern Art.

The Gestalt Theory and Bauhaus School of Architecture

It is known that empathy theories influenced the masters of the Bauhaus school in relation to the Gestalt Theory. In particular, Johannes Itten, Wassily Kandinsky, and László Moholy-Nagy adopted Lipps' theory of empathy and the ideas of Wolf Dohr and his student Émile Jaques-Dalcroze, who studied the coordination of "body and brain" at Hellerau under Lipps' influence. Marianne Tauber, who works on these connections between Bauhaus and the Gestalt school, states that Gestalt psychologists were invited to the Bauhaus School to lecture on the theory of perception, and a seminar was given on this subject. Moreover, she mentions that a student of Paul Klee, a Bauhaus lecturer, found in his lecture notes expressions belonging to Wertheimer, one of the founders of Gestalt psychology. Klee utilized the visual illusions found in the books of psychologists and philosophers influenced by Gestalt psychology and empathy theories to develop his understanding of abstract art, which he adapted to his lectures (Van Campen, 1997). In Itten's studio classes, students were encouraged to gain a natural rhythm through body movements before painting and designing. Itten's other method that supports bodily movements involved the whole body in artistic production by stimulating the tactile senses. He encouraged bodily participation in design through the different types of materials that the students experienced with closed eyes (Mallgrave, 2013).

In his book "On the Spiritual in Art" Kandinsky (1946), a Bauhaus lecturer, states that beyond the physical effect on the act of seeing, colors and lines evoke a "psychic effect" through a "spiritual vibration." In his lectures at the Bauhaus, Kandinsky adopted a method of art science, the foundations of which he laid in his book "Point and Line to Plane" (Kandinsky, 1926). In this book, he states that horizontal lines are cold and vertical lines are warm. According to Mallgrave (2013), Kandinsky's empathy theory lies at the root of the sensory qualities attributed to the types of lines in this book and his subsequent interest in Gestalt Psychology (Mallgrave, 2013). It may be worthwhile to note that Kandinsky and Lipps worked in Munich around the same time. According to Van Campen (1997), Lipps' work on the "psychological analysis of abstract forms" influenced Kandinsky's art theory. He claims that the science of art that both Lipps and Kandinsky worked on is based on perceptual experiments to understand the creative powers of human consciousness by utilizing the different positioning (configuration) of lines and points on the plane. Accordingly, in his Bauhaus classes, Kandinsky taught his students how to investigate the visual forces generated by the different positioning of primary forms. Kandinsky aimed to establish general rules of art through these visual experiments (Van Campen, 1997).

Moholy-Nagy, another Bauhaus teacher, defined architecture in his book "From Material to Architecture (1929) uniquely as the art of "spatial creation," which the architect can achieve "only through the most profound understanding of human life as a total phenomenon within a biological whole" (Mallgrave, 2013). He began his lectures with exercises where students could experience the nature of materials. Moholy-Nagy considered the human biological structure as the basis of design (expression). According to him, man's experiences are created by his senses, and the psychological effect of an experience is the basis of man's relationship with the object. Therefore, the empathic experience constitutes the material basis of art (Mallgrave, 2013).

What the artists, especially those engaged in abstract painting, did in this period was not limited to integrating existing research on the psychology of visual perception into their work, but they also began to conduct visual experiments like psychologists so that there became a field of research where the psychologists also refer to the artists. For example, Edgar Rubin, an experimental psychologist, refers in his work to the publications of Alois Riegl, an art historian, and the works of Kandinsky, an abstractionist artist. The perception of the figure-ground phenomenon that Rubin studied would later influence Theo van Doesburg and Piet Mondrian, members of the De Stijl art group. Van Doesburg praised the potential of the figure-ground phenomenon to bring different color grounds to the foreground by eliminating the background. Indeed, in the context of Modern Art, the De Stijl artists sought to create paintings without depth. However, for Mondrian, more than the overlapping planes of the figure-ground phenomenon was needed to get away from the perception of depth. For this reason, together with Vilmos Huszar, he developed the "raster." In this way, each rectangle is painted in one color to prevent the overlapping effect and eliminate the danger of depth (Van Campen, 1997).

Another essential aspect that the Bauhaus school adopted in its pursuit of establishing the integration of art, psychology, and architecture is the educational approach that focuses on object design. According to Allen (2018), the Bauhaus educational method is based on students designing objects. It is known that Walter Gropius, the first director of Bauhaus, created an educational vision that combines architecture, sculpture, and painting in the opening speech of the school. Gropius' successor, Hannes Meyer stated that objects began to replace architecture through white walls that function as a background for objects, making the architects merely "producers and curators" of objects (Allen, 2018).

In the turbulent atmosphere that Simmel investigated in the growth of cities, the disappearance of culture, and the emergence of the bored individual, architects and artists offer solutions for reconstructing society. For instance, expressionists like Kandinsky seek to reconstruct a "lost sense of community" through "artistic labor." Most artists in this period, like architects, support the destruction of the object. However, Kandinsky and Klee differ from other artists at this point. Although Klee accepts that the object is dead, the sensation of the object stands in an essential place for him. For Klee, the object has a "mysterious inner life" and "life force" (Allen, 2018).

It can be said that Klee's ideas about the object oppose the Kantian idea that objects can only be perceived by a "subjective viewpoint." The basis of this understanding, which Kandinsky also adopted, lies in the empathy theory in the sense of "objectified self-enjoyment." Like Klee, in his Bauhaus classes, Kandinsky "focused on analytical drawing and the elements of abstract form, from which he built up a universally valid grammar of form and color" (Allen, 2018).

With the links he established between "colors and spirit, line and life force," Kandinsky aimed to reach beyond the boundaries of art and to achieve the unity of the human and the divine. According to Allen (2018), this system, which eliminates the artist and other concrete factors (technique) belonging to the object, constitutes the importance of the point where the Bauhaus school stands (Allen, 2018).

As can be seen, the developments that began under the influence of empathy theories resulted in design education by the artists of the Bauhaus school, which in turn enabled the interaction between Gestalt Theory, abstraction, and object design. While Lipps associated aesthetics with the empathic process in the mind, Kandinsky defined "aesthetic phenomena to be organizations that are perceived directly" (Van Campen, 1997).

It is seen that the deep and psychic relationship that exists in the empathy theory with the outside world is replaced by a more superficial and mechanical relationship through Gestalt. Worringerian abstraction or Worringerian empathy theory, which is the basis of Gestalt Theory, offers, in Helg's words, a space of "narcissistic mirroring" for the modern self-image. The empathic attitude here as "objectified self-enjoyment" is achieved through the abstract object with the "exclusion of life." Therefore, this process, which started with empathy theory and continued with Worringerian abstraction, emerged as Gestalt theory within the Bauhaus school. As stated earlier, this new form of empathy theory involves a more mechanical and superficial relationship that the individual establishes with the object in a narcissistic manner. What is meant by the object here is abstract painting in art, while in architecture, it is the product of Modern Architecture purified of its figurative (e.g., historical) layers (Helg, 2015).

Abstraction as a New Version of Empathy Theory in Architecture

Cubism is the first connection between Modern Art and Modern Architecture, reflecting the empathy theory-based changes. As it is known, Cubism searched for a new understanding of reality in art by the representation of objects in space simultaneously from all directions instead of in perspectival depth. Representing a "deeper" reality by eliminating the three-dimensionality started with Cezanne. However, it quickly became a characteristic of the Modern Art after Cubism, which, for Rowe and Slutzky, creates an effect of "transparency" in the sense of "the simultaneous perception of different spatial positions" (Rowe & Slutzky, 1963). Rowe and Slutzky claim that transparency as an effect of Modern Art becomes visible through the examples of Modern Architecture.

Giedion explains the concept of transparency through the relationship between Picasso's L'Arlésienne and Gropius' Bauhaus design (Figure 4). According to him, the Cubism-based transparency and simultaneity that allows both the profile view and the entire face of an object to be seen at the same time in L'Arlésienne is similar to the simultaneity of space-time that occurs in the Bauhaus building with the diversity of points of reference (Giedion, 1959). Soon after Giedion, Rowe & Slutzky (1963) classify transparency under literal and phenomenal concepts.While literal transparency is a condition arising from the transparent nature of matter, phenomenal transparency is related to space organization. For them, the phenomenal transparency in architecture stems from the effect of two-dimensionality, like in Cubist painting, where the matter is the "articulated presentation of frontally displayed objects in a shallow, abstracted space" (Rowe & Slutzky, 1963).

Rowe and Slutzky argue that transparency in architecture can only become a reality when it is freed from the falsity of three dimensions. Therefore, the phenomenal transparency inherent in the cubist attitude in architecture is related to the organization of planes rather than the transparent structure of the material. While in the Bauhaus building designed by Gropius, transparency literally arises from extensive surfaces of glass and therefore has material character, in the Villa Stein designed by Corbusier in Garches (Figure 5), it is but a phenomenal transparency where two-dimensional planes create a sense of depth (seeing through) which is not perspectival (that is, not temporal). According to Rowe & Slutzky (1963) interprets the complementary composition of incomplete and fragmented surfaces as the removal of the three-dimensionality of the object, just like in a cubist painting (Rowe & Slutzky, 1963).

Figure 4. Bauhaus, Dessau, 1926 (Giedion, 1959).

Figure 5. Villa Stein, Garches, 1926 (Fondation Le Corbusier, n.d.).

The idea established by Klee and Kandinsky on transcending the object through abstraction on the artistic plane finds its counterpart in Le Corbusier's architecture under the influence of Purism - a version of Cubism devised by Le Corbusier and Ozenfant. Like in his buildings, he brings together elements in space with a marriage of contours and establishes the objects of modern culture (Allen, 2018).

As mentioned, this is not only about the abstract design of surfaces. Le Corbusier rejects the mono-focal perspective of classical architecture. In Corbusier's architecture, this rejection appears in the architectural promenade (Figure 6) (Charitonidou, 2022a). Architectural promenade

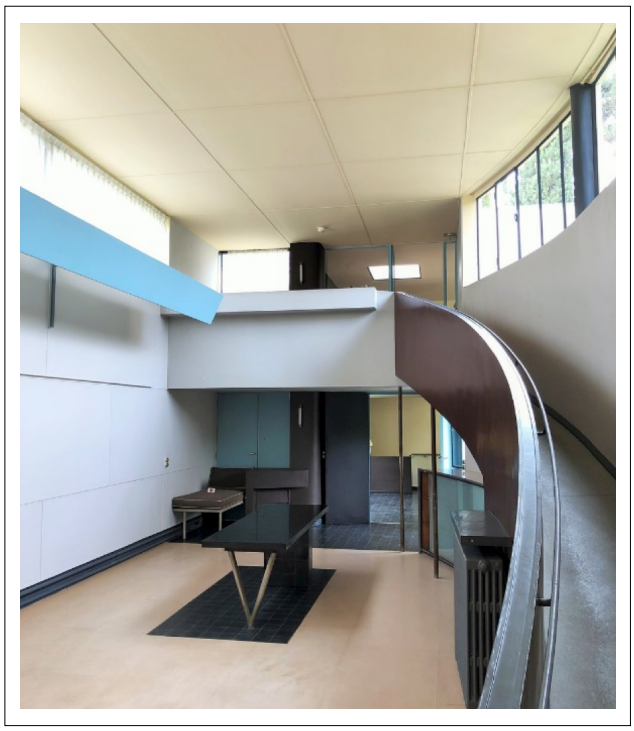

Figure 6. Architectural Promenade, the Maison La Roche, Paris, 1925 (The London List, n.d.).

is the architectural version of the cubist idea of seeing different aspects of an object simultaneously. Accordingly, architectural promenade allows the body to perceive a building by walking in, on, and around it (Lee, 2014).

In contrast to the perspective of classical architecture, which was based on a vantage point, in the architectural promenade, which reflects the empathy theories and especially Schmarsow's concept of "sense of space," space begins to be perceived as a "three-dimensional" volume defined by two-dimensional abstract surfaces. In short, Architectural Promenade offers different viewpoints and perspectives to the body moving inside the house and the city (Charitonidou, 2022a). Moreover, space becomes designed by experience (Charitonidou, 2022b).

Le Corbusier's idea of the "architectural promenade" connects Schmarsow's projection of the empathy theory into architectural space and Rowe and Slutzky's transparency theory in a peculiar way. While the promenade concerns a movement in space with consequent emphatic impressions, the spaces of the promenade receive their definition from a phenomenal expansion of abstract forms out of planar surfaces. Villa Savoye is a prime example of this situation (Figure 7), which, according to Le Corbusier, offers aspects constantly varied, unexpected and sometimes astonishing" (Louw, 2016).

Villa Savoye is not experienced from a single point because the body is in a state of movement on the horizontal and vertical axis, moving, orienting forward, and thus establishing a three-dimensional space. In addition to that, Le Corbusier adds the fourth dimension to the layers of space, which is "time." Although the layer of "time" used by Le Corbusier contains different implications of time in different buildings, it has a meaning based on the experience of "now" in the Villa Savoye. In this context, Le Corbusier connects the strollers walking on the ramp - a tool to facilitate the architectural promenade - to the present moment by making them observe the outdoor space and, thus, the movements in nature. Louw describes the experience here as a cinematographic experience. As in cinema, time is reconstructed in this stroll through slowdowns, accelerations, and different vistas observed during the experience. According to Louw (2016), during this wandering, the subject experiences different seasons, changing angles of light (sun), and different emotional states of his/her own, thus distancing himself/herself from situations that would detach him/her from the present moment.

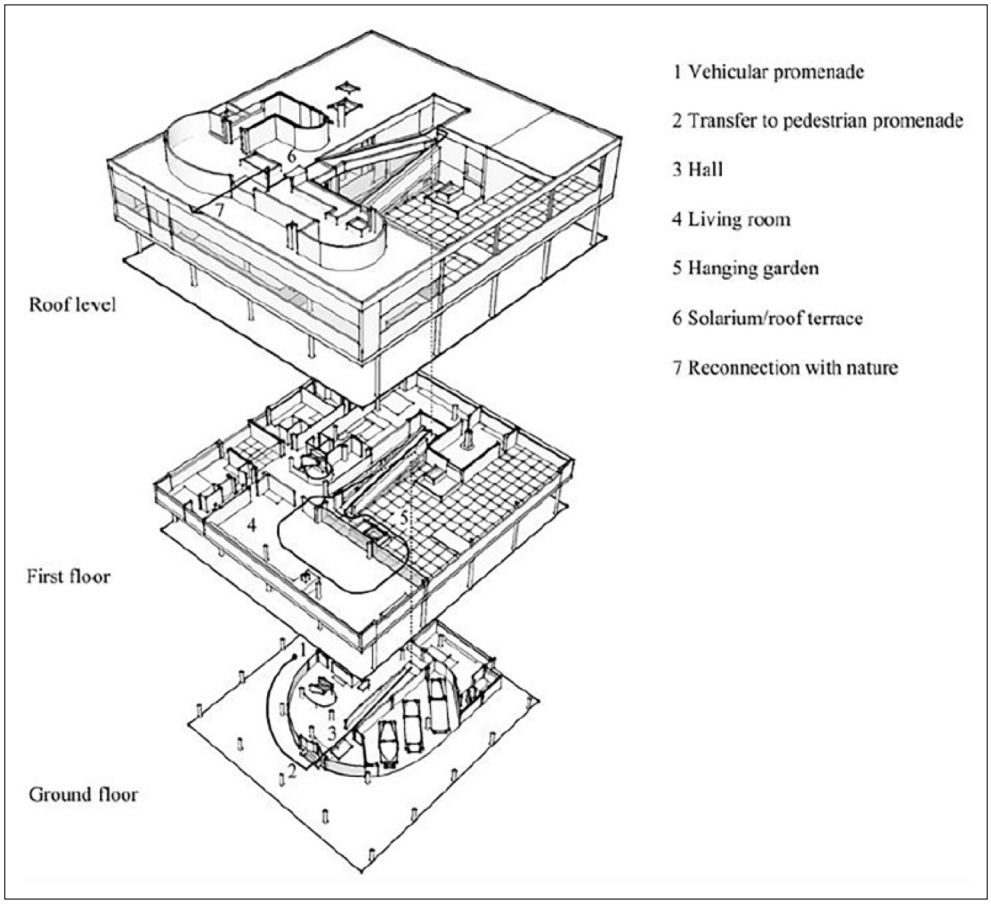

Figure 7. Architectural Promenade, Villa Savoye, Poissy, 1931 (Louw, 2016).

Lee claims that Le Corbusier's architecture reflects both the perspectival tradition of modernity and the phenomenology of bodily experience at the same time. As a matter of fact, contrary to the Cartesian thought that sees the mind as absolute, phenomenology includes the body in consciousness. Consciousness turns towards the object through the body in phenomenological philosophy. Against the perspectival tradition of modernity, in phenomenology, the object is not fixed; the body re-experiences and grasps it every moment. Therefore, although Corbusier's architecture is based on Cartesian thought and the geometric architecture of the societe machineste, it is a sign of the partial emergence of the phenomenological attitude in architecture in terms of designing the body's movement within the structure. This experience approaches nature with a focus on sight, and all senses are not included in the experience (Lee, 2014). Therefore, the architectural promenade continues empathy theory-based approaches in architecture and exhibits some of the first traces of phenomenological approaches.

CONCLUSION

This research assumes that the notion of experience appears in architecture through "*Einfühlung* theory /empathy theory." By revealing the early conceptual links between empathy, abstraction, and spatial experience, this study reframes empathy theory as a foundational influence in the evolution of architectural experience.

This assumption is supported by tracing the historical development of aesthetic theories—from early philosophical inquiries into beauty and emotion to the emergence of empathy theory in psychological aesthetics. The analysis suggests that empathy theory laid the conceptual groundwork for understanding architecture as a space to be perceived and experienced by an embodied subject, ultimately shaping modern architectural paradigms such as *Raumplan* and the *architectural promenade*.

Also, the research reveals the connections of how empathy theory passes from art to architecture. It can be said that the connection of empathy theory with architecture occurs in two ways. The first is that the idea of space, which came to the fore with empathy theory, became directly visible in the early periods of modern architecture through expressions such as "architectural wandering, volume, raumplan" which include the "circulation of the body in space"; another effect is that empathy theory triggered the formation of the idea of abstraction in modern art and then this effect shaped modern architecture.

Le Corbusier's concept of *architectural promenade* is the result of the ideas that started with the empathy theory in art, which merged with its opposite, the abstraction through movements such as Cubism, suprematism, and Purism. In Le Corbusier's architecture, space is organized as a sequence of different moments, allowing the body to move and see different perspectives and images simultaneously. Consequently, an architectural design idea based on "experience" has been created, where the body perceives the space through "simultaneously ordered" abstract surfaces that emphasize space.

As a continuation of Hildebrand's emphasis on empathy theory-based depth, the z-coordinate is felt in the space in addition to the x and y coordinates. Therefore, in modern architecture, the body is not stuck on surfaces. Surfaces are not figurative in space and are constructed to create a sense of volume. Accordingly, architectural structures are designed like two-dimensional paintings, which implies three-dimensionality. The subject in all this new fiction is the body that experiences space mechanically and narcissistically. Since the new space design is less figurative, it is explained by the psychology of space perception rather than the empathy theory as formulated in the late 19th century. Here, the body does not identify with the figurative elements in the space as in the empathic experience. Instead, the space affects the body, which is treated like a perception machine.

According to Pallasmaa (2018), the unique power of architecture lies in its ability to let us momentarily inhabit the world and ourselves through the embodied sensitivity of the creator. This perspective resonates with the empathy-based spatial paradigms discussed throughout this study and reaffirms the enduring relevance of bodily experience in architectural thinking. The empathy-based approach that becomes evident in the architectural promenade continues to inform contemporary architectural thought, particularly in discussions that emphasize embodied spatial perception.

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Article

Building a mission in Ottoman Empire: A research on Istanbul Robert College gymnasium building in the light of new documents

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ABSTRACT

This study analyzes the strategic and operational framework of building a mission in a foreign country within the standards of local, international, and associated systems. The anatomy of the activities of the American Board of Commissioners for Foreign Missions (ABCFM, American Board), the largest missionary organization of the 19th century, is examined through the construction of Robert College and its educational system in the Ottoman capital. The construction journey of Robert College's Gymnasium Building and its architectural changes through time illustrate how the mission's visibility was achieved within the framework of Ottoman laws and the social environment in which it was situated.

In this study, previous works within this scope were first examined. Then, documents accessed for the first time through research conducted at Columbia University, Rare Books and Manuscript Library, Boğaziçi University Architectural Drawings Collection, and the Ottoman Archives of the State Archives Directorate were compiled (archival research continued from 27.05.2022 to 26.06.2024). Based on these documents, the Gymnasium Building was documented, and the construction process was interpreted through the existing traces and alterations on the building. In the light of the data obtained, the first section of the article will describe the permission and the construction process of Robert College. The second section will examine the environment that created the necessity for a Gymnasium building within the school and the sports activities in the Ottoman Empire in a comparative manner. In the third section, the documents obtained from various institutional archives will be published for the first time, and the processes of obtaining permissions, project planning, construction, and the material procurement for the Gymnasium Building will be analyzed. Additionally, this section will evaluate the prepared survey project and the restitution proposals concerning the archival data.

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INTRODUCTION

The 19th century stands out as a period when missionary organizations increased their activities in many parts of the world to spread their religious beliefs. The vast geographical area covered by the Ottoman Empire and its multi-ethnic structure attracted the attention of missionary organizations. Among these organizations, the American Board was the most prominent.

The American Board, particularly from 1839 onwards, operated in many regions of Anatolia, constructing schools, orphanages, and hospitals. Thanks to the organization's meticulous reporting system, all activities were recorded through diaries, periodic and general reports, and projects with detailed drawings, with a significant portion of these documents surviving to the present day. One of the Board's most important undertakings, Robert College, was meticulously documented from the design phase, mainly due to the buildings constructed and the educational system established in Istanbul. These documents were shared with relevant institutions (Ottoman state institutions, the U.S. government, the American Board, and the Robert College Board of Trustees). From the documents currently housed in various archives, it is possible to identify the school's founding, the permission, the construction processes, and its architectural and material characteristics.

Within the scope of this study, the permission and the construction process of the Gymnasium Building, one of Robert College's structures, thoroughly researched both on-site and in archives, could only be clarified through the comparison of various archival sources. As a result of the archival research, the construction process of the building, the implementation of the projects, its original condition, and its current state have been compared using photographs obtained from the archives and the projects prepared during the permission process. In the light of these newly discovered documents, the historical development of the structure has been examined and presented.

METHODOLOGY AND LITERATURE REVIEW

Archival data constitute the primary source for this original study. The most comprehensive and systematic archives of Robert College are housed at the Columbia University Rare Books and Manuscripts Library in New York. Covering a period from the 1850s to the 1980s, this archive contains over 200,000 written and visual documents related to Robert College and the American College for Girls. Boğaziçi University acquired a digital copy of this archive through a protocol signed in 2013 (Kırlı & İleri, 2015). The correspondence, reports, and photographs contained in this archive were used as a source to clarify the college's founding process and the construction of Gymnasium[1].

The Boğaziçi University Architectural Drawings Collection includes 397 architectural drawings related to Robert College and Boğaziçi University, produced between the 1870s and the 1990s. The collection contains original project drawings on tracing paper, sketches, measured drawings on various paper types, and blueprint reproductions (Kırlı & İleri, 2015). As this archive, accessed through the Boğaziçi University Archives Directorate, is still being catalogued, the documents do not yet have file numbers. The original architectural projects in this collection were used to prepare the restitution proposals for two different periods of the Gymnasium.

Another archive utilized in this study is the Ottoman Archive of the State Archives Directorate. Through documents submitted by the Robert College administration or the U.S. Embassy to the Ottoman Empire, the permission and construction processes of the Robert College buildings could be traced. Among the documents submitted by the college to the state are architectural projects, which have served as the basis for restitution and provided an opportunity to compare with other projects in the Boğaziçi University Architectural Drawings Archive.

The autobiographical "My Life and Times" (1893) by Cyrus Hamlin offers a detailed account of Hamlin's own life, including his educational background and his works as a missionary in Istanbul, where he founded the Bebek Theological School and later established Robert College. Aksu (2017) translated the book of Hamlin as "Robert Kolej Uğrunda Bir Ömür". This translation includes an introduction written by the translator.

"The Anatomy of a Tradition: 150 Years of Robert College 1863-2013", published in 2013, and this catalogue has been prepared for an exhibition at Suna and İnan Kıraç Foundation, Istanbul Research Institute. "The Campus, The City, and The Empire: The Early Architecture of Robert College and The American College for Girls" (2013) by Zeynep Çelik is a valuable resource for evaluating the Ottoman Archive data on the College.

"Fifty Years in Constantinople and Recollections of Robert College" (1909) was written by George Washburn, the second president of the College. The book offers comprehensive information regarding the construction processes and architectural development of the college buildings. "A Bridge of Culture: Robert College-Boğaziçi University" (2009) by John Freely is another vital source that provides detailed examinations of the school's permission and construction processes.

Several graduate theses have been produced in Turkish universities that address the history of Robert College and the development of sports activities in the Ottoman Empire. Among them, "*The Robert College: The Building of an American School in Istanbul*" (2023) by Zeki Furkan Arılıcan, completed in the Department of Architecture, focuses on the architectural formation of the college. Similarly, "*Istanbul Robert College in the Light of American Archive Documents*" (2015) by Refika Yavaşer, submitted to the Department of Education, examines the institution through American archival sources. Another significant work is "*Conservation Project of the Kurtuluş Sports Club Building (Tatavla Hercules Gymnastics Association)*" (2018),

authored by Gizem Şenel under the supervision of Prof. Dr. Deniz Mazlum. This thesis presents a detailed investigation of sports-related activities within the Ottoman context, with a particular focus on minority communities.

In addition to these theses, relevant periodical sources have also contributed to the field. Nejla Günay's article "*Osmanlı Devleti'nde Kurulan Spor Cemiyetleri ve Jimnastik Derslerinin Milliyetçilik Hareketlerindeki Rolü*" (2017), published in Belleten, offers valuable insight into the political and cultural significance of sports in the late Ottoman period.

ROBERT COLLEGE CONSTRUCTION PROCESS

In his autobiography, Cyrus Hamlin (1893) describes in detail how he founded an American school in the Ottoman capital in 1863, with the support of C.R. Robert. Hamlin was born in 1811 in Maine, USA. He entered Bridgton Academy and spent two years there. His education then continued at Bowdoin College, where he constructed a steam engine and joined three religious groups, taking leading roles. He decided to become a missionary at the College and became closely associated with the American Board of Commissioners for Foreign Missions (ABCFM) during his theological studies. After graduation, he was a member of the ABCFM and was sent to Istanbul in 1839 by the Board, where he decided to establish a theological school to support missionary activities (Hamlin, 1893). The ABCFM's choice of Hamlin for Istanbul was a highly appropriate one. His creative intelligence, problem-solving skills, and perseverance—consistently demonstrated throughout his student years—were the primary reasons for assigning him to a challenging field.

Hamlin began teaching two Armenian students in a rented house in Bebek. As the number of students grew, he moved the school to a larger house in 1843 (Figure 1) (Hamlin, 1893).

The house was suitably large, in line with the American Board's standards. Properties rented or built by the Board across Türkiye typically shared two key features: they were located far from city centers and were large in size (Figure 2).

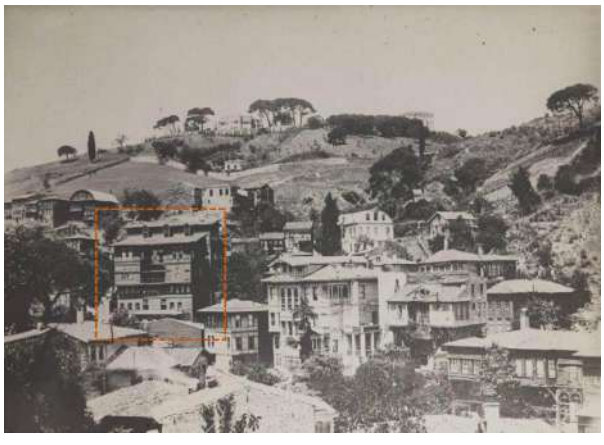


Figure 1. Bebek Theological School (Columbia University, n.d.a).

Figure 2. American Board Mission buildings in Harput (Salt Research, 1902).

In My Life and Times (1893), Hamlin explains that the Bebek Theological School operated until the 1860s, when it was relocated to Merzifon. He states that his views no longer aligned with the Board's, leading him to part ways with the organization in 1860 (Hamlin, 1893). But the true story was different. Establishing an American College in the Ottoman Capital wouldn't be an easy task. The college had to be secular and entirely independent from the American missionaries operating within the Ottoman Empire. Such institutional independence was considered essential to avoid provoking prejudice or resistance among the Ottoman population. In this way, the school would be able to attract students from various national and religious backgrounds (Greenwood, 2003).

So, Hamlin parts ways with the Board, but he describes himself as more of a missionary than ever. He then began discussions with Christopher R. Robert, a New York merchant, about the college he had long dreamed of establishing. He secured the necessary funds for the school from America (Hamlin, 1893).

Robert College Site Selection and Initial Building Permission Process

The land Hamlin desired (Figures 3; Figure 4) was located on the hills of Rumeli Hisarı and belonged to Ahmet Vefik Pasha. He chose this site primarily because it overlooked the Bosphorus (Figure 5) and had a nearby stone quarry, which eliminated the need for costly and difficult stone transportation (Washburn, 1909).

In 1859, when Hamlin selected the site at Rumeli Hisarı for the establishment of the college, he was unable to acquire the land from Vefik Pasha, who was unwilling to sell it for the purpose of founding an American institution (Freely, 2000). However, following the death of Sultan Abdülmecid in 1861 and the accession of Sultan Abdülaziz, Vefik Pasha's position (he was serving as ambassador in Paris) also shifted. After he was removed from his position, Vefik

Pasha, in need of money, offered Hamlin the opportunity to purchase the site (Washburn, 1909). Hamlin made deals with Pasha in 1861 and officially purchased the land in 1862, but was unable to construct the school because he hadn't obtained a building permit from the government (Aksu, 2017). In 1861, Hamlin prepared a historic statement of the origin of the proposed college for the Trustees' review. The report provides insights into the institution's educational philosophy, its qualifications, and the instructional methods to be employed. This report was also sent to the Ottoman Empire to obtain permission to establish the school (Ottoman Archives, 1861). The Ottoman government granted permission for the establishment of the school, but not for the construction of its buildings. This was primarily because the selected site wasn't located within a Christian neighborhood, which was considered inappropriate for a Christian institution. Moreover, the Muslim residents of Rumeli Hisarı expressed discontent with the idea of an American school being built on what they regarded as a sacred site (Ottoman Archives, 1866).

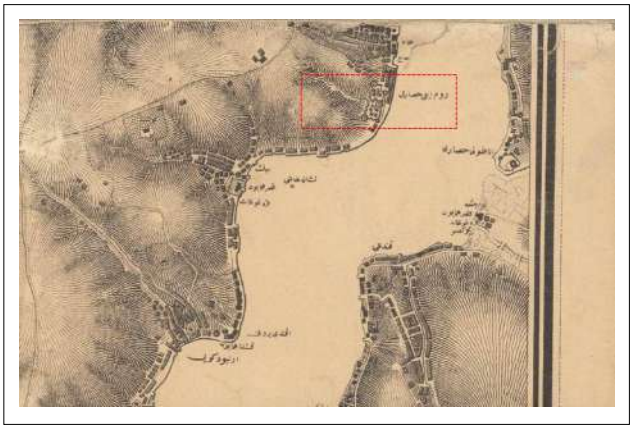


Figure 3. Rumeli Hisarı (Moltke, 1852).

Figure 4. Robert College map (Ottoman Archives, 1910).

Figure 5. Hamlin Hall is located on the hills of Rumeli Hisarı (Eskiistanbul, 1890).

Hamlin repaired the vacant building in Bebek and established Robert College there in 1863. He obtained the building permission for Rumeli Hisarı seven years later, in 1868 (Aksu, 2017). After Admiral Farragut visited Istanbul and had meetings with the Pashas, the permission to construct at the Rumeli site was given as the Sultan's Irade. With the acquisition of the building permission in 1868, construction of the first building began immediately and was completed in 1871 (Hamlin, 1893). In recognition of Cyrus Hamlin's significant efforts to establish Robert College in Istanbul, this building was named "Hamlin Hall." Since the education previously provided in the house in Bebek would now continue in Hamlin Hall, which included classrooms, a dining hall, a kitchen, dormitories, and other facilities (Aksu, 2017). As the school expanded, new functional buildings were added over time, contributing to the growth of Robert College. A large single-story study hall was later built behind the first building (Figure 6) (Çelik, 2013).

Figure 6. Robert College Hamlin Hall, 1870s (Abdulhamid II Photograph Archives, 1870).

After founding Robert College and constructing its first building, Cyrus Hamlin recognized the need for housing for the teachers instructing at the College. To address this need, construction began on two residences. The first, Van Millingen House (also known as Huntington House or Scott House), was built and opened in 1880-81 by Alexander Van Millingen, an expert in Byzantine history and architecture (Freely, 2000). In 1891, Kennedy Lodge was completed as the president's residence (Figure 7). The building was named after John S. Kennedy, who provided the donation that funded its construction and was, at the time, the Chairman of the Board of Trustees of Robert College. Around the same period, Science Hall (later renamed Albert Long Hall) was also opened (Figure 8). Theodorus Hall was completed in 1902. Designed as a preparatory building, its construction was funded by a donation from Olivia Egglestone Phelps Stokes (Çelik, 2013).

With donations from William E. Dodge and his son, Cleveland Dodge, the Dodge Gymnasium (Gymnasium Building) was completed in 1904. In 1906, Washburn Hall, designed by Hamlin's son Alfred Dwight Foster Hamlin[2], was also completed. In 1912, the Engineering Building, or Gates Hall, was finished, followed by Anderson Hall in 1913, which Alfred Dwight Foster Hamlin designed as a classroom/dormitory building. An addition was made to Dodge Hall in 1914. The Henrietta Washburn Hall, intended as a meeting hall and auditorium and named after Hamlin's daughter, was completed that same year (Freely, 2000). In 1925, Sloane Hall (John Sloane Infirmary) was completed, funded by a donation from William Sloane, a Robert College Board of Trustees member, in honor of his late father, a former trustee. In 1932, the Alexander van Millingen Library (Figure 9) was completed, further expanding the Robert College campus (Figure 10) (Çelik, 2013).

Figure 7. Hamlin Hall (left) and Kennedy Lodge (right) (Library of Congress, 1901).

In 1871, while classes were still being held in the Bebek building, the number of students was 99; however, this number rose to 195 in the same year following the relocation to Rumeli Hisarı. While the majority of students were initially Bulgarian and Armenian, the number of Jewish, Turkish, and Greek students also increased over time (Washburn, 1909).

THE CONSTRUCTION PROCESS OF THE GYMNASIUM BUILDING

Before founding Robert College, Hamlin ensured that Robert College was established as a secular educational institution (Aksu, 2017). The presidents who succeeded Hamlin continued this vision, providing students with opportunities to gain practical skills through humanities courses and workshops. Physical activities were included in the curriculum from the school's early years. As a result, structures were later built to accommodate students' participation in sports and social activities (Freely, 2000).

Figure 8. Robert College on the Bosphorus (Library of Congress, 1910).

Figure 9. Alexander van Millingen Library (Columbia University, n.d.b).

Sports Education in the Ottoman Empire and Robert College

Sports activities in the Ottoman Empire during the 19th century were primarily conducted in military barracks and schools as part of military drills. Physical training, gymnastics, or physical education classes were first introduced outside of military schools at Galatasaray Mekteb-i Sultani (Günay, 2017). With the introduction of gymnastics education during the Tanzimat Era, schools with gymnasiums began offering apparatus gymnastics and weightlifting exercises. Instructors were brought from abroad to teach these activities in the early stages. Beyond the gymnastics education provided in schools, from 1880 onward, instructors began to open private gymnasiums in Beyoğlu. By the end of the 19th century, sports clubs started to form (Soyer, 2004). The transition from traditional Ottoman sports structures to formalized club organizations also took place during this period. The first sports clubs in the country were established by Greek communities, in the form of minority associations centered around athletic activities (Günay, 2017).

While these developments were unfolding within minority associations in the fields of sports and the arts, the first Modern Olympic Games were organized in Athens in 1896. However, the Ottoman Empire was not able to officially participate in the event until 1912. During the reign of Sultan Abdulhamid II, Muslims were not permitted to establish clubs. This restriction was lifted with the proclamation of the Constitutional Monarchy, after which the number of sports clubs and associations in the Ottoman Empire rose to over fifty. One of them, and the first established in the Ottoman Empire, is the Tatavla İraklis Gymnastics Society, which dates back to 1896 (Şenel, 2018). Some of the legally established sports clubs of the Ottoman period include Galatasaray, Fenerbahçe, Süleymaniye, Vefa, Beykoz, and Nişantaşı. The development of sports clubs coincided with the establishment of Robert College (Günay, 2017).

In 1871, Robert College moved to Rumeli Hisarı, continuing its educational activities. The large, open spaces of the area allowed students to engage in various outdoor sports easily. However, when weather conditions didn't allow, indoor spaces became necessary. To address this need, temporary facilities were used for sports classes and activities as early as the 1870s (Figure 11) (Çelik, 2013).

In 1896, the Robert College Athletic Association was established to organize sports activities and promote sports

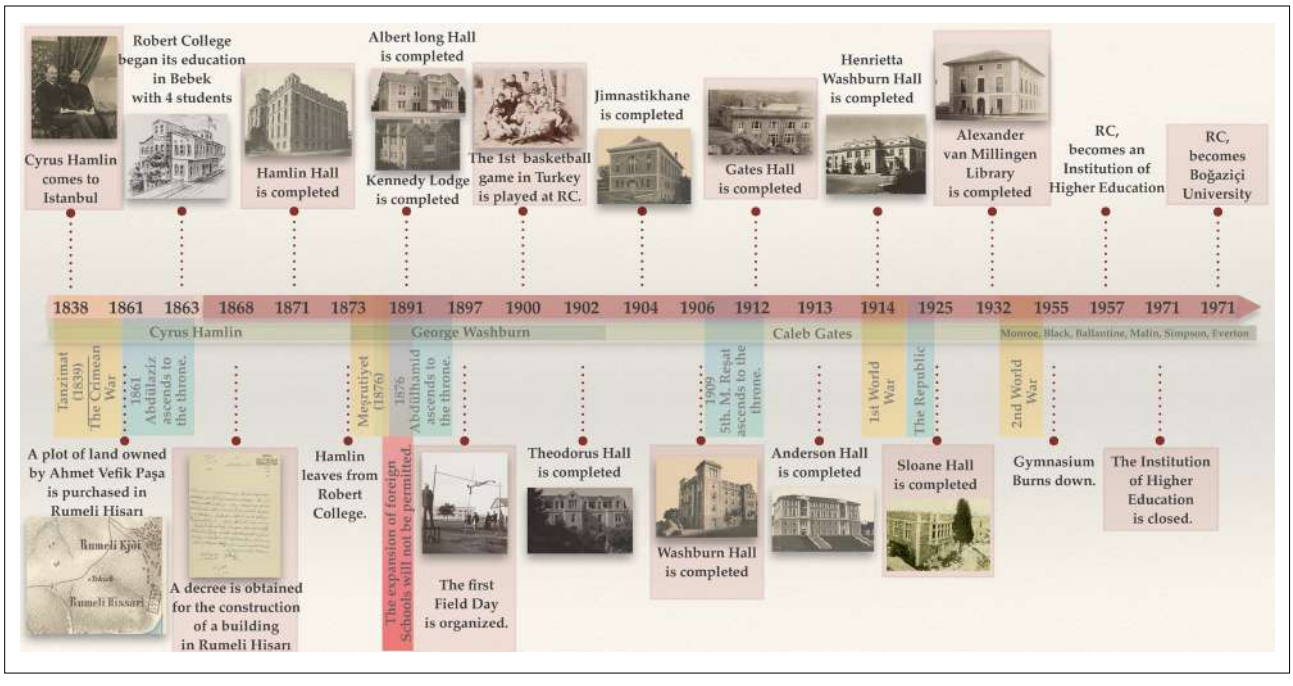


Figure 10. Robert College chronology (Created by the Authors).

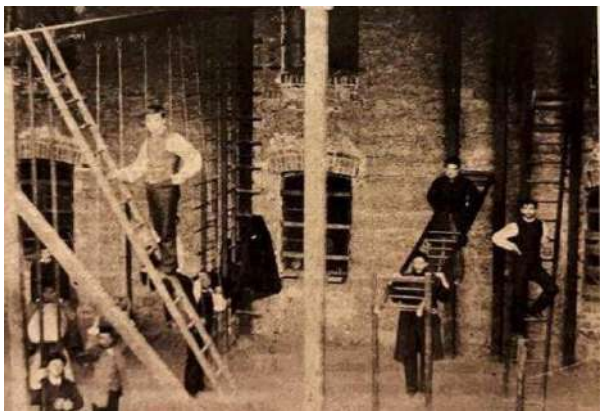


Figure 11. The temporary gymnasium in Hamlin Hall, 1870s (Çelik, 2013).

within the city and the country. Reflecting the rapid spread of Olympic culture in Europe and America at the time the tradition of Field Day began in 1897 (Figure 12). Even in those early years, Robert College organized the most comprehensive sports event in Türkiye, encompassing various sports disciplines (Çelik, 2013).

Thanks to its Anglo-Saxon connections, Robert College could stay informed about developments abroad more quickly. During that period, the school followed sports-related developments in England and America, enabling it to form teams for basketball, football, baseball, and cricket, many of which were the first of their kind in Türkiye. The Robert College basketball team, established in 1900, was the first basketball team in Türkiye (Figure 13) (Çelik, 2013).

Due to the high importance placed on sports at Robert College, there was a need for an indoor sports facility to provide students with systematic training. Up until that time, the following buildings had been constructed within the College: Hamlin Hall, serving as classrooms, laboratories, student dormitories, and faculty residences; the Study Hall, serving as a study and recreation room; the Alexander van Millingen House and Kennedy Lodge, serving as residences; Albert Long Hall, serving as a science building; and Theodorus Hall, serving as a preparatory building and dormitory. The following structure was built in 1904: the Gymnasium (Figure 14). This building was the seventh structure constructed for Robert College and was one of Europe's first indoor sports facilities (Çelik, 2013).

The Building Permission Process and Material Procurement

When the decision was made to construct the Gymnasium Building, the donation was made by William E. Dodge and his son, Cleveland Dodge, both members of the board of trustees (Çelik, 2013). Upon examining the documents submitted to the Ottoman government for the construction,

Figure 12. Field Day, 1904 (Columbia University, n.d.c).

Figure 13. RC Basketball Team, 1900 (Columbia University, n.d.d).

the first document, dated 1902, indicated the intention to build two lodges and a gymnasium (Ottoman Archives, 1902). On June 3, 1903, it was noted that a document was submitted to request permission for the construction of the Gymnasium (Ottoman Archives, 1903a). In a document dated September 18, 1903, permission was requested for the construction of the Gymnasium. However, upon discovering that the foundations of the building had been laid without authorization, the Ottoman government informed that permission needed to be obtained (Ottoman Archives, 1903b). In another document dated September 30, 1903, when the school administration was informed that an official permission was needed for the Gymnasium, the embassy stated that the matter was being processed at the Babıali (Sublime Port) and that construction should be allowed to continue until the procedures were completed (Ottoman Archives, 1903c). In a document sent from the Şehremaneti (municipality) to the Ministry of the Interior on February 22, 1904, it is stated that the Gymnasium was "*large and made of masonry, rising three stories high*" (Ottoman Archives, 1904). A document dated August 22, 1905, lists the materials brought for the Gymnasium and the classroom (Washburn Hall) and those to be brought. When

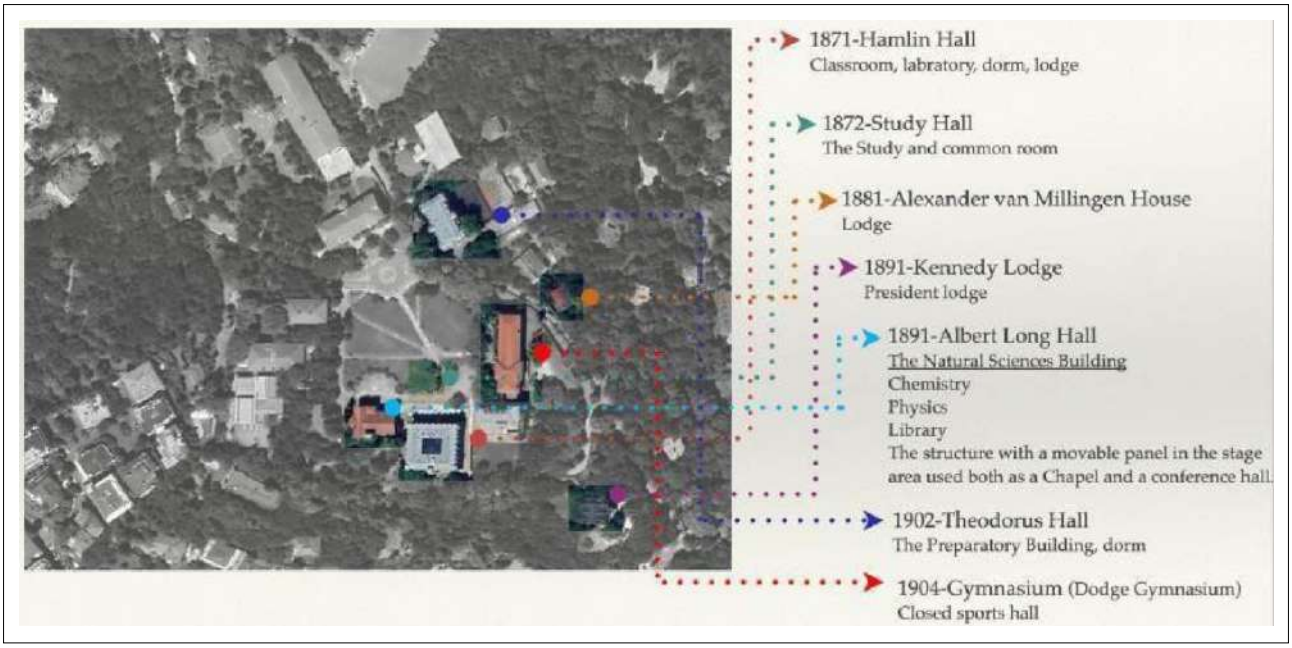


Figure 14. The buildings were constructed at Robert College up until 1904 (Created by the Authors).

the building permission was questioned in this document, it was found that there was no permission for constructing and repairing the Gymnasium (Ottoman Archives, 1905). The documents include the plans submitted with the building permission application. As can be understood from the documents, when the Gymnasium was completed, its permission had not yet been obtained.

The document submitted by the American Embassy to the Ottoman Government requesting the refund of customs duties on the goods brought for the construction of additional buildings at Robert College, including the classroom (Washburn Hall) and the Gymnasium, as well as buildings for teacher accommodations (Figure 15) (Table 1). The document lists the materials that were brought and were to be carried for the Gymnasium and the classroom (Ottoman Archives, 1905).

Although some materials for constructing the Gymnasium were sourced from Istanbul, others, such as iron, tiles, and window and door frames, were obtained from various countries. The gray limestone used as cladding on the building's facade was quarried from the hill of Rumeli Hisarı. Since the imported materials were transported by sea, cities with coastal access and suitable shipping routes were chosen. Iron beams and columns for the Gymnasium were brought from Glasgow, while those for classroom were imported from Sevik, Galatia, and Antwerp (Ottoman Archives, 1905).

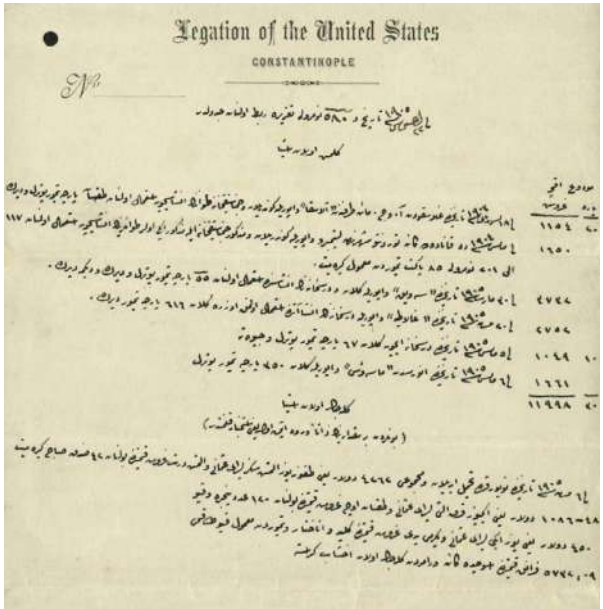


Figure 15. The list of materials requested to be exempt from customs duties (Ottoman Archives, 1905).

Preparing Projects

The chosen location for the Gymnasium is in the northeast of the land. The structure was completed in 1904 as a three-story masonry building measuring 32x14 meters. This building features three large spaces on each floor for indoor sports facilities. The 1905 project found in the Ottoman archives includes a plan, a section, and two elevation drawings. The name and stamp of Architect Arthur E. Henderson is present on the projects. The plan shows that the building was constructed on top of an existing structure. This facade section is noted as an existing cistern wall (Figure 16). When the current survey of the building is compared with these data, it is seen that this section has

Table 1. The list of materials requested to be exempt from customs duties (Ottoman Archives, 1905). Materials are color-coded as follows: orange for the gymnasium, green for Washburn Hall, and blue for materials allocated to both structures.

Date	Material	Origin	Quantity	Price
November (Teşrinisani) 18, 1903	Iron girders and columns	Glasgow	90 units	20 para,1154 kuruş
May 1, 1904	Metal roof tiles	Canada/Toronto	75 packages	1650 kuruş
March 30, 1905	Iron girders, columns, and cast columns	Sevik	55 units	3732 kuruş
April 20, 1905	Iron column	Galatya	616 units	2752 kuruş
May 5, 1905	Iron girders and bolts		67 units	10 para, 1049 krş
May 6, 1905	Iron girders	Antwerp	350 units	1661 kuruş
April 6, 1905 (ship departure date)	Metal roof tiles	New York	46 crates	968 para, 64 kuruş (4262 dolars)
April 6, 1905 (ship departure date)	Door and window	New York	120 units	246 para, 93 krş (47 dolars)
April 6, 1905 (ship departure date)	Locks, keys and iron door sets	New York		102 para, 27 krş (450 dolars)
April 6, 1905 (ship departure date)	Wooden lumber	Swiss/Dramer		5832,09 frank

been accurately documented (Figures 17, 18). Additionally, when the ground floor plan survey of the building is compared with the archival data, it is evident that the identified plan for this floor is entirely accurate (Figure 19).

The accuracy detected in the plan wasn't observed in the section and elevations. In the drawing of the building's rear elevation, no windows are shown in the basement; however, a 1910 photograph from the Columbia University Archives shows that the window arrangement broadly matches the current survey (Figure 19). Additionally, it was found that the large-sized frames and facade trimming levels on the elevations do not correspond with the archival photographs.

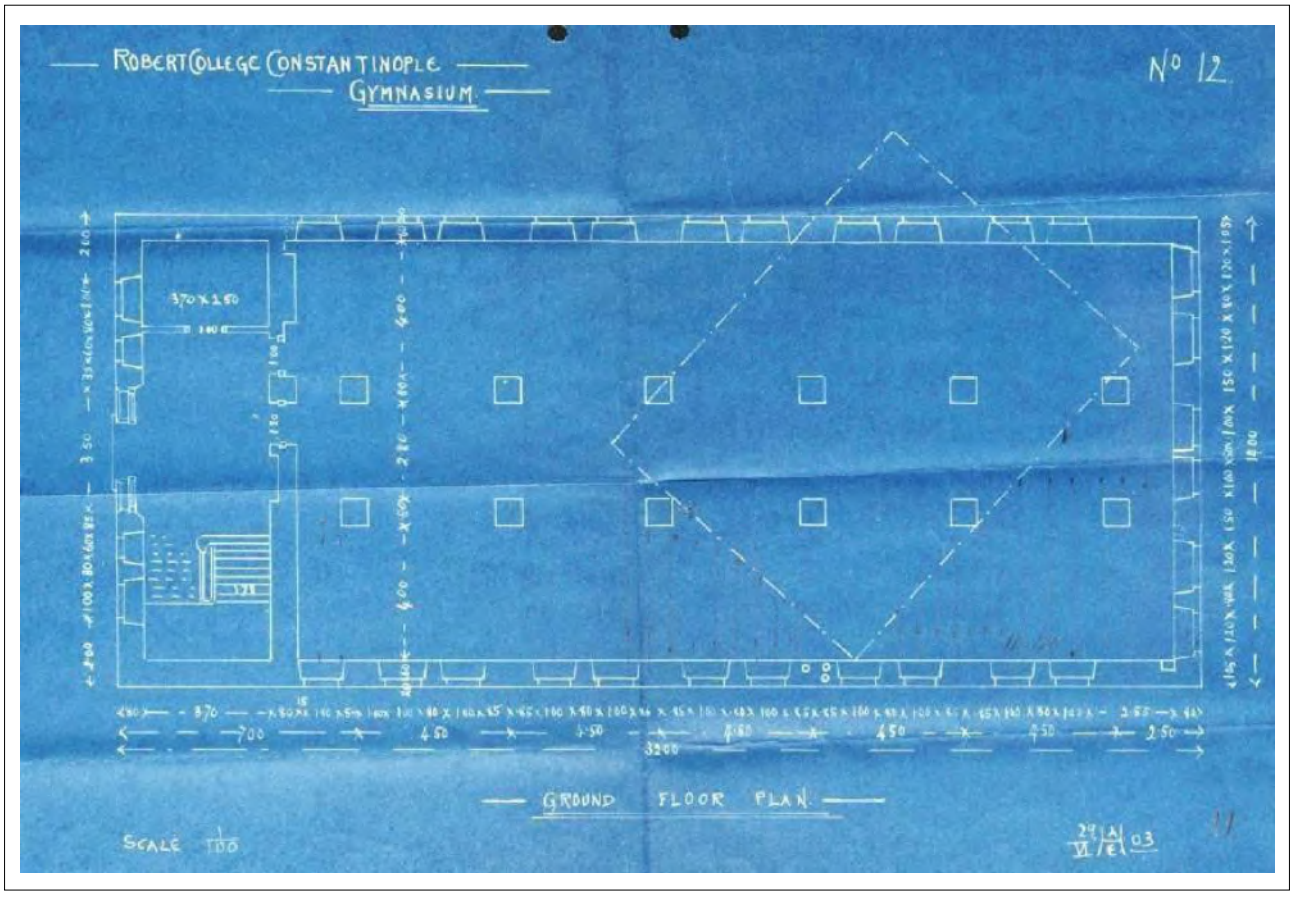


Figure 16. Gymnasium project proposal (Ottoman Archives, 1905).

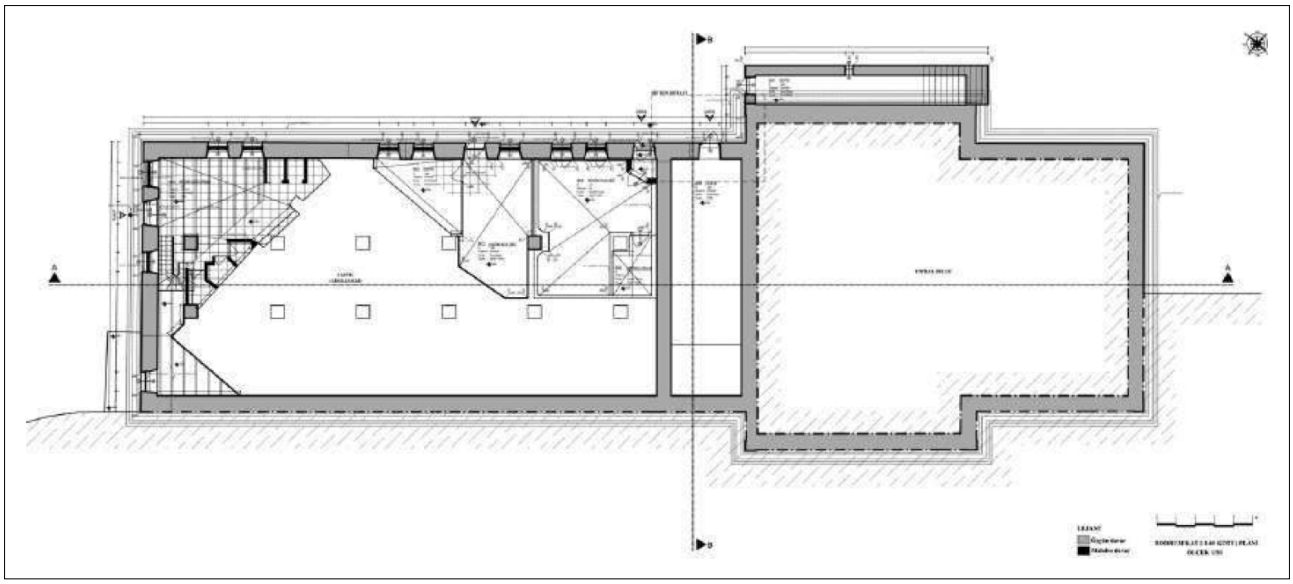


Figure 17. Gymnasium basement floor survey plan (Created by the Authors).

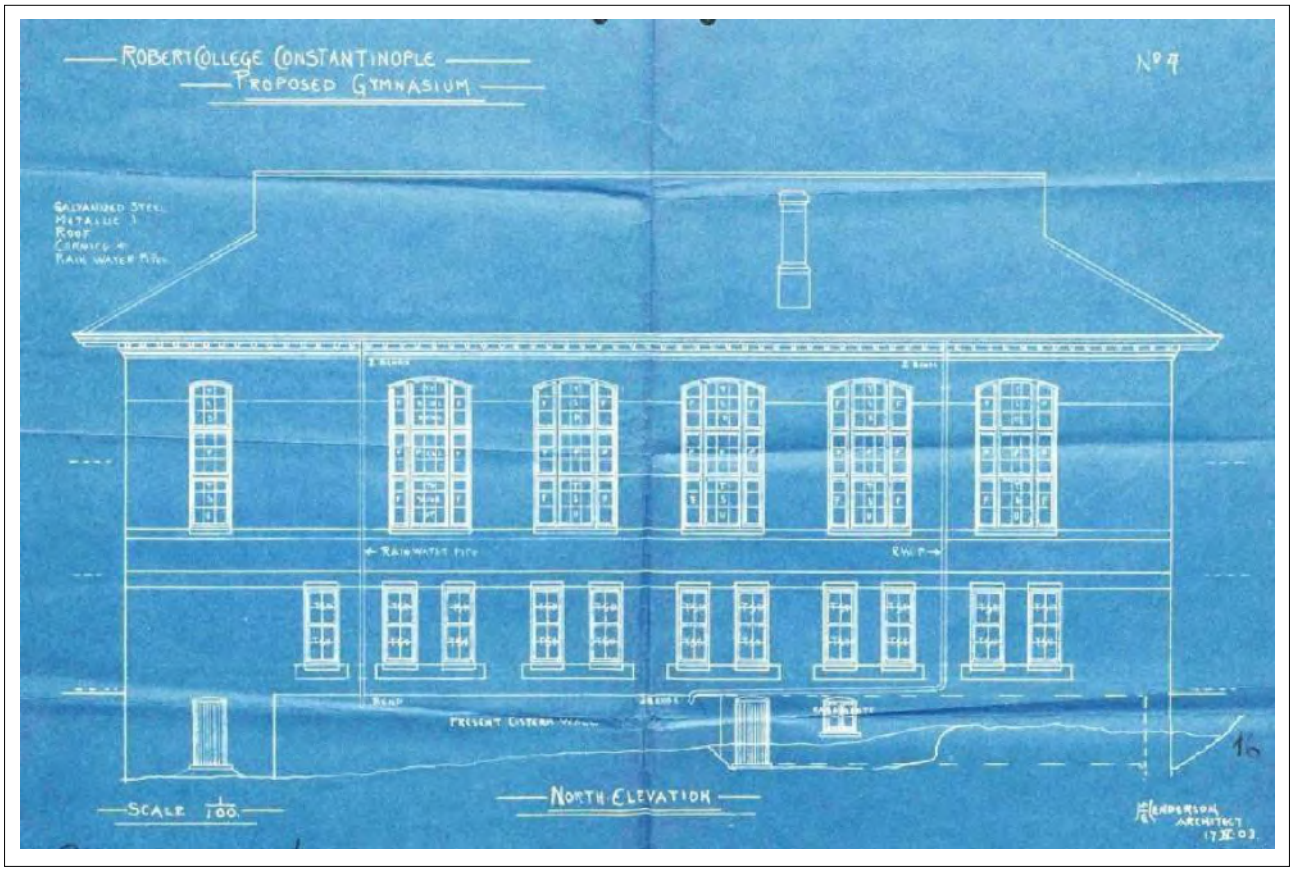


Figure 18. Gymnasium project proposal, northern facade (Ottoman Archives, 1905).

The most significant discrepancy in the section is that the floor between the basement and ground floor is drawn as wooden rather than using iron girders (Figure 20). Aside from this, other details (roof, first floor, etc.) correspond with photographs from that period (Figure 20-22).

Permission and Construction Process for the Gymnasium Annex (Social Hall)

The Gymnasium was used in its original form until 1914, after which expansions were made to the building. In a letter dated December 3, 1910, sent from the American

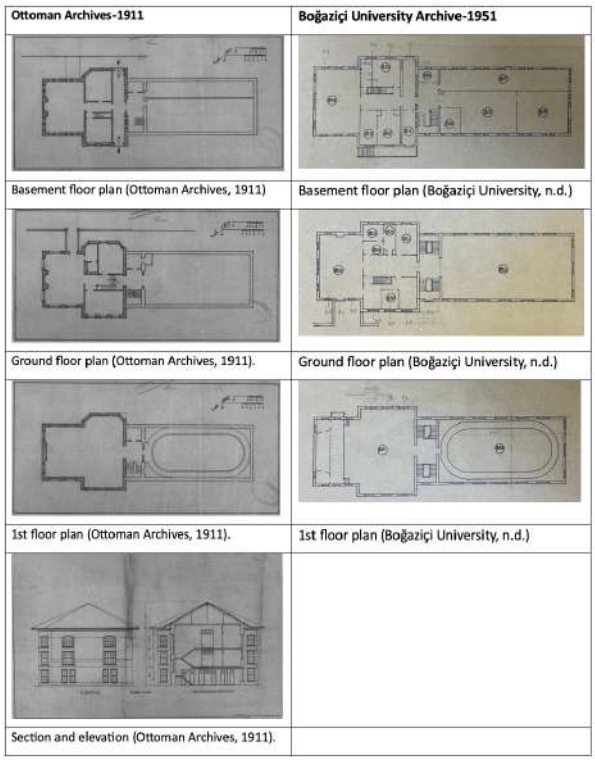


Figure 19. Comparison of the projects found in the archives.

Embassy to the Ministry of Foreign Affairs of the Ottoman Empire, a request was made to add a hall, a reading room, and classrooms to the previously constructed Gymnasium, which had been built with the Sultan's decree. The letter also mentioned that the existing Gymnasium Building was marked in black in the four-sheet project, while the new building to be constructed was marked in red. A construction permission was also requested for these new structures, along with a request for customs exemption on the imported materials (Ottoman Archives, 1911). The building permit was granted on January 31, 1911, by Sultan Mehmed Reşad (Ottoman Archives, 1911).

The newly added building was referred to as the Social Hall. Drawings of the Social Hall have been identified in various archives. The drawings from the Ottoman Archives date back to 1911, while the project found in the Boğaziçi University Archives is a 1951 plan survey. In the project found in the Ottoman Archives, the mass form of the new building is different. The section protruding on the front façade has two corners chamfered at a 45-degree angle, with a window in each section. The degree to which the project submitted to the Ottoman State was implemented can be tracked through the Boğaziçi University Archive drawings. It is observed that the project submitted to the State is quite simplistic. While the general mass size

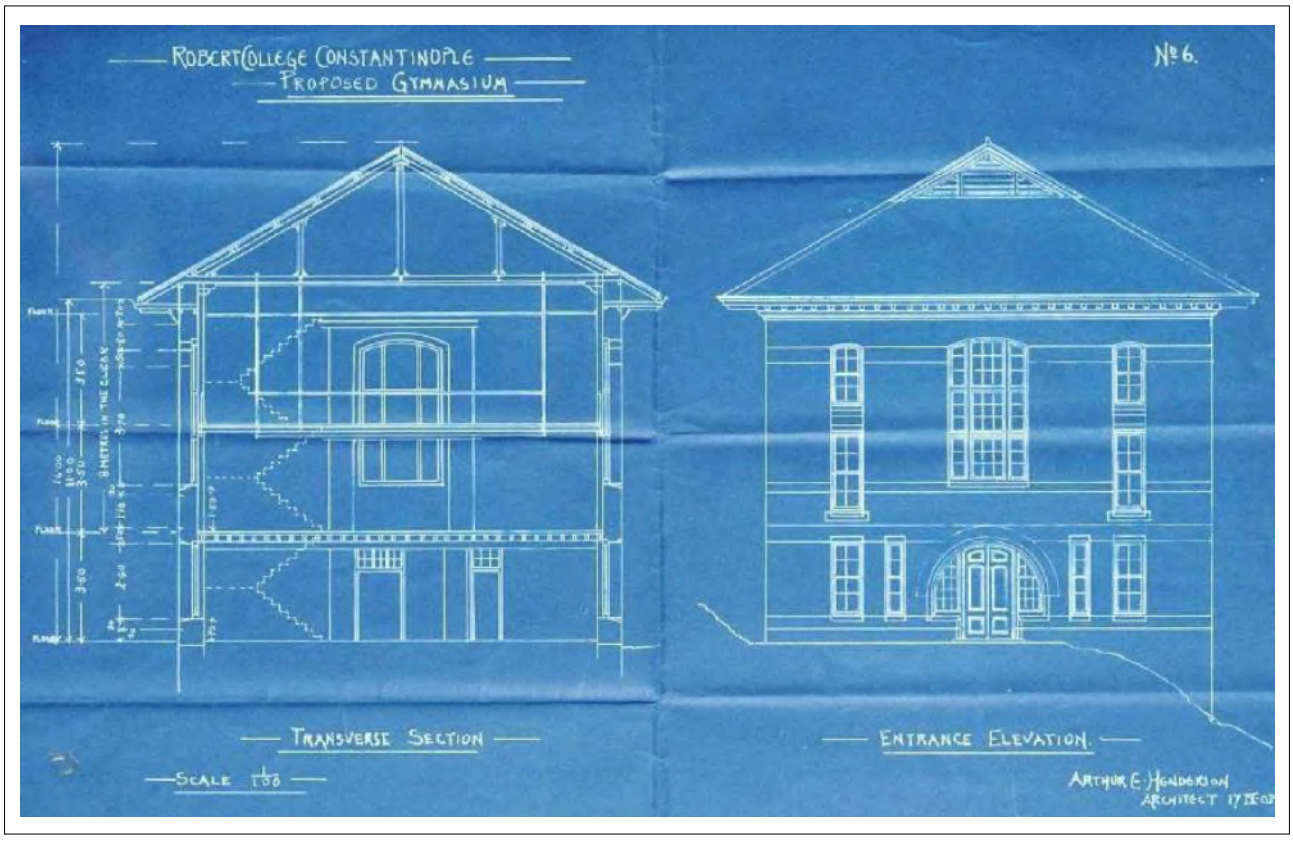


Figure 20. Gymnasium project proposal, 1905 (Ottoman Archives, 1905).

Figure 21. Robert College, 1908 (Columbia, n.d.e).

Figure 22. Robert College, before 1927 (Columbia University, n.d.f).

of the building is accurate, the spatial divisions and the placement of the stairs do not accurately reflect reality (Figure 23).

This building was totally for the students' social activities. The basement floor included a club lounge/game room, a billiard room, a janitor's room, and a kitchen. The first floor housed a lounge, a monitor's room, a private office, a social director's office, a student council room, and a ping-pong room. The second floor featured an auditorium and a stage (Boğaziçi University, n.d.).

In addition to these projects, more detailed plans and two alternative east façade proposals for the Social Hall were found in the Boğaziçi University Architectural Drawings Collection. Although undated, these are understood to be pre-construction proposals by A.D.F. Hamlin. The first design aligns with Washburn Hall, featuring a central arched window and roof overhang, and continues the Gymnasium's dormer motif can be seen on Figure 24, left figure. The second, implemented version is more consistent with the final building form, incorporating cornice-level windows and a prominent lower cornice aligned with the Gymnasium's roofline can be seen on Figure 22; Figure 24, the right figure; and Figure 25.

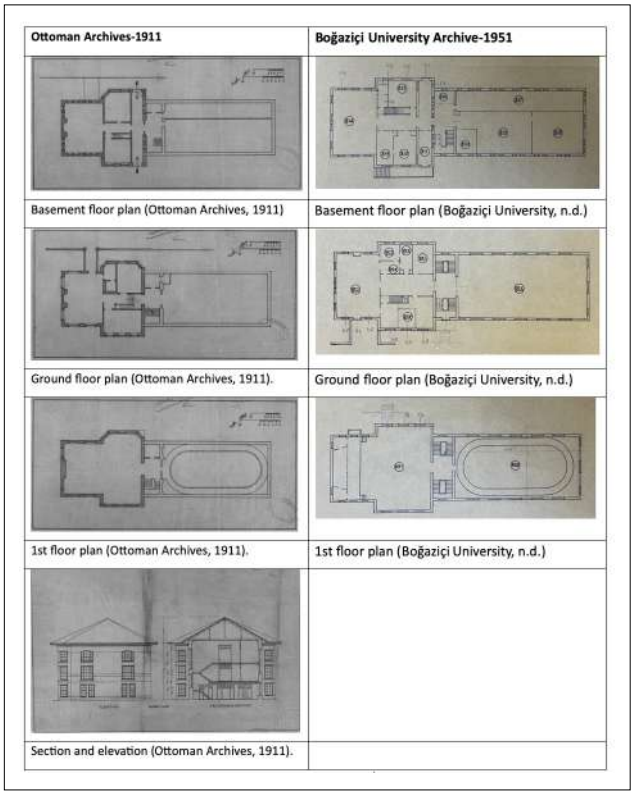


Figure 23. Comparison of the projects found in the archives.

Figure 24. Comparison of the east façade's drawings.

Another project related to the Social Hall is a blueprint containing a plan and section, prepared by A.D.F. Hamlin in collaboration with C.P. Warren and G. Mongeri. A comparison with the current measured drawings reveals a high level of consistency in terms of window dimensions, overall layout, and construction system. Only minor discrepancies are observed, such as slight shifts in door placements and variations in shaft locations (Figure 26).

The legend in the lower right of the blueprint outlines the construction system (Table 2). The building incorporates cut stone, rubble stone, brick, reinforced concrete, and plaster over perforated brick. Load-bearing walls are rubble stone; interior partitions are brick. Cut stone is used as cladding and profiles on the façade, while reinforced concrete is employed in the WC area, between window frames, and

Figure 25. Left: Washburn Hall west façade; right: Washburn Hall North façade (Photos by the Authors)

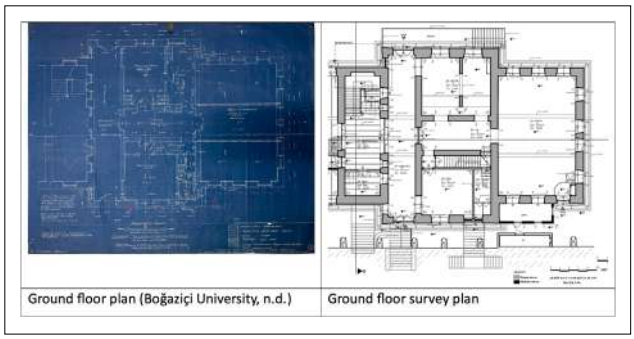


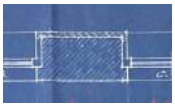
Figure 26. Comparison of the plans of the ground floor.

decoratively on the façade. Plaster over perforated brick is seen in WC partitions and the front of rubble walls (Figure 2; Figure 26).

Two façade sections found in the Boğaziçi University Architectural Drawing Archive exhibit similar ground and first-floor details, while differing at the second floor due to variations in the roof. Archival photographs confirm that the section on the right in Figure 27 was implemented at the time (Figures 28-30).

This study used archival photographs to determine the accuracy and degree of implementation of the Gymnasium's archived projects. As a result, two restitution proposals were prepared, covering the periods 1904-1914 and 1914-1955. The ability to trace every detail of the building from archival data has increased the reliability of these restitution proposals (Figure 31).

Table 2. Legend included in the blueprints (Created by the Authors)

Legend	English	French	Original Drawing
	Dressed stone	Pierre de taille	
	Rubble stone	Pierre bleues-moellons	
	Brick	Briques	
	Re-enforced concrete	Beton arme	
	Furring plaster-hollow brick	Briques creuses et platre	

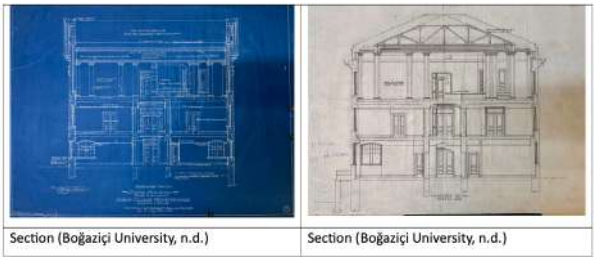


Figure 27. Comparison of the sections.

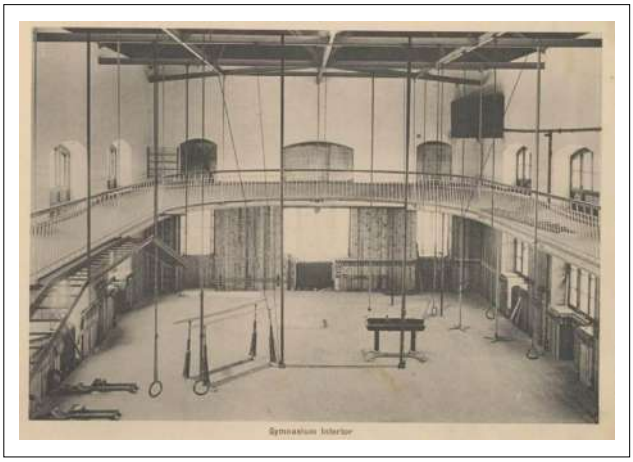


Figure 28. Gymnasium 1910, (Columbia, n.d.g).

Figure 29. Gymnasium, 1924 (Columbia University, n.d.h).

CONCLUSION

Documentation constitutes the fundamental first step in conserving cultural heritage. Written and visual records of the construction processes of historic buildings contribute to a more accurate understanding of their original state. However, archival data must be critically evaluated, as historical building projects often reveal discrepancies between design and execution due to the period-specific conditions of the time. These differences may appear as unexecuted plans, programmatic changes, or material substitutions. Therefore, a detailed assessment of the current condition based on available documents is essential.

This study presents original archival findings on the Gymnasium Building (now known as the Student Activities Center and the building currently includes a gymnasium,

Figure 30. Gymnasium Back Elevation, 1924 (Columbia University, n.d.i).

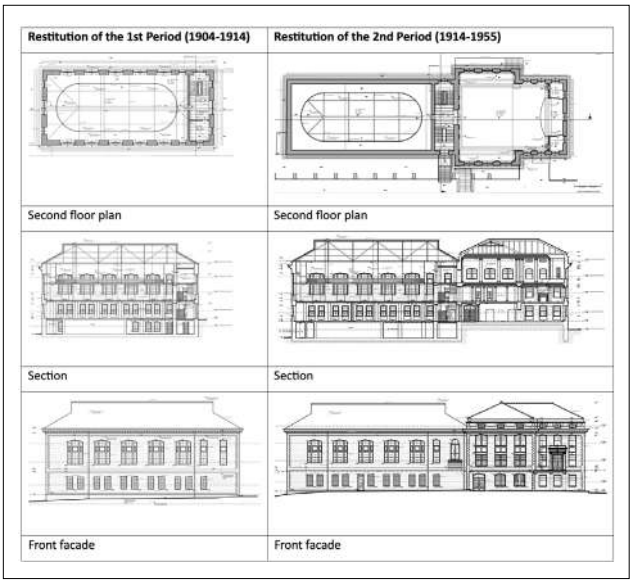


Figure 31. Comparison of the proposed restitutions (Created by the Authors).

student club rooms, a cafeteria, study halls, an auditorium, and office spaces) constructed in two phases at Robert College (founded in 1863), and publishes them for the first time. While examining archival documents, an analytical survey of the building was concurrently carried out in 2023 using laser scanning and manual measurements, with permission from Boğaziçi University. This enabled a comparison between the archival drawings and the actual structure, facilitating an evaluation of the project's implementation. The Ottoman Archives provided records on construction permissions, material procurement, and correspondence between the American Embassy and the Ottoman State, including issues related to customs facilitation. Additionally, detailed project plans were retrieved from the Architectural Drawing Archive of Boğaziçi University. Photographs, reports, and correspondence among trustees, directors, and architects were consulted from the Robert College archives (via Columbia University). These materials were compared

with the current state of the building to verify the accuracy of archival data. Based on this, the construction process was documented, and restitution proposals were prepared in two phases.

The Gymnasium, built in the early 20th century, is examined in the context of sports and missionary activities. Archival analysis sheds light on the working principles and interests of missionaries within the Ottoman Empire, offering insight into broader socio-political dynamics. It also reveals how construction projects initiated by foreign actors were shaped by planning, bureaucratic procedures, material supply, and field practices in the 19th and 20th centuries.

Although direct missionary involvement in the Gymnasium is not immediately evident, letters indicate that their primary concern was fundraising and providing materials. The Board had numerous missionaries stationed across Anatolia, whose needs were met mainly through overseas shipments coordinated via the Bible House and regional stations.

Robert College was the second American college established in Ottoman territories, following the establishment of Syria Protestant College. Due to the sensitivity of founding a Christian institution in Istanbul, Robert College was explicitly declared to be unaffiliated with missionary activities. However, after its foundation, similar institutions began to emerge across Anatolia, adopting comparable curricula and administrative models. Unlike Robert College, these schools did not distance themselves from the Board. The fact that these colleges were established and operated with the same educational objectives indicates that the Board's activities gradually shifted in nature over time.

This study highlights the value of archival research in interpreting both Robert College buildings and foreign-constructed structures in the Ottoman Empire. It also emphasizes that archival documents (particularly historical architectural projects) may not always reflect the built reality and should be critically assessed when developing restitution proposals. Future studies can build on this approach by applying similar methods to other undocumented buildings within the Robert College campus or foreign institutions of the period.

NOTES

[1]Access to the Columbia University Rare Book & Manuscript Library Robert College Archives was obtained through The Boğaziçi University Archive and Documentation Center.

[2]He was born in 1855 in Istanbul and recieved his architectural education at Columbia University (Hamlin, 1893).

[3]In 1955, the building suffered a major fire (Akaş, 2013).

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PEER-REVIEW: Externally peer-reviewed.

CONFLICT OF INTEREST: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Article

Design and manufacturing of building products based on biomaterials: A systematic literature review and a framework proposal based on the meta-synthesis method

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ABSTRACT

The increased usage of resources and waste generation is putting pressure on the natural environment and producing worldwide environmental problems. Different building and manufacturing methods are necessary when the validity of linear production and the discard concept fades. Overconsumption of resources such as energy and raw materials, as well as environmental issues caused by building products throughout their life cycles, are raising environmental awareness in the construction industry and presenting new options such as focusing on biological and natural processes.In this context, there are several design techniques, such as biodesign, in which organisms (algae, bacteria, fungus) are integrated into the design and perform a purpose in the building (energy production, indoor air cleansing, etc.). This situation is generating a new class of materials. Biomaterials are being developed as part of sustainable material and design research, with the objective of implementing biodesign principles. The goal of this study is to develop a framework for designing and manufacturing biomaterial-based building products. In this case, comprehensive literature review and meta-synthesis techniques were used. A thorough literature study provided definitions, terminology, theoretical and practical knowledge on biodesign, and meta-synthesis developed framework stages for biomaterial manufacturing. The framework covers the pre-production, production, and post-production processes, as well as the steps that need to take at each process. Thus, it is believed that the framework, which will be established with a correct description and categorization, will help architects who wish to study in this field and contribute to the acceptance and broad use of biomaterial-based building products.

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INTRODUCTION

Uncontrolled expansion in resource consumption and waste creation stresses the economy and the environment, causing global environmental problems. Currently, the construction industry's requirement for raw materials has a negative impact on the environment, accounting for around 38% greenhouse gas emissions, making it one of the causes of environmental problems globally (UNEP, 2020). Given this, the construction industry consumes 40-50% of all primary raw materials (Blok et al., 2019) and contributes 40% of worldwide energy consumption yearly for building life cycle processes such as manufacturing of building products, use, and destruction (Yadav & Agarwal, 2021). The world's population is predicted to reach over 9 billion people by 2050, with 70% of them expected to reside in cities. It is anticipated that this increase would place previously unheard-of pressure on the natural resources and urban infrastructure already in place (Flynn, 2016). However, about 60% of the world's carbon dioxide emissions will come from the manufacture of materials, which is expected to reach 180 billion tons in 2050. Consequently, while lowering the carbon footprint is one of the building industry's primary goals, new approaches are also required to address these issues. Reducing the usage of materials that rely on fossil fuels may be possible by converting waste and by-products into inexpensive biodegradable materials using a low-energy, carbon-sequestering biofabrication process (Lipińska et al., 2022).

In the literature, the sustainable aspect of building products produced with biomaterials is emphasized. In this context, *Fungi-based products* are biodegradable and require minimal energy for production. Local agricultural wastes can be utilized in production (Gavriilidis et al., 2024; Barta et al., 2024; Lekka et al., 2021). *Algae-based products*, wastewater, etc. can be used to grow algae in the production of building products. Algae-based building products appear to increase carbon dioxide absorption, thermal efficiency and energy efficiency (Roudbari, 2025). *Bacteria-based products*, the use of bacterial cellulose, which is biodegradable and renewable, can significantly reduce environmental issues associated with the construction industry (Massoud et al., 2024). Bioconcrete, bacteria repair by converting soluble organic nutrients into insoluble inorganic calcite crystals that heal cracks (Bashir et al., 2016). This provides an environmentally friendly alternative to concrete, reducing maintenance/repair costs and extending the lifespan of concrete. The potential of biomaterials lies in their renewability, carbon sequestration capacity and ability to improve indoor air quality, all of which contribute to the production of a healthy and sustainable built environment (Chen et al., 2024).

Despite all these advantages of biomaterial-based products, the number of applications is limited. As a reason for this, Waszkowiak (2019) states that information on techniques that actively integrate organisms into architecture is scattered, which limits and complicates examples in this field; Zolotovsky (2017) and Imani et al., (2018) state that there is a gap between the use of organisms on an architectural scale and the methods and processes for performing such studies; and Ozkan et al., (2021) state that organisms are capable of sensing and responding to environmental stimuli, so there is an urgent need to develop new production methods and a framework for designing with organisms.

The study aims to define and classify innovative bio-based materials and to create framework on the design and production of biomaterial-based building products for the use of biomaterials in architecture. It is assumed that an accurate definition, classification and a framework to be created in this field will be effective in the adoption and widespread use of innovative biomaterial-based building products and will be a source of research on the potential of biomaterials. In this context, a systematic literature review and meta-synthesis method were utilized. The selected studies were synthesized within the scope of meta-synthesis and the common pattern in the studies was extracted and the steps to be included in the framework were determined. In line with the evaluation of the results of the analysis, this study defines biomaterials, classifies them in terms of conventional and innovative concepts, and proposes framework to produce biomaterial-based building products for architectural applications of biomaterials.

BIOMATERIALS IN ARCHITECTURE

Biodesign defines new behaviors and properties by combining organisms with artificial systems (Hayos et al., 2022). By incorporating organisms into the architecture, it is aimed at meeting the needs of energy production, cleaning the indoor air, etc. in the building. Therefore, design research is shifting from working with inanimate materials (plastic, glass, etc.) to working with organisms such as fungi, bacteria, etc. (Collet, 2020). In this context, biomaterials are being developed within the scope of sustainable materials for biodesign applications.

According to the literature, most of the biomaterials research focuses on medical applications. Biomaterials are man-made materials that interact with biological system components in a controlled manner (Biyomedtek, n.d.; Güven, 2014), allowing a non-living substance to replace injured or lost live tissue or organs by exhibiting compatibility with a living tissue or organ (Baydemir, 2022).

Biomaterials used in architecture differ from those used in medical applications. Biomaterials are materials taken from or created by living entities such as plants, animals, bacteria, and fungus. These materials are also known as

biologically generated materials (Penn State University, n.d.). Biomaterials used in architecture are categorized as bio-based materials and are thus referred to as bioproducts. Bioproducts include all products obtained from biological sources, such as feed, biofuel, and bio-based materials (Food and Agriculture Organization of the United Nations, 2019). Bio-based materials, including biomaterials, are defined as substances or materials derived from living things. This approach may apply to both natural materials like wood and bamboo, as well as contemporary products (Heil et al., 2023). In this sense, biobased materials are divided into two categories: conventional and innovative (Figure 1).

Conventional bio-based materials are biodegradable and recyclable materials made from animals and plants (e.g., flax, hemp) (Yadav & Agarwal, 2021; Materialdistrict, 2014). These materials can be utilized in construction as raw materials for building elements, but they do not survive inside the structure. *Innovative bio-based materials* are a new type of material that includes organisms like algae, bacteria, and fungi.

- *Algae* are photosynthetic, freely moving aquatic microorganisms that can form colonies and filaments. They are classified into two groups: macroalgae and microalgae (Aktar & Cebe, 2010). Microalgae are the form of algae commonly employed in architectural applications. Environmental elements such as light intensity, temperature, nutrients, pH, water content, CO2 consumption, and O2 availability can all have an impact on algae.
- *Bacteria* are prokaryotic organisms that are almost everywhere (TÜBİTAK, 2023). Temperature, nutrients, pH, and oxygen are environmental parameters to consider for typical species utilized in the creation of bacterial-based building materials.
- *Fungi* are single-celled or multicellular organisms that generate spores and consume organic materials (Jones, 2019). Mycelium is the fungus's vegetative part under the soil, consisting of thin filaments (hyphae) (Heil et al., 2024). In general, light intensity, temperature, nutrients, pH, humidity, and water content all have an impact on mycelium growth.

Innovative bio-based materials are those generated from organisms or that contain manufactured components that enable a structure to interact with its surroundings and adapt to changing situations. Biodesign applications include innovative bio-based materials. Products made from these materials are also referred to as biohybrids or living building products in different studies (Heil et al., 2023), which are derived from organisms, use little energy and produce little waste, are biologically produced and contain at least one biodegradable component (Zolotovsky, 2017; Ghazvinian, 2021), have a structural or non-structural function (BRE Group, 2020), and are developed by integrating organisms into an inanimate building element or building material to fulfill a function (Ataç, 2019). Since these products are created by combining living and man-made components, the new product possesses the characteristics of both (Smith, 2021) and can benefit from many biological system properties such as self-sustainability, self-repair, self-replication, and biosignal responsiveness (Gilbert & Ellis, 2019).

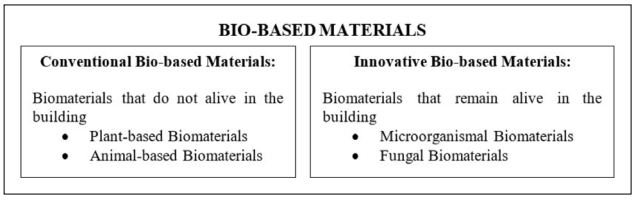


Figure 1. Classification of biomaterials.

This study refers to algae, bacteria, and fungi-based products as *innovative biomaterial-based building products*. Innovative biomaterial-based building products may be created at several levels, including material, piece, and component in the structure. According to their operating mechanisms, these products are classified as *bio-inert, bio-responsive, or bio-active* (Zolotovsky, 2017; Ghazvinian, 2021);

- *Bio-inert products* are those in which organisms are utilized in manufacturing but then killed, resulting in a passive end product. Because of their passive properties, these products can be grouped under conventional bio-based materials; however, because algae, bacteria, and fungal biomaterials represent a new class of materials, bio-inert products are classified as innovative bio-based materials, and an assessment was conducted accordingly. One example of this group is the Hy-Fi pavilion.
- *Bio-responsive* products change their qualities or form in response to environmental inputs. The product responds to environmental signals such as pH, pollutants, pressure, temperature, light etc. Bioconcrete is one example of this category.
- *Bio-active products* respond to biological signals and either interact with or are triggered by them. Such products have the capacity to impact and modify their surroundings through chemical, biological, and mechanical processes. BIQ House is one example of this group.

META-SYNTHESIS METHOD

Among the terms that comprise the notion of meta-synthesis, meta refers to going beyond the research presented, whilst synthesis refers to combining more than one study without compromising the originality of the studies. Meta-synthesis is said to have originated from the requirement to analyze

and synthesize qualitative research in a certain subject together (Polat & Ay, 2016; Tekindal & Tonbalak, 2021), and it was initially proposed by Noblit and Hare in 1988. Meta-synthesis does not imply a comprehensive description of the findings from the research or the collection (Nye et al., 2016; Ozcakir Sumen, 2019). Rather, it is a methodological technique to create new knowledge that is based on interpretative analysis of existing qualitative research data. The objective is to use main study findings as data in a third-order interpretation (Aspfors & Fransson, 2015; Nye et al., 2016). The third level aims to give fresh viewpoints by evaluating data from various investigations. Meta-synthesis is used to establish new ideas, conceptual models, study gaps, extend current knowledge, and provide proof for existing information (Chrastina, 2018). Rather than using statistical methods, researchers in meta-synthesis utilize descriptive narratives to describe and interpret study findings. In such investigations, qualitative findings from research (Toker, 2022) or mixed method studies are reviewed and interpreted. Meta-synthesis is a six-step process.

Step 1: *Identifying research questions*

The research questions are identified first in the study. A carefully chosen research question influences both the study's direction and the quantity of papers included in the synthesis.

Step 2: *Literature review by identifying keywords*

The literature review begins by finding keywords. Databases are searched to find relevant studies. The number of studies included in the synthesis is determined by the researchers' decision-making, the study setting, and the availability of resources (Tekindal & Tonbalak, 2021). In the following stage, a systematic literature review is carried out to identify relevant research. A systematic review requires a well-structured and comprehensive review process. PRISMA standards are often employed in systematic literature reviews.

Step 3: *Identifying the studies to be selected by determining the inclusion/exclusion criteria*

In the systematic review process, inclusion criteria must first be determined. Inclusion criteria are necessary to determine which studies will be included in the research (Toker, 2022). A preliminary decision is made by checking the abstracts of the studies to determine those that meet the inclusion criteria from the studies identified in line with a specific strategy. If the abstract fulfills the inclusion criteria (Toker, 2022), the primary analysis proceeds, with the goal of identifying potential papers for synthesis. Primary analysis entails carefully reading the selected studies. The purpose of this step is to assess whether the studies are appropriate for the scope of the study. Although some suggest the synthesis should only include papers published in academic/refereed journals, others claim that not academic/refereed studies can also provide meaningful results (Noah, 2013). To ensure the currency of scientific discoveries, the publication period might be limited to publications in the last five years for primary research and the last ten years for secondary research (Tekindal & Tonbalak, 2021).

Step 4: *Analyzing and translating the selected studies*

It is the stage at which common themes and sub-concepts within these themes are developed by examining and analyzing the selected studies, as well as revealing and visualizing similarities and differences. The primary goal of this stage is to categorize, arrange, group, and analyze the findings. The topics and concepts in the first study are first summarized throughout the process of translating them into each other (Güneş & Erdem, 2022). Themes should embody the core concept, issue, or solution, or demonstrate a key point. This method is repeated for all papers included in the research, yielding a list of themes (Noah, 2017). The second study is then shown. The second study's themes and concepts are presented, and comments are provided on what is similar to the first study, what may be added to the first study, and where the findings vary. This procedure continues until all of the studies in the synthesis have been examined (Güneş & Erdem, 2022).

Step 5: *Synthesizing study findings*

The findings are synthesized by bringing together translated themes, detecting repeating patterns, and making meaning of them. At this point, the studies are considered as a whole in order to develop a framework. Researchers can use narrative and/or schematic presentation to demonstrate how the investigations are connected (Güneş & Erdem, 2022).

Step 6: *Presenting the process and findings*

This is the final stage of meta-synthesis. It includes a comprehensive report on the process and conclusions. Reporting process (Güneş & Erdem, 2022);

- Conclusions
- Strengths and limitations
- Conclusion and suggestions

Visual tools like graphs, tables, and figures can be utilized to display conclusions with numerical data (Tekindal & Tonbalak, 2021).

REVIEW OF STUDIES ON THE DESIGN AND PRODUCTION OF BIOMATERIAL-BASED BUILDING PRODUCTS USING META-SYNTHESIS METHODS

The steps of selecting studies and reporting the synthesized studies follows the meta-synthesis processes outlined in the third part.

Step 1: *Identify research questions*

- Which steps should a guide for architecture include when designing and producing innovative biomaterial-based building products?

Step 2: *Conduct a literature review by identifying keywords*

Keywords for the study included biomaterials, algae, bacteria, mycelium, architecture, building, construction, and pavilion, which were combined in various ways and searched in databases such as WOS (Web of Science) and Google Scholar.

Step 3: *Selecting research based on inclusion/exclusion criteria.*

Inclusion criteria:

- Studies of architectural scale.
- Projects can be permanent or temporary.
- Biomaterials can be living or non-living.
- Building products can be at the component or element scale
- Studies with at least one species of organism.
- Types of work: bio-inert, bio-responsive, or bio-active.
- Qualitative or mixed methods studies.
- Primary data studies.

Exclusion criteria:

- Projects in the design phase (not built)
- Studies manufacturing for only a single product
- Quantitative research

The review was done in July 2024. To ensure the timeliness of scientific discoveries in the meta-synthesis, and since the first full-scale structure (BIQ House) was erected in 2013, it was deemed suitable to start the time period from 2013. The search was restricted to the years 2013-2024, and 161 results were found using determined keywords. After excluding non-architecture-related fields such as medicine, 25 papers connected to architecture that matched the inclusion criteria were found. Following that, the primary analysis began, and the studies were thoroughly reviewed. The goal of this stage is to establish if the selected studies are appropriate for the study topic. In this case, it was found that 9 of the 25 studies did not fall within the scope of the study. The full text of the remaining 16 studies were examined, and four studies were rejected for reasons such as representing an unbuilt project, using a quantitative research approach, or scale of the biomaterial-based building product. Thus, the systematic literature review determined that 12 studies should be included in the synthesis. To make the included studies simpler to understand, each one was assigned a code (Figure 2).

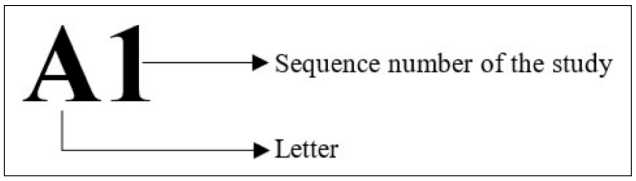


Figure 2. Code representation of included studies.

It is suggested that the research included in the synthesis be academic/refereed. However, at the building scale, relatively few studies have been conducted using biomaterials, either permanently or temporarily. Most of the studies are on fungi biomaterials. However, because tracking only studies using fungal biomaterials would limit the intended framework, not only the studies are included in the synthesis are based on research papers released by the researchers but also the studies that were not academic/refereed publications but were available on the official websites of product manufacturers or those involved in the technique's development were also included in the synthesis. Thus, the studies included in the synthesis concentrated on algal and fungal biomaterials. Only one study was discovered in which bacteria were employed as a structural component, however due to its quantitative method, it was excluded from the synthesis. The literature shows that experiments using bacteria are focused on healing cracks on the concrete surface. Table 1 shows the selected studies based on the inclusion/exclusion criteria.

Step 4: *Transforming studies into one another*

The NVIVO 14 program was used to analyze and translate the studies. The process starts with uploading the studies to the NVIVO system (Figure 3).

The studies uploaded to the system are carefully analyzed, and the concepts and themes in the studies are identified. According to Noah (2017), themes should embody the core concept, issue or solution, or demonstrate a major point. In NVIVO, the process of developing themes and concepts is known as coding. To begin analyzing the studies uploaded to the system, click the Codes section from the Coding section on the left side of the NVIVO screen and create a new code (Figure 4).

After identifying the themes and concepts in the first study, the themes and concepts in the second study were determined, and the similarities and differences between the two studies were revealed to determine what could be added to the first study and where it differed from the first study. This process was repeated until all studies included in the synthesis had been examined. From the synthesized studies, 7 themes were identified for design and production with biomaterials: *environmental sustainability, economic sustainability, social sustainability, biomaterials, design, production and risks*. In this context, the themes and concepts belonging to the themes and their relationship with the synthesized studies are shown in Table 2.

Table 1. Studies selected for meta-synthesis

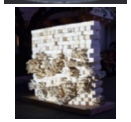
Study Information				Properties of Bio-product							References
				Final Product				Behavior			
Code	Name	Image	Year and Place	Material	Piece	Components	Elements	Bio-inert	Bio-respond	Bio-active	
A1	Monolito Micelio		2018 Georgia Tech School of Architecture				•		•		(Olive, 2019)
A2	Mycelium Mockup Project		2015 AFJD Studio			•				•	(Dahmen, 2016)
A3	Living Room		2023 Farrell Centre, Newcastleupon-Tyne.				•		•		(Scott et al., 2024)
A4	BioKnit Prototype		2022 OME, Newcatle University				•		•		(Agraviador et al., 2022)
A5	Hy-FI Pavilion		2014 Moma PS1		•			•			(Brown, 2017)
A6	Growing Pavilion		2019 Ketelhuisplein				•	•			(The Growing Pavilion, n.d.)
A7	L'orso Fungino		2022 Kansas State University			•			•		(Dessi-Olive, 2022)
A8	MycoTree		2017 Bienal		•			•			(Heisel, 2017)
A9	Air Bubble		2021 Poland			•				•	(ArchDaily, 2024)

Table 1. Studies selected for meta-synthesis

Study Information				Properties of Bio-product							References
				Final Product				Behavior			
Code	Name	Image	Year and Place	Material	Piece	Components	Elements	Bio-inert	Bio-respond	Bio-active	
A10	BIQ House		2013 Hamburg			•				•	(Tallou et al., 2022)
A11	Photo.Synth.Etica		2018 Dublin			•				•	(Pasquero, n.d.)
A12	Urban Algae Canopy		2015 Milano			•				•	(Violano, 2019)

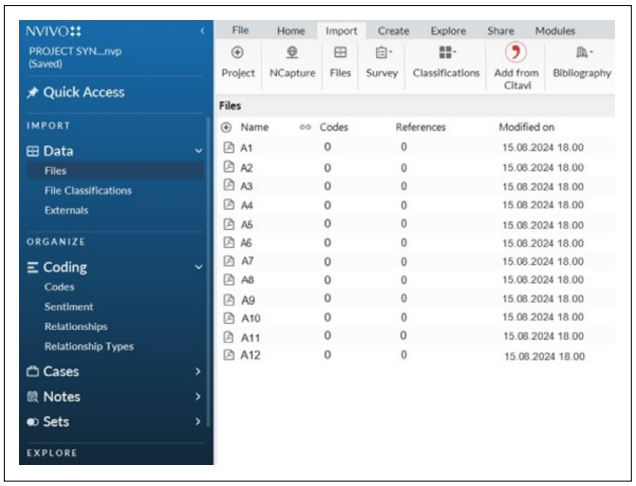


Figure 3. Files uploaded to the NVIVO program.

Step 5: *Synthesizing the findings of the studies*

Analyzing the studies revealed innovative biomaterial-based building products have the potential to achieve the building's sustainability goals. In this context, the environmental sustainability of biomaterials comes to the forefront in the studies. While biomaterials manufacturing can help with resource efficiency and waste reduction, it also allows buildings to produce energy and clean the air. Furthermore, using waste as a resource for producing biomaterial-based building products can help to promote the circular economy. Production using organisms allows for on-site production, which can cut logistics expenses.

Biomaterials are not simply materials, but also collaborators, as they are the living components of constructions. With organisms as part of the architectural product, the idea of vitality becomes a design consideration. In this context, the living/non-living condition of organisms in a building product influences how the end product interacts with its surroundings. In a state of sustained vitality, the product evolves into a living system that interacts with its surroundings. The living/non-living condition of organisms influences design and manufacturing processes. Conditions that ensure the organism's vitality must be provided in order for it to persist in the end product. In this context, the product's form can be beneficial in both sustaining the organism's life circumstances and assuring its structural integrity, as well as the aesthetics of the final product. Form in conventional building products is determined by manufacture, but form in biomaterials is determined by organismal growth and development. As a result, form is no longer something that is created, but rather something that the product finds its own form. This indicates that designing with organisms involves not just generating form but also regulating life processes and forecasting organismal behavior. Another thing to consider is that a behavior is being created (healing, producing energy etc.). As a result, the behavior of the product to be created should

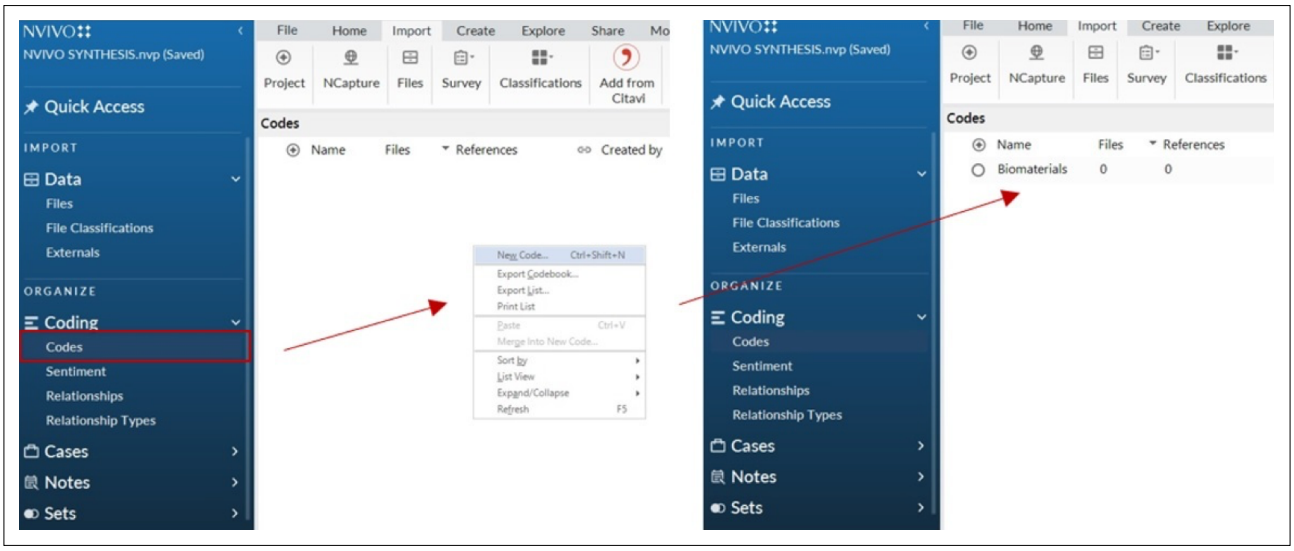


Figure 4. Creating a code in NVIVO.

Table 2. Themes and concepts created

Themes	Concepts	Studies	(f)
Environmental Sustainability	Acoustic comfort	A10, A3, A6, A9	4
	Bio-degradable	A1, A2	2
	CO_2 reduction	A8, A11, A12	3
	Energy efficiency and energy production	A1, A2, A5, A10, A12	5
	Material efficiency	A1, A2, A3	3
	Thermal comfort	A10, A12, A6	3
	Visual comfort	A10, A12	2
Economic Sustainability	Circular economy	A1, A11, A5, A8	4
Social Sustainability	Public participation	A10, A12, A2, A3, A6, A7, A8, A9	8
Biomaterials	Algae	A9, A10, A11, A12	4
	Bacteria	A4	1
	Mycelium	A1, A2, A3, A4, A5, A8	6
	Living/not-living	A11, A2, A9, A1, A3, A4, A7	7
Design	Geometry	A1, A3, A4, A7, A8	5
	Parametric design / digital technology	A1, A3, A4, A7, A8, A11, A12	7
Manufacture	Scale		
	- Monolithic	- A1, A2, A3, A7	4
	- Discrete elements - blocks	- A1, A7	
	Digital manufacturing	A11, A3, A7, A8	4
Risks	Biological risks	A1, A3, A4, A7	4
	Material risks	A1, A3	2

be predicted from the start of the process, and decisions should be made appropriately. The usage of parametric tools in design can be useful for organizing the process and conducting appropriate analyses. In general, studies focus on the influence of form on product performance and which forms are the most efficient. The scale of production is one aspect to consider during the manufacturing process. The scale of production also influences the organism used, the manufacturing process, and the tools utilized in production. Therefore, material, design, and production are all intimately connected. Production with organisms introduces novel micro-macro-scale design techniques

and can help to establish new architectural production models. Because the manufacturing of building products is dependent on the growth of organisms, this situation alters the idea of production. In other words, unlike conventional building products, the product is grown rather than manufactured. This kind of manufacturing process alters architecture, taking it beyond design and into the realm of biological system production. Working with an organism involves a multitude of biological and material *risks*. The selected organisms must not be dangerous to people or other living things. Another concern is that products made with organisms may fail to achieve the desired performance parameters.

Step 6: *Reporting of the process and finding*

The synthesized studies highlight the environmental sustainability of innovative biomaterial-based building products (Figure 5). This supports the need to limit the negative environmental effect of building products.

Economic and social sustainability continue to be overlooked. One explanation for this might be that the selected studies have no direct bearing on the economic and social sustainability of innovative biomaterial-based building products. However, the synthesized studies can still provide insight into the economic and social sustainability of these products. The examined studies appear to focus on fungal biomaterials. One explanation for this might be that fungal biomaterials are simple to get and grow, requiring no expensive tools. The reason for the scarcity of research on bacterial biomaterials is because most of them are focused on manufacturing materials like bioconcrete, and it is outside the scope of the study. Another issue is that there has been few research on biomaterials used in facade applications, such as bacterial cellulose, and the available studies cannot be included in the meta-synthesis since they were conducted quantitatively.

The studies provided information on form and design tools. In general, studies focus on the impact of shape on product performance and which forms are the most efficient. In terms of manufacturing, the most crucial information collected is the product's scale. The scale of the product is crucial since it influences the design and manufacturing processes. In this context, it is clear that studies in literature concentrate on the production of discrete elements (bricks, panels, etc.). This might be because production is easier and more controllable. Although monolithic manufacturing reduces costs owing to on-site production and transportation, it brings several challenges in process management. The studies revealed broad information about the tools used in the design and production processes.

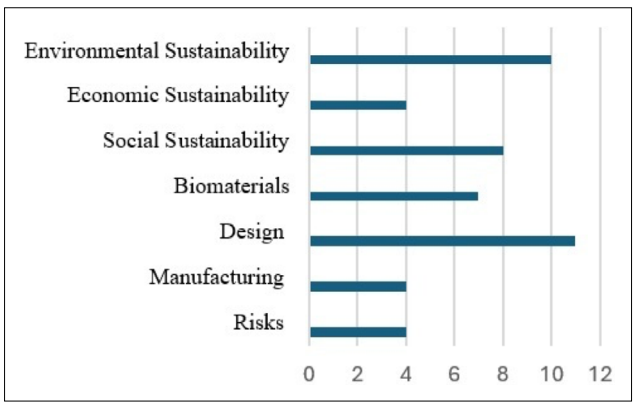


Figure 5. Themes obtained from meta-synthesis.

When organisms are used to produce building products, viability criteria are included in the process. As a result, laboratory tests are required to understand the factors influencing viability and the organism-environment relationship. Laboratory tests are also required to establish the qualities of the material conditions in which the organism will be transferred, as well as the end product's performance. Because biomaterial-based building products are manufactured by merging biological and man-made components, the end product possesses properties of both. As a result, during the pre-production phase, it is vital to establish which biological system characteristics, such as self-repair and self-sustainability etc., will be included into the end product and to make decisions appropriately. However, decisions should be made not just about the product, but also about its relationship with the ecosystem, the organism, the material context in which the organism will be transferred, design, and user needs. In general, the literature focuses on making specific items (bricks, panels, etc.) and assessing their performance. However, it does not specify what decisions must be made in the run-up to production. Similarly, there is little information available on the steps that must be taken during the post-production process. Pre-production process shapes the production and post-production processes. As a result, the pre-production process is critical for planning the entire process. There are only a few studies in the literature that have built a model for building products using algae, bacteria, and fungal biomaterials. One possible explanation is because biomaterials are not standardized, therefore a single model with definite decisions cannot be used in every study. Although dealing with biomaterials necessitates different production stages depending on the demands and organism, there are certain common steps that may be taken. In this context, developing a framework consisting of general stages might serve as a guide for architects interested to engage in this subject. The synthesized studies give significant information on organismal production (e.g., mycelium composite production), but little guidance on how the process should be organized and what decisions should be made at each stage with the exception of some ideas for identifying related steps (Figure 6).

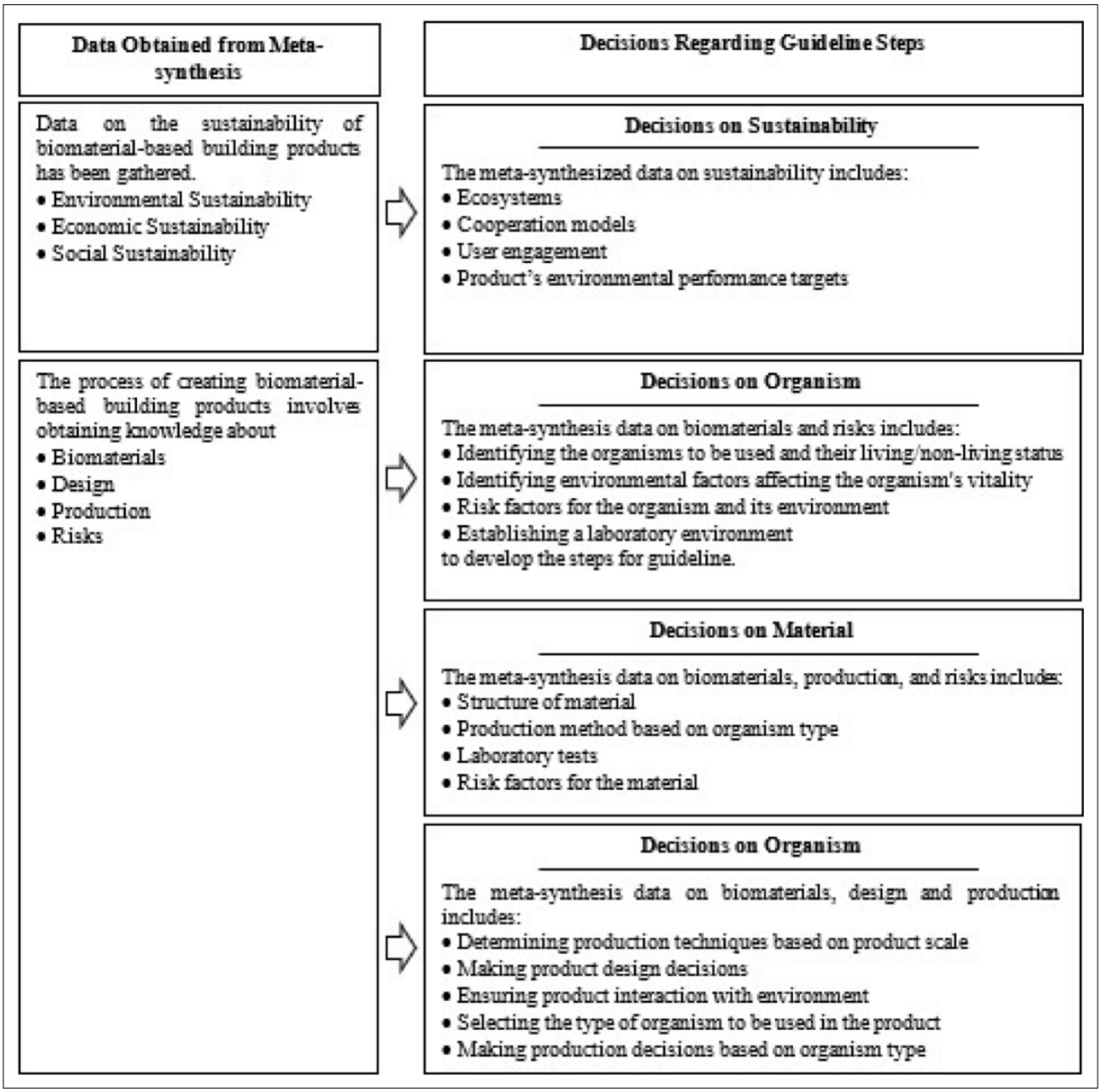


Figure 6. The themes derived from the meta-synthesis and the outline for the framework steps.

CONCLUSION AND RECOMMENDATIONS

The growth in resource use and waste output stresses the ecosystem and contributes to worldwide environmental problems. The construction industry is one of the industries where building products have an impact on the environment throughout their life cycle. It is expected that increased global material production in 2050 would result in higher carbon dioxide emissions. As a result, one of the construction industry's key goals is to reduce its carbon impact. Biofabrication technologies may be used to turn byproducts and waste into low-cost biodegradable materials, reducing the need for fossil fuel-based resources. In this context, there are numerous design strategies available, such as biodesign, which includes embedding organisms into architectural products to address user problems. Biodesign applications aim to include organisms into the design to provide services such as energy production, air cleaning etc. As a result biomaterials are being developed in biodesign. Biomaterials used in architecture are biobased materials that are generated or produced by living organisms.

There are two types of biobased materials: conventional and innovative. Biodesign applications include innovative bio-based materials. Innovative bio-based materials are a new

type of material composed of algae, bacteria, and fungi. These materials enable the production of sustainable, living, and dynamic structures by allowing the building to interact with its surroundings and become a part of the ecosystem. The new class of materials necessitates new design and manufacturing procedures. A meta-synthesis study was conducted to investigate innovative biomaterial-based construction products, revealing their effects on sustainability, design, and production. While the cases analyzed demonstrate how organisms are incorporated into both sustainability and design and manufacturing processes in the production of architectural products, they also highlight the obstacles and risks encountered in this field.

From a design perspective, the utilization of innovative bio-based materials represents a fresh approach to architecture. However, further research and laboratory tests are required to ensure that these materials fulfill architectural flexibility, structural stability, and utility. Since the organism is required to perform a role in the finished product, it is critical to understand the parameters impacting the organism's vitality and how to preserve it. However, the focus should not be only on the organism's resilience. The aim here is not just to produce a product using organisms. Other aspects, such as ecosystem compatibility, building products' environmental performance, user needs etc. should be considered and included in the design process as well.

Although working on biomaterials needs different production processes depending on the requirements and organism used, there are certain common steps that may be followed. In this context, the steps to be taken in the pre-production, production, and post-production processes using biomaterials, as well as the relationships between these processes, have been addressed holistically by producing a framework consisting of general steps. Thus, the process is intended to be controllable, straightforward, and comprehensible. Each step in the framework was developed using data gathered from the meta-synthesis of the studies examined (Figure 7).

Pre-Production Process

Step 1: *Ecosystem decisions; in this step, the goal is not only* to create innovative biomaterial-based building products, but also to ensure that these products interact with the environment on a larger scale. In this context, the region's energy and water cycles should be examined to establish the function of the biomaterial-based product that will be produced within the system. In this stage, a large-scale and sustainable manufacturing model may be planned by developing collaboration models that use waste as a resource.

Step 2: *Product decisions; the process begins by examining* the previous step's outputs and considering the decisions taken. The selections made for the ecosystem can help choose the most appropriate organism type based on the ecosystem cycles and the type of waste created in the following stage. In this step, a precise definition of the product to be produced helps to choose the organism, design, and production methods. In addition, the product's scale, design decisions, and environmental performance standards that the end product will fulfill should also be determined. The environmental performance goals that the product has to meet will also help to determine the final product's behavior (producing energy, healing cracks, etc.). As a result, determining the product's behavior will be beneficial when making the initial decision on which organism to select.

Step 3: *Organism decisions; the process begins by examining* the previous step's outputs and considering the decisions taken. The integration of organisms in architectural products transforms the material from a passive to an active component of the architectural system. Determining the environmental factors that impact the organism is critical in terms of constructing the organism's habitat. Laboratory tests are necessary to establish which environmental conditions influence the organism and how.

Step 4: *Material decisions; the process begins by examining* the previous step's outputs and considering the decisions taken. At this step, the organism must be able to exist in the material's habitat to which it will be relocated. As a result, material testing must take place during this stage.

Production Process

Step 5: *Production with biomaterials;* the process begins by examining the pre-production process's outputs and then proceeds to suitable production. Although production methods vary depending on the selected organism, production should take into account the organism's biotic and abiotic components. The tools utilized may vary depending on the scale of production. If a problem emerges during this stage, the decisions taken by returning to the previous stage should be reviewed, and production should be repeated. At this point, performance tests should be performed to assess whether the finished product fulfills the performance goals.

Post-Production Process

Step 6: *Monitoring and inspection;* at this step, the product that was produced undergoes testing to determine if it corresponds to the specified performance criteria. A product that does not match the specified performance criteria or is produced wrongly must be reproduced.

Step 7: *Operation;* products that fulfill the desired requirements are tested on-site through installation/ assembly.

Step 8: *Maintenance:* During this step, the product is maintained at periodically. Product maintenance can be done by the user or, if necessary, by the producer.

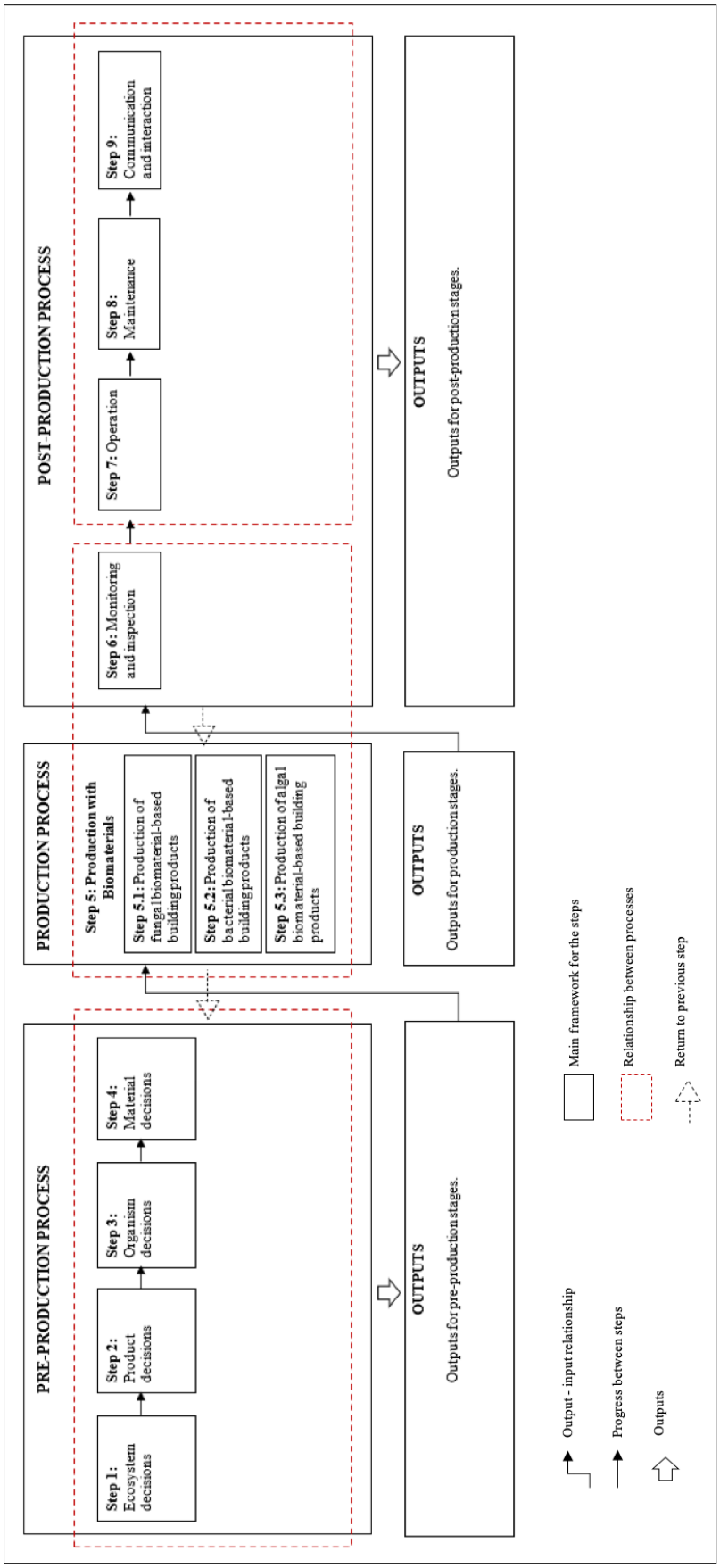


Figure 7. Proposed framework for biomaterial-based building product design.

Step 9: *Communication and interaction;* this is the stage at which the end product is introduced and engagement with the end user is ensured. Various ways, such as art, DIY and GIY kits, or direct technical knowledge on the product, can be used to provide this interaction.

If a problem arises during this step, the product should be maintained first, and if this does not fix the problem, it should be returned to the monitoring and inspection stage, and the process examined. If the problem continues, re-production should be carried out. The study divided the process into stages with the framework developed, and each step was detailed in depth. Since pre-production decisions will have an impact on production and post-production processes, it is recommended that the process be carried out with as much detail and clarity as possible, that every decision be made meticulously.

Products made using innovative bio-based materials are expected to contribute to environmental and economic sustainability by making better use of resources and materials, being biodegradable and waste-free, and reusing waste. However, because there has been a lack of research on the design and manufacture of innovative biomaterial-based building products, this study might serve as a basis for future studies and research.

For future research:

- Studies should be conducted to standardize the use of innovative bio-based materials in architecture,
- Experimental studies should be encouraged to explore their impact on various architectural forms and functions,
- Increasing the durability and manufacture efficiency of innovative biomaterial-based products.
- Cost assessment throughout the production stage

are recommended.

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Article

A bibliometric analysis of green and/or smart hospital buildings and a proposal for an integrated design model

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ABSTRACT

This study aims to systematically examine the transformation in hospital architecture through the approaches of "green and smart hospitals" in an era where green and smart technologies are rapidly evolving and the concept of "smart" is increasingly defined as the new "green." In this context, publications on green hospitals, smart hospitals, and green-smart hospitals were compiled from the Web of Science and Scopus databases. A total of 1,178 publications covering the period from August 2024 to February 2025 were analyzed using bibliometric methods. Co-occurrence network analysis, keyword trend analysis, and thematic clustering were conducted through the VOSviewer and Bibliometrix software.

The analysis results reveal that, despite the shared sustainability goals and common design criteria of these two approaches, they are generally handled separately in the literature, and integrated design strategies remain limited. To address this gap, a model consisting of four stages-data collection, analysis, synthesis, and design guidance was developed. The model was structured based on the intersection of sustainability and technological criteria.

In this respect, the study goes beyond bibliometric analysis of existing research by proposing an integrated design model grounded in the gap identified through the analysis. It aims to contribute to future interdisciplinary architectural practices and offer solutions to the current gaps in the literature.

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INTRODUCTION

Technology has always shaped architecture throughout history. Beyond being a technical tool, it reflects societal needs and paradigms. With industrialization and Artificial Intelligence-AI based systems, technology has evolved into both a means and an end. Concepts such as ***"Green Building"*** and ***"Smart Building"*** emerged from this transformation and have become key themes in architectural discourse.

Industrialization brought not only progress but also environmental degradation. In response, architecture developed sustainability-oriented paradigms like green and ecological buildings. As resources declined, ***"Green Building Technologies (GBTs)"*** emerged as design-based solutions to restore environmental balance.

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Green technologies focus on the idea of implementing sustainable strategies to keep the environment healthy and support the longer life of all living species (Ajmeena & Rana Mahanta, 2019). It refers to the technologies used in built environments to ensure that users are more comfortable and productive, to minimize environmental impacts such as climate change, energy and water consumption, waste production, etc. (Gibberd, 2019).

These technologies are integrated throughout the building lifecycle, resulting in healthier and more sustainable structures known as ***"Green Buildings (GB)"***.

Technology is not a static phenomenon, and new developments are witnessed every moment in the information age. Many new concepts such as Internet of Things-IoT, Edge Computing, Fog Computing, Cloud Computing, etc., which we were unfamiliar with just ten years ago, have now become a part of daily life (Erdal & Ergüzen, 2020).

At first glance, these concepts can be thought to be related to the fields of science and professions such as computer, software, programming, etc. Of course, it is so in terms of working principle. However, these concepts, which have a wide usage area, are effective in many different sectors such as architecture, health, environment, logistics, wearable technologies, industrial applications, etc. and they are the basic terms for ***"Smart Buildings (SBs) / Intelligent Buildings (IBs)"*** in the field of architectural science.

"Smart building", is the product of new technologies that increase the building's capacity to operate more efficiently, flexibly, interactively and sustainably and enable smarter resources and processes by incorporating information technologies into the design (Froufe et al., 2020). When adapted to architecture and the city, it is an all-encompassing expression of everything created by advanced technological change that is supported to provide safer, healthier, more comfortable and efficient ways of living (Figueiredo et al., 2019). Therefore, when the relationship between architecture and technology is evaluated in the context of smart buildings, there is a directly proportional ***"developing technology-smartness level"***. Smart building technologies are a transformative movement towards more sustainable and efficient designs because they will enable the production of buildings that are both technologically rich and supported by environmentally sound technology.

This approach to creating the ***"Smart and Green"*** is indicative of a broader trend in the building sector that aims to balance technological innovation and development with ecological management (Umoh et al., 2024). In a sense, as technology shapes architecture, the architectural form will use technology in line with sustainability principles and function; being smart will necessitate being green, and being green will necessitate being smart.

Intelligent Buildings Institute-IBI defines smart buildings as buildings in which systems such as Heating, Ventilating and Air Conditioning-HVAC, acoustics, data communication, etc. are integrated with each other to manage resources in a coordinated and efficient manner to maximize user performance, investment and operating cost savings and flexibility (Hawkins, 1983).

In nutshell, all the elements considered for sustainability are similar to the objectives in the smart building concept and working principle and form an intersection in the context of smart building and green building in the spatial dimension. This intersection creates the ***"Green and Smart Building"*** approach, which is the main theme of the study.

As long as they exist, buildings create different impacts according to their scale and function; the impacts continue to affect the environment even after the building is destroyed. As the scale changes and the function becomes more complex, the impacts in both the construction and the process of use change and environmental impacts increase. The environmental impacts of a residential building and an educational or commercial building are different, as are their contributions to sustainability.

The theme of this study, ***"the state of being green and smart for hospitals"***, refers to designing for minimization of adverse effects on the environment and optimization of environmental conditions by balancing green and smart with an integrated manner.

A review of the literature reveals that studies on green and smart hospitals are generally addressed separately, and there is a significant lack of design models that evaluate these two approaches in an integrated manner. Despite their shared sustainability goals, no comprehensive proposal has been developed that combines green and smart systems within a unified framework. Furthermore, there is a notable absence of a concrete design framework in terms of definition, criteria, and implementation across these concepts. This gap complicates both the architectural decision-making processes and the development of performance-based decision support systems. Therefore, this study aims to bridge this gap by establishing a conceptual, functional, and design-oriented link between green and smart approaches. In this context, a bibliometric analysis was conducted on studies related to green hospitals, smart hospitals, and green-smart hospitals retrieved from the Web of Science (WoS) and Scopus databases, demonstrating the need for an integrated design approach in the context of green and smart hospital buildings. Within the scope of the study, the proposed "Green'S'Mart Hospital Model: An Integrated Design Framework for Green and Smart Hospital Buildings" is structured as a holistic model that focuses on the life-cycle stages of green and smart hospital buildings-design, construction, operation (including maintenance

and management), and demolition/deconstruction-as well as the inputs involved in these processes and the resulting outputs. The study aims to develop integrated solutions specific to healthcare facilities, based on the necessity of redefining the built environment through the principles of sustainability and digitalization.

In the first part of the five-chapter study, the subject is explained in general terms and the background of the main theme and definitions are given in the second part. In the third chapter, the study structure was created for the basic problem, questions and solutions that led to the research and in the fourth chapter, bibliometric analysis was carried out to examine the place of the subject in the literature. In the fifth chapter, the results of the analysis are detailed, and suggestions are made based on the findings. The model to be addressed within the scope of the PhD thesis is limited to the scale of the proposal in the article.

THE BACKGROUND AND DEFINITIONS

"Green Buildings" and "Smart Buildings"

Building production has an impact on the environment and human health apart from intensive resource consumption and waste production. For this reason, sustainable pursuits in architecture have emerged over time to minimize resource consumption, waste production and negative health impacts.

Sustainability-based approaches were expressed as "Environmental Design" in the 1970s, "Ecological Design" in the late 1980s and 1990s, and "Sustainable Design" since the mid-1990s (Arsan, 2008). These concepts, which are presented with descriptions such as green, environmentally friendly, healthy, ecological, smart, environmentally sensitive, high performance, etc., are alternatives of each other and are under the umbrella of sustainability.

Green buildings are defined as buildings where green building technologies are used with the aim of creating minimum impact on the environment and these techniques are maintained throughout the life of the building (design, construction, use, demolition/dismantling). They are designed, constructed, used and demolished/dismantled at the end of their life cycle in line with ecological principles to promote user health and minimize the impact of buildings on the natural environment (Kibert, 2004). It is expressed as any form of design that minimizes damage to the environment by integrating with the processes experienced. Integration means that the design respects species diversity, minimizes resource consumption, protects nutrient and water cycles, maintains habitat quality, and considers human and ecosystem health. In a sense, it means effectively adapting to and integrating with the processes of nature (Ryn & Cowan, 2007).

The first examples of green buildings, which are about a century old in origin, were given during the application of passive systems such as underground air cooling box, roof fan, etc. to adjust the indoor temperature of the British Palace building at the first world exhibition in Milan in the 19th century and the design of windows embedded in the walls to refract sunlight in the New York Times and Flatiron Buildings in the 20th century (Li et al., 2014). At this point, it is seen that even a century ago, sustainability in architecture was tried to be supported with technology and equipment as much as the conditions allowed and there was an effort to bring green and technology together.

With the popularization of the idea of sustainability, strategies for smart cities and smart buildings that form the identity of the city have started to be developed in order to ensure sustainability and healthy living conditions at the city scale, and the CityPlace office building, which started construction in 1981, became the "World's First Smart Building" (Hawkins, 1983; The New York Times, 1983). Smart buildings are buildings that address intelligence, control and construction processes as an integrated building system by meeting the elements that positively direct the development of the building such as energy efficiency, sustainability, longevity, comfort and user satisfaction (Buckman et al., 2014). It is shaped by the installation and use of highly integrated building technology systems (Sinopoli, 2010).

When the philosophy of green building and smart building is examined, it is recognized that both approaches are based on sustainability and adopt the idea of "integration", "coordination" and "integration" with effective tools and functions to ensure sustainability. This leads to the ***"Green and Smart Building"*** approach, which is a synthesis of both green and smart.

"Green and Smart Buildings"

Green and smart buildings are buildings that carry the common principles of green and smart design as well as the characteristics of a green building and a smart building separately, supporting, strengthening and monitoring the green side with the smart side, identifying and solving the problems that may arise during the process of use and ensuring that the system continues to function properly. It adopts an understanding that sustainability, which forms the basis of green thinking, will be maintained through smart systems throughout the life cycle.

Buildings that combine a green building approach and smart building technologies are safe, healthy, comfortable, user-friendly, efficient and energy efficient. It optimizes energy management, increases resource efficiency and improves quality of life through the integration of environmental sustainability principles and advanced technology solutions (Wen et al., n.d.). It provides quality control, assurance, efficiency, comfort, accessibility and systematic monitoring

of the activities within it. It aims to increase environmental sustainability and building quality using sustainable, smart, local and recycled materials in its construction. In addition, technologies are used to save time and cost, improve labor quality, improve waste management, produce affordable buildings, etc. (Patil et al., 2022).

The designer's goal is to create healthy buildings using a green and smart approach that ensures monitoring and improvement throughout the building's life cycle. This process spans from design to demolition. The goals of both green and smart systems are aligned, as reflected in their definitions and shared themes in the literature. While green design focuses on environmental principles, smart systems ensure monitoring and control. This article centers on hospital buildings shaped by the synergy of both approaches and explores their place in the literature.

PROBLEMS, RESEARCH QUESTIONS AND METHODOLOGY

The study focuses on the idea of evaluating the state of being green and smart through hospitals in an age where everything has evolved into digital and equipped with smart systems. Within the scope of the study, a large pool of resources including studies on sustainability, technology, green building, smart building, green and smart building, green hospital, smart hospital, green and smart hospitals was created and how the subject was handled in the resources was examined.

The first adopters of smart buildings were banks and offices. Although it has been seen for smart housing, hotels, shopping centers, educational campuses, etc. over time, few research and examples have been recorded for healthcare buildings that humanity always need.

The number of studies conducted in the field of architecture science is insufficient. There are reviews on definitions, components and general characteristics and they are generally in the form of compilations and adaptations of interdisciplinary (computer, software and electrical electronics, etc.) studies to the field of architecture (Table 1).

Each research question is fed by the existence of a possible problem. The main problem for Research Questions-RQs is that the green and smart building approach is not sufficiently addressed for hospitals where health and sustainability is a necessity. In this context, three interrelated research questions are at the center of this study:

"RQ1: What is Green Hospital?"

"RQ2 What is Smart Hospital?"

"RQ3: What is a Green and Smart Hospital, and What is Its Contribution to the Literature?

Buildings create different impacts according to their scale and function, and the impacts persist even after the building is destroyed and the larger the scale and the more complex the function, the greater the impacts. The topic of the study ***"green and smart for hospitals"*** refers to designing for minimization of adverse impacts on the environment and optimization of environmental conditions by balancing green and smart with an integrated approach.

Hospital projects are different from residential, office or service building projects. It is based on many principles, from the work team in construction to the health and comfort of patients and staff. It has a strong aspect of shaping social responsibility and urban design (Castro et al., 2012). For a hospital building to be green and/or smart, it needs to be designed in line with common principles that make it both green and smart, unlike traditional hospital buildings. These principles are as follows (Ozdemir & Tuna Taygun, 2022):

- Realization of hospital building life processes with a holistic approach,
- Integration of design principles required by being green and smart.

Smart hospitals are a type of smart buildings that have gained momentum in the last decade and are the structures in great need of sustainability and technological infrastructure. It is designed with the idea of providing healthy, comfortable and safe environmental conditions to

Table 1. Literature review and summary of the research gap

Topic	Literature			
	Design Criteria	**Evaluation Tools**	**Architectural Literature**	**Interdisciplinary Literature**
Green Hospital Buildings	●	●	●	◑
Smart Hospital Buildings	◑	◑	◑	●
Green and Smart Hospital Buildings	○	◑	○	◑
Legend				

● Criteria Met; ◑ Criteria Partially Met; ○ Criteria Not Met.

different users in different units twenty-four hours a day, seven days a week, providing optimum parameters in terms of temperature, humidity, light, indoor air quality, noise level, etc. and continuously monitoring these parameters and trying to optimizing them when they change (Ozdemir & Tuna Taygun, 2022).

The basic principle is to provide and maintain many operations that cannot be ensured during the usage process of hospital buildings designed with traditional systems. Similarly, technological power is needed for green hospitals to protect and maintain the features that provide greenness throughout the life of the building. These needs have motivated designers, and the idea of implementing both smart and green buildings simultaneously and producing green and smart hospital buildings using the approaches and design principles suggested by both situations emerged (Ozdemir & Tuna Taygun, 2022).

Bibliometric analysis was used to see the current status of the problems that created the central questions of the article and to identify a possible scientific gap. Bibliometrics is the quantitative classification of previously published studies in the literature (Schrader, 1981). The method, referred to as science mapping or bibliometric mapping, is a representation method that shows the relationship between disciplines, fields, specialized subjects and personal documents or authors (Small, 1999). The purpose of these analyses is to reveal the distribution of keywords used in the research, author/co-author, country, citations, etc. and to perform due diligence.

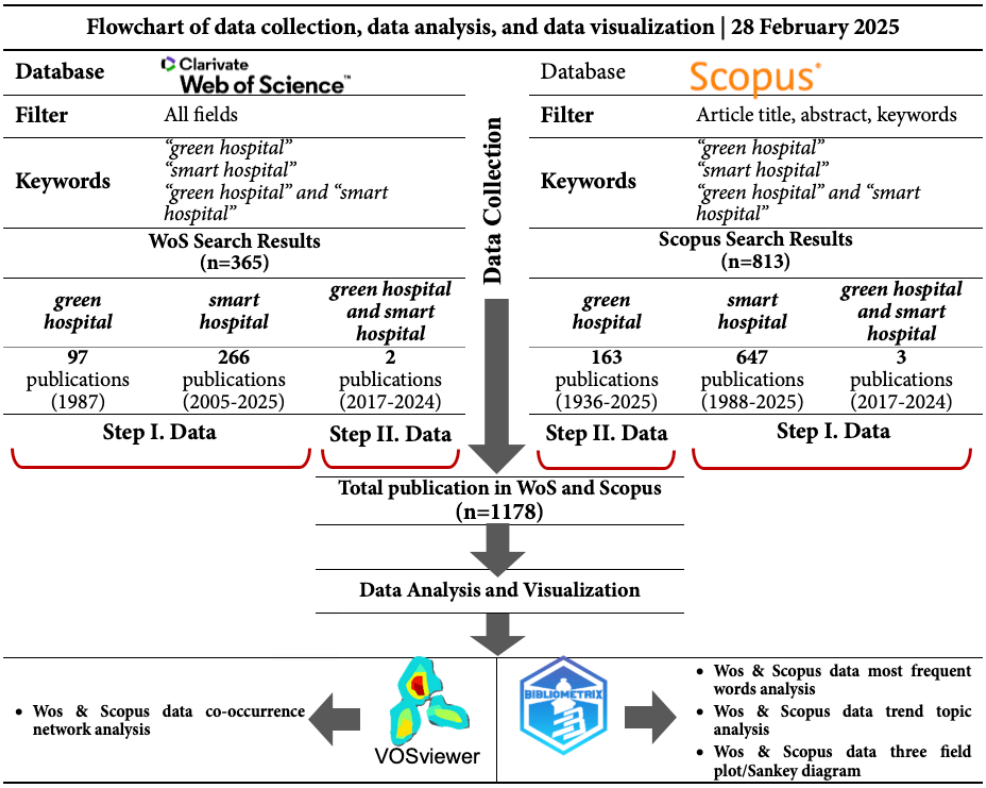
In the article, two of the most popular databases Web of Science (WoS) and Scopus were used to access more data and VOSviewer and Bibliometrix (Biblioshiny app) were used for analysis and visualization. VOSviewer is a software used to create and visualize bibliometric networks related to the selected research topic (VOSviewer, 2025). Other analyses and visualizations were made with Biblioshiny, the web interface of the R package Bibliometrix (Aria & Cuccurullo, 2017). The analysis data was monitored between August 2024 and February 2025; current data recorded in February 2025 was used. In the searches made on WoS Core Collection and Scopus, publications indexed with the keywords "green hospital", "smart hospital", "green hospital" and "smart hospital" were searched with the "All Fields" filter. The study design and methodology, which provide additional context and relevant details concerning the subject, are summarized below (Table 2).

As a result of the searches:

In the WoS database

- 97 publications dated between 1987 and 2025 for "green hospital",
- 266 publications dated between 2005 and 2024 for "smart hospital",

Table 2. Flowchart of the study methodology



- 2 publications dated between 2017 and 2024 for "green hospital" and "smart hospital" were identified.

In the Scopus database

- 1,711 publications dated between 1895 and 2025 for "green hospital",
- 4,478 publications dated between 1988 and 2025 for "smart hospital",
- 21 publications dated between 2017 and 2024 for "green hospital" and "smart hospital" were identified.

In the Scopus database, initial searches conducted using the "All Fields" filter revealed a significant number of interdisciplinary publications that were not directly related to the subject-mostly from fields such as computer science, electrical-electronics, and software engineering. Therefore, the filtering process was revised, and the search was restricted to "Article title, abstract, and keywords."

In this case:

- 163 publications dated between 1936 and 2025 for "green hospital",
- 647 publications dated between 1988 and 2025 for "smart hospital",
- 3 publications dated between 2017 and 2024 for "green hospital" and "smart hospital" were identified.

As a result, 365 publications retrieved from the WoS database and 813 from the Scopus database (reduced from 6,210 after filtering) constituted the final sample of 1,178 publications used in this study. The analyses were conducted in two stages by associating them with the research questions; In the first stage, the "green hospital" and "smart hospital" concepts related to RQ1 and RQ2, and in the second stage, the relationships between the "green and smart hospital" concepts related to RQ3 and the intersectional sustainability were examined.

BIBLIOMETRIC ANALYSIS AND FINDINGS

In the bibliometric analysis of the collected data, VOSviewer and the open-source Bibliometrix R package, along with its web application Biblioshiny (Aria & Cuccurullo, 2017) were utilized. The purpose of using two different analytical tools was to validate the results through outputs from different platforms and to present them in a more comprehensible manner. To fully understand the position of the topics within the literature and to obtain accurate results, no date restriction was applied. Instead, the analysis was conducted using all publications indexed with the relevant keywords in WoS and Scopus up to February 28, 2025. Co-occurrence network and keyword analysis were performed using VOSviewer, while most frequent words, three-field plot/ Sankey diagram, and trend topic analysis were carried out using Bibliometrix (Bibliyoshiny app).

Step I- Analysis and Findings for RQ1 Green Hospital (GH) and RQ2 Smart Hospital (SH)

- **Authors' keywords' co-occurrence network analysis, and most frequent words analysis for GHs and SHs:**

It is an analytical method that examines the relationship between the keywords of the publications produced on the subject of the study and the use of these words together. When the analysis results are visualized, a network structure containing the keywords emerges. Each node in the network shows a keyword, node size shows the repetition of the keyword, and node link shows the simultaneous use relationship between different keywords. Each color represents a specific thematic cluster (Donthu et al., 2021). The most frequent words analysis identifies the most commonly used keywords related to the research topic in the collected data. When visualized, the results are presented in a linear graph showing the frequency of each keyword.

The analysis results of WoS data (Figure 1):

- The keywords of GHs are categorized into five thematic clusters. Purple (carbon footprint-4, covid-19-2, energy-3, environment-6, environmental protection-2, green healthcare-4, green hospital-32, sustainable development-3, sustainable healthcare-3), Red (climate change-7, environment-6, carbon footprint-4, energy, sustainable development-3, energy consumption-2), Blue (sustainability-10, management-3, eco-initiatives, pharmacy carbon footprint-2, green hospital pharmacy-2, zero waste-2), Yellow (energy consumption-2, fuzzy control-2, green building-4, green hospital building-3, hospital-6, leed healthcare-2, patient satisfaction-2) and Green (waste management-4, energy efficiency-2, green benefits-2, green buildings-2, green hospitals-2, hospitals-2) are seen to be clustered under these thematic keyword groups.
- The keywords of SHs are categorized into sixteen thematic clusters. Examples include Cyan (smart hospital-94, facility management (fm)-2, patients-2, augmented reality-2, ehealth-2, fuzzy logic-2), Blue (health care-4, simulation-3), Green (artificial intelligence-11, rfid-8, healthcare-20, smart gateway-2), Red (sensors-8, iot-17), Purple (big data-3, smart hospitals-8, smart healthcare-10, architecture-2, blockchain-3, facility management-2, framework-2, patient care-2, quality of service-2, sensors-8, simulation-3, smart hospitals-8, telecommunications-3, telemedicine-6), Pink (internet of things-23, availability-2, remote sensing-2, internet-of-things (iot)-1), Salmon (smart home technology-2, accessibility-2, automatic speech recognition-2, digital transformation-4, natural language processing-3, rehabilitation hospital-2, smart healthcare-10, smart medical-2, smart medicine-2, smart patient room-3), and others, which are seen to be clustered under these thematic keyword groups.

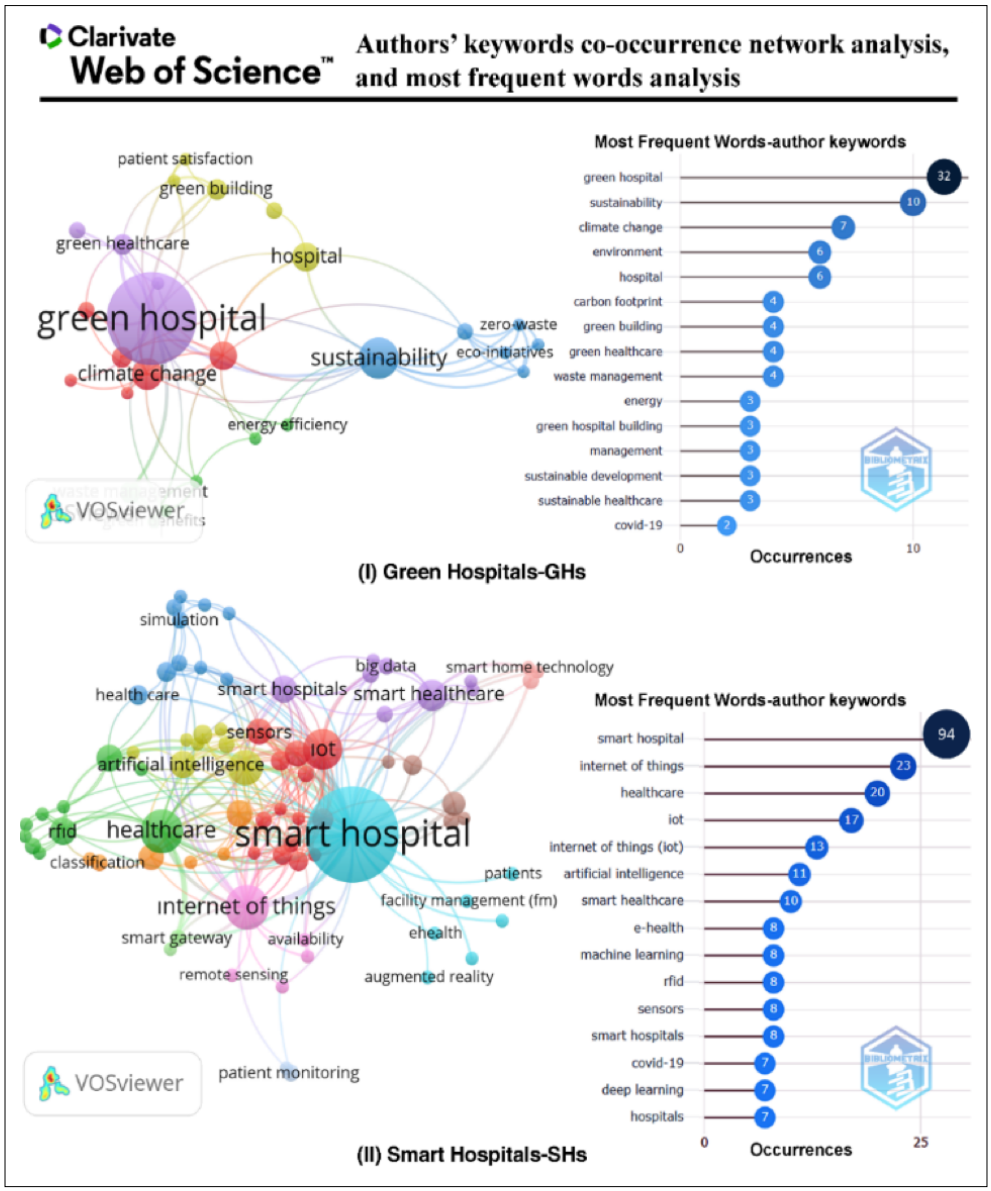


Figure 1. WoS database authors' keywords' co-occurrence network analysis and most frequent words analysis for (I) GHs, (II) SHs.

The analysis results of Scopus data (Figure 2):

- The keywords of GHs are categorized into seven thematic clusters. Cyan (biophilic design-4, green hospital building-2, hospital-6, leed-3, service quality-2), ***Green*** (carbon footprint-5, climate change-9, energy-4, environment-7, environmental protection-2, green healthcare-5, green hospital-38), ***Purple*** (conservation of natural-2, environmental footprint-2, environmental health-2, sustainable development-6, waste management-5), ***Yellow*** (evidence-based design-2, green building-9, leed healthcare-4, sustainable design-2, patient satisfaction-2), Orange (green innovation-2, medical waste-2, sustainable healthcare-5), ***Blue*** (green hospital building-2, hospital-6, service quality-2), ***Red*** (continuous improvement-2, energy efficiency-3, environmental management-2, hazardous waste-3, healthcare-4, healthcare sector-2, hospitals-4, renewable energy-3, supply chain-2) are seen to be clustered under these thematic keyword groups.
- The keywords of SHs are categorized into twenty-seven thematic clusters. Examples include ***Pink*** (smart hospital-165, smart healthcare-21, smart health-9, digital hospital-4), ***Blue*** (internet of things-63, iot-51, smart cities-9, smart technology-2), ***Green*** (hospital-13, healthcare-47, healthcare technology-2, rfid-15), Orange (led-6, localization-3, industry 4.0-4), ***Red*** (energy consumption-2, digital twin-9, simulation-3, fog computing-6, data mining-4), ***Purple*** (home

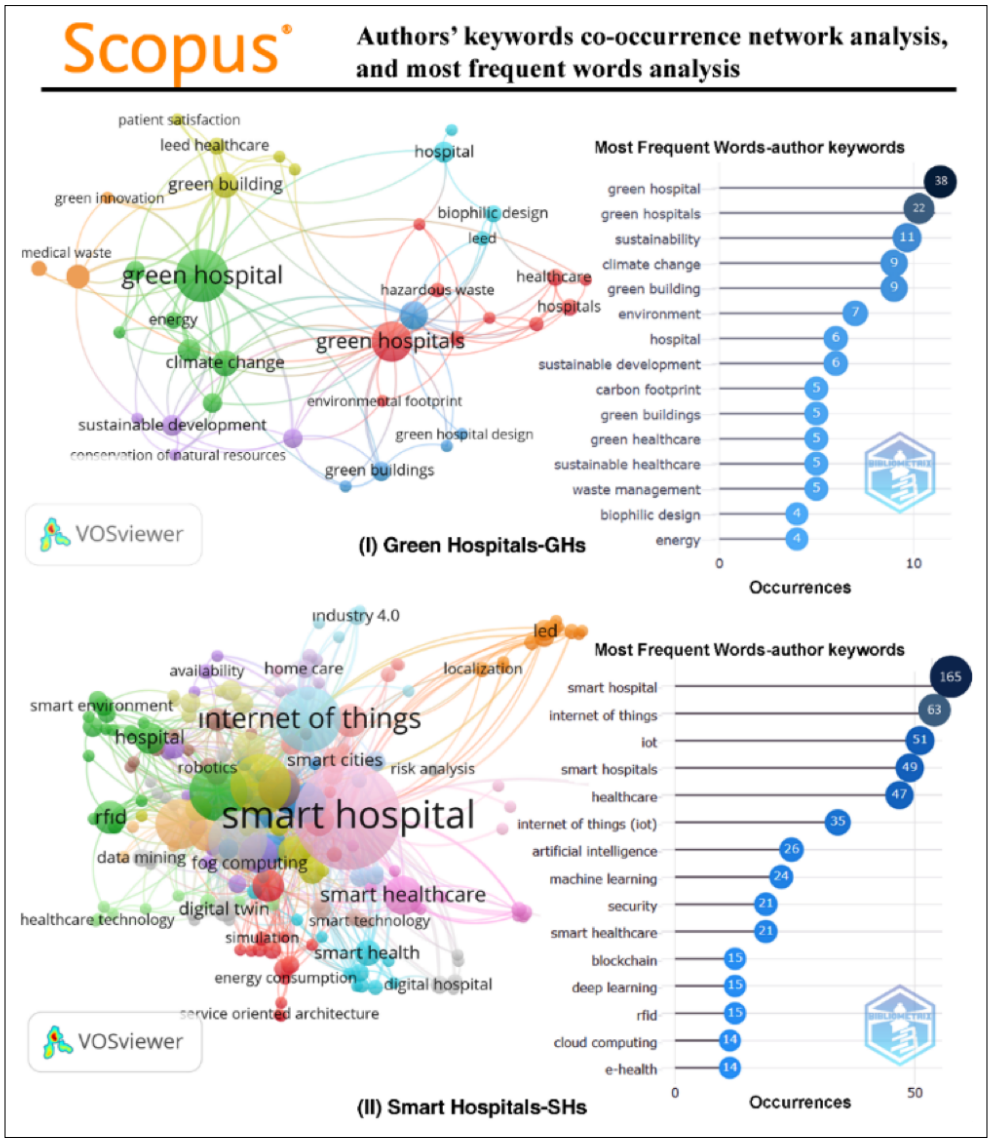


Figure 2. Scopus database authors' keywords' co-occurrence network analysis and most frequent words analysis for (I) GHs, (II) SHs.

care-4, availability-3, risk analysis-2, service-oriented architecture-1, path planning-2), and others, which are seen to be clustered under these thematic keyword groups.

The co-occurrence analysis of author keywords from both Web of Science (WoS) and Scopus databases highlights distinct thematic focuses in studies on Green Hospitals (GHs) and Smart Hospitals (SHs). GHs-related terms predominantly cluster around environmental sustainability and healthcare architecture, emphasizing ecological integration, energy efficiency, and sustainable development. In contrast, SHs related keywords form a broader and more diversified landscape, centered on digital infrastructure and technological innovation. Recurring terms such as smart hospital, internet of things, artificial intelligence, and cloud computing indicate a growing emphasis on intelligent systems and data-driven healthcare models. These differences reflect the dual evolution in hospital research: while GHs studies concentrate on environmental and structural concerns, SHs research is oriented toward automation, system scalability, and digital transformation. Overall, the analysis reveals a clear thematic divergence-GHs aligning with sustainability-driven architectural frameworks, and SHs emerging as complex technological ecosystems-demonstrating the interdisciplinary and evolving nature of hospital-related scholarship.

- **WoS and Scopus database three field plot analysis/ sankey diagram for GHs and SHs**

Three-field plot analysis, performed via Bibliometrix (Biblioshiny app), is an analysis method that evaluates the relationship between certain factors on the subject of

the study. These are variables such as sources, countries, affiliations, keywords, leading authors, cited sources, keyword plus, and the relationships between them are visualized (Yaqoub et al., 2023).

The analysis results of WoS data (Figure 3):

- According to GHs data, the analysis was conducted through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, "green", "hospital", "sustainability", "environment"; in the keywords, "green hospital", "sustainability", "climate change"; in the keywords plus, "healthcare", "performance", "life-cycle assessment", "sustainable development" are prominent. These relationships show that the studies conducted on green hospitals are addressed with an integrated approach with the environmental sustainability dimension.
- According to SHs data, the analysis was conducted through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, "smart", "hospital", "healthcare", "system"; in the keywords, expressions related to digital health technologies such as "smart hospital", "internet of things (IoT)", "machine learning", "artificial intelligence" are prominent. The presence of terms such as "internet", "technology", "management", "framework" in keywords plus shows that these concepts are linked to digital transformation, artificial intelligence and data management in studies on smart hospitals.

The analysis results of Scopus data (Figure 4):

- According to GHs data, the analysis was made through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, "green", "hospital", "sustainability", "management", "health"; in the keywords, "green hospital", "sustainability", "climate change", "green buildings"; in the keywords plus, "hospitals", "waste management", "sustainable

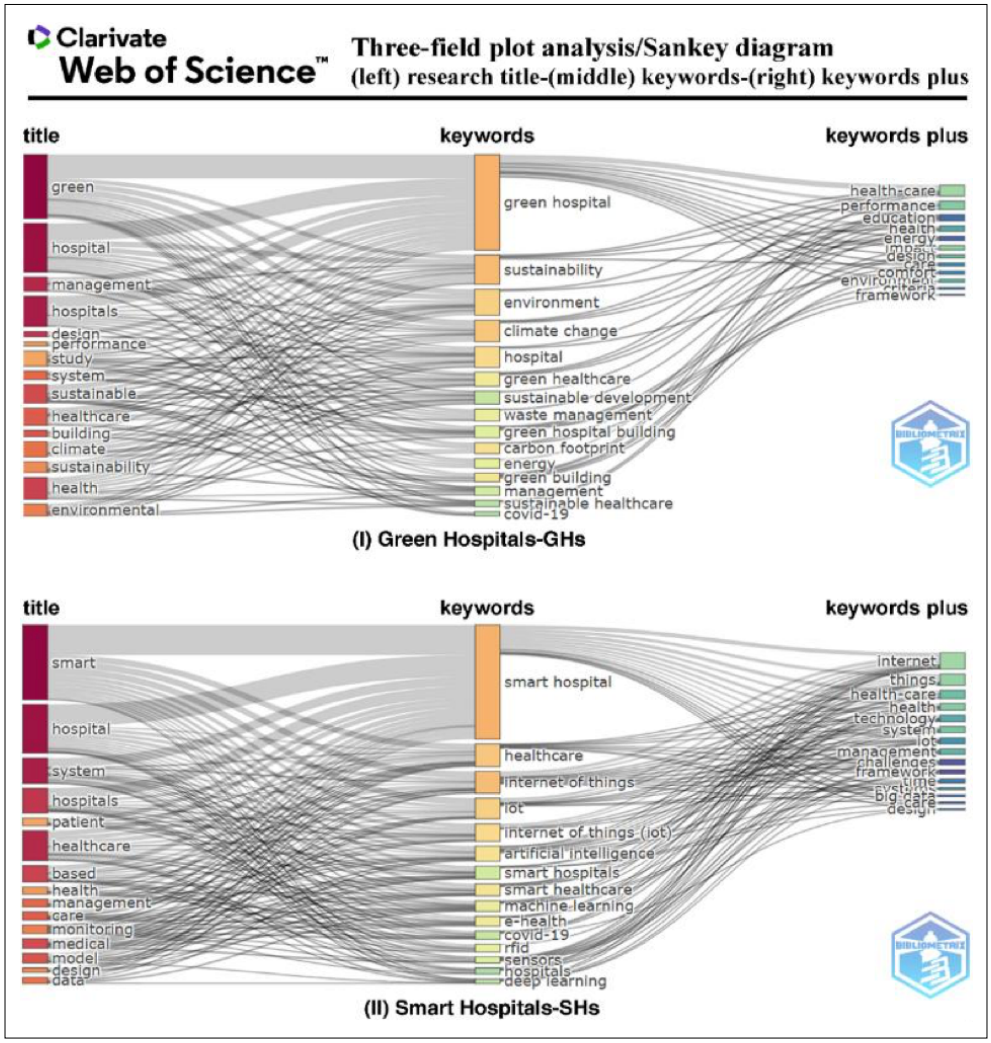


Figure 3. WoS database research title-authors' keywords-keywords plus three-field plot analysis for (I) GHs, (II) SHs.

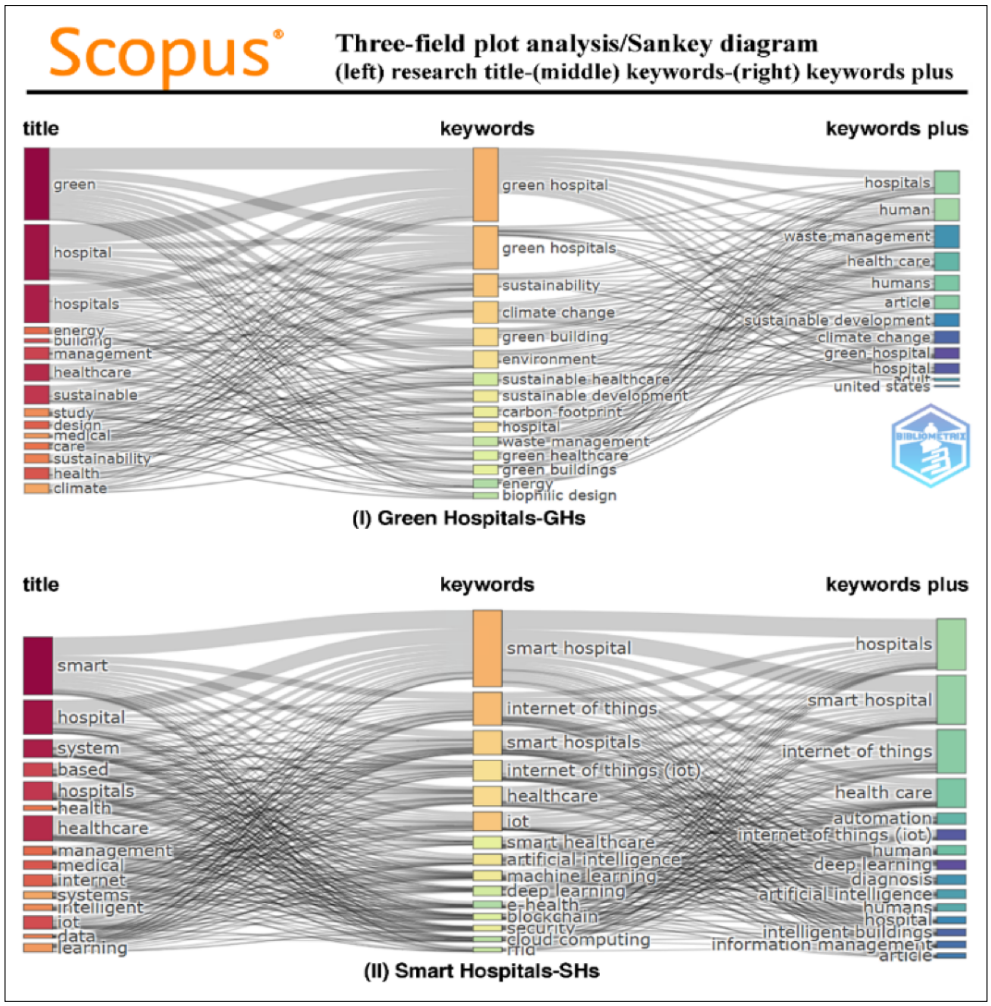


Figure 4. Scopus database research title-authors' keywords-keywords plus three-field plot analysis for (I) GHs, (II) SHs.

development", "environmental impact" are prominent expressions. It shows that green hospitals are being worked on in an integrated manner with health, environmental sustainability and waste management. These relationships emphasize the relationship between the studies conducted on green hospitals and issues such as sustainability, waste management and energy efficiency.

- According to SHs data, the analysis was made through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, expressions such as "smart", "hospital", "internet", "monitoring", "system", "learning"; in the keywords, expressions such as "smart hospital", "internet of things", "machine learning", "blockchain", "telemedicine" technological transformation attract attention. The presence of expressions such as "automation", "artificial intelligence", "deep learning", "telemedicine", "security" in the Keywords Plus shows that automation, security and artificial intelligence applications are the priority issues in smart hospitals.

The Sankey diagrams reveal distinct thematic orientations between Green and Smart Hospitals. GHs-related terms consistently converge around sustainability, environmental impact, and healthcare infrastructure, reflecting an ecologically integrated research focus. In contrast, SHs studies emphasize technological transformation, highlighting concepts such as automation, artificial intelligence, and data systems. This contrast demonstrates how GHs are framed within environmental and architectural contexts, while SHs are positioned within a digitally driven, innovation-focused paradigm. The diagrams thus reinforce the evolving divergence in priorities across hospital research, bridging environmental responsibility with intelligent system integration.

- **WoS and Scopus database trend topics analysis for GHs and SHs**

Trend topics analysis performed via Bibliometrix (Biblioshiny app) shows the distribution of trend topics related to the study topic over time. The horizontal axis represents the

years in the analysis, the vertical axis represents trending topics, and the size of the nodes represents the frequency of trending topics (Yaqoub et al., 2023).

The analysis results of WoS data (Figure 5):

- For GHs, between 2016-2018, topics such as "green healthcare", "green hospital building", and "green building" attracted attention and were included in research. It was observed that "sustainable healthcare", "waste management", "carbon footprint", and "environment" were frequently studied between 2019-2020, and "sustainability", "climate change", "management", and "energy" were frequently studied between 2022-2023. The "green hospital" topic showed a significant increase in 2022 and became one of the most researched topics.
- For SHs, topics such as "pervasive computing", "rfid", "data mining", and "smart home" attracted attention in the early periods, while "IoT", "cloud computing", and "security" gained importance between 2016-2017. As of 2018, artificial intelligence-based applications such as "machine learning", "artificial intelligence", "deep learning" and after 2020, "digital twin", "remote sensing", "smart hospitals" and "AI", "blockchain", "5G", "interoperability" related to technological developments were discussed in the studies.

The analysis results of Scopus data (Figure 6):

- For GHs, between 2016-2018, topics such as "green healthcare", "green hospital building", and "green building" attracted attention and were included in research. It was observed that "sustainable healthcare", "waste management", "carbon footprint", and "environment" were frequently studied between 2019-2020, and "sustainability", "climate change", "management", and "energy" were frequently studied between 2022-2023. The "green hospital" topic became

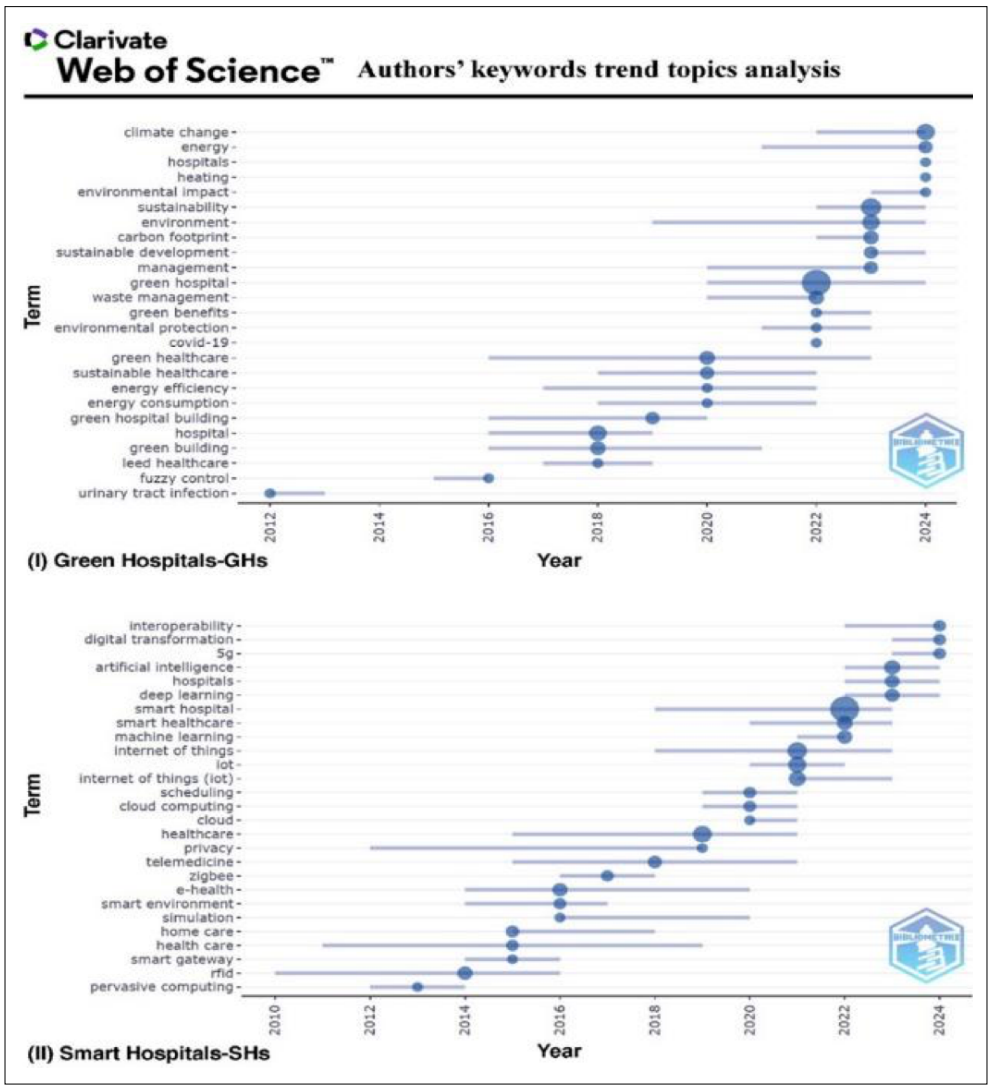


Figure 5. WoS database authors' keywords trend topic analysis for (I) GHs, (II) SHs.

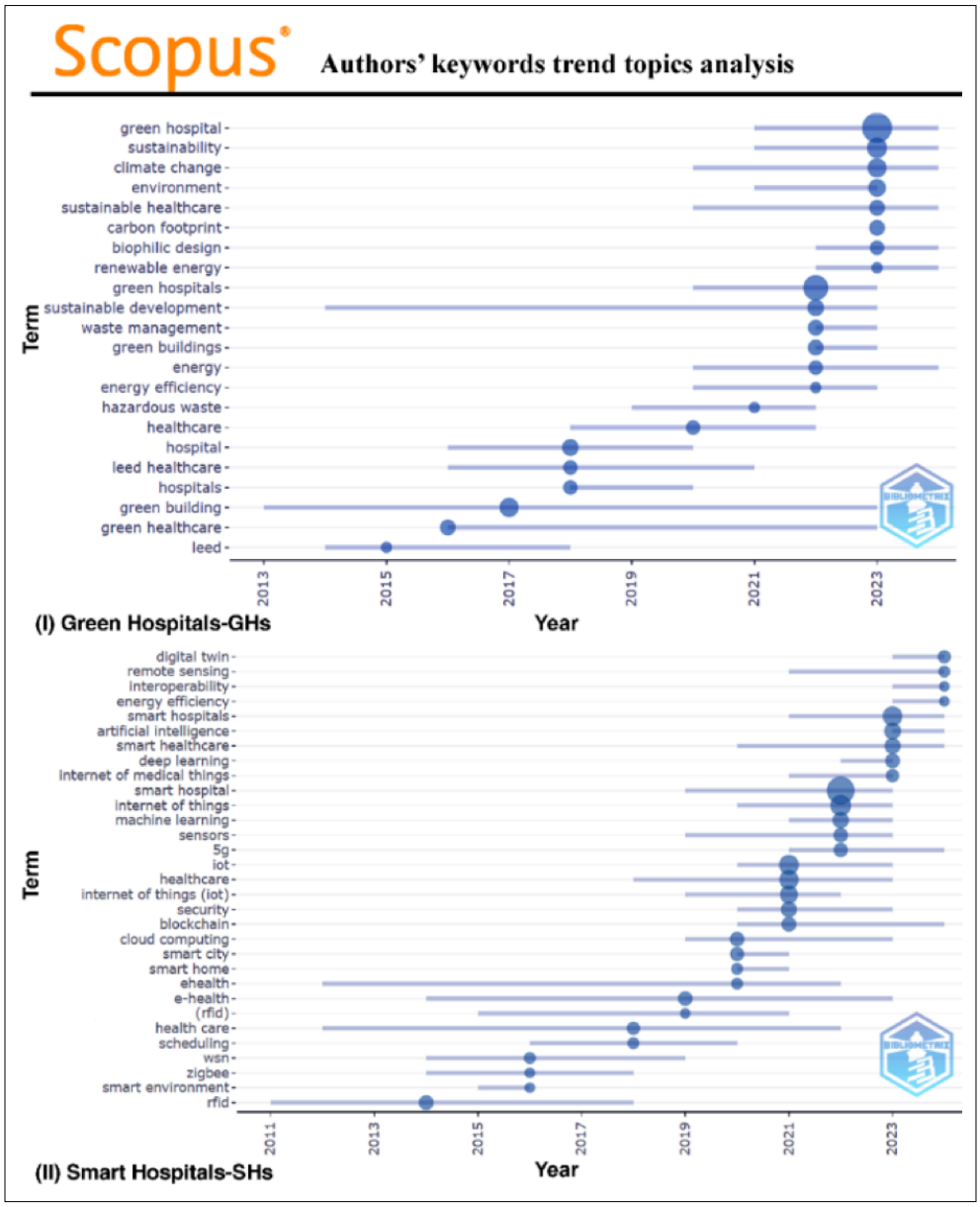


Figure 6. Scopus database authors' keywords trend topic analysis for (I) GHs, (II) SHs.

one of the most researched topics in 2022.

- For SHs, in the early periods, topics such as "pervasive computing," "Radio Frequency Identification-RFID," "data mining," and "smart home" attracted attention and were included in research. It was observed that "IoT," "cloud computing," and "security" gained prominence between 2016-2017, while from 2018 onwards, artificial intelligence-based applications such as "machine learning," "artificial intelligence," and "deep learning" became prevalent. After 2020, studies frequently addressed topics like "digital twin," "remote sensing," and "smart hospitals," along with technology-related concepts such as "AI," "blockchain," "5G," and "interoperability.

According to the analysis results, in GHs studies, environmental themes such as "green building," "waste management," and "sustainability" became prominent after 2016, with "green hospital" emerging as a key term in recent years. In SHs literature, post-2018 trends show a rapid rise in topics like "AI," "IoT," "machine learning," and "blockchain," reflecting a shift toward data-driven healthcare and digital transformation.

Step II- Analysis and Findings for RQ3 Green and Smart Hospital (GRSH)

- **Authors' keywords' occurrence network analysis, and most frequent words analysis for GRSHs**

The analysis results of WoS and Scopus data (Figure 7):

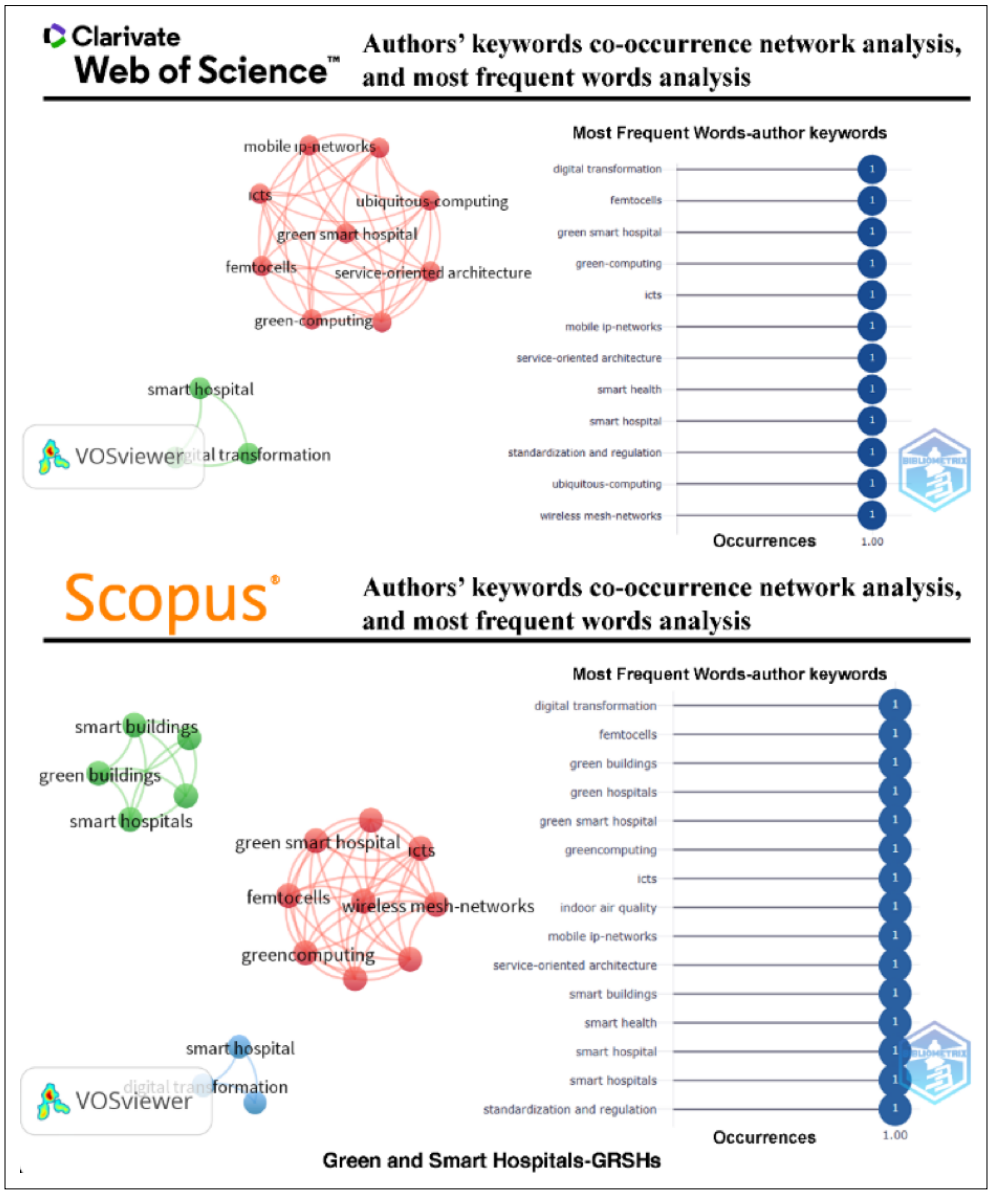


Figure 7. WoS and Scopus database authors' keywords' co-occurrence network analysis, and most frequent words analysis for GRSHs.

- The GRSHs keywords obtained from WoS categorized into two thematic clusters. Red (femtocells, green buildings, green hospitals, green smart hospital, green computing, icts, indoor air quality, mobile ip-networks, service-oriented architecture, smart buildings, smart hospitals, standardization and regulation, ubiquitous-computing, wireless mesh-networks -1), and Green (digital transformation, smart hospital, smart health-1),
- The GRSHs keywords obtained from Scopus are categorized into three thematic clusters. Red (femtocells, green smart hospital, green computing, icts, mobile ip-networks, service-oriented architecture, standardization and regulation, ubiquitous-computing, wireless mesh-networks -1), Green (green buildings, green hospitals, indoor air quality, smart buildings, smart hospitals-1), and Blue (digital transformation, smart hospital, smart health-1) are seen to be clustered under these thematic keyword groups.
- GRSHs network analysis has a different network structure than GHs and SHs analyses. Some items in the collected data are not connected. Therefore, there is no connection between some cluster items and separate clusters are seen. 12 items are not connected for WoS data of GRSHs. The largest cluster of connected items consists of 9 items, and 17 items are not connected for Scopus data of GRSHs, the largest cluster of connected items consists of 9 items again.

Although the publications originate from different databases (WoS and Scopus), the overlapping data suggest that GRSHs studies are limited and largely stem from the same sources, indicating a lack of distinct research.

- **WoS and Scopus database three field plot analysis/ sankey diagram for GRSHs**

The analysis results of WoS and Scopus data (Figure 8):

- According to GRSHs WoS data, unlike the (left) Titles-(middle) Author's Keywords-(right) Keywords Plus (left) relationship in other three field plot analyses, it was made through Titles-(middle) Author's Keywords-(right) Abstract relationships because the number of data collected from the WoS database is not sufficient to obtain the three-field plot. Expressions such as "hospital", "smart", "enable", "green", "efficiency", "computing" show that smart and green hospitals are associated with the concepts of efficiency-digitalization-environmental sustainability in the studies.
- According to GRSHs Scopus data, the analysis was made through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. Expressions such as "hospital-care", "data-driven", "hospitals", "indoor air quality (IAQ)", "green", "smart", "review" stand out in the studies. Especially the existence of concepts such as "indoor air quality" and "air" related to health, comfort and environmental conditions shows that smart system elements and environmental sustainability dimensions are examined together in the studies.
- **WoS and Scopus database trend topics analysis for GRSHs**

The analysis results of WoS and Scopus data (Figure 9):

- According to WoS data for GRSHs, topics such as "smart hospital", "smart health", "digital transformation" have attracted attention in 2023 and have been heavily included in research. On the other hand, concepts such as "green computing", "green smart hospital" have gained importance in studies in recent years.

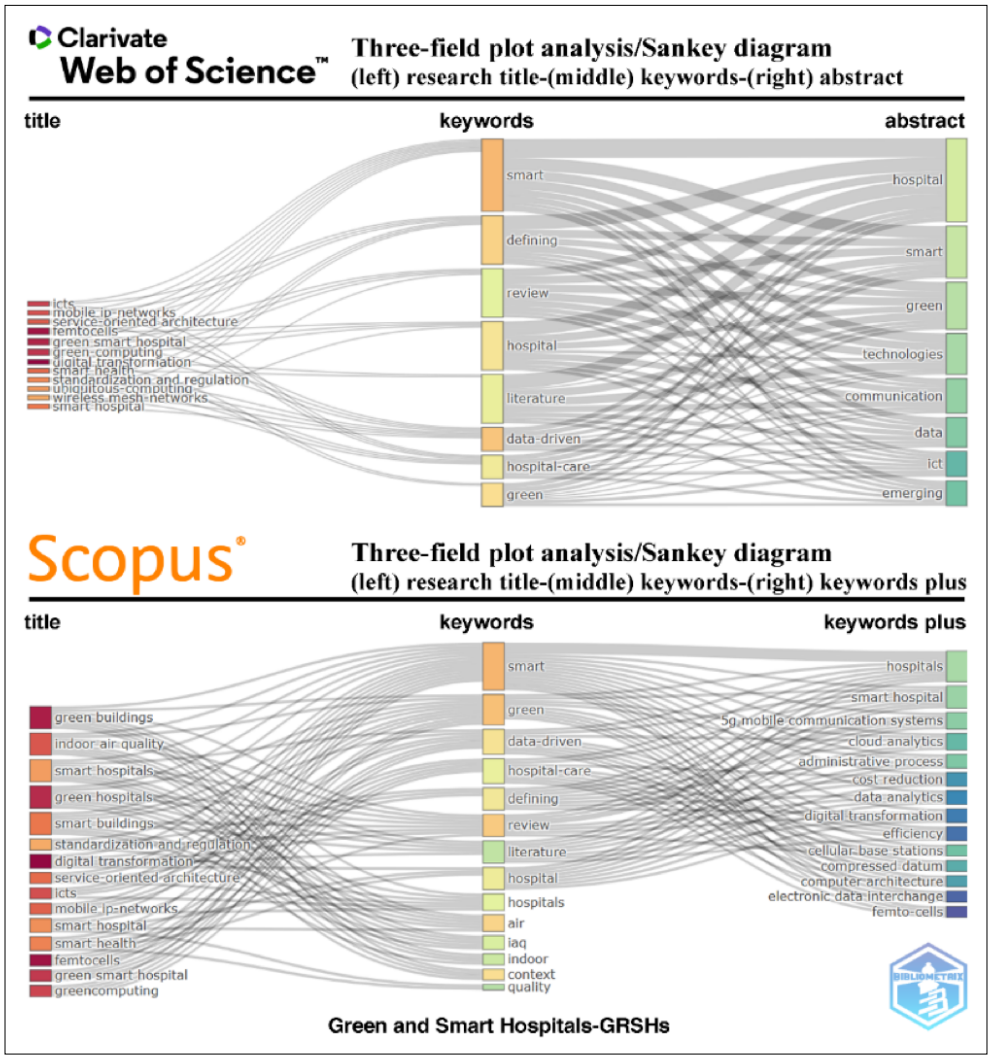


Figure 8. WoS and Scopus database research three-field plot analysis for GRSHs.

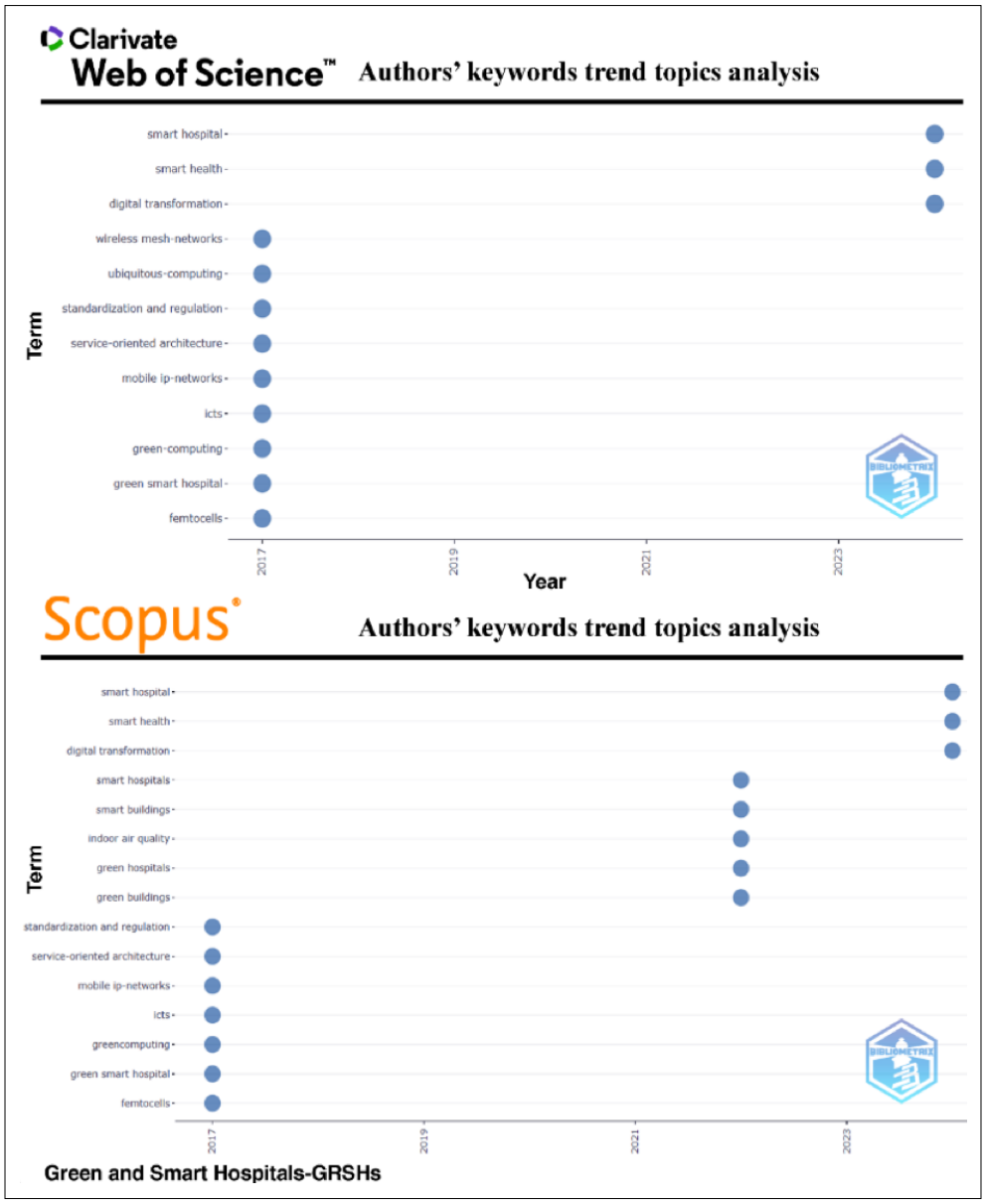


Figure 9. WoS and Scopus database authors' keywords trend topic analysis for GRSHs.

- According to GRSHs Scopus data, environmental sustainability-based topics such as "smart hospital", "digital transformation", "green hospitals", "green buildings", "indoor air quality" have been included in research.

In both databases, GRSHs studies have increasingly focused on environmental sustainability and digital health by 2023, indicating a strengthening trend toward interdisciplinary research within the field.

The bibliometric analyses conducted in the second phase of the study were addressed not only quantitatively but also qualitatively, and their contributions to the literature were evaluated. Two publications from the WoS database and three publications from the Scopus database were examined using the keywords "green hospital" and "smart hospital" in relation to RQ3. Two of the publications found in the WoS database also appear in the Scopus database, while the third Scopus entry is a book chapter.

Spyropoulos et al. (2017), Toward the Data-Driven "Smart" And "Green" Hospital-Care focused on the use of information and communication technologies (ICTs) in smart and green hospitals. It was predicted that hospitals are complex and high-cost structures and energy, and resource efficiency can be achieved with ICTs. Although not directly related to architectural design, the study shows how digital systems can serve green hospital goals at the implementation level (Spyropoulos et al., 2017).

Ozdemir & Tuna Taygun (2022), Green and Smart

Hospitals: A Review in the Context of Indoor Air Quality examined indoor air quality (IAQ) in green and smart hospital buildings. The study questioned the integration of smart building technologies with green technologies and how they support them in the context of HVAC. The architectural dimension was addressed at a conceptual level, implementation and design were not detailed. The study offers a perspective on the integration of smart technologies with green hospital buildings in the context of indoor air quality, which is a common principle for both approaches (Ozdemir & Tuna Taygun, 2022).

Anthopoulos et al. (2024), Defining the "Smart Hospital": A Literature Review is conducted to define the concept of a smart hospital, examine its historical development, and provide features that differentiate it from other hospital designs (green, hybrid, and agile hospitals). The study emphasizes the role of new generation technologies such as big data, artificial intelligence, the internet of things (IoT), cloud computing, and 5G in increasing the efficiency and quality of healthcare services. The conceptually strong study clearly reveals the basic features that distinguish the smart hospital concept from other models, and it provides a theoretical basis for smart hospitals (Anthopoulos et al., 2024).

All three studies above address the concepts of green and smart hospitals from important perspectives, but architectural design and spatial decision processes are limited or indirectly included (Table 3). In this context, architecture-based, holistic and application-oriented approaches are needed.

As a result, according to the literature research, analysis and findings it is concluded that

- Studies have gained importance and increased especially after Covid-19 pandemic,
- Existing studies largely address the issues of green building, smart building, green hospital, smart hospital and are numerous,
- The common goal in almost every study is to ensure economic-social-environmental sustainability,
- The concepts of smart hospital, green and smart building, green and smart hospital have not been examined in depth in the context of architectural design or there is no design method,
- In existing studies on green and smart hospital, technological components such as IoT, Radio Frequency Identification-RFID, computing, e-health are mainly addressed and the technological side is more dominant, however the relationship with architectural design has not been examined,
- The conceptual framework of the studies is presented rather than technical or practical aspects,
- In studies on smart hospitals and green and smart hospitals, electronic infrastructure and software systems are prioritized rather than architectural design.

CONCLUSION AND PROPOSAL

The analyses and mapping results revealed that, for GHs, SHs, and GRSHs, the most frequently recurring keywords are predominantly associated with sustainability and its environmental, social, and economic dimensions. These keywords-such as energy efficiency, renewable energy, smart energy management, water management, waste management, indoor environmental quality, lighting control, natural ventilation, thermal comfort, patient comfort, staff comfort, resource optimization, green materials, certification compliance, etc.-are found to be closely related to the most frequent terms, concepts, and thematic topics identified in the literature.

The study analysed the concept of green and smart buildings in hospital architecture through bibliometric analysis of 1178 publications using VOSviewer and Bibliometrix. The results revealed that the most frequent keywords for GHs, SHs, and GRSHs-such as energy efficiency, renewable

Table 3. Comparative analysis of selected studies

Study	Design Criteria	Evaluation Tools	Architectural Literature	Interdisciplinary Literature
Spyropoulos et al. (2017), Toward The Data-Driven "Smart" and "Green" Hospital-Car	◑	●	○	●
Ozdemir and Tuna Taygun (2022), Green and Smart Hospitals: A Review in the Context of Indoor Air Quality	●	◑	◑	◑
Anthopoulos et al. (2024), Defining the "Smart Hospital": A Literature Review	◑	◑	○	◑
Legend				

● Criteria Met; ◑ Criteria Partially Met; ○ Criteria Not Met.

energy, indoor environmental quality, thermal comfort, and resource optimization-are clustered under sustainability and its environmental, social, and economic dimensions. These parameters are largely common to both GHs and SHs (Figure 10). Thus, integrating green and smart hospital approaches can guide designers toward a unified design framework and simplify decision-making processes.

When the design of hospital buildings is examined through the lens of green and smart technologies, it becomes clear that the concepts of "green hospital" and "smart hospital" are both well-defined in the literature, with overlapping design components largely aligned with shared sustainability goals. However, the extent of this overlap, the depth of its treatment in the literature, and the existence of a scientific gap formed the foundation of the research problem. To investigate these issues, a bibliometric analysis was employed. The results supported the study's initial assumptions by demonstrating substantial convergence between the design components of green and smart hospitals. However, the analyses also confirmed that studies addressing these two approaches in an integrated manner-both theoretically and practically-are significantly limited. In this respect, the research problem highlighted the necessity of a bibliometric analysis; the results of which reinforced the study's purpose and provided a foundation for the development of the proposed integrated design model.

The analysis indicates that research on Green and Smart Hospitals (GRSHs) remains limited. Although the data reviewed spanned from August 2024 to February 2025, little advancement was identified in the integrated design of green and smart hospital buildings. While the quantity of research is not a direct indicator of necessity, the goal here is not to count publications, but rather to understand how these hospital typologies are addressed—individually and collectively—and what contributions they make to architectural discourse. The findings suggest that despite the shared goals between green and smart hospitals, existing studies are both quantitatively insufficient and thematically fragmented, reinforcing the need for integration. Although many shared design principles exist for green and smart hospitals, a standard definition, method, tool, or guideline that brings these two approaches together has not yet been established in the literature. While both concepts exist independently, how they should be interpreted and applied by designers remains uncertain. In response to this, the study proposes an integrated "Green'S'Mart Hospital Model," developed through comparative network analyses of GHs, SHs, and GRSHs, structured around their common goals and shared components.

The model consists of following four steps (Figure 11):

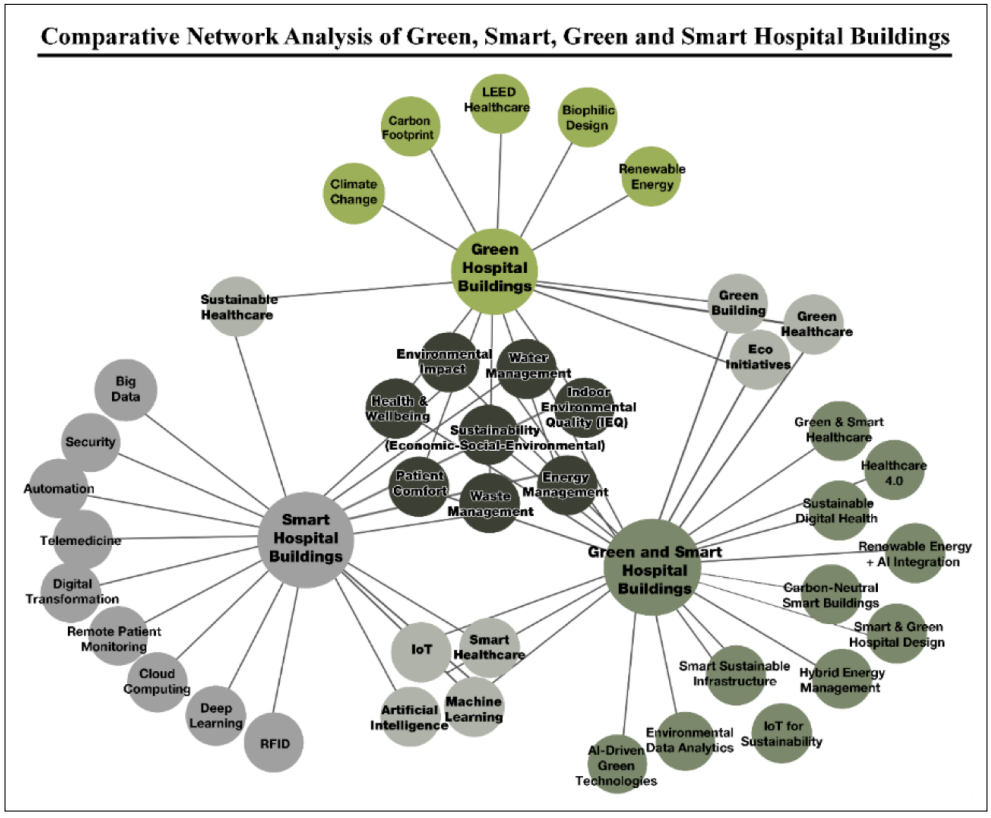


Figure 10. Comparative network analysis of GHs, SHs, GRSHs (Figure prepared by the Authors).

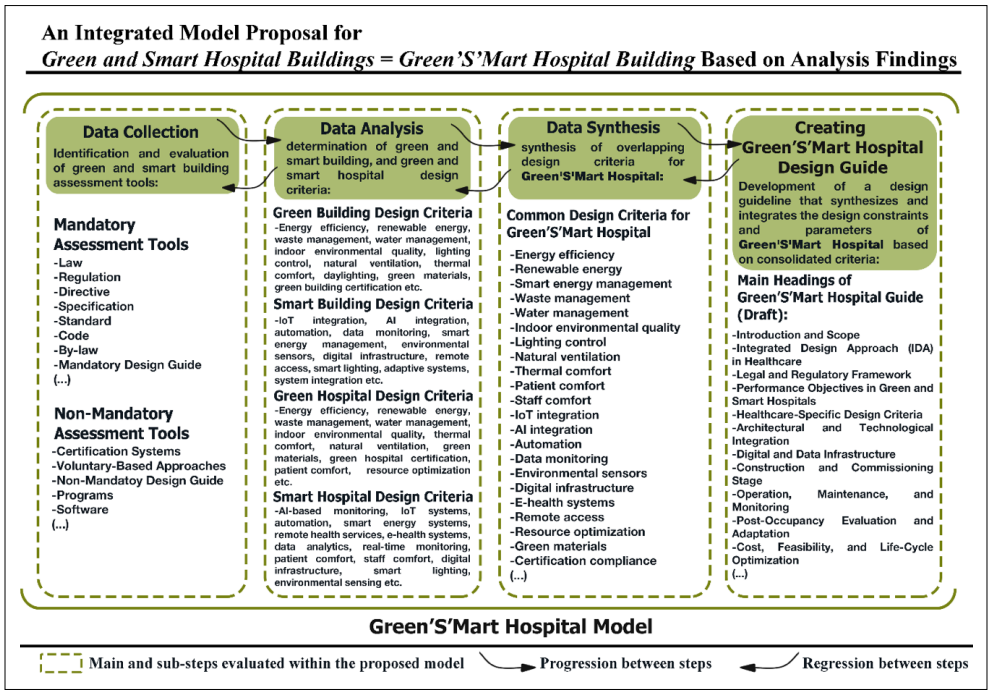


Figure 11. Green'S'Mart hospital proposed model based on the findings comparative network analysis GHs, SHs, GRSHs (Figure prepared by the Authors).

- **Data Collection:** Determination of current green and smart building assessment tools from the resource pool obtained during the literature research,
- **Data Analysis:** Analysis of the criteria in the collected green and smart building tools,
- **Data Synthesis:** Synthesizing the analysed green and smart building main and sub-criteria,
- **Design Guide:** Creation of a design guide that includes the criteria, constraints and requirements of green and smart hospital buildings based on overlapped common criteria of green and smart hospital building.

The main and sub-steps of the model are addressed within the scope of the PhD thesis supported by the Yildiz Technical University Scientific Research Project Coordination Graduate Thesis Project.

In architectural research, where sustainability and technology intersect, new questions will generate new methods. This study aimed to explore the intersection of sustainability and smart technologies in hospital architecture and to identify their shared design criteria. It contributes to the field by mapping the scientific landscape through bibliometric analyses and uncovering the fragmented nature of integrated approaches. Through the comparative network analysis of GHs, SHs, and GRSHs, the study proposes the Green'S'Mart Hospital Model as a conceptual framework to unify sustainable and smart design strategies. Future research may test and refine the model through real-world implementations, performance assessments, and interdisciplinary collaborations. Expanding the model with user-centred data, environmental metrics, and policy frameworks may further enhance its practical relevance and applicability across various healthcare design contexts.

ETHICS: There are no ethical issues with the publication of this manuscript.

PEER-REVIEW: Externally peer-reviewed.

CONFLICT OF INTEREST: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Article

Energy retrofitting of modern heritage in accordance with passive building standard: The case of Yenişehir Cinema

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ABSTRACT

Improving the energy performance of existing buildings is crucial for reducing energy demand and transitioning towards renewable energy sources in the building sector. The **Passive Building Standard** serves as a valuable guide by providing a set of strategies for achieving high energy efficiency. **Yenişehir Cinema**, an important modern heritage building, has remained vacant for nearly 12 years. Given its cultural and historical significance, integrating it back into urban life through energy-efficient retrofitting can contribute to urban sustainability.
This study aims to enhance the energy performance of Yenişehir Cinema by transforming it into a **passive building**. The proposed retrofitting strategy involves implementing a **heat recovery ventilation system, improving the building envelope, and mitigating overheating**. The energy performance of both the baseline and retrofitted scenarios was assessed using **energy models developed in Design Builder**.
The results indicate a **92% reduction in annual heating demand** and a **41.3% decrease in total carbon emissions** compared to the baseline scenario. Furthermore, the additional investment costs required for the proposed improvements can be recouped within **seven years**. However, while the overheating in the building was reduced by **40%,** this improvement remains insufficient to fully ensure **thermal comfort**.

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INTRODUCTION

The construction sector accounts for 36% of global energy consumption and 39% of carbon emissions resulting from energy use (Global Alliance for Buildings and Construction, 2020). Given this impact, the widespread adoption of passive and hybrid systems and their climate-specific optimization are among the key long-term global objectives (Global Alliance for Buildings and Construction, 2020). To reduce the dependence on fossil fuels and minimize carbon emissions, both existing and newly constructed buildings must be designed with high energy efficiency (Sharma et al., 2022). In Europe, 48% of existing buildings were constructed between 1961 and 1990 (Volf et al., 2018), highlighting the urgency of retrofitting older buildings to align with current climate conditions and the growing scarcity of resources.

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Reducing the energy demands of existing buildings should be achieved while maintaining occupant health and comfort (Ruparathna et al., 2016). Passive buildings are designed to have minimal energy demand for heating, yet they still provide high indoor comfort levels (Mihai et al., 2017). The EnerPHit certification system, which allows existing buildings to be upgraded to Passive Building Standard, significantly reduces their heating and cooling loads (Passive House Institute, 2023).

Extensive research has been conducted on the energy retrofitting of existing buildings. A study conducted in China applied Passive Building Standard principles by insulating the building envelope, ensuring airtightness, and integrating a high-efficiency heat recovery mechanical ventilation system. As a result, heating demand was reduced by 90% and cooling demand by 70% compared to the baseline scenario (Liu et al., 2021). Similarly, a study in Sweden demonstrated that carbon emissions could be reduced by 50% to 82% through the use of various insulation materials, facade enhancements, and window improvements (Piccardo et al., 2020). In the UK, a year-long study comparing a conventional house and a passive house found a 62.2% reduction in energy consumption and a 24% improvement in indoor temperatures. Numerical modeling further indicated that heating demand could be reduced by 80% in existing buildings through energy-efficient renovations (Liang et al., 2017).

Retrofitting historical buildings in accordance with Passive Building Standard is also critical for preserving cultural heritage while ensuring energy efficiency. A study on a historic building in Egypt found that thermal comfort levels could be increased to 66% through the implementation of hybrid passive strategies (Ibrahim et al., 2021). Similarly, a 19th-century historic building retrofitted using three passive building strategies achieved a 51.8% reduction in primary energy demand. The payback period for the implemented interventions was estimated at 18 years (Qu et al., 2021).

Türkiye, which remains heavily dependent on foreign energy resources, aims to reduce its primary energy consumption by 14% between 2017 and 2023 in accordance with the National Energy Efficiency Action Plan (Republic of Turkey Ministry of Energy and Natural Resources, 2023). The average energy consumption for heating in buildings across Türkiye is 110 kWh/m² (Allplan GmbH, 2013), whereas maximum permissible heating demand values in other countries are significantly lower: 35 kWh/m² in the UK, 34 kWh/m² in the Netherlands, and 23 kWh/m² in Denmark (Allplan GmbH, 2013). This substantial difference highlights the urgent need for stricter energy efficiency regulations and more effective enforcement mechanisms in Türkiye.

Despite the increasing emphasis on energy efficiency, a lack of legal coordination and institutional collaboration between organizations responsible for heritage protection and energy efficiency poses a significant challenge (Jahed et al., 2020).

Several studies have explored energy retrofitting strategies for historic buildings in Türkiye. Ulu & Arsan (2020) examined 22 buildings in the historic urban fabric of İzmir, demonstrating that proposed retrofit strategies could achieve up to 48% energy savings. Similarly, Timur et al. (2022) analyzed two traditional houses in Muğla, evaluating interventions such as HVAC system optimization, thermal insulation, buffer zone integration, double-glazed windows, and airtightness improvements. Their findings indicated that these measures, when applied together, could reduce annual energy consumption by up to 30%.

Since historical buildings require careful intervention to preserve their architectural integrity and cultural value, energy retrofitting must be approached with sensitivity. Ozbalta et al. (2021) assessed multiple active and passive energy efficiency scenarios for a historic building in İzmir. Their results showed that the optimal energy retrofit combination required 34% less energy compared to other alternatives.

Previous research has demonstrated that implementing Passive Building Standard in existing buildings leads to substantial reductions in energy consumption and carbon emissions, particularly in heating and cooling loads (Liu et al., 2021; Liang et al., 2017; Piccardo et al., 2020). The benefits of Passive Building Standard have also been observed in historic buildings, particularly in terms of energy savings and thermal comfort improvements (Ibrahim et al., 2021; Qu et al., 2021). Most energy retrofitting studies have focused on historical buildings in the Aegean region, primarily examining annual energy savings when passive and hybrid systems are integrated (Ulu & Arsan, 2020; Timur et al., 2022; Ozbalta et al., 2021). However, the complex interrelated parameters that influence overall energy performance are often overlooked.

The novelty of this study lies in its comprehensive approach, which simultaneously considers energy efficiency, carbon emissions, thermal comfort, and cost-effectiveness. The primary objective of this research is to retrofit Yenişehir Cinema—an example of modern cultural heritage—following Passive Building Standard. The target audience includes industry stakeholders, passive building practitioners, Kardemir Steel Industry Inc. (the entity holding the building's usage rights), and academics interested in energy-efficient retrofitting strategies.

MATERIAL AND METHODOLOGY

This section outlines the case study, and details the methodology applied in this research. The validation of the 3D model, software, and climate data is conducted. Following this validation, decisions regarding the energy model for the operational phase are presented. Finally, the databases and methodologies used for thermal comfort, cost analysis, and environmental impact assessment are described.

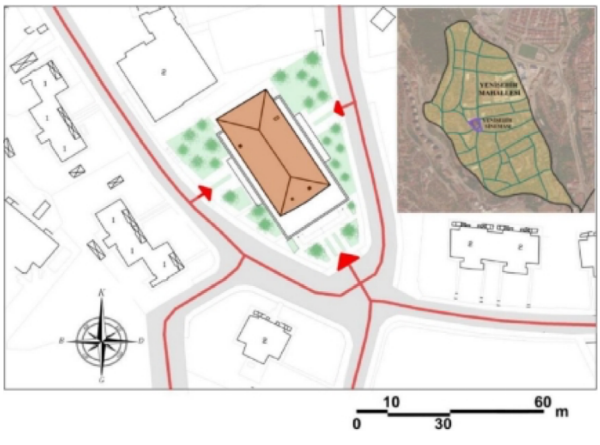


Figure 1. Master plan of Yenişehir Cinema Building (Güneş, 2017).

Case Study

The primary subject of this study is Yenişehir Cinema, located in Karabük Province, Türkiye. The building is situated in the Yenişehir Neighborhood, within an urban conservation area and a third-degree natural conservation zone. Although it was actively used as a cultural center for a period, the building itself is not officially registered as a heritage structure.

The cinema building covers a total area of 1,500 m², with three open facades and additional facilities at the rear. The net area of the building is 1,350 m², and it has a seating capacity of 750. Additionally, registered pine trees are present in the garden surrounding the cinema.

Architecturally, Yenişehir Cinema was designed by Supreme Architect Münci Tangör, a prominent figure of the Early Republican Period in Türkiye. The construction of the building took place between 1954 and 1958 (Güneş, 2017; Ulusoy, 2022).

Historically, the cinema was among the most popular and well-attended theaters in Türkiye between 1958 and 1990. Between 2008 and 2013, it continued functioning as a cultural center. However, since 2013, the building has remained closed and out of use. In 2017, restoration drawings were initiated, but the project was never implemented (Güneş, 2017). The site plan of the building is presented in Figure 1.

The historic Yenişehir Cinema, which once attracted significant public interest, has remained vacant for nearly twelve years. Yalçınkaya & Bal (2019) highlight the importance of reintegrating Yenişehir Cinema into urban life while preserving its cultural and historical significance to support urban sustainability. Similarly, Güneş (2017) emphasizes that maintaining the building's original function is essential for ensuring both social and spatial sustainability. The exterior and interior views of the building are presented in Figure 2.

Figure 2. **(a)** South facade, **(b)** East facade, **(c)** Registered trees, **(d)** Cement-based material (Authors' Archive), **(e, f)** Interiors (Güneş, 2017).

The outer walls of the building are constructed using concrete blocks. The roof structure consists of both hipped and flat sections, covered with tiles and ceramic tiles, respectively. The building system is reinforced concrete. For flooring, vinyl material is used, while most of the windows in their current state feature double glazing. The main exterior door is made of wood, contributing to the building's architectural character. The thermal properties of the existing materials are detailed in Table 1.

Methodology

The Passive Building Standard is based on five fundamental principles, which include:

1. High-level insulation (Ud<0.15 W/m²K)
2. High-performance, insulated window and door systems (Up<0.8 W/m²K)
3. Airtight building envelope (<0.6 /h @50 Pa)
4. Architectural detailing to eliminate thermal bridges
5. High-efficiency, heat recovery mechanical ventilation system (Sustainable Energy Association, n.d.).

Additionally, to comply with the Passive Building Standard, a building's annual heating and cooling demand must not exceed 15 kWh/m², and its primary energy demand should remain below 120 kWh/m². From a thermal comfort perspective, indoor temperatures must not exceed 25°C for more than 10% of the total annual hours (International Passive House Association, 2018). However, existing buildings may not fully meet these strict criteria, necessitating the development of the EnerPHit certification system, which provides two alternative compliance pathways. Meeting either of these criteria is sufficient for certification.

The first pathway focuses on building component performance, ensuring that all structural elements adhere to Passive Building Standard. The second pathway is based on energy demand, where the maximum heating load is set at 25 kWh/m² for cool-temperate climates, while the cooling demand limit remains at 15 kWh/m².

The energy demand-based approach further categorizes buildings into three classes: Classic, Plus, and Premium, based on their energy performance (Passive House Institute, 2023). In this study, the EnerPHit Standard was applied using energy demand-based criteria.

Following the Passive Building Standard, the energy retrofit process included:

- Installation of a heat recovery mechanical ventilation and heating-cooling system
- Insulation and airtight sealing of the building envelope
- Upgrading window and door systems.

Firstly, the existing building model was generated and validated. Once the climate data and building model is checked, baseline energy model is adjusted with decisions made in advance. Thereafter, energy retrofits were applied in sequence. According to the simulation results, the overheating was determined and the thermal comfort requirements were evaluated according to the (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ASHRAE-14 Standard. At the conclusion of the study, economic and environmental analyses were conducted. Finally, the results were discussed on the axis of sustainable architecture (Figure 3).

As for the limitations of the study, the side and rear facades of the building are covered with rough plaster, while the entrance facade features mosaic coatings, which enhance

Table 1. Material properties of the existing structure

Building component	Material	Thickness (m)	Thermal conductivity (W/mK)	Specific heat (J/kg-K)	Density (kg/m³)	U value (W/m²K)
Wall	Plaster	0.02	0.4	1000	1000	1.88
	Concrete block	0.3	1.15	1000	1800	
	Plaster	0.02	0.4	1000	1000	
Hipped roof	Roof tile	0.025	1	800	2000	3.71
	RC	0.12	1.15	1000	1800	
Flat roof	Ceramic tile	0.018	0.85	840	1900	3.76
	RC	0.12	1.15	1000	1800	
Floor	Vinyl flooring	0.002	0.2	1000	1000	3.08
	RC	0.12	1.15	1000	1800	
Window	Double glazing	-	-	-	-	2.71
Door	Wooden					2.80

RC: Reinforced concrete.

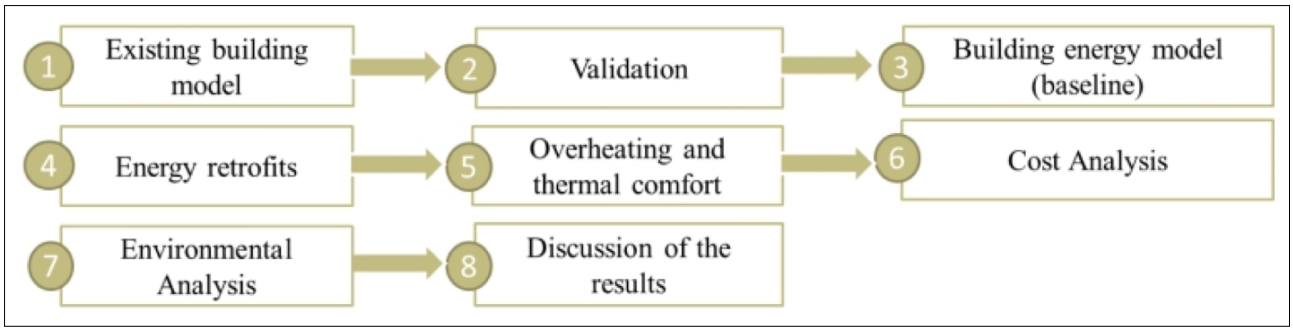


Figure 3. Methodology of the study.

its aesthetic quality. Consequently, any proposed external insulation measures would primarily impact the entrance (south) facade. However, this adjustment is beyond the scope of this study. Nonetheless, it is anticipated that the overall exterior appearance of the building will remain unaffected by the other proposed energy efficiency improvements.

Databases and Methodologies for Validation

Based on the collected data—including architectural plans, photographs, and information on building materials—a digital model of the structure was developed, and energy simulations were conducted using Design Builder v6.1 software. To ensure accurate climatic inputs, annual climate data for Karabük province was obtained from NASA's Prediction of Worldwide Energy Resources (POWER) Data Access Viewer (DAV) v.2.4.9 (NASA, n.d.).

To validate the accuracy of the simulations, real-time temperature measurements were collected using an RC-51H device, recording data at 1-hour intervals from January 3 to January 7, 2023. Due to the deteriorated state of the building, where windows are broken, measurements were limited to a single room that was as isolated as possible from external environmental influences. The selected room has no direct windows facing the outside, ensuring that the recorded indoor climate data closely represents the building's actual indoor conditions.

The ASHRAE Guideline 14 was utilized to validate the energy model, ensuring its accuracy in representing the building's actual thermal performance. Two widely used statistical methods, Mean Bias Error (MBE) and Coefficient of Variation of the Root Mean Square Error (CV(RMSE)), were employed to minimize discrepancies between the energy model predictions and the real indoor environment (Yılmaz & Oral, 2019; Guo et al., 2021; Li et al., 2021).

To validate the model, temperature measurements obtained from the indoor space were compared with corresponding simulated data generated by the energy model. Based on this comparative analysis, error margins were determined using the following equations:

$$MBE(\%) = \frac{\sum_{i=1}^{n}(Mi-Si)}{\sum_{i=1}^{n}(Mi)} \times 100 \quad (1)$$

where MBE represents "Mean Bias Error", n denotes the number of the data, Mi stands for the measured data, and Si indicates simulation results.

$$\mathrm{CV(RMSE)}(\%) = \frac{\sqrt{\sum_{i=1}^{n}\left(\frac{(Mi-Si)^2}{n}\right)}}{M} \times 100 \quad (2)$$

where CV(RMSE) stands for "Coefficient of Variation of the Root Mean Square Error", M denotes the mean value of the collected data in the field.

According to ASHRAE Guideline 14, for an energy model calibrated with hourly data, the margin of error between real-time measurements and energy simulations should not exceed 10% for Mean Bias Error (MBE) and 30% for Coefficient of Variation of the Root Mean Square Error (CV(RMSE)). In this study, the number of data points (n) was set to 24, corresponding to the number of hours in a day, with measurements recorded hourly.

Baseline and Retrofitted Energy Models

In the energy simulations, the baseline case was evaluated under the assumption that the building is still in use. However, since the building has been vacant for an extended period, the occupancy rate, as well as the heating and cooling setback temperatures, were determined based on assumptions.

The basement floor was excluded from the energy simulations, as such areas are typically unheated spaces (Dascalaki et al., 2011). The building's operational hours were assumed to be 08.00 am–10.00 pm, every day. The window-to-wall ratio was calculated as 5%, and some of the trees on the southwest side of the building, which are officially registered, were modeled as shading elements, as they are located along the sun-exposed facade.

Primary energy demand accounts for the total energy consumption associated with room electricity, lighting, heating, cooling, ventilation, and hot water. Historical records indicate that the building was previously heated with solid fuel and naturally ventilated during its period of use.

The baseline energy model represents the closest approximation of the building's original state when it was operational. The assumptions for both the baseline and retrofitted energy models are provided in Table 2. The building is heated and cooled with a variable refrigerant flow system with heat recovery (VRF-HR) in the retrofitted case. A VRF-HR system recovers heat from cooling zones and transfers it to heating zones, enabling simultaneous heating and cooling (Zhang et al., 2018). Additionally, a 3D model image generated in Design Builder is presented in Figure 4.

Thermal Comfort Criteria

In addition to the Passive Building Standard, the thermal conditions of the building after energy retrofits were assessed using the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) methods. These methods are designed to predict thermal comfort under steady conditions and are based on a 7-point Likert scale (Cheung et al., 2019).

For the calculations, the thermal comfort tool developed by Berkeley University, which is based on ASHRAE 55 Standard, was used (Center for the Built Environment, n.d.). According to this methodology:

Table 2. Baseline and retrofitted energy model decisions

Parameters	Baseline	Retrofitted
Heating period	October-March	October-March
Heating temperature - set back	20 ºC-12 ºC	20 ºC-12 ºC
Heating system	Boiler and radiators	VRF-HR
Total efficiency	-	70%
Cooling period	-	June-August
Cooling temperature - set back	-	23ºC-28ºC
Cooling system	-	VRF-HR
Ventilation system	Natural	Mechanical with HR
Occupancy rate	08.00 am-10.00 pm	08.00 am-10.00 pm
Infiltration rate (ac/h)	0.7	0.59

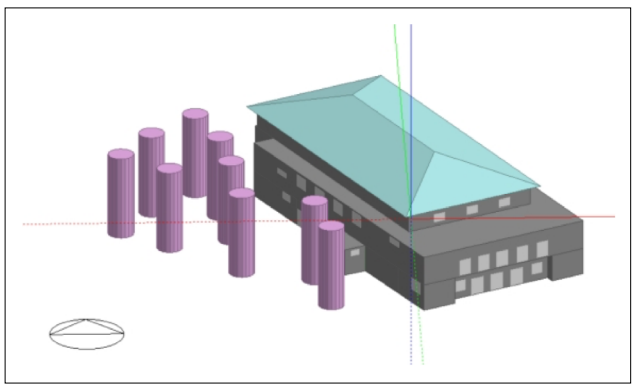


Figure 4. 3D model of the building from Design Builder.

- The clothing insulation value (clo) was set to 1.0 clo for typical winter indoor clothing and 0.5 clo for summer indoor clothing, based on operative temperatures. The metabolic rate was taken as 1 met, assuming occupants are seated quietly while watching a movie. Operative temperature and relative humidity values were determined using standard deviation and mean values, ensuring that two-thirds of the data falls within one standard deviation of the mean. Air speed was assumed to be 0.1 m/s.

Calculation of Economic Savings

At the conclusion of the study, the total costs of all energy improvement measures were calculated to evaluate the economic feasibility of the proposed interventions. This analysis aimed to determine whether the costs associated with the retrofits could be recouped within the building's remaining service life.

The unit prices for key energy efficiency components—including the VRF-HR, rockwool insulation, and low-emissivity (low-E) triple glazing system with argon filling—are detailed in Table 3. Notably, for the VRF-HR system, pricing was obtained on a per-project basis. The cost of insulating the exterior door was excluded from the calculations, as it was considered negligible in comparison to other retrofit measures. The post-retrofit service life of the building was estimated at 30 years, and the electricity tariff (kWh/₺) used in the economic analysis was sourced from the Energy Agency (n.d.). To estimate the payback period of the initial investment costs, the annual energy savings and cumulative cost recovery over time were analyzed, taking into account that electricity tariffs for the public sector in Türkiye increase by 30% annually as indicated by Energy Market Regulatory Authority (*Enerji Piyasası Düzenleme Kurumu, EPDK*) in 2024 (Dünya, 2023).

Database for Environmental Analysis

A comprehensive environmental analysis requires the assessment of both operational and embodied carbon emissions. The energy retrofits considered in this study include mechanical systems with heat recovery, insulation, and argon-filled triple-glazing window systems.

Table 3. Unit costs of proposed applications

Senarios	Unit	Unit price	Source
VRF	Per project	€200,000	Personal communication, July 24, 2024
Insulation	1 m² 1 cm	€0.6 + %18 VAT	Koca, 2023
Window	1 m²	1459.15 ₺ + 18% VAT	Yaşasan, 2024
Argon gas	1 m²	45 ₺ + 18% VAT	Yaşasan, 2024

VAT: Value added tax.

The embodied carbon of conventional buildings typically accounts for less than 20% of the total life cycle carbon (LCC). However, in low-energy buildings, embodied carbon can constitute up to 80% of the LCC (Akbarnezhad & Xiao, 2017). Given this disparity, it is crucial to evaluate both operational and embodied carbon emissions simultaneously to obtain a holistic understanding of environmental impact.

The system boundary for this study is defined as the production stage (A1–A3), while the impact category under investigation is total global warming potential (GWP-total) for embodied carbon calculations. GWP quantifies the amount of heat trapped in the atmosphere by a greenhouse gas relative to CO_2, meaning that a higher GWP indicates a stronger warming effect (U.S. Environmental Protection Agency, n.d.). GWP-total is also recognized as one of the seven key environmental impact categories outlined in the EN 15804+A2 Standard (Hill et al., 2018).

To obtain accurate embodied carbon data, this study utilizes the Environmental Product Declaration (EPD) of the selected materials, as detailed in Table 4.

The energy consumed during the operation phase of traditional buildings accounts for approximately 90% of their total energy consumption (Koç et al., 2022). To calculate operational carbon emissions, the electricity consumption point emission factors specified by the Ministry of Energy and Natural Resources were used (Republic of Turkey Ministry of Energy and Natural Resources, n.d.).

According to official data, 1 MWh of electricity consumption corresponds to approximately 0.445 tons of CO_2e. Since electrical energy is used for heating, cooling, ventilation, and all other operational activities within the building after energy retrofits, carbon emission calculations were conducted and compared for both the initial (pre-retrofit) and final (post-retrofit) states. For the environmental analysis, the service life of the building was assumed to be 30 years.

FINDINGS AND DISCUSSION

This section covers the validation and analyzes the material properties and operational energy consumption of the baseline case, followed by the energy simulation of the reference model. Energy savings are calculated based on the reference model, assessing the feasibility of retrofitting the existing building.

Additionally, a comprehensive evaluation is conducted covering energy savings, overheating and thermal comfort, environmental impact, and cost analysis of the proposed interventions. The results are subsequently discussed in detail.

Validation of the Energy Model

The error margins obtained from the measured and simulated indoor temperature data were compared with the acceptable limit values defined in ASHRAE Guideline 14-2002.

For the climate and building energy model validation, the Mean Bias Error (MBE) was found to be in the range of -6.95% to -10.01%, while the Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) ranged from 11.85% to 23.80% (Figure 5).

Since these values remained within the acceptable thresholds specified by ASHRAE Guideline 14, the building energy model was deemed reliable. Consequently, a comparative analysis of annual energy consumption, carbon emissions,

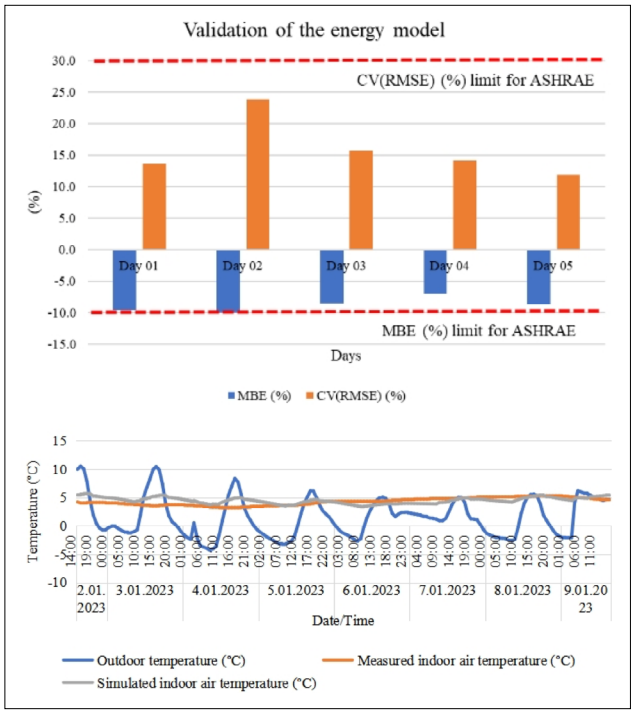


Figure 5. Validation of the building energy model (above), real-time measurements and simulation results for the indoor temperatures (below).

Table 4. Unit embodied carbon values (A1-A3) of the energy retrofits

Material/System	Unit	Embodied Carbon (kg CO_2-e)	Source
VRF-HR units	1 product	5.43E+02	Daikin, 2024
Rock wool (0.037W/mK, 60 mm, 33 kg/m^3)	1 m^2	2.62E+00	Knauf, 2021
Triple glass unit (4-12-4-12-4)	1 m^2	4.80E+01	Environdec, 2023

costs, and thermal comfort criteria was conducted for both the baseline and retrofitted scenarios, considering the in-use condition of the building.

Energy Simulations

Energy simulations were conducted based on the assumptions used to generate the building energy models. The results indicate that the heating load of the baseline energy model is 90.7 kWh/m²/year. To achieve Passive Building Standard compliance, an 83.4% reduction in heating load is required. Additionally, the primary energy demand is 163.1 kWh/m²/year, necessitating a 26.4% reduction to meet passive building criteria.

Thermal comfort analysis shows that the average indoor temperature exceeds 25°C for 17.6% of the year, while operative temperatures surpass 25°C for 16.4% of the year. According to the Passive Building Standard, these values should be reduced to below 10% to mitigate overheating risks.

The first stage of energy retrofitting involved the integration of energy-efficient HVAC units. Heating and cooling were provided using a heat recovery air conditioning unit, specifically a VRF-HR system.

As a result of this HVAC intervention:

- The heating load decreased to 58.3 kWh/m²/year, representing a 35.7% reduction.
- The primary energy demand dropped to 145.4 kWh/m²/year, achieving a 10.8% reduction.

In the second stage, rock wool insulation panels were applied to the building envelope, increasing its thermal inertia (Table 5). The thicknesses of the insulation layers were determined to ensure that the thermal transmittance of building components remains below 15 W/m²K, as required by the Passive Building Standard.

Furthermore, it was assumed that the airtightness of the structure improved, with air leakage decreasing to 0.59 air changes per hour (ac/h) following the addition of insulation layers.

As a result of the energy simulation, the heating load decreased by 87%, reaching 7.2 kWh/m²/year. Additionally, the primary energy demand was reduced by 36.1%, falling to 94.3 kWh/m²/year. These improvements successfully met the Passive Building Standard requirements for heating and primary energy demand. However, the addition of the insulation layer resulted in a 10.8% increase in cooling load.

In the third stage of the energy retrofit, windows and doors were upgraded to enhance thermal performance. The thermal transmittance (U-value) of the windows was reduced from 2.71 W/m²K to 0.78 W/m²K by installing argon-filled triple glazing. Additionally, insulation was applied to the doors, which are made of painted oak wood, reducing their U-value to 0.56 W/m²K. In addition to enhancing the window glazing, 1-meter-long shading elements made of moderately reflective metal slats were installed inside the windows. In-glass blinds were programmed to remain open during summer (June–August) to optimize thermal performance.

According to the simulation results, the heating load remained unchanged compared to the baseline case, while the cooling load decreased by 13.4%, reaching 14.1 kWh/m²/year. A 2.3% reduction in primary energy demand was achieved, resulting in an energy consumption of 92.1 kWh/m²/year.

Table 5. Improving the thermal performance of the building envelope with insulation

	Material	Thickness (m)	Thermal conductivity (W/mK)	Specific heat (J/kg-K)	Density (kg/m³)	U value (W/m²K)
Wall	Plaster	0.02	0.4	1000	1000	0.143
	Rock wool	0.24	0.037	840	33	
	Concrete block	0.30	1.15	1000	1800	
	Plaster	0.02	0.4	1000	1000	
Hipped roof	Roof tile	0.025	1	800	2000	0.148
	Rock wool	0.24	0.037	840	33	
	RC	0.12	1.15	1000	1800	
Flat roof	Ceramic tile	0.018	0.85	840	1900	0.148
	Rock wool	0.24	0.037	840	33	
	RC	0.12	1.15	1000	1800	
Floor	Screed	0.05	1.4	650	2100	0.146
	Rock wool	0.24	0.037	840	33	
	RC	0.12	1.15	1000	1800	

After implementing all energy retrofits, the study determined that a 92% reduction in heating load was achieved, while cooling load and primary energy demand fully complied with Passive Building Standard requirements. VRF-HR system contributed to a 35.7% reduction in heating load, while insulation and airtightness accounted for 88.3% of the total heating reduction. However, window retrofits had no significant impact on heating demand due to the low window-to-wall ratio.

Regarding cooling load, the impact of the VRF-HR system could not be determined, as the building did not previously have a cooling system. Floor, wall, and roof insulation, along with airtightness improvements, caused a 10.8% increase in cooling demand, while window retrofits played a 13.5% role in cooling demand reduction.

Regarding total energy savings, the contributions of individual retrofit measures were as follows: the VRF-HR provided a 10.8% reduction in primary energy demand, insulation and airtightness contributed to a 35.1% reduction, and window improvements resulted in a 2.3% reduction. These combined efforts led to a total energy saving of 43.5% (Figure 6).

Overheating and Thermal Comfort

After the energy improvements, the operative temperature, which serves as an indicator of thermal comfort and is calculated as the arithmetic average of the radiation temperature and indoor dry-bulb temperature, was analyzed to assess overheating, a key criterion of the Passive Building Standard. According to the passive building requirements, the operative temperature should not exceed 25°C for more than 10% of the hours in a year. The results indicate that the operative temperature exceeds this threshold for 9.8% of the annual hours, demonstrating compliance with the standard. The implemented measures resulted in a 40.2% reduction in overheating hours per year (Figure 7).

Additionally, the average indoor temperature range between 19.4°C and 27.8°C, which falls within the comfort range specified by ASHRAE Standard 55-2017. The average indoor humidity remains between 40% and 60%, meeting the required comfort conditions. These findings confirm that the retrofitting measures not only improved energy efficiency but also prevented the building's overheating (Table 6).

The thermal comfort conditions were also evaluated using the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) methods, in accordance with ASHRAE 55-2023 (Center for the Built Environment, n.d.). The results confirmed that overheating alone is not a sufficient criterion for ensuring user thermal comfort. Instead, a comprehensive assessment of is necessary.

The PMV-PPD analysis revealed that only two of the datasets met the thermal comfort criteria. During the summer period, up to 87% of users are likely to experience discomfort (cool) when the operative temperature is below average (Table 7). This suggests that the current conditions may not be optimal for occupant comfort.

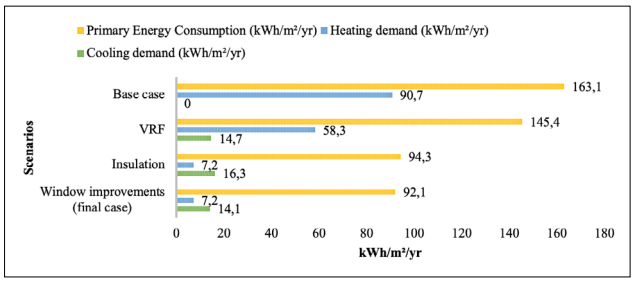


Figure 6. The effects of the improvements on the energy performance of the building.

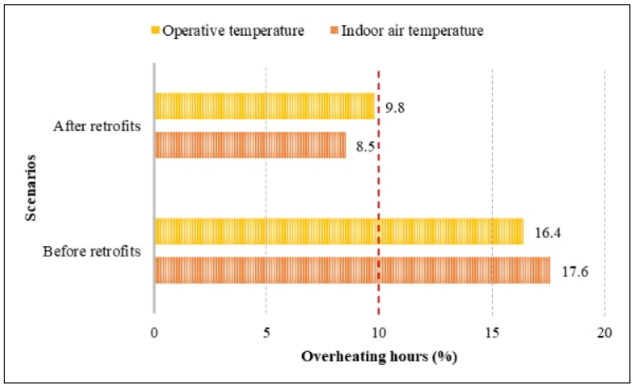


Figure 7. Overheating before and after the retrofits.

Table 6. Overheating hours of the building during the year after improvements

Overheating status	Average indoor air temperature	Operative temperature	Relative humidity	Outside dry-bulb temperature
Minimum	15.1	17.1	10.2	-9.7
Maximum	31.5	29.9	78.7	38.6
Mean	21.9±2.1	22.4±2	43.8±12.5	13±9
Hours above 25°C (uncomfortable)	741	860		
Total hours in a year	8760			
Uncomfortable hours (%)	8.5	9.8		

Table 7. Thermal comfort based on PMV/PPD method

Operative temperature (°C)	Relative humidity	Clothing level (clo)	PMV	PPD (%)	Sensation
20.4	31.1	0.5	-2.25	87	Cool
20.4	56.3	0.5	-2.09	81	Cool
20.4	31.1	1.0	-0.89	22	Slightly cool
20.4	56.3	1.0	-0.73	16	Slightly cool
24.4	31.1	0.5	-0.77	18	Slightly cool
24.4	56.3	0.5	-0.57	12	Slightly cool
24.4	31.1	1.0	0.16	6	Neutral
24.4	56.3	1.0	0.36	8	Neutral

However, adjusting the operative temperature to above average during winter conditions significantly improves thermal comfort. Under these conditions, the percentage of users experiencing discomfort is reduced to only 6-8%, ensuring that the thermal comfort threshold is met (Figure 8). These findings indicate that careful temperature regulation is necessary to maintain an optimal indoor environment throughout the year.

Cost Analysis

Following the completion of the energy retrofits, the initial investment costs and payback periods of the applied measures were calculated to evaluate their feasibility within the scope of the project. In addition, the total costs were determined by incorporating both initial investment costs and 30-year operating expenses.

For accurate cost assessment, foreign exchange transactions for Euro (€) to Turkish Lira (₺) were based on the Indicative Exchange Rates of the Central Bank of the Republic of Türkiye as of 24.07.2024 at 15:30 (Table 8). This ensures that cost evaluations reflect real-time currency values, enhancing the reliability of the economic analysis.

After calculating the costs, the annual energy savings were determined by comparing the baseline annual energy consumption with the total annual energy consumption of retrofitted case. This corresponds to a total energy saving of 142,000 kWh per year.

As a result of the calculations, it was determined that:

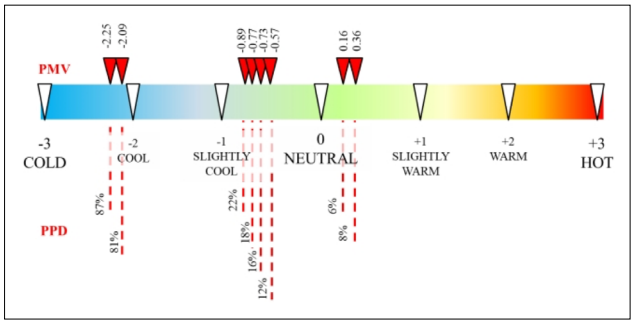


Figure 8. PMV/PPD results and thermal comfort assessment.

Table 8. Total quantity and price calculation of the applications proposed for the project

Scenarios	Total amount	Total cost
VRF-HR	20 high static pressure concealed ceiling type indoor units (ducting, copper piping and installation)	200,000 €+18% VAT =8,413,400 ₺
Insulation	3310 m^2 24 cm	47,664 €+18% VAT =2,005,062 ₺
Window (with argon gas)	50.26 m^2	73,336 ₺+18% VAT =86,536 ₺
		2,261 ₺+18% VAT =2,668 ₺
Total		10,507,666 ₺

- Window replacement costs (86,536₺) can be fully recovered within the first year.
- Insulation costs (2,005,062₺) can be covered within the first three years.
- VRF-HR costs (8,413,400₺) will be recouped within seven years.

The findings indicate that the proposed energy retrofitting measures are financially viable, with relatively short payback periods, making them a cost-effective solution for improving building energy efficiency.

Finally, the additional investment costs and 30-year operating costs were evaluated together to determine the overall economic feasibility of the proposed retrofitting measures. The annual primary energy demand in the final scenario was calculated by accounting for inflation-driven increases in energy costs and compared with the operating costs of the baseline case.

According to the results, the total initial investment and 30-year operating costs of the proposed passive building were found to be 43.4% more economical compared to the operating costs of the baseline case alone (Table 9).

Table 9. Calculation of operating and investment costs

Years (2024-2053)	Baseline	Passive building
Operational cost (₺)	12,957,131,748	7,316,688,130
Additional cost (₺)	-	10,507,666
Total cost (₺)	12,957,131,748	7,327,195,796
Saving (%)	-	43.45

These findings highlight that, despite the initial capital investment, transitioning to a Passive Building Standard yields significant long-term financial benefits, making it a cost-effective and energy-efficient solution.

Environmental Impact

Both embodied carbon emissions and operational carbon emissions were assessed to evaluate the overall environmental impact of the proposed energy retrofits. The total embodied carbon emissions resulting from the retrofits were calculated based on Environmental Product Declaration (EPD) data sheets. According to these calculations:

- VRF-HR system contributed 10,860 kg CO_2-e,
- Insulation accounted for 34,689 kg CO_2-e,
- Windows contributed 2,412 kg CO_2-e,
- Leading to a total embodied carbon footprint of 47,961 kg CO_2-e.

The total annual operational carbon emissions were calculated based on annual energy consumption. The energy-to-carbon conversion factor from the Ministry of Energy and Natural Resources (n.d.) was used, where 1 MWh of energy consumption corresponds to 0.445 tons of CO_2-e.

In the baseline case, with an annual energy consumption of 163.1 kWh/m²/year, the corresponding operational carbon emissions were 72.6 tons CO_2-e per square meter per year. After implementing the retrofits, with an annual energy consumption of 92.1 kWh/m²/year, the operational carbon emissions were reduced to 41 tons CO_2-e per square meter per year. As in the cost analysis, the operational period for environmental analysis was considered as 30 years. Over this period, the total operational greenhouse gas (GHG) emissions would have been 2,177 tons per square meter in the baseline case. After the retrofits, this value decreased to 1,230 tons per square meter. When embodied carbon emissions from the production stage (A1-A3) were included, the total emissions after retrofits amounted to 1,277 tons per square meter.

As a result, the GHG emissions from operational energy consumption were reduced by 43.5%, while the total carbon emissions decreased by 41.3% compared to the baseline scenario, demonstrating the significant environmental benefits of the energy-efficient retrofits (Figure 9).

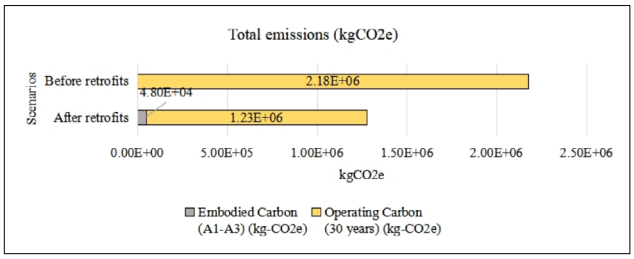


Figure 9. Environmental impact of the energy retrofits.

Assessment of the Results

This study aimed to promote sustainability in the architectural domain by retrofitting Yenişehir Cinema in accordance with Passive Building Standard requirements. Additionally, the project envisions reintegrating Yenişehir Cinema into urban life as a passive building, ensuring both economic and environmental sustainability. Economic sustainability is achieved through applicable energy-efficient solutions, while environmental sustainability is targeted by reducing the building's carbon footprint. To accomplish these goals, passive building strategies were systematically implemented, fulfilling all required conditions.

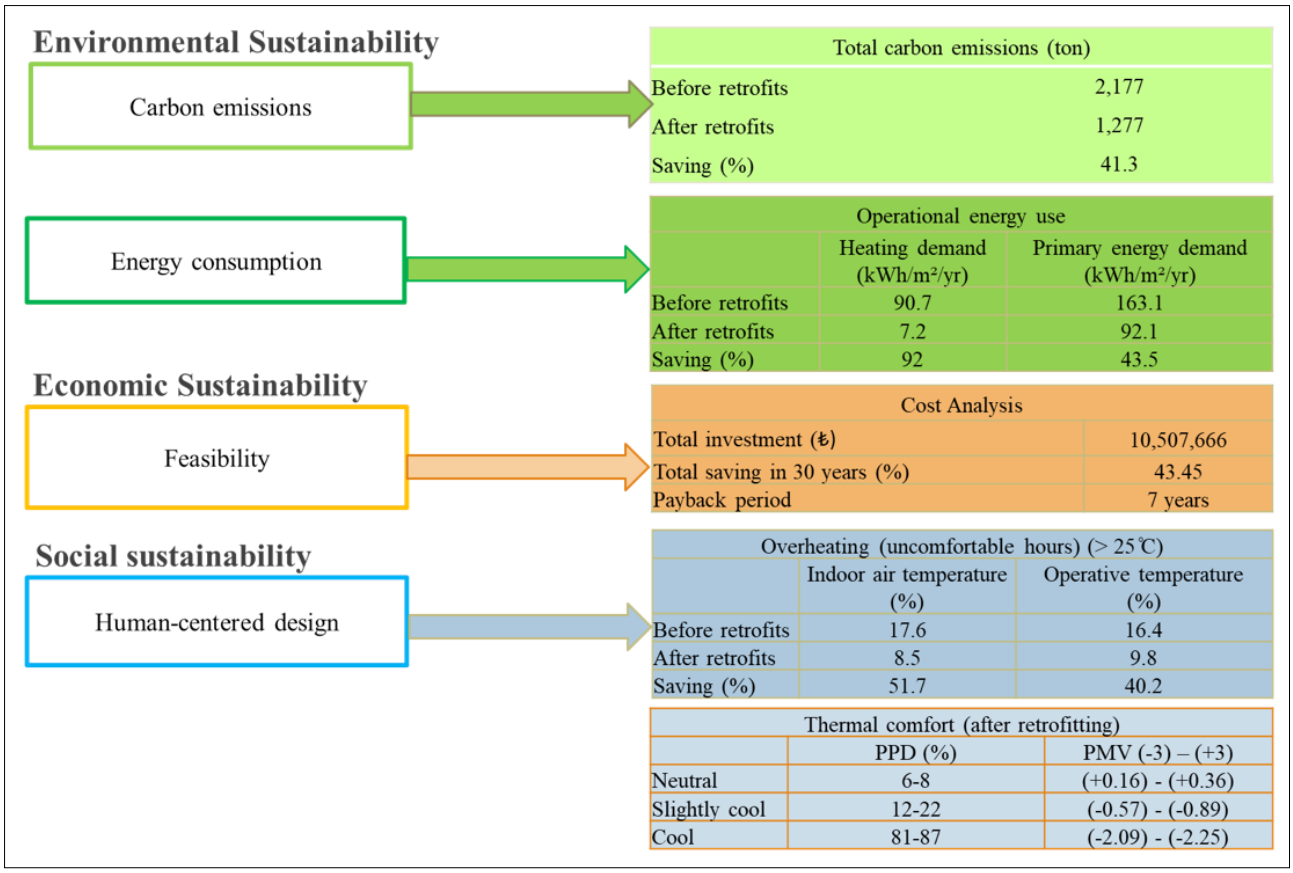
The desired thermal transmittance values for walls, doors, and windows were successfully achieved, and a heat recovery ventilation unit was integrated into the building. As a result, the heating, cooling, and primary energy demands were reduced to below threshold values, and the overheating level of the building was significantly minimized.

Comparing the baseline case with the retrofitted case, the results indicate a 43.5% reduction in annual primary energy demand, while heating demand decreased by 92%. Although the overheating issue was reduced by 40%, further improvements are required to ensure optimal thermal comfort for users.

The proposed retrofits are financially feasible, with a total payback period of 7 years. Furthermore, the total carbon emissions of the building were reduced by 41.3%, demonstrating the environmental benefits of energy-efficient interventions. Consequently, the study has successfully achieved ecological, economic, and social improvements, paving the way for Yenişehir Cinema to be reintroduced into urban life as a retrofitted passive building (Figure 10).

CONCLUSION AND RECOMMENDATIONS

The depletion of non-renewable resources and the ongoing challenges posed by climate change present significant obstacles to the sustainability of existing buildings. As a result, it is crucial to enhance the energy performance of such buildings to ensure their continued viability. The Passive Building Standard provides a comprehensive range of solutions to address this challenge. According to the



Total carbon emissions (ton)	
Before retrofits	2,177
After retrofits	1,277
Saving (%)	41.3

Operational energy use		
	Heating demand (kWh/m²/yr)	Primary energy demand (kWh/m²/yr)
Before retrofits	90.7	163.1
After retrofits	7.2	92.1
Saving (%)	92	43.5

Cost Analysis	
Total investment (₺)	10,507,666
Total saving in 30 years (%)	43.45
Payback period	7 years

Overheating (uncomfortable hours) (> 25℃)		
	Indoor air temperature (%)	Operative temperature (%)
Before retrofits	17.6	16.4
After retrofits	8.5	9.8
Saving (%)	51.7	40.2

Thermal comfort (after retrofitting)		
	PPD (%)	PMV (-3) – (+3)
Neutral	6-8	(+0.16) - (+0.36)
Slightly cool	12-22	(-0.57) - (-0.89)
Cool	81-87	(-2.09) - (-2.25)

Figure 10. Interpretation of the results in the perspective of sustainable architecture.

standard, energy demands should be balanced to maintain user comfort throughout the year, and the integration of hybrid systems is recommended to optimize performance.

Yenişehir Cinema, a notable modern architectural building, holds significant value in the collective memory of the community. Currently, the building is vacant, but it is believed that the structure can be successfully retrofitted using the principles of the Passive Building Standard and reintegrated into urban life. In alignment with the EnerPHit certification system, the thermal performance of the building envelope was enhanced by incorporating active air conditioning systems, adding insulation, and improving transparent surfaces. One of the major barriers to energy efficiency and comfort was the lack of insulation in the building envelope. Consequently, 35.1% of energy savings in primary energy consumption were achieved solely through improvements to insulation and airtightness. Additionally, the installation of a heat recovery ventilation system prevented heat losses, resulting in a 10.8% reduction in energy consumption. However, due to the building's low transparency, the improvements to windows and doors contributed the least to energy performance, accounting for only 2.3% of the total energy savings. As a result, all requirements to achieve the EnerPHit certification system have been completed.

From an economic standpoint, the window improvements can be covered within the first year, insulation applications within three years, and the VRF-HR system within seven years.

By ensuring thermal comfort, it is possible to create a user-oriented interior space, fostering an environment where social interactions can thrive. The study found that while overheating can be prevented according to the Passive Building Standard, this alone is insufficient to ensure the required thermal comfort. The PMV/PPD method demonstrated that additional measures are necessary to achieve and maintain optimal thermal comfort. While implementing these measures, passive approaches, such as Trombe walls and innovative insulation materials, should be considered to prevent the building from consuming excessive energy during the use phase while ensuring thermal comfort.

Although the proposed improvements led to an increase of 48 tons in the embodied carbon of the building, the overall total carbon emissions decreased by approximately 41% due to the reduction in carbon emissions during the operational phase. This indicates that the retrofitting measures yield positive environmental sustainability outcomes.

Increasing legal regulations and financial support mechanisms that encourage passive building conversions in Türkiye will contribute to the sustainable transformation of the existing building stock. Projects promoted through public-private partnerships would help similar practices to become widespread and YES-TR certificates to be obtained.

Future research can focus on advanced technologies and innovative materials that can be applied to heritage buildings. A comprehensive approach that addresses the energy-carbon-cost triangle is essential for achieving long-term sustainability. Similar passive building transitions can be tested in different climate zones to assess the applicability of passive building strategies in various climatic conditions in Türkiye. Further research can be conducted on how to optimize energy efficiency strategies in different geographical regions. Furthermore, in addition to thermal comfort, visual comfort, acoustic comfort, and the indoor air quality should be considered to ensure the creation of a truly sustainable built environment.

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