LIVENARCH IX

livable environments & architecture



PRIORITIES IN / OF ARCHITECTURE

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September 25-27 2025 Trabzon TÜRKİYE

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KARADENİZ TECHNICAL UNIVERSITY
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TECHNOLOGY / DESIGN

FUTURE BUILDERS: THE ROLE OF ARTIFICIAL INTELLIGENCE IN ENCOURAGING CHILDREN'S INVOLVEMENT IN A PARTICIPATORY DESGIN PROCESS

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ABSTRACT

In recent years, the participatory design approach has gained prominence in line with the objectives of democratizing design and acknowledging local contexts, ensuring the active involvement of users in the design process. Within this framework, identifying who contributes and in what manner is of critical importance. The inclusion of disadvantaged groups, in particular, is essential for advancing the democratization of participation, as it allows their needs and perspectives to be voiced within the process. Among these groups, children occupy a unique position: although they are pivotal actors in shaping the future, they remain significantly disadvantaged in articulating their views. Consequently, the question of how children can participate in the design of schools they attend, the parks they frequent, and the public spaces they inhabit has become increasingly relevant. Participatory design encompasses a wide range of methods, including consultation, dissemination of information, co-creation, and involvement in implementation. With the advancement of digital technologies, participatory practices have increasingly migrated into digital domains, broadening their reach while simultaneously reflecting existing inequalities in access. In this regard, gamification has emerged as a noteworthy method. It not only enables the elicitation of children's spatial perceptions and ideas but also facilitates educational engagement. The present study aims to provide a comparative analysis of spaces designed with children and the participatory methods employed. Ultimately, the serious game approach is highlighted as a promising tool situated at the intersection of education and play within participatory processes involving children.

Keywords: Participation, Children Participation, Gamification, Large Language Models, Serious Game

INTRODUCTION

Participatory design approaches are currently used in many fields such as urban management (Falanga, 2019), educational research (Cumbo & Selwyn, 2022), rural area design (Johnson & Hellem, 2024), and computer sciences (Kensing & Blomberg, 1998).

The primary motivation in participatory design is to ensure that people affected by design are involved in the design process and have a say in the final outcome (Lundmark, 2018). In architecture, participatory processes are known to positively contribute to the creation of spaces that people embrace and feel comfortable in (Sanoff, 2006). Within this scope, participatory design (PD) processes often face challenges in ensuring the participation of individuals who cannot participate or who are in a disadvantaged position for participation. Participation processes where only dominant or 'competent' groups have a say cannot fully succeed in democratizing design. Moreover, participatory design studies, due to their multi-layered processes, may also fail in terms of the final product. Nevertheless, success can be discussed from different perspectives. Lundmark (2018) defines these as 'secondary successes,' such as the transformation of roles, situated learning, and organizational change. In this regard, participatory design processes are also considered as tools for learning. It is an important means both for children to communicate their needs and desires regarding the spaces they use to designers, and for children themselves to engage in learning within the desired context. This can be described as secondary learning.

When products, spaces, or services are created by adults expressing children's needs and ideas, the outcomes may be inadequate. On the other hand, involving children in the design process has positive effects such as (1) making the products more suitable, (2) developing children's decision-making skills, (3) allowing children to express their ideas freely, (4) fostering children's awareness of democratic participation, and (5) enabling children to feel valued. Especially in the field of architecture, involving children in participatory design processes emerges as a significant method for shaping the spaces of the future, embedding environmental awareness and an understanding of sustainable spaces from an early age.

In participatory design processes, problems can be encountered such as different stakeholders trying to dominate each other, language deficiencies, and the inability to understand children's expectations. While different technological approaches like Large Language Models are used in these processes (Sartori & Orrù, 2023); (Zhou, Lin, Jin, & Li, 2024), some deficiencies and obstacles can also arise, such as the

model's inefficiency during the transformation process and language barriers (Goli, Teymournia, Naemabadi, & Garmaroodi, 2022).

Goli, Teymournia, Naemabadi, and Garmaroodi (2022), influenced by the work of Liapis, Gravina, Kastbjerg, and Yannakakis (2012), stated that they overcome various obstacles of artificial intelligence through deep learning. In this context, Goli, Teymournia, Naemabadi, and Garmaroodi (2022) used a Convolutional Neural Network (the CNN) as a method to eliminate the efficiency barrier of machine learning in their serious game studies developed for architectural learning. In this context, the serious game approach has the potential to be an integrative method that focuses on education, works to remove barriers in digital processes by being trained with CNNs, and also entertains.

In this context, the serious game approach has the potential to be an integrative method that both focuses on education (Irabor, et al., 2025), tries to remove the barrier in digital processes by training with CNNs (Goli, Teymournia, Naemabadi, & Garmaroodi, 2022), and entertains.

In this sense, the serious game approach is used in many fields such as architectural history learning (Cellura, 2024); system thinking learning (Irabor, et al., 2025); cultural heritage (Bellotti, Berta, De Gloria, & Fiore, 2012). The main purpose of this approach is to teach while having fun. Serious game approach can be created both with traditional methods such as pen and paper (Voulgari, Vouvousira, & Fakou, 2020) and digital methods (Goli, Teymournia, Naemabadi, & Garmaroodi, 2022). Translated with DeepL.com (free version)

In participatory design processes, focusing on education for children is an important step for a significant portion of the world's population and for increasing the educational level of future adults. Within this framework, encouraging learning from the process, rather than just focusing on the final product, is a method that increases the efficiency of participatory design processes. The serious game approach has the potential to be an important tool for children that is both entertaining and educational. It is believed that integrating these two methods will encourage participation while entertaining children (Figure.1).

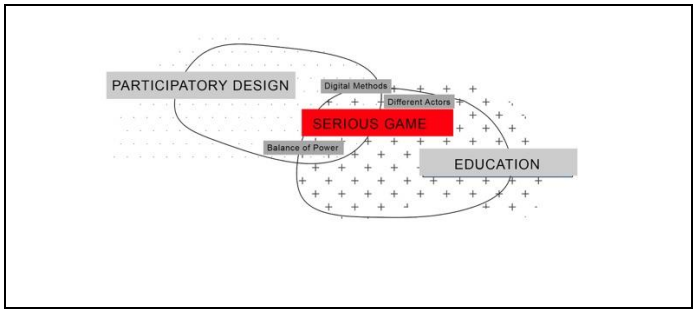


Figure 1. Intersection of Participatory Design and Education

Studies based on the literature show that the stage of getting ideas from children is insufficient in participatory design processes carried out with children for children. The use of digital participation methods, which have a high capacity to increase participation in this field, has not yet reached the desired level. In this context, it is necessary to integrate technological developments into the traditional participatory design process. The aim of this study is to develop a framework that aims to increase children's participation in design processes by focusing on the process instead of focusing only on the final product, to transfer the child's perspective to design, and to learn from the process in areas such as environmental awareness, sustainable living spaces and climate sensitive environmental design.

An Important Actor in Participatory Design: Children

Children need special care and protection and are dependent on adult decisions. Article 12 of the UN Universal Declaration of the Rights of the Child states: "Every child has the right to express his or her views freely and to have his or her views taken into account in all matters concerning him or her". However, in practice, it is not always possible to exercise this right and children adapt to the spaces and lives constructed by adults.

In this context, ensuring children's participation in design processes is an important step. However, different methods and understandings are needed in the field of involving children in participatory design processes than those used in other participatory studies. For example; (Stenberg & Fryk, 2021) emphasizes the need to create design research that encourages learning processes integrated into daily life practices rather than creating methods and tools for existing practices in child participation. In this way, children can become not only participants in participatory processes, but also designers of the processes. Similarly, (Hart, 2008) states that when working with children, it is necessary to stay away from rigid models and find ways of working that relate to everyday life. On the other hand, (Schepers, Dreessen, & Zaman, 2018) emphasize

that involving children in participatory design processes through games is important for true participation by (1) seeing children as process designers and (2) removing the designer from the position of manager. (Behnia, Kheirollahi, Sahragard, & Soltanifar, 2021) developed a model of deep involvement in children's participation in design processes, which consists of 4 main components: contextual, proactive, motivational, and architect-oriented.

In participatory design processes, basic components such as democracy and power distribution can take a back seat by prioritizing design solutions (Smith & Iversen, 2018). It is stated that today's participatory design approaches progress independently of technology, and that technological and social transformations have a solution potential in this context. In order for participatory design to have a real impact; (Smith & Iversen, 2018) developed a holistic framework consisting of 3 dimensions: scoping, developing and scaling. In this framework, scoping represents a process in which the concept of participation is not limited to the design process, but rather the formation of continuous ties; developing represents the existence of processes that are not independent of technology; and scaling represents the existence of a process in which projects constantly follow each other between different actors. This approach includes actions such as pilot workshops, training and learning processes, digital fabrication processes, and different participation methods. Katılımcı tasarım süreçlerinin öncelikleri;

-Inclusion of disadvantaged individuals
-Inclusion of technology in the process
-Equal distribution of the balance of power
-Involvement of different actors in the process

Fun and Educational Approach for Participatory Design: Gaming

Gamification is often used in participatory design processes (Demirel & Alanyalı Aral, 2025). In other words, gamification as a method is a good way to facilitate decision-making in participatory design processes (Odendaal & Barreda, 2024). On the other hand, including games as a technique in participatory design processes creates a fun process in which actors have equal power (Demirel & Alanyalı Aral, 2025). In this process, (1) the participatory process becomes a jointly defined process and (2) behavioral elements have a significant impact on the educational goals of participatory games that emerge through relationships framed by social play conditions. In this context, one of the games used in participatory design processes is Minecraft. Block by Block uses Minecraft in its work to visually involve participants in the

process. On the other hand, board games are used in the process (Demirel & Alanyalı Aral, 2025); (Odendaal & Barreda, 2024).

On the other hand, just like the use of games in participatory design processes, there are studies that use participatory design by focusing on education in game design processes (Voulgari, Vouvousira, & Fakou, 2020).

The gamification approach mentioned here also emerges as an important method for the learning from the process part of the study, which is described as secondary success in participatory design. In this context, the Serious game approach emerges as a game approach that is both instructive and educational (Koupritzioti & Xinogalos, 2020). Serious game is based on interaction; it is a fun game approach that focuses on active learning (Stoerger, 2007). Stoerger, 2007 states that in this framework, serious game can meet the learning objectives with open-ended education. For example; (Goli, Teymournia, Naemabadi, & Garmaroodi, 2022) used the serious game approach as a method for architecture students to both teach and exchange information with each other.

The priorities of the Serious game approach can be listed as follows:

- Using the game as a method of collecting data from the user
- Education-oriented
- Adopting a participatory approach

These features transform gamification into a tool that enables both learning from the process and the democratic achievement of the final product in the combination of education and participatory design processes. In this respect, SG, which is also suitable to be supported by generative AI and LLM tools, has the potential to enrich participatory processes for design purposes.

METHODOLOGY

The methodology of the study is an exploratory approach using qualitative methods. Following the comparison, a theoretical model integrating current technological developments is presented for discussion. In this study, the Mama Lucinda Park, Istanbul is Asking Children, Superkerpic Children's Library, Open Classrooms, OpenPlay, Hayat Park Improvement projects were examined and compared in terms of data collection method, use of digital methods, number of actors, involvement of education and training in the process, and processes involving children.

The methodology of the study consists of 2 basic steps. First, participatory design practices involving children are evaluated within the context of the priorities of serious game and participatory design and their positive and negative aspects are identified. The serious game approach was then put forward as a theoretical model that both teaches and encourages participation for children in order to overcome these negativities.

In this study, a total of 6 participatory design practices were analyzed. The examples evaluated within the scope of the study are 1) the development of children's spaces with ideas for the creation of children's spaces, 2) the participation of children in participatory processes at different stages, 3) projects that seek solutions to urban / spatial problems together with children / seeking solutions for children. Table 1 provides basic information about the project analyzed in this study.

Table 1. Project Information

Project Name	Year	Location	Application
Mama Lucinda Parkı	2014	Lima	Yes
Super Adobe Children's Library	2023	Kahramanmaraş	Yes
Open Classes	2019	Madrid	Yes
OpenPlay	2019	Göteborg	Yes
Life Park Improvement	2024	Adıyaman	Yes
İstanbul Asks Children	2022	İstanbul	No

PARTICIPATORY DESIGN SAMPLES

In this section, 6 participatory design projects in which children were involved in the design or implementation stages are analyzed. These projects were evaluated on the basis of the method used in the study, the method of collecting data from children, whether digital methods were used, the number of actors, whether there was training in the process, and the stage in which children took part.

MAMA LUCINDA PARK IN LIMA: BLOCK BY BLOCK

The Block by Block team uses Minecraft as an important tool for engaging communities in building resilient cities. Their first workshop was organized in Nairobi in 2013. The basic working steps are as follows; selecting and modeling the site, finding 30 to 60 people willing to support the work in the study area and mobilizing them for the work, creating 2-

4 day workshops with 30-60 participants, 2-4 people per computer, informing the participants about the project and developing mixed dialogues, exploring the area with the participants, training the participants based on the Minecraft game, (Imam & Lahoud, 2021): forming groups of 2-4 people for Minecraft, participants conveying their ideas to local administrators and other actors, all actors discussing the ideas within the scope of the desired goal, budget planning through the Minecraft model, production, and finally encouraging the repetition of the process and continuity in other projects (Block By Block , 2025); (Imam & Lahoud, 2021).

The project started in 2014 and was completed in 2016 in the Villa El Salvador neighborhood of Lima, South America. The main objective of the project is to regularize the uneven quality of life that varies between different settlements. It involved the transformation of an existing park in Villa El Salvador to create a public space accessible to all. In this context, the project consists of micro-interventions such as playgrounds, sports facilities, walking trails, meeting points for families and sustainable irrigation systems (Building Vibrant Community Gathering Places In Lima, 2025)

The actors in the project were; (1) Fundación Avina (2) UN Habibat, (3) local people, while Universidad Científica del Sur joined the actors in 2016. In the project, the minecraf game was used as a tool to try to understand how local people think about the park. In this way, the locals designed the park in blocks under the working system of the block by block team Figure 1. (Building Vibrant Community Gathering Places In Lima, 2025).



Figure 2. Participatory Design Process in Lima

SUPER ADOBE CHILDREN'S LIBRARY

The project was implemented between 2023 and 2024 in Kahramanmaraş, Turkey. The main objective of the project is to create a library, workshop and educational space, especially for children and

women, based on the lack of socialization space for the local community after the February 6 earthquake (Figure 3).

The actors in the project are (1) Architecture for All, an NGO, (2) Poçolana Works, (3) the local government, (4) All Hand and Hearts, (4) Koluba Collective, (5) the local community.

The building is made of earth, a material suitable for the criteria of locality, accessibility, ease and collective production. The building consists of 2 domes with a diameter of 3.5 meters. The form and size of the building is designed in accordance with the collective production process. The scale of children was taken into account when creating window heights and forms in the building (Architecture for All, 2024).

In this study, children were not consulted, but they helped the adults during the implementation phase. The design of the building was predetermined by civil society organizations. In this project, the relationship with children is partly based on the involvement of children in the practice and the space being for children.



Figure 3. Participatory Design Process in Süperkerpiç

OPEN CLASSES BY RECETAS URBANAS

The project was implemented in Madrid, Spain in 2019. The main aim of the project was to create both play spaces and spaces for outdoor learning in a school courtyard.

As part of the participatory processes, children were invited to the process and a presentation was made to them. Participatory educational workshops for children were then organized (Figure 4). The training process focused on the concepts of architecture and construction, carpentry and tool use, and teamwork. Thus, children had the opportunity to participate in the implementation process together with their families (Recetas Urbanas, 2025).

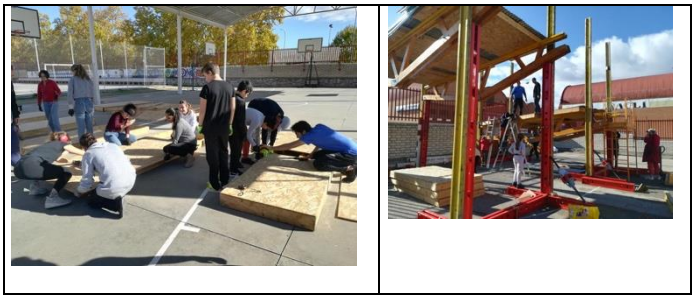


Figure 4. Participatory Design Process in Açık Sınıflar

OpenPlay by Recetas Urbanas

The project was realized in Gothenburg, Sweden in 2019. The project consists of an outdoor classroom and playgrounds based on the water cycle concept to draw attention to the social, economic and environmental challenges caused by global warming (Figure 5).

The project consists of containers and benches with functions that transform for different purposes and functions. For example, the container is used both for storage and for play and entertainment purposes together with the bench. The project was realized in 5 weeks with the participation of 152 people, including 38 primary school students (Recetas Urbanas, 2025). In this study, the relationship with children was realized through the participation of children in the design phase by expressing their needs and wishes and thus being considered as active individuals in the decision-making process.



Figure 5. Participatory Design Process in Openplay

Life Park Improvement

The project was realized in 2024 in Adıyaman, Turkey. The main aim of the project is to revitalize the urban memory and sense of justice after the disaster through art. In this context, there are 5 different works in the project. The improvement of Hayat Park is the one related to children.

Hayat Park involves the transformation of an existing area into a permanent learning and experience space for children (Figure 6). It is planned to organize informative workshops and trainings for children in this transformed area (Perre Children and City Biennial, 2025). In this context, the park includes playground equipment for the development of gross motor skills and an open classroom with an exhibition layout.

The project team set out with the idea that children are more affected by disasters than adults. In this context, they stated that children moving, spending time and establishing a routine in public and open spaces have positive effects (City Detective , 2025).

In this context, participation workshops were held for 3 days with children in the 6-17 age group. In these workshops, children of different age groups were asked for ideas on what kind of a park they wanted and children chose the play elements of the park. Afterwards, Adıyaman Municipality designated a suitable location as the application area for this study (Şehir Detektifi , 2025).

The actors in the project are Adıyaman Municipality, City Detective, Spatial Justice Association, Anamed and children.



Figure 6. Participatory Design Process in Hayat Parkı İyileştirme

İstanbul Asks Children

The main aim of the Istanbul City Council in relation to children is to create a road map together with children without any interference with their views. In this context, instead of perceiving children as disadvantaged in any way, it is to share a process with children from different ethnic origins, different age groups and different income groups.

The project was realized in Istanbul, Turkey in 2021-2022 with the involvement of 6,601 children. The main aim of the project is to get

children's ideas not only for educational spaces or playgrounds, but also for a city, and to realize their participation in a realistic manner.

The project was realized through 3 main methods: workshops, excursions and online applications. In the workshops, children were informed through maps and visuals, and together with the children, they produced visual and written works with pencil and paper. In this context, the project consists of 7 steps: (1) assignment, (2) Istanbul for me, (3) Istanbul under the lens, (4) Istanbul's medals, (5) attention, Istanbul's problems, (6) for a better Istanbul, (7) care instructions for Istanbul. A total of 52 actors are involved in this project. In this context, this study can be considered as a practice where children were involved in a participatory process of information exchange, which resulted in the local government being informed. The outputs included in the evaluation report have been implemented in practice.

DISCUSSION

Table 2. Comparison of Projects

Project Name	Objective	The method used in the process	Data collection method	Use of digital methods	Number of actors	A process based on education	The Stage Where Children Are Involved
Mama Lucinda Park	Transformation of the existing Park	Minecraft yöntemi	Digital	Var	3-4	Information about the Minecraft game	Design, Implementation
Super Adobe Children's Library	Creating a socialization space for children and women	Workshops	Traditional	Yok	5	Yes, especially for the application of a different material	Implementation
Open Classes	Creating play areas and open classrooms	Workshops	Traditional	Yok	-	Yes, during the carpentry and tool use phase	Implementation
OpenPlay	Transforming containers according to function and creating outdoor classrooms and play areas	Workshops	Traditional	Yok	-	-	Implementation
Life Park Improvement	Creating permanent learning and experience areas for children	Workshops	Traditional	Yok	5	-	Consultation
Istanbul Asks Children	Creating a road map with children	Workshops, Tours, Online Methods	Digital and Traditional	Var	52	Information about how they will score and what it means in the process	Consultation

By analyzing these projects it is observed that children were not consulted to a great extent while creating spaces for children; however, children participated in the implementation process. Digital methods were used in two studies where children were consulted and traditional methods were used in one study. In this context, digital methods have an important potential in getting ideas from children.

In participatory design processes, children are mostly trained about the methods to be used in the process or about materials and their applications. This situation shows that success in participatory design processes is not only focused on the final product, as stated by (Lundmark, 2018). In other words, in participatory design processes, children have the potential to be trained within the scope of the targeted subject.

On the other hand, digital methods are not used intensively in participatory design processes. However, gamification of participatory design processes with the serious game approach, which has recently gained popularity and is used for educational training potentials in different fields (Karaarslan, 2020), has the potential to be a successful method by prioritizing both the use of digital methods and education.

CONCLUSION

One of the most important elements in participatory design processes is the active, creative and enthusiastic involvement of children. At this point, gamification and serious games methods stand out as tools that strengthen children's participation and make the process more meaningful. In this context, in participatory design processes where the serious game method is applied, it is predicted that (1) it can increase children's motivation by attracting children's attention with the advantage of being game-based, (2) it can encourage children's creativity since game environments do not limit imagination, (3) it can strengthen democratic participation with game rules, and (4) it can improve decision-making, cooperation and responsibility skills.

As a result of this study, it is seen that there are processes that are planned to involve children; however, it is seen that children are mostly not involved in these processes at the implementation stage. However, it is seen that the studies that have turned into practice are generally designed by designers and children's participation is ensured in practice, children are included in the processes to a limited extent, and children maintain their relatively passive position in designing the process.

If the creative ideas of children are to be incorporated into design processes through digital methods, the mere reliance on artificial

intelligence and Gen AI tools may prove insufficient. In this regard, gamification constitutes a promising alternative. Specifically, when the serious game approach—originally developed within educational contexts—is integrated with both traditional and digital modes of child participation, it not only facilitates children's learning but also empowers them to actively shape the design process. Such an approach fosters a participatory model in which children and AI systems are co-trained, thereby generating outcomes that can guide design professionals while simultaneously producing knowledge-enhancing benefits for practitioners.

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POSTPLASTICISM: REDEFINING PRIORITIES IN 21ST-CENTURY ARCHITECTURAL DESIGN AND FABRICATION

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ABSTRACT

Architecture in the 21st century faces the dual challenge of ecological responsibility and technological innovation. This paper introduces Postplasticism as a design framework that redefines architectural priorities by departing from the rigid geometries of Neoplasticism and addressing the ecological and material crises of a society driven by plastic. The aim is to integrate sustainable materials, robotic fabrication, and speculative aesthetics into a coherent methodological approach.

A research-through-design strategy structured in six phases—conceptual framing, material selection, experimentation, design development, execution, and evaluation—was adopted. Three projects (Postdigital Natures of Planet B, Quadrifoglio, and HOPE) were developed at the Robotic Experimentation Lab (REX|LAB) using biopolymers, recycled plastics, and bio-based composites. Robotic 3D printing and parametric toolpath design were employed to explore gradient material transitions, deposition intelligence, and multi-material integration. Results show that Postplasticism produces identifiable architectural traits, including layering, bead continuity, gradient articulation, controlled porosity, and zones of translucency. These effects emerged directly from fabrication protocols and material performance rather than stylistic overlays. Prototypes demonstrated pathways to scalable applications, such as façade screens, lightweight lattices, interior panels, and service-integrated wall systems; however, challenges remain in certification, durability, and regulatory compliance. The findings suggest that Postplasticism offers a viable paradigm in which sustainability, functionality, aesthetics, and technology act as co-drivers rather than trade-offs. By coupling materials, processes, and speculative design, the framework advances both ecological responsiveness and creative expression, positioning Postplasticism as a methodological and conceptual contribution to contemporary architecture.

Keywords: 3D printing, Research-through-design, Biodesign, Material gradients, Toolpath design

INTRODUCTION

The capacities of contemporary architectural production and the technological advancements of the last few decades are necessary to tackle the impact of the discipline on climate change, as well as to adapt to new working/design modes. The swift technological changes (e.g., from CAD to AI) shift design paradigms drastically and at an unprecedented pace, which theoretical beacons can guide and evaluate in a constant experimental state. It is important to describe a new framework and theoretical concept considering the shifts/fulgurations in architectural production. The synthesis and utilisation of sustainable materials, robotic fabrication, mixed realities, and advanced digital design tools are usually discussed in the niches of their respective fields (bio-inspired design and all its derivatives, robotic fabrication, simulation, VR, XR, AR and material research). A design-theoretical investigation of these overlapping and interdependent topics should identify traits, protocols, and even a potential stylistic tendency in contemporary design explorations within the complex field

of architectural research. We believe that approaching design from the notion of *Postplasticism* challenges conventional architectural priorities, offering a new perspective on the balance between functionality, aesthetics, sustainability, and technological integration (Figure 1). This paper frames the design-theoretical concept of Postplasticism by describing/comparing, and discussing three exhibited design-build projects done by the authors over the last three years.

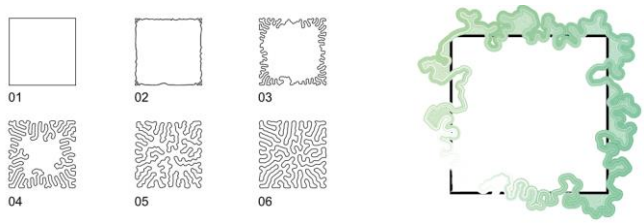


Figure 1. Transformation from geometric to organic form.

Aims and Research Questions

The aim of this study is to define and demonstrate the architectural potential of Postplasticism as a design framework integrating sustainable materials, robotic fabrication, and speculative aesthetics. It is guided by the following questions: (1) How do contemporary sustainable materials, robotic fabrication strategies, and multi-media design tools contribute to shaping the design framework of Postplasticism? (2) What formal, material, and ecological traits emerge from the integration of Postplasticist design principles? (3) How can small-scale, prototypical interventions shape future large-scale, sustainable architectural practices?

Defining Postplasticism

Postplasticism proposes a new "biodesign" (Diniz, 2023) framework for the 21st century, departing from the legacy of the 20th century and its rigid geometries of Neoplasticism, also known as *De Stijl*: the austere, geometrical, abstract style labelled by Dutch painter and art theoretician Piet Mondrian (Mondrian, 1920; Albers, 1950), which focused on strict, geometric forms and primary, applied colors. The traits of Postplasticism, on the contrary, embrace properties borrowed from digital design technique, e.g. complexity and elegance, as well as material practices such as rapid prototyping with gradual transitions (Schumacher, 2016; Oxman, 2020), moving towards fluid, biomorphic

forms and sustainable material practices (Toshev, Bengs, Helo & Zamora, 2024).

Postplasticism, as used in this research, refers to a design paradigm that synthesises ecological responsibility, material experimentation, and advanced digital design—beyond the legacy of *Neoplastic* abstraction and beyond the dominance of petroleum-based plastic thinking (Roudavski, 2009; Grigoriadis & Lee, 2024.

However, Postplasticism is an ambiguous term. It addresses/references two different fields of action. First, it is rooted in the history of architecture, referring to the epochal or style categorisation of Neoplasticism of the early modern period. Second, Plasticism implicitly evokes a material connotation that refers to polymer sciences or a socio-political description of a plastic-driven society. The second notion is unintentional but not deniable. Hence, Plasticism is understood as a formal concept or an expression of material and technology through form, and as a socio-ecological concept of an era after plastics, without neglecting the performative aspects of the material. It is not only a material research agenda, but it also stands as a *pars pro toto* for the global challenges. The addition of the prefix post adds ambiguity. On the one hand, it signals "the end of one period and its displacement by another" (Kwastek, 2015). On the other hand, it points at "subtle cultural shifts and ongoing mutations" of that preceding period (Cramer, 2015).

METHODOLOGY

For this study, we adopted a research-through-design strategy that triangulates (i) theoretical investigation (concept and discourse formation), (ii) material exploration (bench-scale testing and prototyping), and (iii) practical application through robotic 3D printing at architectural scale. The six interrelated phases outlined in this paper—conceptual framing, material selection and limitation, experimentation, design development, execution, and evaluation—structure the inquiry as an iterative loop rather than a linear pipeline, allowing findings from fabrication to continually re-inform theory and design.

On the materials side, we explore bio-based polymers and composites (e.g., PLA (Polylactic acid) blends with lignin/cellulose fillers), recycled polymers (e.g., rPET (polyethylene terephthalate), and selected mineral/organic mixtures (e.g. clay), chosen for printability, stability, and expressive potential. Each material undergoes a printability window study (nozzle temperature, feed rate, layer height, bead width, and cooling), adhesion tests (intra- and inter-layer), and gradient feasibility trials (mixing ratios, translucency/colour modulation, and density

variation). These tests constrain and inform the additive manufacturing (AM) strategy for each project—toolpath topology (raster, spiral, contour-offset, branching), deposition sequencing, and multi-pass logics—so that formal effects emerge from material behaviour and process intelligence rather than post-hoc styling. Additive manufacturing enables precision and freedom in continuous material deposition while minimising waste and expanding the possibilities of material experimentation (cf. Roudavski, 2009; Grigoriadis & Lee, 2024). This approach not only supports resource awareness but also facilitates the creation of complex, free-form designs (Toshev, Bengs, Helo & Zamora, 2024) that were previously unattainable through conventional manufacturing methods (Jones, 2017; Bledzki & Gassan, 1999).

On the fabrication side, we utilise 6-DoF (Degrees of Freedom) industrial robotic arms equipped with extrusion end-effectors, ranging from pellet-fed systems to 1K paste extrusion nozzles, enabling continuous, multi-material deposition with fine spatial resolution and high differentiation capacity. The maximum printable dimensions were constrained by the robotic system's effective reach of 1.65 m. The use of computational tools like Rhino 3D and Grasshopper is integrated with toolpath design and simulation, allowing geometry, gradient recipes, and build order to be co-authored across media.

Evaluation combines qualitative and quantitative lenses: geometric fidelity (bead stability, overhang success), gradient fidelity (optical/translucency and tactile effects), structural/adhesive performance at prototype scale, waste rate and rework, print time/energy proxies, and post-processing intensity. Findings are fed back into the design framework to refine protocols and identify scale-up constraints (material availability, durability, certification). Methodologically, this positions sustainability as an early design driver—via material selection and deposition strategies—while stopping short of full life cycle assessment (LCA) claims, which are reserved for future work.

Design Process and Development

The three projects presented in this study emerged from the observation of a shift from the modern premises of form found in Neoplasticism toward a contemporary plasticism, where appearance, performance, and materiality fundamentally differ. Accordingly, the design development, grounded in theoretical assumptions, progressed through speculative experimentation and culminated in prototypical implementations. The design process can be broken down into six interrelated phases (Figure 2): (1) conceptual framing, (2) material selection and limitation, (3) experimentation (constraining the design

framework), (4) design development (utilising tools and logics), (5) execution, and (6) evaluation.



Figure 2. The workflow from conceptual framing to evaluation is structured in six phases.

(1) Conceptual Framing: The design process began by identifying and selecting key contemporary research fields in architecture. These included bio-inspired design, robotic fabrication, simulation, extended realities (VR, XR, AR), and sustainable materials—particularly biocomposites and biodegradable materials. This framing established a speculative terrain by superimposing diverse disciplinary genres and methodologies.

(2) Material Selection and Limitation: A broad spectrum of established and experimental sustainable materials was evaluated, with particular attention to their compatibility with specific fabrication processes. This phase resulted in the selection of either multiple materials or a single material focus, often emphasising properties that allow for gradual transitions (e.g., colour, texture, or transparency). The outcomes of this phase informed the AM strategy in each project (Figure 3).

(3) Experimentation and Constraining the Design Framework: This phase extended the material inquiries of Phase 2 into systematic experimentation. A series of tests and prototypes explored various geometric configurations and morphological strategies. The aim was to reveal limitations and potentials in both material behaviour and fabrication processes. From these explorations, design protocols and operative frameworks were derived.

(4) Design Development: Building on the experimental findings, this phase combined speculative design methods—including AI-driven image generation, simulations, and mixed-reality interactions—with the frameworks developed in Phase 3. This plurivocal and disruptive process challenges the notion of singular authorship, embracing the multi-scalar,

multi-agent nature of contemporary design. Phase 4 evolved iteratively in parallel with the experimentation of Phase 3.

(5) Execution: This phase involved the materialisation of the projects, with a focus on realising specific synergies or seizing moments of innovation within fabrication. It introduced the highest levels of logistical and managerial complexity, particularly in translating prototypes into full-scale interventions. While not primarily research-analytical, this phase yielded critical insights into scaling processes and the real-world application of Postplasticist strategies.

(6) Evaluation: The final phase assessed the extent to which the projects fulfilled their research aims. This included evaluating the implementation and effectiveness of sustainable materials, as well as their formal and performative outcomes and potential contributions to circular economy models. The feedback from this phase informs future design cycles and methodological refinement.

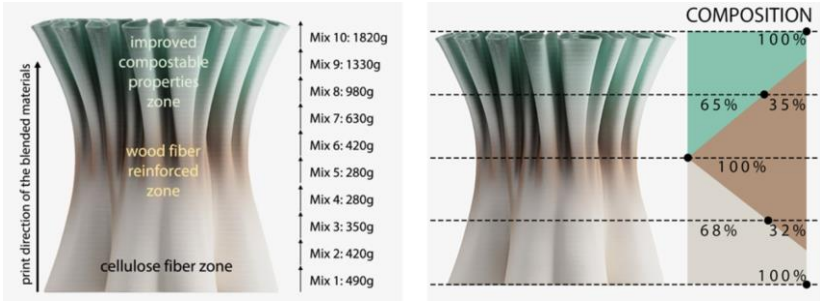


Figure 3. Gradient material composition.

Three Artifacts

Three projects, designed and fabricated at the Robotic Experimentation Lab (REX | LAB) at the Department of Experimental Architecture at the University of Innsbruck, Austria, served as test beds for robotic fabrication with sustainable materials and form the core of the practical application phase of this research, demonstrating the versatility and potential of Postplasticism in various architectural contexts:

The installation *Postdigital Natures of Planet B* (Massin, Körner, Colletti, Grasser, Uitz & Bauer, 2023) by PDNB, exhibited at the Ars Electronica Festival 2022 in Linz (Figure 4), Austria, utilises a diverse range of sustainable, biodegradable, and recyclable materials: 3D-printed clay vessels are crafted from locally sourced, fired and glazed clay; small vessels 3D-printed from biocomposite PLA blends like UPM Formi &

Tecnaro ARBOBLEND, PLA-blends with lignin, natural waxes, oils, fatty acids, cellulose, organic additives and natural reinforcing fibres. The largest objects, so-called 'pistils', were also robotically fabricated, but from rPET plastic pellets—usually not used for 3D printing but for injection moulding—and liquid wax gel used to close the porous structures. Equally challenging to create were the smallest vessels, made from a paste of sawdust, methylcellulose, water and vinegar essence, which serve as bases for the embedded cacti, succulents, and grasses, representing the resilient greenery of a drier, uncertain future, and thus operating on both a metaphorical and tangible level. T he project surveys a spectrum of sustainable materials for 3D printing, from established PLA blends to highly experimental biodegradable mixtures, each revealing a distinct performance range and set of design affordances. Toolpath design explored contour offsets and meanders, modulating spacing and speed to shift surfaces from opaque to porous while maintaining slender, tall elements limited primarily by robot reach. Although rPET is common in recycling streams, its use in large-scale robotic extrusion for architectural prototyping is novel. At the experimental end, a sawdust–methylcellulose mix required a custom end effector, a new material recipe, and a dedicated printing routine developed from scratch. During printing, the mix offered little strength and plasticity; once cured, the parts became lightweight, stiff, and thermally insulating. Ecologically, the rPET elements utilise recycled feedstock and reduce demand for virgin polymer, while the sawdust–methylcellulose mix is both renewable and biodegradable at the end of its life. The ecological stance is embedded in material choice rather than added post hoc. Across these materials and tools, the project exemplifies a plurivocal authorship model in which parametric modelling, bespoke slicer scripts, and robotic deposition work with material behaviour to define the outcome. The guiding design principles are layering, continuity of bead paths, gradient articulation, and controlled porosity, yielding an aesthetic of continuous curvature and fluid, meandering topologies. These results demonstrate how Postplasticism functions as a methodological framework in which material behaviour, CAM-controlled toolpath design, and robotic deposition collectively contribute to the architectural outcome. At the building scale, the rPET strategy indicates potential for gradient façade screens and lightweight lattices, and the cured sawdust mix suggests interior panels with thermal and acoustic value. The primary barriers to translation are certification, long-term durability, joint weathering, and maintenance protocols.



Figure 4. Postdigital Natures of Planet B.

Quadrifoglio: Gradual Furniture by REX|LAB, exhibited at the Isola Milan Design Week 2024, is a series of stools named after the Italian four-leaf clover symbol of good fortune. Leveraging industrial robotics and additive manufacturing, the stools showcase intricate geometries—and, more importantly, smooth and continuous multi-material gradients—using PLA blends, namely UPM Formi, Tecnaro ARBOBLEND, NaKu PLA mixed with EcolGreen PLA to achieve a light green colour hue. Focusing on renewable resources and non-toxic finishes, the design hopes to maintain a tactile, warm and yet non-rigid aesthetics that profits from digital design and robotic technologies. Methodologically, the project treats material composition and process parameters as design variables. Toolpath design tuned bead width, layer height, and path spacing to produce continuous gradients that calibrate stiffness at load points and softness at contact surfaces. The gradient is performative: ARBOBLEND is concentrated in the base and at leg junctions to provide stiffness and secure load transfer. The composition then transitions through intermediate mixes and reaches NaKu in the seating area, where a softer response improves comfort and tactile quality. The slicing strategy shifts from planar to three-dimensional paths to follow the ergonomic seat profile, which reduces stair-stepping, aligns deposition with

curvature, and improves interlayer adhesion in high-contact zones. Robotic single-shell printing reduced supports and waste, and parameter logs enabled repeatable prints across iterations. Evaluation focused on geometric fidelity, gradient legibility, seat comfort, and surface tactility under repeated use. The results show that multi-material deposition combined with three-dimensional slicing can deliver ergonomic compliance where needed while maintaining structural stability without heavy post-processing. In relation to the research questions, *Quadrifoglio* demonstrates how materials, robotic strategies, and design tools co-author outcomes (Figures 5-6); it clarifies formal and material traits specific to gradient deposition; and it indicates a path from prototype to product-ready components, with remaining tasks in wear testing, UV and cleaning resistance, and standardisation of print parameters and slicing routines for consistent production.



Figure 5. NakU and EcolGreen distribution.



Figure 6. ARBOBLEND distribution.

HOPE: Hybrid Organic Postplastic Environments by REX | LAB, exhibited at the Ars Electronica Festival in Linz, Austria, 2024, is a micro-living-working environment designed within a (phantom) shipping container and based on adaptive, multifunctional design strategies that optimise limited space without compromising comfort or performance and offering reconfigurable solutions (Ratti & Claudel, 2015). The project investigates adaptive architectural elements using the same biocomposite PLA blends as in the aforementioned project, along with Ingeo PLA to enhance transparency. Robotic 3D printing is utilised to achieve complex geometries, allowing for precise material deposition and minimal waste (Figures 7-8). Customisation and ergonomics also play a central role, with 3D printing enabling highly personalised layouts, seamless integration of furniture, and adaptive, evolving spaces. By integrating biophilic design principles, such as natural light, ventilation, and greenery, the connection to the natural environment is enhanced (Vale & Vale, 2000) while maintaining high functionality (Hensel, 2013). Methodologically, the project scales the research to an architectural scope by treating walls as multifunctional printed assemblies. Toolpath design and slicing embed channels and recesses for furniture interfaces, lighting runs, and HVAC fixtures, as well as register points for augmented reality interaction in the completed space. Structural wall elements test branching strategies that typically conflict with extrusion continuity, causing on-off artefacts. The printing routine mitigates this by increasing travel speed during non-deposit moves when swapping between branches and by aligning bead restarts along concealed seams. Material composition is adjusted locally, with PLA blends used for structure and Ingeo PLA for applications requiring partial transparency or light diffusion. In relation to the research questions, HOPE shows how materials, robotic strategies, and design tools co-author outcomes at the spatial scale. It clarifies the formal and material traits associated with

Postplasticism, including layering, branching continuity, graded density, and controlled translucency, which together produce a legible aesthetic rather than a purely technical assembly. It also indicates pathways from prototype to building-scale elements, such as reconfigurable partitions and service-integrated walls. The principal barriers remain certification and code compliance, as well as the long-term durability and fire performance of PLA-based blends, anchoring and jointing details, and maintenance access for embedded services. These findings present Postplasticism as a framework in which material behaviour, deposition intelligence, and speculative aesthetics are co-drivers of architectural design.



Figure 7. Hybrid Organic Postplastic Environment.



Figure 8. Digital Implementation at HOPE installation.

DISCUSSION

The three projects show how Postplasticism can be operationalised through direct engagement with materials, robotic 3D printing, and design tools across media. Design intent is negotiated with material behaviour and deposition intelligence rather than imposed upon them. Authorial voice is plurivocal, since protocols and outcomes are co-authored by parametric modelling, slicer routines, robotic motion, and the materials themselves. Across the three projects, sustainability, functionality, aesthetics, and technological innovation act as co-drivers rather than trade-offs, and the priorities advance together through design-for-fabrication strategies.

RQ1: How do materials, robotic strategies, and multi-media tools shape Postplasticism?

Across the projects, materials and processes set the brief for form and performance. In Postdigital Natures of Planet B, a spectrum from rPET pellets to a sawdust–methylcellulose mix established distinct printability windows and prompted different toolpath families that move from opaque to porous surfaces. Quadrifoglio treats composition as a design variable and utilises tuned toolpaths and three-dimensional slicing to drive the creation of gradient seating shells. HOPE scales these logics to walls by embedding service cavities and coordinating branching paths that would otherwise break extrusion continuity. In each case, Postplasticism is enacted by coupling material choice with CAM-controlled toolpath design, robotic execution, and transmedial design development. This comparative lens demonstrates the viability of design-for-fabrication at the project scale, featuring parameter logging and repeatable routines, single-shell prints that minimise support requirements, and branch-management strategies that maintain deposition continuity.

RQ2: What formal, material, and ecological traits emerge?

A coherent set of aesthetic traits is discernible across projects, including layering, continuity of bead paths, gradient articulation, controlled porosity, and fluid curvature. HOPE adds branching continuity, graded density, and zones of translucency for light diffusion. These effects are not stylistic overlays but outcomes of deposition order, bead width, path spacing, speed control, and slicing strategies. Ecologically, traits are embedded in material selection rather than added post hoc. Recycled feedstock for rPET reduces demand for virgin polymer, and renewable, biodegradable mixes introduce low-impact alternatives. Bio-based PLA blends enable non-toxic finishes and a warm, tactile feel at the furniture

and component scale. Together, these traits characterise Postplasticism as an aesthetic that is legible because it is performed by the materials and processes that produce it. From an environmental perspective, waste is limited by continuous deposition and low-support strategies, while recycled rPET feedstock and renewable fibre-based mixes align material choice with low-impact aims. These choices suggest pathways that support circular-economy principles without claiming full life-cycle verification at this stage.

RQ3: How can small-scale prototypes inform future large-scale practice?

Each project indicates a pathway from prototype to architectural application. The rPET strategy suggests gradient façade screens and lightweight lattices. The cured sawdust mix is used to point interior panels with thermal and acoustic value. Quadrifoglio demonstrates product-ready components through repeatable prints, ergonomically tuned gradients, and three-dimensional slicing. HOPE demonstrates service-integrated wall elements and reconfigurable partitions, positioning human-robot interaction as a service-furniture device within the completed space. AR interaction occurs after printing as part of the spatial use. The principal barriers to translation remain certification and code compliance, long-term durability and fire performance of PLA-based blends, weathering of joints, anchoring and repair protocols, and maintenance access to embedded services. These constraints define the technical agenda for future work, confirming that Postplasticism can scale without compromising its material and aesthetic commitments. Future work will focus on enhancing print-path efficiency, standardising material recipes, and aligning regulations to enable the development of certified, durable, and building-scale components using low-waste robotic workflows and recycled or renewable feedstocks.

CONCLUSION

This paper advances Postplasticism as a design framework that integrates sustainable materials, robotic 3D printing, and speculative aesthetics, and demonstrates how this framework can be operationalised through a six-phase research-through-design process. Across three projects, design intent was negotiated with material behaviour and deposition intelligence, allowing form, performance, and expression to emerge from the coupling of materials, CAM toolpath design, and robotic execution.

In relation to the research questions, the work demonstrates that materials, robotic strategies, and multimedia design tools co-author

outcomes when coordinated through explicit design-for-fabrication routines. Second, a coherent set of traits becomes legible: layering, continuity of bead paths, gradient articulation, controlled porosity, fluid curvature, and, at architectural scale, branching continuity and zones of translucency. These traits are not stylistic overlays but the direct result of toolpath logic, slicing strategy, and process parameters. The ecological stance is embedded in material choice, with recycled rPET and renewable fibre-based mixes used where appropriate. Third, clear pathways to building-scale practice are indicated, from gradient façade screens and lightweight lattices to service-integrated partition walls and interior panels, while recognising constraints such as certification, durability and fire performance, jointing and repair protocols, and maintenance access to embedded services.

The contribution is threefold: **conceptual**, by reframing priorities so that sustainability, functionality, aesthetics, and technology act as co-drivers rather than trade-offs; **methodological**, by codifying a transferable six-phase process that links theory, prototyping, and fabrication; and **technical**, by demonstrating that multi-material robotic deposition and three-dimensional slicing can deliver ergonomic compliance and structural stability with reduced waste and minimal post-processing. Postplasticism is not a style, but a framework for plurivocal authorship in which materials and machines participate meaningfully in the design process. Future work will focus on durability testing and exposure trials, fire and safety ratings for bio-based blends, standardised print parameters and gradient recipes, print-path efficiency, supply-chain reliability for recycled and renewable feedstocks, and regulatory alignment, so that the prototypes reported here can translate into certified architectural components at scale while preserving their aesthetic and ecological commitments. In conclusion, Postplasticism presents a compelling vision for redefining architectural priorities in the 21st century, striking a balance between sustainability, technological innovation, and social responsiveness. The approach not only addresses current environmental concerns but also opens new avenues for creative expression and functional design in architecture.

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DIGITAL TRANSFORMATION IN DESIGN EDUCATION: INTEGRATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES

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ABSTRACT

The technological developments in line with the requirements of the age have shown their effect in the field of education and have led to substantial transformations. These transformations, which have affected many fields of life, have also caused educational methods to shift from traditional approaches toward digitally based models. In this context, the discipline of interior architecture has also become one of the fields where the effects of digitalization are intensely felt. This study analyzes the advantages and disadvantages of AI-supported applications in interior architecture education, with a focus on three-dimensional atmosphere creation. In this context, a workshop was conducted with second-year Interior Architecture and Environmental Design students using an AI-supported application. It has been observed that there are certain difficulties, especially at the second-year level, in transferring material, lighting, color and texture knowledge to the third dimension. Therefore, within the scope of the workshop, second-year students carried out a study using artificial intelligence applications based on their current projects. The workshop is based on students conducting a study focused on atmospheric design using the AI-powered design application called PromeAI within the scope of their current studio projects. The three-dimensional outputs produced were analyzed in terms of creating atmosphere. Findings indicate that students could be productive when AI tools were guided appropriately.

Keywords: Artificial Intelligence, Design Education, Interior Architecture, Studio Education, Creating Atmosphere

INTRODUCTION

Rapidly advancing artificial intelligence technologies are bringing about significant transformation in education. Artificial intelligence is increasingly being utilized in many stages of education through methods such as virtual learning, information analysis, mapping, and machine learning (İşler & Kılıç, 2021). The use of these technologies in education has the potential to make teaching and learning processes faster and more effective. One of the areas where this transformation is most noticeable is design education. In this context, the aim of this study is to examine the role of AI-supported applications in interior architecture education, how students benefit from these technologies in the design process, and the advantages and possible limitations of these technologies.

As the number of experimental studies and research on the use of artificial intelligence in education increases, how new generation technologies can be used efficiently or identifying their harmful aspects has become an important topic of study. Today, there is a perceived need to make teaching/learning methods faster and more effective, and it is assumed that problems can be solved by using more 'digital learning materials' in education. In this context, artificial intelligence applications can serve as a technology-supportive educational tool (Camilleri & Camilleri, 2017). As artificial intelligence technology rapidly advances and gains new capabilities, scholars have discussed its potential to play a greater role in design processes, mimic human creativity, and even generate new forms of creativity (Ural et al., 2024). In the context of design education, it remains uncertain how interior design education positions itself within these developments and to what extent design processes are influenced by them.

Design is the cognitive process of imagining and attempting to create what does not yet exist (Akdemir, 2017). Design is a series of steps that includes: defining the goal, gathering and organizing the information necessary to achieve this goal; Analysis; presenting alternative solutions for the design problem awaiting a solution based on the information gathered during the process; Synthesis; evaluating the solution options created in the previous steps according to the specified criteria and selecting the most appropriate solution. In this context, artificial intelligence, which promises great opportunities in interior architecture and environmental design education, must be properly analyzed and recognized. This will enable future work in the field to be taken to a higher level (Yıldırım & Demirarslan, 2020). Design thinking and process cannot be evaluated separately; they involve a series of interconnected cognitive abilities (Cross, 2011). Design is a broad concept that

encompasses different disciplines. Considering the inclusive and interdisciplinary nature of the concept of design, Interior architecture exemplifies a discipline that embodies this concept through a contemporary perspective. Interior architecture is defined as a discipline that draws on art, shapes itself according to the desires and needs of users, and creates livable and aesthetic spaces. Interior design can also be defined as a profession that addresses spaces in terms of functionality, usability, and aesthetics to meet the needs of individuals, considering users' mental, physical, and behavioral characteristics (Saraf, 2013). It is a design discipline that can create and organize spaces by aiming to provide volume, safety, comfort, and aesthetic needs for the elements and actions required within the space and addressing these from a functional aesthetic perspective (Demirarslan, 2006; Demirarslan and Demirarslan, 2017).

Interior design education questions the relationship between space and people and analyzes space through its users. At the same time, interior design is defined as a discipline that shapes the relationship between space and users through function, users, and aesthetics. The fundamental areas of work in interior architecture consist of people and space. The focus is on people's engagement with space and contributing to the lives of individuals within that space. To create quality spaces in interior architecture, the presence of holistic components such as materials, light, color, and texture appropriate to the character of the space is important. All of these elements together create the concept of "atmosphere" in an interior space. Cordan (2017) states that the meaning of the word "atmosphere" still remains somewhat vague in people's minds. Therefore, it emphasizes the need to consider the multi-layered structure of atmosphere creation in design-related fields. It states that revealing the hidden, implicit, and concealed dimensions of atmospheric spaces, which are perceived/felt through unseen senses, is important for discovering socio-cultural values and parameters related to time and space in a place. For this purpose, interior design education requires students to internalize the aforementioned components and use them effectively in the design process. The selection of components that capture the appropriate and desired design language that reflects the character of the space depends on the designer's design skills, aesthetic understanding, and mastery of current developments (Onay, 2014). Material knowledge and the understanding of design based on this knowledge are important in the space design phase (Bunulday, 2003). Throughout the process, the variety, performance, texture, color, structural characteristics, character added to the space, selection criteria, methods used in application, and design concept of the materials used in the design are considered. In this sense, material courses offered in interior architecture education are designed to help

students acquire this awareness. In projects undertaken in design studios, quality increases with the correct use of materials, which are critical in determining the atmosphere of the space. Therefore, it can be said that material knowledge is an important part of interior architecture education in terms of atmosphere design. The atmosphere of a space is related to the state of mutual interaction that emerges through the subject-object dialogue centered on the lived experience. Just as interior space is constructed, its atmosphere is also deliberately created. The creation of a space's atmosphere and, consequently, the conception of the space itself, reflects the perception and meaning world of the space designer. The user experiences the space according to their own world of perception and meaning. Material harmony is important in creating atmosphere because the texture, hardness, and acoustic properties of the material affect and direct perception. The material gives the feeling of the space and creates the feeling of warmth and coldness of the space. Different materials come together to create a different touch and a different sound each time. Materials engage multiple senses, as perception occurs through sight, touch, smell, and hearing (Uysal & Cordan, 2022). According to Böhme (2018), who deeply analyzes the phenomenon of atmosphere in architecture, every space has an atmosphere. A space is not just a volumetric void, an abstraction, or a potential; it is something more than all of these, namely, an atmosphere. Although structurally invisible, atmosphere can be perceived through multiple sensory channels within a space. Therefore, when we describe a space as heavy, invigorating, fun, grand, elegant, calm, serious, etc., we are actually referring to the atmosphere of the space. We can speak of a powerful atmosphere, an atmospheric effect, or an atmospheric representation.

METHODOLOGY

This research examines the advantages and disadvantages of AI-supported applications in interior architecture education, with a particular focus on three-dimensional atmosphere creation. In this context, the research investigates how AI technologies contribute to the design processes of interior architecture students, focusing on atmosphere creation in three-dimensional visualization. Within the scope of the study, academic sources (books, articles, theses, and papers) published on AI-supported design education were examined through a literature review, and the existing knowledge base was analyzed. Based on this information, a workshop concept was developed for second-year, second-semester Interior Architecture and Environmental Design students. Second-year Interior Architecture students take courses on materials and lighting, which provide important data for creating atmosphere, starting from their first semester, thus establishing awareness and a foundation in this regard. However, it has been observed that there are certain difficulties, especially at the second-year level, in transferring this knowledge to the third dimension.

Therefore, within the scope of the workshop, second-year students carried out a study using artificial intelligence applications based on their current projects.

In interior design education, the project course is one of the important courses where students learn by experiencing design, develop different ways of thinking, and learn to create their own design language. In project courses, which form the basis of interior design education, students strive to create projects of different square footage and concepts throughout their education.

The workshop is based on students conducting a study focused on atmospheric design using the AI-powered design application called PromeAI within the scope of their current studio projects. PromeAI, selected as the primary tool for the workshop, is an AI-based design and visualization platform. It supports participants in visual content production, development, and conceptual design processes. Its visual outputs, particularly those related to elements that create spatial atmosphere, such as materials and lighting, highlight the tool's potential contributions in the design context. PromeAI can realistically simulate various material and texture types based on user inputs (prompts); it can automatically adjust material scales to appropriate ratios, which are manually set in traditional rendering processes. It also offers users customizable solutions for parameters such as light and surface characteristics. Its open-access model ensures equal accessibility for all participants In this context, integrating PromeAI into the workshop process allows students to directly experience AI-powered design tools while also laying the groundwork for more in-depth evaluations of the impact of these tools on interior design education.

Students will produce three-dimensional (3D) visualizations related to spatial design using common digital programs such as V-Ray, Lumion, Enscape, Twinmotion, and D5 Render; at the same time, they will re-conceptualize the same project through PROMEAI in an atmosphere-focused manner with artificial intelligence support. The output of both production processes will be organized in a way that allows for comparison.

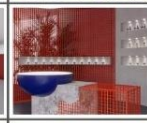
FINDINGS

At the beginning of the workshop, students collected atmospheric references from various sources. After scanning, students were asked to select the image they considered best expressed the atmosphere of the space. With the help of AI-powered tools, they were able to explore how to integrate these atmospheric references into their designs and test them in a spatial context. The workshop aimed to reveal the advantages that artificial intelligence tools offer students in terms of improving their decision-making processes, providing innovative solutions and alternative perspectives, and gaining speed and creative approaches to the process of creating materials and atmospheres.

The workshop evaluated the applicability of atmospheric decisions such as material selection, color, lighting, and texture in the three-dimensional spatial visuals produced by students using both traditional digital and AI-supported methods. By comparing the three-dimensional visuals created by the students,

this enabled a comparative analysis of the advantages and disadvantages of AI methods. The workshop was conducted with a total of 20 students. Since these students carried out their project work in pairs, a total of 10 projects were evaluated. Table 1 lists all the projects examined. The projects vary in terms of function and designed space. Each group tried to create the atmosphere of the space based on a visual they found for the atmosphere.

Table 1. Workshop Analysis for Second Year Students

Students' Grade Level	Project Topic	Evaluation of the Atmospheric Visual	Project Rendering	Atmosphere Visual	Ai Render	Did the student find it useful?
2nd Grade	Exhibition Area	Futuristic				No
2nd Grade	Exhibition Area	Futuristic				No
2nd Grade	New Generation Office	Futuristic				No
2nd Grade	Exhibition Area	Futuristic				No
2nd Grade	Exhibition Area	Modern				No
2nd Grade	Hotel Lounge	Futuristic				Yes
2nd Grade	New Generation Office	Biophilic				Yes
2nd Grade	Store	Biophilic				Yes
2nd Grade	New Generation Office	Industrial Modern				Yes
2nd Grade	New Generation Office	Modern Industrial				Yes

The project shown in Figure 1 is an exhibition stand project. Throughout the project period, students researched visuals from various sources, considering alternatives, and selected the example visual that best reflected the brand identity and brand expectations from among these visuals. It was observed that the students, who were careful to ensure that this visual had a futuristic atmosphere, provided this data in their selections. The three-dimensional visual produced by the students was created using the "Lumion" software.

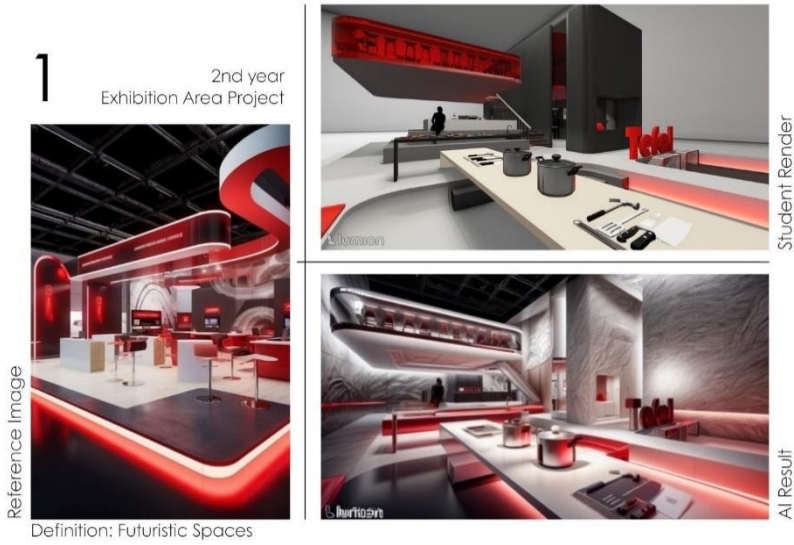


Figure 1. The exhibition project examined within the scope of the workshop

The visuals created by the students using the three-dimensional program and artificial intelligence application were examined in terms of material use, lighting, color, and texture in relation to the atmosphere. The use of materials, lighting, and texture in the AI-generated in the space visual created with artificial intelligence brings a positive perspective to the atmosphere of the space. Furthermore, the visual produced by artificial intelligence shows students that they need to consider the floor, ceiling, and wall surfaces of the space in terms of material and texture. In their evaluation, the students reported that the AI application was inadequate in accurately recognizing material mapping settings. However, they noted that the visual created by artificial intelligence contributed to recognizing the atmospheric effect.

Another project examined is shown in Figure 2. When comparing the outputs of the project given as a hotel lobby, it was seen that some

openings were added to certain enclosed areas in the AI-supported rendering. Some furniture selections have changed. Students found these changes useful. In their feedback, they commented, "While trying to create a modern futuristic atmosphere, we were lost in terms of material selection, and the AI-supported rendering positively influenced the atmosphere of the space by using materials that we would not normally use." In this context, although the AI application was weak in terms of details, it was beneficial in terms of the atmosphere it created. The color and texture quality were found to be beneficial for the overall concept. The use of lighting also supported the atmosphere.

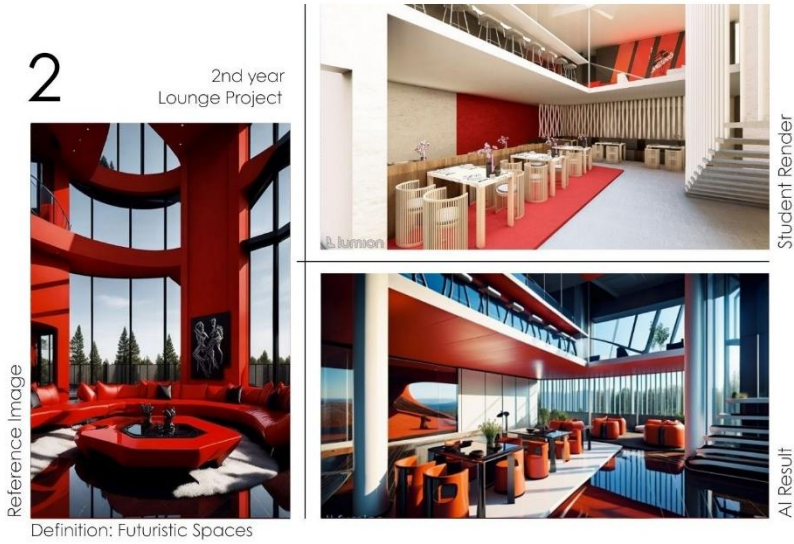


Figure 2. Hotel lounge project examined within the scope of the workshop

The project shown in Figure 3 is a store project. When comparing traditional methods with AI-supported visualization outputs, it was observed that the AI application made different decisions regarding scale. In particular, there was a scaling issue regarding the height of the space. The relationship between closed and open spaces was also not correctly perceived by the artificial intelligence in this project. However, the students found the method useful and stated that the artificial intelligence application gave them a different perspective, that they chose a reference image considering the materials they used, but that it followed a different path, and therefore this different perspective diversified them in terms of materials. Upon detailed examination of the visuals, although natural light was observed as an important factor in the design of this space, the artificial intelligence output eliminated it. It is

seen that blocking the point where the space would receive natural light weakened the three-dimensional spatial perception.



Figure 3. The store project examined within the scope of the workshop

The project shown in Figure 4 was designed as an exhibition hall. It can be seen that at the end of the scanning process, the students selected a visual that was more related to the form of the space than the atmosphere. Consequently, there were difficulties in terms of creating the desired atmosphere.

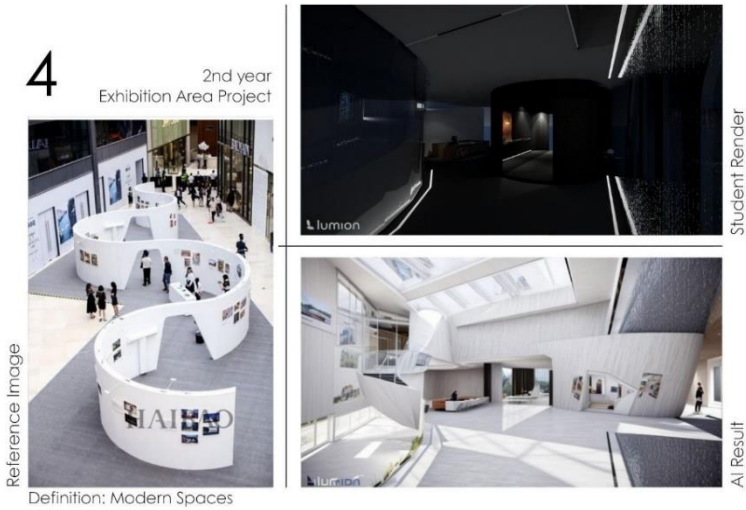


Figure 4. The exhibition project examined within the scope of the workshop

In the project shown in Figure 4, it is evident that the students wanted to create a dimmer environment in terms of atmosphere. However, the form-focused selection of the reference image caused the AI application to also focus on form and, due to the selected image, added natural lighting elements to the space. At the same time, it played with scale and produced an output that was much larger than the given area. The AI failed to correctly assess the balance between open and closed spaces in this project as well. Students stated that the AI application tended to alter the design by adding various elements that deviated from the core of the design and that it also failed to provide any benefit in terms of atmosphere. In this project, it was observed that students focused on form rather than atmosphere when scanning visual references. At this point, re-evaluating with a visual that could serve as an example of atmosphere alone would guide students more accurately in terms of atmosphere.

Overall, based on the data obtained within the scope of the workshop, the attitudes of second-year students towards AI-supported applications were largely positive. Participants particularly noted that the artificial intelligence application was useful in creating atmosphere through components such as materials, lighting, color, and texture. Especially in terms of lighting, it was seen that the application generated useful ideas for atmosphere through the visuals it created. It was observed that the artificial intelligence application provided ideas, particularly in the selection of materials and colors for atmosphere, which is frequently

encountered at the second-year level. Furthermore, its ability to generate various alternatives in a short time can be stated as another feature that students found useful. However, it was observed that some of the images generated by the AI application had scaling issues. It can be stated that it experienced difficulties, particularly in the perception of form. At the same time, it is possible to say that the AI application predominantly used the materials and colors found in the reference image.

CONCLUSION

Today, artificial intelligence applications are seen as a tool that accelerates and diversifies the process of creating atmosphere in the field of design. This study demonstrates how theoretical knowledge can be applied in practice by focusing on atmosphere creation through key elements of interior design such as materials, lighting, color, and texture. Through the AI-supported interior atmosphere workshop, interior architecture and environmental design students explored the possibilities offered by today's digital technologies in the design process and experienced how these technologies could be integrated into the process. The main objective was to observe how the atmosphere created by the materials, light, color, and texture used in the three-dimensional images obtained by students using traditional digital methods and with artificial intelligence support made a difference. Therefore, this study evaluated whether artificial intelligence technologies could be used as a tool in interior design.

The workshop conducted as part of the research aims to raise awareness about how artificial intelligence and traditional methods can work together and how this work can benefit the design process. Students were made aware not only of the potential of artificial intelligence but also of its limitations during the workshop. The main expectation of the workshop was that students would be able to produce alternative solutions by taking advantage of the possibilities offered by artificial intelligence during their work. However, during this process, students also experienced a number of technical difficulties and problems such as not achieving the expected results. This situation created an awareness that the artificial intelligence application needed to be guided with accurate and clear information.

During the design phase of the project, which was carried out using traditional digital drawing techniques, students engaged in a serious research process regarding atmosphere creation and material selection. It was observed that students frequently discussed questions such as, “Which materials can create which atmosphere?” or “Which

materials can provide the atmosphere defined in the concept?" Students stated that they gained the ability to use AI in their projects in a beneficial way with accurate visuals through a process that integrated AI-supported digital methods. This method not only provided students with a significant benefit in time management but also allowed them to quickly test their design decisions and achieve accurate results through the alternative generation capabilities of AI tools. The various material alternatives suggested by AI tools have also increased students' ability to expand the range of materials they use in their projects and to combine unconventional material selections instead of repeating material usage. Through workshop activities, it was observed that some students gained awareness in their projects regarding the analysis of material types, understanding the textures, colors, and light interactions of materials, and generating original solutions with different materials. In terms of creating alternative atmospheres, it was observed that students experimented with different atmospheres using AI-supported tools and analyzed these atmospheres to integrate them into their own projects. This process is important in terms of developing alternatives in design and producing alternatives by observing various approaches.

On the other hand, findings indicate that students could be productive when AI tools were guided appropriately. They may be using the application for the first time, and in this case, they may experience difficulties both technically and in expressing themselves correctly with commands. Therefore, this situation may lead to inefficiencies in students' workflow. There are numerous options offered by artificial intelligence tools. It is important for students to direct these options correctly in order for the application to deliver the desired results.

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THE ROLE OF ARTIFICIAL INTELLIGENCE IN ARCHITECTURE: A TRANSFORMATIVE PRIORITY

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ABSTRACT

Today, artificial intelligence (AI) stands out as a technology that is bringing about fundamental changes in the discipline of architecture. This study aims to question the transformative role of AI in architectural practice and education based on literature and to discuss whether this should be a priority. The research systematically examines the integration of AI into architectural design, planning, and construction processes over the past decade. The effects of AI on architecture in the literature are grouped under four main themes: (1) Generative Design (algorithm-optimized form discovery), (2) Data Analytics (urban-scale modeling and prediction), (3) Sustainability (energy performance simulations), and (4) Construction Technologies (robotic production and autonomous construction). For example, AI-based tools (Grasshopper + AI plugins, DALL-E) enhance designers' creativity in the conceptual phase. However, with the widespread adoption of these technologies, criticisms such as skill gaps, the risk of design standardization, and ethical issues (data privacy, unemployment concerns) have also become more prominent. The study is based on a thematic analysis of more than 50 articles searched in the Web of Science and Scopus databases using the keywords "artificial intelligence in architecture." The findings show that AI has become a strategic priority that shapes the future of the discipline, beyond being merely a "tool." AI-supported approaches are particularly prominent in solving complex urban problems (climate change, population growth). In conclusion, this research argues that the architecture community should embrace AI not as a "threat" but as a "partner" that expands design potential. Future studies should address AI-architecture interaction from a human-centered perspective and focus on developing ethical frameworks.

Keywords: Artificial Intelligence, Architectural Design, Generative Algorithms, Digital Architecture, Sustainable Planning

INTRODUCTION

Today, digital spaces designed in a digital environment with artificial intelligence support are created in a qualified manner, together with the architectural concepts that form the space, ideas, concepts, and images that also constitute the semantic dimension. In this respect, computers and artificial intelligence have become an alternative to paper and pen, the classic representation tools in the field of design. Computers, which offer designers opportunities to discover new forms and provide convenience in many ways, have created artificial representation environments where lines, colours, and forms are expressed mathematically, accelerating the design process. However, products designed using computer technologies in the design process are sometimes limited by the characteristics of interfaces and software. Designers conceptualise the space they perceive as a product with the user in mind and visualise it by ensuring its symbolic nature. In this respect, problems arising from the technologies of the interfaces and software used in the design process influence or constrain designers, leading to the transformation of the product that emerges during the design process. Similar contemporary designs that we often encounter are mostly computer-aided products.

Artificial Intelligence (AI) has increasingly emerged as a transformative and vital priority within the architectural discipline in recent times. Its growing prominence signifies a fundamental and significant shift in contemporary design methodologies and construction practices. The applications of AI have begun to profoundly influence various aspects of building development, artistic exploration, and creative workflows, while also enhancing the management of design processes, team interactions, and effective communication. These advanced capabilities empower architects to respond more rapidly and efficiently to evolving client needs and dynamic societal demands, thereby enhancing the overall design experience. As AI continues to evolve and integrate, its potential to reshape architectural practices is becoming more apparent.(Li et al., 2023). The technology's integration thus marks a disruptive phase promising to reshape Archi-tecture by impacting its underlying foundations and presuppositions.

Early AI-driven architectural tools initially concentrated on the automatic generation of architectural plans and structural systems, significantly shifting traditional methodologies in profound ways. Within this expansive landscape, meticulously defined terminologies were developed for various architectural elements, all intricately tethered to specific stylistic and organizational contexts that influence design choices. These conceptual frameworks were thoughtfully designed to

emulate core architectural ideas, such as hierarchy, modularity, and spatial relationships, directly enabling the rapid and efficient creation of comprehensive building layouts that effectively cater to various diverse functional needs. Concurrently, a dedicated and passionate community of architects and designers began to thoroughly explore the experimentation of computational morphologies, pushing boundaries in design and form, and challenging conventional norms. Over the past decade, the applications of artificial intelligence alongside advancements in materials engineering have rapidly grown more closely interwoven with the intricate processes of design production, thus greatly enhancing the overall efficacy and effectiveness of architectural projects in innovative ways. During the project execution phase, advanced Machine Learning (ML) algorithms effectively utilize extensive training data to validate, refine, and enhance virtual design models, providing invaluable real-time insights through diligent and thorough construction-site monitoring that improves project outcomes. Alongside these dynamic advancements, sophisticated intelligence models that incorporate intricate elements of architectural cognition and computation continuously facilitate the generation of innovative design concepts and forms. These concepts are all grounded in a deliberate balance between essential functional necessities and aesthetic principles, driving the future of architecture towards a more intelligent, adaptable framework that responds to the ever-evolving needs of contemporary society.

2.Historical Context of AI in Architecture

Artificial intelligence has become more than just a design tool; it is now an intellectual partner that guides design decisions, analyzes spatial data, anticipates user experiences, and manages construction processes. Therefore, it is inevitable that this transformation will fundamentally change the current structure of architecture and its future role. Consequently, the AI-driven transformation occurring today is more profound and comprehensive than any previous change (Mitchell, 2020).

One of the most significant contributions of artificial intelligence to architectural design is the acceleration of data-driven decision-making mechanisms and the enabling of more complex spatial solutions. In traditional design processes, architects spent a lot of time and effort on stages such as drawing, modeling, and simulation, but thanks to AI-based tools, these processes have been automated and made more flexible (Burry & Burry, 2016).

For example, generative design algorithms can generate thousands of alternative design proposals based on specified parameters, thus offering architects a wide range of options to choose from. Tools such as Autodesk's "Project Dreamcatcher" process data such as functional requirements and material properties to produce innovative solutions that human designers could not have anticipated (Aish & Hanna, 2017).

However, AI-supported optimization methods contribute to sustainable architectural production by considering performance criteria such as energy efficiency, natural light utilization, airflow, and acoustics (Turrin, Buelow, & Stouffs, 2011). For example, machine learning algorithms working on large data sets make urban planning processes more accurate and scientific by performing climate analysis at the city level (Zhou, Deng, & Lin, 2020). However, the complete autonomy of AI-supported production processes has also brought ethical debates. The question of whether human creative intuition or mathematical calculations of algorithms will dominate design is still being debated in the field of architecture (Mitchell, 2018).

This section examines how artificial intelligence is addressed in architectural literature through a thematic analysis. The methodology of the study is based on content analysis of more than 30 articles published between 2010 and 2023 in the Web of Science and Scopus databases. The findings are classified under four main themes: (1) Generative Design, (2) Data Analytics, (3) Sustainability, (4) Construction Technologies.

Generative Design (Algorithmic Form Discovery)

generative design is one of the areas where artificial intelligence is most intensively used in architecture. In this approach, algorithms generate design variations based on specific performance criteria. For example, Autodesk Generative Design can offer thousands of design alternatives that optimize structural efficiency and material usage (Autodesk, 2020). Rhino/Grasshopper plugins integrate with artificial intelligence to provide architects with learning systems that go beyond parametric design (Stasiuk, 2019). The literature provides strong evidence that generative design enhances creativity, particularly in the conceptual design process (Cabral & Duarte, 2019). Today, generative design systems are tools that generate alternative solutions based on parameters defined by architects (Gerber & Lin, 2013). However, in the future, these tools will not only offer alternatives but will also evolve into autonomous systems that develop design proposals on their own.

For example, AI that analyzes the environmental, economic, and social data of a structure can develop optimal solutions without designer intervention and will only require human intervention during the final approval process (Goodfellow, Bengio, & Courville, 2016). However, the risks of homogenization of designs and loss of originality are also being addressed (Oxman, 2017).

Data Analytics (Urban-Scale Modeling and Forecasting)

Decision-making processes in architecture are increasingly becoming data-driven. User behavior data, climatic parameters, and urban dynamics are analyzed in large data sets to guide design (Li, Yang, & Li, 2019). In the future, architects will adopt a more "scientific" design approach based on data analysis produced by algorithms, in addition to intuitive decisions.

At the city level, artificial intelligence, combined with big data analytics, is developing predictive models. Batty (2018) emphasizes that artificial intelligence is one of the most critical components of smart cities. Models developed based on traffic density, energy consumption, and climate data are used as decision support systems in urban planning. Therefore, smart city visions are one of the most visible areas of AI's impact on architecture. Processes such as traffic flow, energy consumption, and waste management in cities are monitored using data collected through sensors and optimized by artificial intelligence (Eastman et al., 2018). This development also directly affects architects' urban-scale design decisions. Machine learning-based systems, in particular, produce simulations for complex dynamics such as rapid population growth and migration (Kandt & Batty, 2021). Thus, artificial intelligence plays a decisive role not only in building design but also in the sustainable management of cities.

Sustainability (Energy Performance Simulations)

Sustainability is one of the fundamental priorities of contemporary architecture. Artificial intelligence-supported energy simulations optimize the environmental performance of buildings. For example, artificial neural networks are used to predict the energy consumption of buildings and increase energy efficiency (Amasyali & El-Gohary, 2018). The role of architecture in combating climate change is increasingly important. Artificial intelligence develops strategic solutions in areas such as calculating the carbon footprint of buildings, planning adaptation according to climate scenarios, and integrating renewable energy (Wang & Gu, 2021). This transformation demonstrates that architecture is not only related to structures but also to sustainability on

a planetary scale. Again, AI-based tools produce solutions in areas such as building envelope optimization, natural lighting, and climate adaptation (König, 2019). Studies in the literature in this field show that artificial intelligence is a critical tool in achieving sustainability goals.

Construction Technologies (Robotic Manufacturing and Autonomous Construction)

Artificial intelligence, automation, and robotic technologies are gaining prominence in the construction industry. Bock and Linner (2015) argue that robotic industrialization will fundamentally transform construction processes in the future. Autonomous machines, unmanned construction sites, and 3D printing technologies will revolutionize the application of architecture. Furthermore, artificial intelligence-supported BIM (Building Information Modeling) systems reduce the margin of error in construction site management and increase cost efficiency (Tan et al., 2021). This demonstrates that architecture is undergoing a transformation not only in design but also in implementation and production processes.

From an economic perspective, AI-supported production processes reduce costs, save time, and increase efficiency in the construction industry. In particular, prefabrication and robotic construction techniques, combined with AI integration, enable faster and lower-cost projects to be implemented (Gramazio & Kohler, 2014). However, this process is leading to transformation in the labor market, and the replacement of unskilled labor by automation is raising new debates about social justice (Frey & Osborne, 2017).

One of the most important concepts that has been partially overlooked in the literature is "human-machine collaboration." In the architecture profession, the concept of "human-machine collaboration" has become increasingly important. While architects focus on the conceptual and aesthetic aspects of design, AI systems take on technical calculations, optimizations, and data analysis. This division of labor enables the profession to be practiced in a more creative and innovative way (Picon, 2021). According to Kuntz et al., the new design paradigm is based on collaboration between humans and machines. Architects will manage not only aesthetic and cultural decisions but also the ethical framework within which AI systems operate (Kunz, Smith, & Zhao, 2022). In this process, the architect's role will go beyond that of a "designer" and take on new dimensions such as "technology curator" and "data manager."

3.1 Artificial Intelligence Tools and Algorithms Used in Architecture

Artificial intelligence (AI) has evolved beyond being merely a tool that facilitates the design process in the field of architecture today, becoming one of the fundamental drivers of design. The use of artificial intelligence is becoming increasingly widespread, particularly in areas such as generative design, parametric modeling, energy efficiency analysis, and automatic plan optimization (Chollet, 2019). The adoption of artificial intelligence tools in architecture enables designers to find much faster and more systematic solutions to problems that were previously difficult to solve manually.

In traditional architectural design approaches, designers initiate the drawing process by envisioning a specific form; in AI-based approaches, design problems are defined by algorithms and the solution space is explored by the computer. Thus, the designer becomes not only the selector of solutions but also the manager of the process (Mitchell, 2020). In this context, a detailed examination of artificial intelligence tools and algorithms is critical to understanding the future direction of the architecture profession.

Computer-Aided Design (CAD) and Building Information Modeling (BIM) software used in architectural design are now supported by artificial intelligence add-ons. For example, Autodesk Revit's generative design modules or Archicad software's artificial intelligence-based energy simulation tools enable architects to make much more accurate and efficient decisions (Eastman, Teicholz, Sacks, & Liston, 2018). Additionally, machine learning algorithms used in BIM systems analyze the performance data of building materials to suggest the most suitable options in terms of cost and sustainability. This demonstrates that not only design but also construction management processes are being transformed by artificial intelligence.

In the context of Optimization Algorithms and Generative Design, one of the most widely used AI-supported tools in Architecture is generative design software. For example, Autodesk Generative Design or Grasshopper + AI plugins can optimize thousands of alternative forms according to specified criteria (Gerber & Lin, 2013). The genetic algorithms and artificial neural networks used here produce optimal solutions by modifying design parameters.

These tools develop multidimensional solutions that take into account not only aesthetic forms but also performance criteria such as energy consumption, user comfort, and structural durability. We can also mention the most important artificial intelligence tools in architecture in the context of Image Processing and Object Recognition Tools. In recent

years, AI systems focused on visual production, such as DALL·E, Stable Diffusion, and Midjourney, have become powerful tools for architects in the conceptual design phase. This software can produce not only abstract sketches but also photorealistic renderings, interior designs, and alternative facade solutions (Kunz et al., 2022).

In addition, computer vision-based artificial intelligence software provides functions such as automatic facade recognition, building typology classification, and pre-implementation visualization by analyzing existing urban fabrics. In particular, Google's DeepMind technologies' image classification algorithms are used in urban-scale data analysis.

Finally, when examining artificial intelligence tools used in interior design, AI-based tools in the field of interior design focus on enhancing user experience and spatial comfort. Software such as Planner 5D, Homestyler, and DecorMatters analyze user preferences through machine learning to provide personalized design suggestions (Wang & Gu, 2021).

Additionally, AI-based texture mapping tools (e.g., Adobe Firefly, NVIDIA GauGAN) enable interior surfaces to be automatically covered with different material alternatives and photorealistic visualizations to be created. These tools have a wide range of applications, from interior design students to professional design offices.

3.2 Artificial Intelligence Algorithms and Architectural Applications

Architecture is undergoing a fundamental transformation by integrating algorithms such as Artificial Neural Networks, Genetic Algorithms, Deep Learning, and Reinforcement Learning. The most important reason for using these algorithms in architecture is to take design processes to a level of complexity and optimization that cannot be achieved with traditional methods. This makes it possible to produce data-driven and rational solutions instead of intuitive decisions.

These four algorithms, when integrated, offer unique potential for solving architectural problems. Artificial Neural Networks and Deep Learning can analyze complex spatial data to predict factors such as light, acoustics, and energy performance. Therefore, even in the early stages of design, in-depth information about the building's performance can be obtained. Genetic Algorithms can be used to find the best solution among thousands of design alternatives based on specific criteria (e.g., material usage, cost, or structural efficiency). This accelerates the optimization and form discovery processes. For example, Reinforcement Learning can determine the most efficient strategies for smart building

systems by simulating an architectural model's adaptation to environmental conditions or user behavior. These algorithms empower architects to design structures that are not only more efficient but also more sustainable, more aesthetic, and more functional (Leach, 2022). We can briefly describe these artificial intelligence models.

Artificial Neural Networks, (ANN) ANNs are used in architecture, particularly in areas such as heating and cooling load estimation, energy performance analysis, and user behavior modeling. By processing large datasets related to buildings, they can predict the most suitable solutions in terms of energy efficiency (Li, Yang, & Li, 2019).

Genetic algorithms enable design optimization by mimicking evolutionary processes found in nature. They are particularly effective in areas such as complex form generation, structural stability analysis, and light-shadow calculations (Holland, 1992). Architects can use these algorithms to select the most suitable option from hundreds of different design alternatives.

Deep learning models provide significant convenience in visualization and rendering processes. For example, Convolutional Neural Networks (CNNs) can generate new facade designs by transferring styles from spatial images (Goodfellow, Bengio, & Courville, 2016). Furthermore, GAN-based (Generative Adversarial Networks) structures can automatically generate different variations of architectural concepts.

Reinforcement Learning algorithms are particularly prominent in robotic construction and autonomous building systems. These algorithms enable machines to learn optimal construction methods through trial and error (Sutton & Barto, 2018). This minimizes human error on construction sites and speeds up processes.

3.3 Benefits Provided by Artificial Intelligence Tools in Architecture

Artificial intelligence is positioned not only as a tool that accelerates the design process in the field of architecture, but also as a partner that encourages creativity. The benefits it provides are multidimensional and these benefits create significant advantages for both designers and users.

Efficiency and Speed in Design

AI-based tools can complete tasks that could take weeks in the traditional design process in just a few hours. Generative design systems, in particular, simultaneously produce different scenarios for a building (e.g., facade variations, spatial configurations, energy performance)

and accelerate the designer's decision-making process (Gerber & Lin, 2013). This increases the competitiveness of architecture firms and enables more accurate decisions to be made in the early stages of projects.

Solving Complex Problems

Urbanization, population growth, and climate change have made the field of architecture more complex. AI algorithms can process multidimensional data to provide optimal solutions at the urban scale. For example, deep learning-based simulation tools can analyze the heat island effect in a city and suggest the most suitable locations for new green spaces (Li, Yang, & Li, 2019).

Customized Architecture

YZ also plays an important role in the development of user-centered designs. Machine learning algorithms used in interior design applications can develop customized design recommendations based on individuals' lifestyles, habits, and preferences (Wang & Gu, 2021). Thus, architecture is transforming into a discipline that goes beyond merely producing physical spaces to directly improving individuals' quality of life.

Sustainability and Energy Efficiency

Today, sustainability has become an indispensable aspect of architecture. AI-supported software predicts the energy consumption of buildings and recommends the most efficient design decisions, while also minimizing environmental impacts in processes such as sunlight optimization, natural ventilation scenarios, and material selection (Eastman, Teicholz, Sacks, & Liston, 2018).

Innovation in Construction Technologies

Robotic systems and autonomous machines are becoming smarter with the support of AI. Autonomous cranes, 3D concrete printers, and unmanned inspection drones used on construction sites are reducing the burden on human labor and lowering the margin of error (Sutton & Barto, 2018).

Design action as a condition that occurs in the world of images is concerned; during the design process mind works at the level of the duration of the abstraction, the fact that most of the sources of inspiration for non-existent abstract concepts are seen. Interior Architecture is one of the important basic discipline in design that is

rapidly developing, renewing itself according to the rapid change in technology and living standards in daily life.

The integration of artificial intelligence (AI) within the dynamic and ever-evolving field of architecture signifies a profound and essential shift from what was once considered merely a fleeting trend to a genuinely transformative priority that increasingly demands our focused attention, considerable resources, and decisive action. The strategic alignment between intricate design tasks and sophisticated AI techniques remarkably accelerates the overall architectural production process by significantly enhancing not only problem-solving speed but also the overall quality of the outcomes produced by these innovative approaches. With the rapid and ongoing development of advanced tools that are capable of generating a remarkably diverse array of design options based on a wide range of specific inputs, architects now possess the extraordinary ability to explore many more possibilities than they have ever had access to before in their creative processes and design strategies. What was once largely confined to academic settings and experimental domains is becoming commonplace in established professional practices.

Space is the phenomenon of other components that make up itself as a fiction. In a paradoxical structure of life and fluctuating of the time that individuals live, gain some experiences by give meaning to spaces that thanks to the the images were created by using the forms. The design of interior space (space) only when associated with the attributes, inward-looking place, it is the reflection of the shell (outer mass) is a reflection of the global outward-looking place. Therefore, they were not against to each other even if they are nested, complementary to each other by overlapping.

The advent of robust, strong, and affordable AI software has dramatically extended its positive impact across a myriad of design projects, intricate construction processes, and extensive urban strategies that are crucial for modern urban development. Furthermore, Building Information Modelling (BIM) continues to be an indispensable and critical component in the formulation of complex, innovative architectural projects. These significant advancements are now greatly facilitated by the expanding capabilities and functionalities of AI technologies. Beyond the traditional applications found within architecture and the construction fields, AI has begun to assume an influential and pivotal role in the increasingly relevant realm of smart city initiatives, as well as in advanced traffic management platforms. This development underscores AI's expansive, multifaceted potential in shaping the future urban landscapes that communities aspire to create

and sustain over time. As the rapid technological evolution continues to advance further and further, substantial opportunities are anticipated to arise that will deepen the integration of AI within architectural processes, thus fostering enhanced creativity and efficiency. Such ongoing integration not only maintains AI's status as a vital transformative priority, but also represents an essential area of focus that architects around the globe must actively not only acknowledge but also engage with and address continuously in their daily practice. This engagement is necessary to remain competitive, forward-thinking, and genuinely innovative in an industry that is rapidly evolving and changing in significant ways. (Nourian et al., 2023)(Li et al., 2023)

3. The Fascinating Intersection of Artificial Intelligence and Architectural Design

A creative design solutions begin with a good design concepts. This means the concept will lead the way and give a direction for design decisions, than final product.

Each design item is unique according to its inspirational source of possible new innovation and is fully adapted to give meaning to its own close environment. Inspirational sources can vary according to the imagination of its designer. The most important effects of inspiration source are directly related with the problem solving methodology that can help to create new standards for interior architecture, users, design field and society.

A designer as well as being an inventor who expresses his or her creativity must have an inspiration point or source. Creativity is calling an imaginative force to solve the design problems together with the abilities to expand limitations of ideas and concepts. To reach essential ability that a designer has to reach and internalise to his or her designer identity. An original design has to specifiied by the designers' different angled way of thinking and approaches.

Artificial intelligence (AI) occupies an increasingly prominent and significant role in architectural practice across the globe, reshaping and redefining how architects conceive, plan, and implement their projects. Formally defined as the intelligence demonstrated by machines rather than humans, AI seamlessly transforms the design process, moving it away from traditional, manual methods into a new and innovative paradigm that is heavily mediated by sophisticated computational techniques and advanced algorithms. Architects and designers are already utilizing advanced AI tools such as Generative Design, Parametric Modeling, and Building Information Modeling (BIM), which profoundly enhance both creativity and efficiency throughout the

design and construction processes. These powerful capabilities enable a combinatorial approach that effectively integrates expert knowledge with sophisticated data science, inventive exploration, and global search techniques. This well-rounded combination fosters the discovery and exploration of innovative design alternatives that may not have been readily apparent through traditional or conventional methods of architectural design. Further research continues to examine and explore the myriad applications of AI at urban scales, thereby supporting the development of smart cities and intelligent traffic management systems, all with a keen focus on promoting sustainable, low-carbon growth strategies that benefit communities. Consequently, the integration of AI into architectural practice no longer just represents an interesting trend but forms a critical and urgent priority for the future education and training of architects. As the discipline evolves and advances, architects must adapt to an increasingly digital and interconnected environment where technology and design intertwine deeply. This necessitates the acquisition of new skills and knowledge to leverage AI's transformative potential effectively and meet the multifaceted challenges of contemporary architecture and built environments. (Li et al., 2023) (Nourian et al., 2023)

Artificial intelligence (AI) refers to the remarkable capacity of machines to simulate and replicate numerous aspects of human intelligence. As a result, any device or system that mimics activities characteristic of a person's cognitive processes — such as learning, reasoning, and effective problem-solving — can be described as exhibiting artificial intelligence. One notable subfield, known as machine learning, employs complex algorithms to learn from extensive sets of data and recognizes intricate patterns that might be unobtainable through traditional means. Generative design, another fascinating application, leverages these powerful algorithms to autonomously generate and evaluate a multitude of design options that align with user-defined goals and specific criteria. In addition to this, a related technique known as rules-based design enables the agile creation of design variations that are responsive to changing parameters and conditions, ultimately allowing for greater flexibility and responsiveness in the overall design process.

In the rapidly evolving domain of interior architecture, AI presents numerous exciting new possibilities and innovative pathways to explore. By employing sophisticated tools such as advanced 3D visualization, immersive virtual reality, and engaging augmented reality, interior architects can create captivating environments that enhance both presentation quality and user experience. These advanced AI technologies empower interior architects to make not just informed but also intelligent design decisions by drawing on rich, detailed data

regarding user behavior and space utilization patterns. Such data-driven decisions can significantly lead to optimizations and refinements in spaces that more aptly satisfy specific functional and aesthetic requirements, promoting a balanced relationship between form and function.

Interior designers are increasingly seeking innovative inspiration and effective solutions from artificial intelligence (AI), meticulously mapping intricate details and requesting a variety of AI-driven configurations to bridge the gap between imagination and reality. The fascinating convergence of interior architecture—a specialized domain that comprehensively addresses spatial comfort, optimal functionality, and captivating aesthetics—and AI unfolds a transformative and evolving landscape filled with possibilities. AI's diverse and expansive study domains invite profound inquiries into its specific applications within the realm of interior architecture, as well as the crucial role of designers who find themselves subject to intense competition fueled by advancements in AI technology (Almaz et al.2024).

The fusion of AI and interior design extends the prospect of innovative developments from distinct yet allied frameworks. Interior design endeavors to craft harmonious spatial environments that align form with usage and exude artistry. Since the 1960s, AI has embraced tasks traditionally suitable only for humans, such as natural language processing, driving artificial agents (e.g., self-driving cars), and managing complex planning and scheduling problems, collectively ushering a new era of interior architecture.

Architectural innovation effectively incorporates advanced AI technologies to generate high-quality and innovative spatial solutions while adeptly addressing a multitude of unexplored challenges that frequently arise during the intricate design process. In contemporary design practices, professionals confront a diverse array of critical considerations, including essential elements such as lighting, acoustics, ventilation, spatial layout, and overall accessibility. Here, AI-driven generation truly becomes an invaluable tool, enabling the creation of efficient, highly creative, and uniquely customized architectural space solutions that are meticulously tailored to meet specific requirements and needs of the users. The seamless synergy between interior architecture and AI not only anticipates potential issues but also actively enhances spatial comfort and usability through the careful selection and application of premium branded materials. Ultimately, this thoughtful integration significantly bolsters overall design productivity and effectiveness, empowering architects and designers to push the

boundaries of what is feasible in crafting truly inspiring, aesthetically pleasing, and functional l spaces for diverse purposes.

Furthermore, interior architects can utilize AI effectively to meet critical sustainability imperatives in their work. The analytical capabilities of AI allow for the proposal of innovative and cutting-edge design concepts that not only promote energy conservation but also diligently optimize material usage across various projects. By thoughtfully integrating these AI-driven strategies into their workflow, interior architects are not only better equipped to create spaces that are visually appealing, functional, and efficient but also environmentally responsible. This powerful combination demonstrates a strong and unwavering commitment to sustainable design practices that ultimately benefit both the users and the planet, ensuring that future generations can enjoy environments that are as harmonious with nature as they are with human needs.

3.1. Generative Design

Generative Design (GD)—primarily fueled by the remarkable advances in Artificial Intelligence (AI)—utilizes a diverse range of sophisticated algorithms, prominently including genetic algorithms and evolutionary algorithms, to optimize and innovate architectural design by thoroughly exploring vast solution spaces that are clearly defined by established project objectives. Operating within a multifaceted context that is characterized by intricate spatial, technical, economic, and environmental constraints, GD systematically and autonomously generates an extensive array of alternative designs. It rigorously evaluates these alternatives against a comprehensive set of both quantitative and qualitative criteria in order to effectively identify the most optimal outcome among them. This powerful and innovative tool empowers architects to create, explore, and instantly assess a multitude of high-quality alternatives that might have otherwise been completely disregarded or hastily dismissed during the traditional iterative design process. As a result, GD plays an undeniably vital and significant role in managing and executing large-scale infrastructure projects, greatly enhancing both efficiency and creativity within the ever-evolving architectural field, ultimately paving the way for new possibilities in design and construction. (Nourian et al., 2023)

In the expansive realm of architectural design drawing generation, Generative AI undeniably plays a pivotal and transformative role in the seamless integration of essential building design requirements, along with the intricate regulation rules that govern such constructions. This integration leads to the smooth creation or modification of intricate floor

plans and detailed, comprehensive elevations, both of which are essential for the successful execution of any architectural project. This innovative technology significantly enhances architectural video production by empowering designers to deliver presentations that are not only more expressive but also visually captivating and engaging for audiences. This dual advantage aids in simultaneously reducing overall costs associated with traditional design processes, which can often be cumbersome and time-consuming. Furthermore, it provides substantial support for immersive virtual and augmented reality technologies, which are increasingly being utilized in a diverse range of applications across multiple industries. These applications extend to architectural spaces, urban planning, landscape design, and even include disaster simulation and various response strategies that are crucial in emergency management situations. Moreover, Generative AI proves to be invaluable in the dynamic generation and editing of three-dimensional architectural forms. By leveraging this cutting-edge technology, designers gain greater flexibility and an openness to new ideas, creating a unique opportunity that fosters innovation and personalization in the architectural form design process. This evolution in design capabilities not only enhances creativity but also significantly transforms the manner in which architects conceptualize and realize their visions. It paves the way for groundbreaking designs that were once considered to be beyond reach, fundamentally altering the landscape of architectural practice. As a direct result of this integration, the incorporation of Generative AI into architectural practices is not merely a step forward; it represents a radical revolution that is set to redefine the boundaries of what is possible in the ever-evolving field of architecture and design. Ultimately, this transformative journey through technology opens up new horizons for architects, enabling them to push the limits of creativity while meeting functional requirements more efficiently than ever before. (Li et al., 2024)(Shi et al.2024)(Salem et al.2024)

3.2. Parametric Modeling

Parametric modeling is an exceptionally innovative and highly sophisticated computational design technique that employs intricate mathematical relationships and advanced algorithms to effectively generate and manipulate a vast variety of architectural forms and structures. This powerful and dynamic method empowers architects to create intricate, complex, and dynamic structures by simply adjusting a well-defined set of parameters instead of manually modeling each and every individual component of a design. The traditional approach to modeling can often be both tedious and painstakingly time-consuming, and parametric modeling offers a refreshing alternative that streamlines the design process. The application of parametric design provides

several distinct advantages over more conventional modeling techniques, most notably by facilitating the straightforward and efficient creation of intricate geometries that would otherwise consume an overwhelming amount of valuable time and considerable effort to produce thoughtfully. Furthermore, the unique parametric framework enables architects to swiftly explore a vast array of diverse design variations by means of flexible modification of the underlying input parameters, thereby significantly accelerating, enriching, and enhancing the iterative design process as a whole. As modifications are made throughout the design process, they propagate seamlessly and consistently throughout the entire model, ensuring uniformity and facilitating the accommodation of various design changes that may arise during the lengthy development phase. The educational benefits of engaging with parametric modeling are particularly noteworthy, as many students embark on their journeys in architectural education without a strong foundation in crucial computational design concepts such as variables, parameters, and essential functions. An innovative augmented reality (AR) approach that visualizes geometric transformations has been shown to greatly enhance the understanding and retention of the underlying mathematical logic that governs crucial digital design processes. This impactful incorporation of AR technology significantly enriches the overall learning experience for students. Not only does this methodology enhance their skills and competencies in parametric modeling, but it also prepares them effectively for the continuously evolving and dynamic landscape of contemporary architectural design. Thus, it cultivates their ability to adapt and respond to new technologies, concepts, and methodologies that will undoubtedly shape the future of architecture in meaningful ways. (Li et al., 2023)(Ko et al., 2023)(Shaghaghian et al., 2021)

3.3. Building Information Modeling (BIM)

Building Information Modeling (BIM) facilitates project delivery and collaboration by integrating 3-D models, scheduling, site utilization, and resource allocation, supporting multiple data inputs and outputs. Architects typically employ BIM for detailed design, while engineers utilize it for structural planning and material quantification. Designers can link models with spatial data, optimize operations, and engage various stakeholders throughout the building lifecycle. BIM fosters interoperability and collaborative practices across disciplines, fundamentally altering industry operations, and serving as a modeling and testing environment prior to construction. Virtual preconstruction models predict building performance, with diverse applications including project delivery, quality takeoff, clash detection, energy analysis, and schedule integration. Architects play a pivotal role in

defining, creating, reviewing, and communicating BIM constructs. BIM tools encompass capture, authoring, analysis, and collaboration functions, often integrated as multi-agent systems. Architectural geometry is numerically defined and can be parametrically or algorithmically transformed, enabling generative design at multiple scales. Models derive from graphical entities, associated data, or both, typically employing solid modeling. Enhanced visualization and performance analysis influence the design process through iterative optimization. BIM development involves establishing knowledge representations with specified levels of detail, supported by documentation such as Employers Information Requirements. Effective BIM management delivers just-in-time data, functioning as a decision-support system. Achieving optimal design outcomes combines sketching, physical models, and digital tools, underscoring the continued relevance of tactile, traditional methods alongside digitalization. Deploying BIM technology in intelligent architecture further increases productivity by enabling three-dimensional modeling that improves project quality and cost management throughout the cycle. By providing intelligent elements representative of the final design, BIM helps architects and engineers realize intelligent buildings from the earliest stages, enhancing consistency and reducing waste of time and resources (Coates et al., 2018) (Fadakari, 2016).

4. AI Technologies in Design Processes

Artificial intelligence (AI) refers to the remarkable capacity of machines to simulate and replicate numerous aspects of human intelligence. As a result, any device or system that mimics activities characteristic of a person's cognitive processes — such as learning, reasoning, and effective problem-solving — can be described as exhibiting artificial intelligence. One notable subfield, known as machine learning, employs complex algorithms to learn from extensive sets of data and recognizes intricate patterns that might be unobtainable through traditional means. Generative design, another fascinating application, leverages these powerful algorithms to autonomously generate and evaluate a multitude of design options that align with user-defined goals and specific criteria. In addition to this, a related technique known as rules-based design enables the agile creation of design variations that are responsive to changing parameters and conditions, ultimately allowing for greater flexibility and responsiveness in the overall design process. In the rapidly evolving domain of interior architecture, AI presents numerous exciting new possibilities and innovative pathways to explore.

By employing sophisticated tools such as advanced 3D visualization, immersive virtual reality, and engaging augmented reality, interior

architects can create captivating environments that enhance both presentation quality and user experience. These advanced AI technologies empower interior architects to make not just informed but also intelligent design decisions by drawing on rich, detailed data regarding user behavior and space utilization patterns. Such data-driven decisions can significantly lead to optimizations and refinements in spaces that more aptly satisfy specific functional and aesthetic requirements, promoting a balanced relationship between form and function.

Furthermore, interior architects can utilize AI effectively to meet critical sustainability imperatives in their work. The analytical capabilities of AI allow for the proposal of innovative and cutting-edge design concepts that not only promote energy conservation but also diligently optimize material usage across various projects. By thoughtfully integrating these AI-driven strategies into their workflow, interior architects are not only better equipped to create spaces that are visually appealing, functional, and efficient but also environmentally responsible. This powerful combination demonstrates a strong and unwavering commitment to sustainable design practices that ultimately benefit both the users and the planet, ensuring that future generations can enjoy environments that are as harmonious with nature as they are with human needs.

Also, Artificial Intelligence (AI) has carved a pivotal role in the quest for sustainability within the architectural domain, profoundly influencing both design methodologies and operational frameworks. Architecture is estimated to be responsible for approximately 40% of global greenhouse gas emissions (Genkin & J. McArthur, 2022). AI emerges as a critical enabler in advancing sustainable solutions by enhancing energy efficiency and optimizing materials and resources. At the urban scale, the introduction of smart cities aims to tackle climate change-induced challenges such as population growth, urbanization, and pollution; however, concerns persist regarding the societal impacts of rapid technological adoption (Li et al., 2024).

AI assists designers in meeting these needs by providing optimized material selections and identifying energy-efficient layouts within broader climate-adaptive design strategies. Analysis of a 30-year building energy dataset illustrates AI's capability in monitoring and predicting energy consumption, guiding energy-saving measures and informing urban energy optimization.

Within the context of urban development, the growing integration of smart technologies necessitates reconsideration of a city's cyber-

infrastructure, collaborative governance, and monitoring regimes. Data-driven approaches incorporating machine learning, the Internet of Things (IoT), and cyber-physical systems underpin the governance and operation of smart sustainable cities. Ongoing discourse addresses the trade-offs and synergies between efficiency, sustainability, resilience, and equity, underscoring the need for coherent interdisciplinary consensus in shaping sustainable urban futures.

5. Challenges and Limitations of AI in Architecture

The construction, installation, production, infrastructure, and waste management industries have undeniably contributed significantly to the worldwide environmental crisis. Buildings, in particular, are responsible for consuming more energy and emitting more carbon than any other sector globally. Addressing this critical issue requires the urgent creation of more energy-efficient and sustainable structures that utilize innovative materials and cutting-edge technologies while also being better equipped to respond to the challenges of climate change. One significant challenge that we face lies in effectively transitioning from the traditional architectural conception phase, which typically includes task analysis, preliminary and detailed designs, simulation, and post-occupancy evaluation. This transition calls for the successful application of artificial intelligence (AI) amidst varying degrees of resource scarcity and limited availability of essential materials. Such an approach is vital for ensuring a more sustainable future. (Li et al., 2023)

Technical obstacles present a multitude of significant challenges that create serious hindrances to the full and effective adoption, as well as the implementation, of artificial intelligence (AI) technologies by architecture firms, as well as by architectural practices that function across a variety of sectors and domains. The inherent structural complexity of projects and the interdisciplinary nature of the architecture, engineering, and construction (AEC) sector only serve to complicate the seamless integration and incorporation of advanced AI technologies into the current workflows and processes within these environments, thereby creating a landscape that is often resistant to rapid transformation and change. Developing robust, effective, and sophisticated AI models typically necessitates extensive, rigorous, and costly data collection efforts, along with careful and detailed annotation of such data. This undertaking can be overwhelmingly demanding, especially in terms of the financial resources required and the invaluable investment of precious time and effort from skilled personnel whose capacity is already stretched thin due to ongoing project demands and commitments. In addition to these pressing challenges, there exist numerous issues related to privacy,

confidentiality, and security that can significantly limit the willingness of firms and proprietors to share essential and crucial data, which in turn further constrains the comprehensive training of AI algorithms that heavily rely on diverse datasets that are critical for their success and utility. Moreover, AI systems themselves occasionally exhibit opaque black-box mechanisms that obscure and conceal the underlying rationale behind their recommendations and decisions, creating a significant barrier that ultimately leads to diminishing trust and confidence among users within the architecture profession. Such professionals may become hesitant to rely on AI-driven insights and outputs due to this lack of transparency. As a direct consequence of these issues, even though AI undeniably holds considerable promise and potential for transforming architectural design, engineering practices, and operational efficiencies in exciting and innovative ways, these persistent and formidable technical impediments continue to restrict, limit, and inhibit its widespread and effective adoption within the complex, multifaceted, and dynamic industry landscape that is constantly evolving and adapting to new challenges and realities. As the industry seeks to navigate these hurdles, it is essential to prioritize collaborative efforts aimed at addressing these concerns, fostering an environment that can embrace the potential of AI while simultaneously tackling the technical, ethical, and practical challenges that currently exist. (Li et al., 2023)

AI is broadly defined as sophisticated computer systems performing tasks that normally require human intelligence and cognitive capabilities. In today's rapidly evolving technological landscape characterized by unprecedented advancements, organizations strive to develop comprehensive ethical AI frameworks that not only include key principles such as transparency, fairness, non-discrimination, and accountability but also align with the strict guidelines set forth by the European Union. Ethics surrounding AI are increasingly being incorporated into the education and training of influencers, technologists, and other key stakeholders. This aims to thoroughly explain the myriad societal implications that arise from the deployment of these advanced systems, which are capable of transforming industries and influencing daily lives. To ensure responsible usage of AI technologies, ethical impact audits are meticulously conducted before the deployment of AI systems. These audits allow organizations to determine whether their systems align adequately with the vital social values and community standards, ensuring that they do not inadvertently cause harm or reinforce existing biases. Engaging in participatory design processes that directly involve communities affected by AI significantly increases the inclusiveness of the development process and fosters an environment for critical assessment and constructive feedback.

Furthermore, the implementation of robust standards and certification mechanisms not only helps to foster trust among users and stakeholders alike but also actively motivates the ethical adoption of AI technologies across various sectors, thereby enhancing overall public confidence in these innovations. Moreover, multidisciplinary teams consisting of diverse professionals, such as linguists, psychologists, and philosophers, come together to collaboratively address the complex challenges posed by AI, particularly in relation to generative models. In these instances, the nuances involved often extend far beyond the technological domain and can be quite difficult to anticipate without the valuable insights that arise from these varied perspectives and expertise. This collaborative effort is essential for responsible AI development because it diligently takes into account the ethical ramifications and social responsibilities that are intricately tied to these powerful technologies, ensuring that their benefits are maximized while minimizing potential risks. (Giralt Hernández, 2024)(Farisco et al., 2020)

6. The Future Trends in AI and the role of Designers in an AI-Driven Future

Architectural design is undergoing a remarkable transformation as it increasingly integrates advanced artificial intelligence technologies to explore a wide array of innovative possibilities. This integration is not just a trend; it represents a significant shift in how architects and designers approach their projects, applying cutting-edge technologies that promise to yield broader and more impactful benefits for society as a whole. The adoption of generative design techniques, combined with parametric modelling and Building Information Modelling (BIM), serves not only to support the creative workflows of architects but also to enhance geometric abstraction and optimisation processes. These tools facilitate greater synchronisation and foster clear, effective communication of design proposals among all stakeholders involved in the architectural process.

AI will undoubtedly continue to dramatically transform architectural space through the innovative integration of virtual reality, advanced architectural intelligence, and cutting-edge AI construction methodologies. The ongoing expansion of AI design tools is presenting designers with a significantly greater variety of choices and enhanced flexibility, which empowers them to accomplish well-known tasks—such as intricate construction quantity calculations, comprehensive rule analyses that account for numerous variables, and meticulous evaluations of material quality—more efficiently and with heightened accuracy. Additionally, Augmented Reality navigation systems, when effectively applied to the construction sector, serve to further illustrate and highlight AI's significant and transformative impact on the overall

construction process. As an essential force in the evolution of modern architecture, AI has not only improved architectural design methods across the board but has also accelerated development in key areas such as Construction Industrialization and Building Industrialization.

The rise of artificial intelligence (AI) has sparked debate over its implications for architecture and other creative professions. Some argue that AI will displace architects, while others view it as a tool that augments human creativity and expands the architect's toolkit. Architects will almost certainly change how they work to accommodate AI, acquiring new skills in coding, data analysis, and machine learning to efficiently engage with AI tools. Beyond skills, there is a need to reconsider what humans uniquely contribute to design, thereby clarifying the architect's evolving role and synergy with AI (Li et al., 2023).

Architectural practice is already well suited to AI. The profession remains highly inventive in design but also relies on rule-based processes, numerous trade-offs, and a plethora of rules and regulations. Architects routinely use extensive data and established processes, much of which can be automated. AI-powered tools help explore alternatives, generate design options, and predict environmental performance, swiftly handling what were once labor-intensive calculations. As a result, the architect's role becomes more about reviewing AI-generated ideas than manually crafting each option.

None of this implies that AI will produce entire buildings without human input. Machine learning relies on past data, and architecture, being intensely personal and variable, defies easy-pattern capture. Historical trends prove challenging to model, given the constant evolution of architectural expression. Such limitations further emphasize the need to focus on human contributions, ensuring that the profession remains vibrant amidst advancing technologies.

A significant future trend that is emerging within the realm of artificial intelligence (AI) and architecture is the innovative integration of virtual reality (VR) technologies. Recent findings from a comprehensive survey of 28 academic papers, which collectively garnered an impressive total of 1,716 citations, reveal that the architecture–engineering–construction (AEC) industry is increasingly adopting VR applications to significantly enhance the process of digital architectural design. The unique advantage of virtual reality lies in its ability to facilitate the evaluation of architectural designs at virtually any stage of the product life cycle. This transformative technology allows for a level of visual immersion in architectural forms that empowers architects, designers, and urban planners to conduct early assessments of their design concepts. Through

the use of VR, users have the opportunity to explore and anticipate various spatial experiences, engaging with environments that may include natural landscapes, historical settings, and urban trials, effectively enriching their understanding of the design. Furthermore, the latest developments concerning impact assessment, as well as evaluations for history learning, are presented to vividly demonstrate the powerful use of virtual reality in advancing both architectural and urban design practices. This evolution in design methodologies not only enhances the creative process but also allows for a deeper connection between the designed environment and the users who will interact with it. (Sahraei Loron & Sahraei Loron, 2016)

Virtual reality (VR) has emerged as a reformative approach to digitally visualize architectural designs. The use of head-mounted displays (HMDs) enables users to experience fully immersive environments wherein digital content can be directly projected onto the user's eye. Recent headsets are characterized by the minimization of simulated sickness with realistic visual and auditory cues, as well as sensitive interaction devices (Tang, 2019). VR not only offers an alternative media for rendering architectural designs but also introduces a fundamental change in the traditional approaches to architectural visualizations and infuses human experimental learning into the digital media.

Embedding VR with AI allows the creation of virtual environments that make it possible for architects and engineers to inspect the models with a high degree of realism. The user automatically understands spatial relationships and, to a certain degree, the quality of natural lighting within the models. Multiple users are able to conduct real-time walkthroughs, allowing both client and designer to discuss the model through the support of telepresence. Although a number of issues remain such as communication, workload, and information management, a prototype AR framework has been proposed. Such a system clarifies existing problems and addresses key obstacles and, therefore, constitutes a milestone toward incorporating AR services into AEC procedures.

Moreover, this powerful technology is gaining considerable prominence for its remarkable capability to assist in urban planning initiatives, effectively addressing and resolving the pressing city issues that many communities are currently facing. In light of these rapid advancements, the roles of architects and designers are required to undergo considerable evolution, necessitating increased collaboration and interaction with data scientists, technologists, and other multidisciplinary teams. This collaboration will be essential to meet future challenges that architecture will inevitably face and to encourage widespread AI

adoption among the public. Despite these promising advancements, it is critical to acknowledge that significant unresolved challenges within construction cycles, effective governance, social acceptance, and the establishment of regulatory frameworks persist and demand immediate attention. It is evident that effective policy-making, accurate forecasting, and well-structured regulation—which support and promote robust two-way interaction and dialogue between authorities and citizens—will be crucial for the sustainable and effective integration of AI within the dynamic field of architecture. (Li et al., 2023)

No longer will architects function solely as designers; they will evolve into multifaceted problem-framers, curators, and collaborators. This evolution encourages a more integrated approach to both design and construction, ultimately leading to more sustainable and innovative architectural solutions that can respond to the complex challenges of modern society. The intersection of technology and design redefines not only the products of architectural practice but also the very methodologies and philosophies that underpin them.

AI has recently emerged as a transformative priority for architecture. While broad adoption across the architectural landscape remains in its infancy, projects throughout the space illustrate the trajectory and technological demands ahead.

Architects, interior architects, designers can generate design options concurrently with clients through conversational interaction, rather than relying on iterative, single-option workflows. Engineers employ AI to quickly develop and enhance construction schedule and cost models. Vendors and fabricators use automated systems for real-time production planning and resource allocation. During construction, AI solutions monitor worksite quality and safety with advanced sensors.

7. CONCLUSION

The integration of AI into the architectural field has the potential to transform professional roles significantly. Adding AI to the toolkit inevitably reshapes the ways architects collaborate and communicate with each other, consultants, and clients. As implied by the development of Building Information Modeling, AI's influence extends far beyond design alone. Architectural educators and practicing architects must therefore focus on cultivating top-tier interdisciplinary skills. Ignoring this integration could devalue architects' traditional expertise in form, function, and structure. Instead, AI tools should be harnessed to achieve enhanced efficiency, sustainability, and aesthetic appeal in architectural projects.

The progress and developments of AI over the past decade highlight the need for policy and regulation to govern the development and deployment of AI and to address the ethical, social, and economic challenges. In the traditional AI governance framework, regulation represents one among several mechanisms to influence the evolution of the AI technology landscape and its deployment. AI governance studies still focus overwhelmingly on the regulatory debate and policy issues, while the full breadth of policy-making, including the analysis of the political and bureaucratic contexts that shape the AI governance debate, merit greater attention (Perry & Uuk, 2019).

Artificial intelligence (AI) boasts the technological prowess to revolutionise architectural methodologies, enabling conceptualisations of forms and systems beyond human capacities. Bridging digital and physical realms, it remains an emergent figure in the architectural design arena.

Generative-Design, Parametric Modeling, and BIM, not for robotic architecture. Focus will shift toward AI automation of the construction process itself. Other areas where AI is driving change include sustainability and energy efficiency through Building-Performance Modelling, as well as Project and Construction Management, addressing issues in collaboration, communication, and efficient delivery. Efficient collaboration with data scientists and technologists will form an important part of future architectural practice. Given the general public's growing concerns regarding AI, community engagement with future AI architectural projects becomes crucial at the community and local development planning stage.The current implementation of AI tools in design is for the enhancement of human creativity through

Recognizing that AI in architecture exists at the confluence of multiple disciplines, the field is currently heavily relying on the expertise of data scientists and technologists. Currently, AI research in architecture is dominated by these groups who possess the necessary programming knowledge and research infrastructure. Training architects in computer programming from an early stage is essential for engaging more deeply with AI systems development. Although existing programming and computer vision courses lay foundational knowledge, more advanced and specialized coursework is required to elevate architect-developers to the same level. Ultimately, architectural practice and research must adopt at least one of these two future pathways, either developing architects as specialized AI developers or continuing close collaboration with dedicated development teams.

To sum up, artificial intelligence offers architects enhanced methods to generate spatial configurations that fulfill a broader range of functional, social, and economic goals, signifying its transformative priority in the design of spatial assemblies (Li et al., 2023). By supplying architects with suitable AI software, data, and computational resources, the intuitive and creative development of innovative architectural spaces accelerates. When coupled with parametric design and expert systems, AI contributes to rapid and intelligent architectural space formulation, reinforcing its status as a transformative priority. Consequently, architects can deliver superior design solutions more rapidly.

Extensive historical research and recent advancements provide context for this role of AI as a transformative priority in architecture (Nourian et al., 2023). The concept that new technologies fundamentally redirect architectural practice underscores the discipline's receptiveness to AI. Nevertheless, implementation across building design, city planning, project delivery, and policymaking encounters obstacles and challenges that necessitate further research and development. Although AI integration continues to advance, its transformative impact remains nascent. Growingly, evidence illustrates AI's role as a transformative priority in architectural design, highlighting the need to address barriers and fully realize its potential.

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DESIGN / INTERIOR DESIGN

CREATIVE SOLUTIONS WITH FLEXIBLE DESIGN CRITERIA: STUDIO EXPERIENCE

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ABSTRACT

Flexibility is a principle that responds to users' changing needs, defined through adaptability, mobility, modularity, transformation, and change, and recognised as an important approach in contemporary design. This study addresses flexibility in the context of design education, aiming to enhance the ability of fourth-year students in the Department of Interior Architecture and Environmental Design at Avrasya University to develop functional and adaptive solutions. Within the Industrial Product Design course, students were asked to design an office set based on flexible design criteria, allowing them to experience flexibility directly. The methodology followed three stages: pre-design, design process, and post-design. In the pre-design stage, flexibility parameters were determined through literature research. During the design process, students analysed different user needs, generated alternative solutions, and produced sketches and models. In the implementation phase, ten students produced eight office set designs using real materials. In the post-design stage, projects were evaluated in terms of functionality, material selection, and flexibility, and the findings were summarised in a table. As a result, students created flexible designs incorporating modularity, add-on/removable features, portability, and multi-purpose usage. This process strengthened their creative thinking and problem-solving skills, enhanced their experience with materials, and encouraged a more adaptive approach in design practice. The study shows that flexible design not only provides functional and aesthetic solutions but also contributes to the development of creative, user-centred, and sustainable approaches in design education.

Keywords: Flexibility, Flexible Design, Design Education, Studio Experience, Design Process

INTRODUCTION

Today, the concept of flexibility stands out as a contemporary design approach defined as the ability to respond to changing user needs (Bayazıt, 1979, p. 87). The natural change and transformation of the current user's needs throughout their life cycle makes flexibility important and relevant in design. İsmailoğlu and Usta (2018) define flexibility as the dynamic establishment of relationships between space and users based on changing social living conditions, stating that it can enable alternative designs that can change depending on the environment, technology, and function.

When evaluated within the discipline of design, flexibility is a multidimensional concept comprising parameters such as adaptability, mobility, modularity, transformation, and change. In architectural design, flexibility aims to ensure that the architect's duties and responsibilities do not end with the transfer of control of the designed space to the user, but rather continue throughout the usage process. According to Forty (2000), flexibility enables architects to gain insight into the long-term transformations of their projects and is an important concept that prevents the termination of use after user occupancy. According to Schulz (1963, pp. 170-175), flexibility can be achieved through the addition or removal of elements, provided that the integrity of the structure is maintained, or through the growth or reduction of the structure, or through the modification of elements and their relationships. Karabekir and Ozanözgü (2023) state that strategies such as mobility, modularity, neutral areas, combinability/divisibility, multi-purpose use, different plan types, and addability/removability are utilised to demonstrate the flexibility approach in space design. Ökem, on the other hand, addresses flexibility through furniture, stating that flexibility in furniture can be achieved by enabling the furniture to serve different actions, adding different functions to unused sections, and overlapping action areas (Ökem. 1998).

Uzun evaluates flexibility in furniture under five different headings. Firstly, the ability of a piece of furniture to meet different needs without undergoing any changes is an important indicator of flexibility. Secondly, the ability of furniture to serve multiple functions without changes to its system is also one of the fundamental elements of flexible design. In addition, adding or removing furniture elements or rearranging the relationships between them are important approaches that lend flexibility to the design. Another type of flexibility is the ability of furniture to adapt to different conditions without changes to its system. Finally, when furniture usage preferences change, reassessing it for a different purpose reveals the dynamic and user-centred nature of furniture

flexibility. (Uzun, 2006). The flexible use of furniture within the home can be achieved through the principles of lightness, detachability, foldability, storability, mobility, dimensional flexibility, functional diversity, and modularity (Özdemir, 1999; Bayram, 2011).

According to Usta and İslamoğlu (2018), flexibility strategies are addressed under three headings: design, usage, and construction flexibility. Design flexibility refers to the flexibility anticipated by the designer for the user when making design decisions. Design flexibility is the usage flexibility provided by the designer to the user in terms of space and fixtures. These decisions made during the design phase are formed using strategies such as modularity, neutral areas, different plan types, and the possibility of adding or removing elements. Usage flexibility encompasses the changes and adjustments that the user can make in the space without interfering with the structure of the building (Karabekir and Ozanözgü, 2023). Construction flexibility, on the other hand, is a type of flexibility that allows for different structures and various spatial organisations within the building, based on fixed building systems or elements (Uzel, 2001, p. 5).

Flexibility strategies are considered an important tool for supporting creative thinking not only in design processes but also in design education. Design education, which generally combines theoretical and practical learning, focuses on developing skills and enhancing these skills through application. Another element that makes design education unique and distinctive is that its content is based on a learning approach that involves doing and experiencing (Schön, 1995; Onur and Zorlu, 2017). Thanks to this approach, students take an active role in the design process while reinforcing their theoretical knowledge with practical applications, and they have the opportunity to experience their individual creativity. Studio classes are one of the most important components of this active process, which prepares students for their profession by transferring the design process to them and enabling them to develop their designs through various critiques received from the instructor. The design problems given to students in studio classes are structured to enable them to develop different perspectives. In this study, fourth-year students of the Interior Architecture and Environmental Design Department at Avrasya University were given the design problem of 'designing an office set based on flexible design criteria' as part of their Industrial Product Design course. The aim of this approach is to provide students with different and creative perspectives, while also enabling them to experience flexibility, one of the contemporary design approaches. Thus, the objective is for students to develop their ability to create both functional and adaptive

solutions and to understand the importance of the flexibility approach in design.

METHODOLOGY

This study focuses on office set design within the framework of flexible design principles. The design process offers students the opportunity to gain an in-depth understanding of the concept of flexible design through the compilation of theoretical knowledge and its support with practical applications. In this context, each stage of the research process aims to develop students' creative thinking skills and improve design processes. To this end, the study has been structured in three phases: pre-design, design process, and post-design. Figure 1 illustrates the stages of the study.

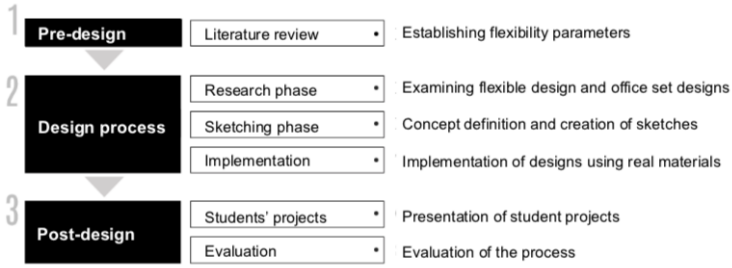


Figure 1. The stages of the study

Pre-design: This stage begins with a literature review on concepts such as design education, flexible design, industrial design, and office set design. The research process aims to establish the theoretical foundation of the study by compiling and analysing existing theoretical knowledge. In this stage, flexibility parameters in design were established based on the data obtained from the literature. These parameters will be used to evaluate the projects during the assessment phase of the study.

Design process: This phase covers studio work. The studio work was carried out over a ten-week period in a total of ten classes. This phase was carried out in three steps.

Research phase: In this step, students conducted detailed research on flexible design and office set design. Research is critical to understanding current design approaches and user needs. By examining different design examples, students will identify the advantages and disadvantages of flexible design.

Sketching phase: Based on the research results, a concept will be defined and flexible office set design alternatives will be developed. During this process, students created various sketches and models. They have developed their designs based on the feedback received throughout the process. In this phase, students will develop their creative thinking skills while receiving feedback at every stage of the design process.

Implementation: In this step, a total of 8 different designs were produced by 10 students. The office set design created by the students was implemented using real materials. This stage is a process where theoretical knowledge is put into practice and students have the opportunity to test their design skills in real-world conditions. The implementation stage allows students to overcome the challenges they encounter in the design process and develop creative solutions. Furthermore, their knowledge of material selection and implementation will increase the functionality of their designs.

Post-design: This stage involves the review and evaluation of student projects, as well as the assessment of the studio work process. It was carried out in two steps.

In the first step, student projects were explained in detail, covering aspects such as the starting point of the design, the functions it serves, the materials used, flexibility characteristics, etc.

The second step was the evaluation stage. In this step, the students' projects were evaluated according to flexibility parameters in design and summarised in a table. Based on the data obtained, conclusions were drawn regarding flexibility parameters in student designs, and these conclusions provided important information about the design processes. In addition, evaluations were made regarding the students' learning experiences and the development of their design skills in relation to the workshop process.

FINDINGS

Flexibility Parameters in Design

The flexibility parameters were primarily established based on the literature. In this context, studies related to flexibility in different design disciplines were examined. Within the scope of the study, flexibility parameters were addressed under nine headings: modularity, addability/removability, convertibility, functional diversity, lightness/portability, foldability, stackability, and dimensional flexibility (Özdemir, 1999; Bayram, 2011; Kızmaz and Cimşit Koş, 2015; Bal, 2017;

Tavşan et al., 2018; İslamoğlu and Usta; 2018; Durmuş and Asımgil; 2021; Karabekir and Ozanözgü, 2023; Seçer Kariptaş et al., 2023).

Modularity: This refers to the ability to independently change and rearrange parts of the design. In this approach, the components of the product are designed to work in harmony with each other, even though they are independent. This means that parts can be easily replaced when necessary. Modular design also lays the foundation for a grid-based organisation, and this structure allows for various changes, such as additions or removals, resulting in a flexible design. (İslamoğlu and Usta, 2018). Modular systems are more easily transportable and can quickly adapt to changing preferences (Bayram, 2011). As a result, the product becomes more durable and can be customised according to user needs.

Addability/Removability: This refers to the ability to easily add new components to the existing design and remove existing components for reuse. This strategy relies on the capacity to add or remove components horizontally or vertically to adapt the design to changing requirements (İslamoğlu and Usta, 2018). At the same time, a design gaining new functions by adding a different unit or removing an existing unit is also part of this approach (Tavşan et al., 2018).

Convertibility: This refers to the design changing its function or form to adapt to different usage scenarios according to user needs and changing conditions. This approach enables a single product to serve multiple purposes. For example, a seating unit that can be converted into a bed is a good example of a transformable design. This design feature offers a significant advantage, especially in confined spaces. Thus, it can adapt to changing needs and increase usage efficiency (Karabekir and Ozanözgü, 2023). When evaluating office set designs, the new functional features and formal differences gained through form transformation were taken into account.

Functional Diversity: This refers to the capacity of a design to perform multiple functions. This approach allows users to meet different needs with a single product, saving both space and costs. Functional diversity enables multi-purpose use of the product and increases efficiency of use.

Lightness/Portability: Lightness refers to the ease of transport and assembly achieved by reducing the physical weight of the design. Lightness can be achieved through various design decisions, from material selection to production methods. Mobility is possible not only through lightness but also through additional features of the design. In

terms of use, lightness/portability improves the user experience and is particularly important in workspaces with constantly changing or dynamic usage needs. When evaluating office sets, although some are designed to be placed on a table, the use of lightweight materials and compact dimensions were taken into account.

Dimensional Flexibility: The dimensional flexibility feature also allows the design to adapt to different body sizes. At the same time, the adaptability feature means that the product can be used for different functions (Bayram, 2011). In terms of use, it refers to the ability to adjust the size of a product or design to suit different spaces and various needs. This feature allows users to make more efficient use of space by changing the dimensions of the product. When considering dimensional flexibility, the variability of the usage area occupied by the set on the table was taken into account based on the foldability and stackability features of the designs.

Review of Student Projects

At this stage, eight office set designs developed within the scope of the course and in accordance with flexible design criteria were reviewed. The characteristics of the resulting student projects, such as the concept of the design, the functions it serves, the materials used, and its flexibility features, were explained in detail.

Project 1 is a four-piece office set that reflects the concept of dynamism in the architecture and design process through triangular forms and varying heights. Detailed explanations of Project 1 are provided in the table below (Table 1). With its modular structure, the set allows users to easily adapt to different working arrangements while also offering functional storage and organisation solutions. Triangular forms are not merely an aesthetic choice; they also optimise the layout on the desk by allowing for the ergonomic placement of elements. Developed with flexibility and ease of use in mind during the design process, this set aims to increase the efficiency of creative processes.

Table 1. Information regarding Project 1

Project 1	Inspired by the dynamic nature of architecture and the design process, this office set employs triangular forms to create a lively aesthetic. Varying heights reinforce the sense of dynamism, with the tallest piece serving as a lighting element and the others functioning as storage for pens, notepads, and paper clips. Crafted from plexiglass in red, yellow, and blue, the modules bring colour and energy to the workspace. Designed to be attached to the base in a specific order, the set offers users a playful, problem-solving experience alongside functionality.
	
Student: Mehtap Kahraman	
Concept: Dynamism	
Material: Plexiglass	

Project 2 is a four-piece office set specially developed for office-based interior designers, designed based on the concept of 'house'. The modules can be offered with different colour options and personalisation possibilities to give the user greater flexibility. The modules offer an ideal solution for creating an office environment that is both functional and aesthetically pleasing. Detailed descriptions of Project 2 are provided in the table below (Table 2).

Table 2. Information regarding Project 2

Project 2	The forms obtained by abstracting the house structurally give rise to modules that can be assembled in different ways. The layered joining of MDF panels allows the modules to interlock, creating a mobile and dynamic perception. The lighting element is distinguished from the other modules by being coloured black. The other modules function as a phone holder, pencil holder and notepad. The pieces can be arranged together in different ways or used individually. The set consists of four pieces, but can be expanded by adding different modules according to the user's preference.
	
Student: Nilay Görmüş	
Concept: House	
Material: MDF	

Project 3 is a three-piece office set designed for architects and interior designers, inspired by the deconstructivist movement, which brings together different functions. The modular structure allows for different uses by pushing the boundaries of deconstructivist forms. The pieces can be used both together and independently, offering the user flexibility and an aesthetic experience. When used independently, the pieces can be placed on different surfaces, offering transformability, and can be personalised by creating different shapes with the modules. Detailed explanations of Project 3 are provided in the table below (Table 3).

Table 3. Information regarding Project 3

Project 3	The lighting element consists of three modular parts: a pen holder, a phone holder, and a notepad. Inspired by deconstructivism, the design creates irregular yet fluid relationships between components, blending functionality with abstract aesthetics. The pen holder maintains order within the modular system while aligning with its geometric language. The third piece doubles as a phone holder and notepad, addressing practical needs. Made of MDF and finished in modular black, the element highlights a dynamic, flexible design that unites usability with contemporary visual expression.
	
Students: Seden Kutay, Aysu Yaranlı	
Concept: Deconstructivism	
Material: MDF	

Project 4 has been designated with 'Istanbul' as its starting point. While the pieces together form the silhouette of Istanbul, they are also suitable for individual use. When establishing the relationship between the pieces, a common design language, harmony of forms, and continuity of the modular structure were prioritised to ensure visual integrity. Detailed explanations for Project 4 are provided in the table below (Table 4).

Table 4. Information regarding Project 4

Project 4	The design is inspired by Istanbul's iconic structures, abstracted into modern forms that reflect the city's dynamism and fluidity. References such as the Bosphorus Bridge and Galata Tower inform the structural language, resulting in modular and flexible solutions. The four-piece set includes a lighting element, candle holder, pen holder, and notepad holder. Made from white PVC foam, the modules combine aesthetics with functionality, offering both unity and independence. By establishing formal connections between pieces, the design provides users with a holistic, harmonious experience while maintaining practicality and adaptability in use.
	
Student: Beliz Özdikicioğlu	
Concept: İstanbul	
Material: PVC Foam	

Project 5 was designed based on the De Stijl movement. It consists of four pieces and offers users creative combinations with its concept of asymmetrical balance. Detailed explanations of Project 5 are provided in the table below (Table 5).

Table 5. Information regarding Project 5

Project 5	The lighting element is composed of three parts: a pen holder, a phone holder, and a notepad. Inspired by deconstructivism, the design introduces irregular and fluid relationships between the components, creating both functional and aesthetic value. The pen holder contributes to organisation while integrating seamlessly with the geometric language of the modular system. The phone holder also functions as a notepad, meeting practical needs with versatility. Constructed from MDF and finished in modular black, the design emphasises a dynamic, flexible structure that balances usability with abstract and expressive form.
	
Students: Büşra Öksüz, Vildan Balaban	
Concept: De Stijl	
Material: Concrete	

Project 6 is designed based on the concept of fragmentation. It consists of four parts. It creates a modern aesthetic by presenting simplified geometric forms. It offers flexible usage options to the user. Modules can be arranged side by side to create different shapes. It is also suitable for single use. Detailed explanations of Project 6 are provided in the table below (Table 6).

Table 6. Information regarding Project 6

Project 6	The project is developed around the concept of fragmentation, where a basic square prism is divided and reorganised into new modular forms. Geometric simplification is prioritised, resulting in a clean and modern design highlighted by a black-and-white colour scheme. Plexiglass was selected as the main material due to its durability, lightweight structure, and ability to provide efficient lighting. The fragmented forms are reshaped into practical modules such as a lighting element, pencil holder, coaster, and accessory organiser. This modular approach enhances flexibility and customisation, while also maintaining order in office spaces, offering users both functional and aesthetically striking solutions.
	
Student: Yaren Bozkaya	
Concept: Fragmentation	
Material: Plexiglass	

Project 7, designed for office-based interior designers, draws inspiration from the concept of dynamism and is based on triangular forms. The angular and mobile structure of the triangle aims to create a sense of continuous flow and balance rather than static planes. Triangular forms of different sizes come together to create various functional arrangements. Detailed descriptions of Project 7 are provided in the table below (Table 7).

Table 7. Information regarding Project 7

Project 7	Lighting elements, pencil holders, notepads, accessory organisers, desk clocks, and A4 paper organisers provide users with dynamic organisation on their work desks. The A4 paper organiser allows users to organise papers on their desks while its foldable design also facilitates the transport of papers. The asymmetrical placement of the PVC foam and plexiglass components adds visual movement to the design. The components can be combined in different ways, taking advantage of the geometric benefits of the triangular shape, or used individually. Designed as a six-piece set, this office set offers options with fewer or more components depending on user needs.
	
Student: Doğukan Karadeniz	
Concept: Dynamism	
Material: Plexiglass and PVC foam	

Project 8 was designed based on Kandinsky's painting 'Composition VIII' to provide a table arrangement for painters working in the painting workshop. The ability of the modules to be arranged in different ways increases flexibility. Detailed explanations of Project 8 are provided in the table below (Table 8).

Table 8. Information regarding Project 8

Project 8	Inspired by Kandinsky's *Composition VIII*, this office set translates the painting's abstract forms into three-dimensional design, adding an artistic touch to the workspace. The dynamic composition informs the creation of four modules: a lighting element, pencil holder, notepad holder, and accessory organiser. Made of plexiglass, the pieces offer flexibility, as they can be arranged in various combinations or used independently, balancing creativity, functionality, and aesthetic harmony.
	
Student: Hasret Şentürk	
Concept: Composition VIII	
Material: Plexiglass	

EVALUATION

This study highlights the dynamic and multidimensional nature of design education, examining elements of design such as creativity and functionality within the context of flexibility through projects developed by students. The projects not only offer flexible solutions but also reinforce the ability to produce user-centred and aesthetically pleasing solutions. Within the scope of the study, flexibility is addressed under the headings of modularity, addability/removability, convertibility, functional diversity, lightness/portability, foldability, stackability, and dimensional flexibility, as defined in the literature (Table 9). These parameters increase the ability of projects to adapt to different usage scenarios, demonstrating the versatility of designs and their ability to respond to user needs. Each project demonstrates how it integrates these elements of flexibility, showcasing students' innovative approaches and problem-solving skills in the design process. This further emphasises the fact that design is not just an object, but also an experience and an interactive process (Table 8).

Table 8. Assessment of student projects in accordance with flexibility parameters

Office Sets	Flexibility Parameters: Modularity	Addability/ Removability	Convertibility	Functional Diversity	Lightweight/ Portability	Foldability	Stackability	Dimensional Flexibility
Project 1	∉	∉		∉	∉			
Project 2	∉	∉	∉	∉	∉		∉	∉
Project 3	∉		∉	∉	∉		∉	
Project 4	∉			∉	∉			
Project 5	∉	∉		∉	∉			
Project 6	∉	∉		∉	∉		∉	∉
Project 7	∉	∉		∉	∉	∉	∉	∉
Project 8	∉			∉	∉			

The projects developed by students reflect the dynamic and interactive nature of the design process, while also reinforcing their ability to produce user-centred solutions. Analysis of the projects reveals how these elements come together and what kind of innovative approaches students adopt in their design practice. This highlights the potential of the experience gained in design education to enhance the professional competence of future designers. Flexibility and Modularity: Most projects offer flexibility through modular structures, allowing users to make different arrangements. This is an important advantage in terms of

adapting to the dynamic nature of office spaces. In this regard, when the findings obtained within the scope of the study are evaluated;

- Flexibility is at the heart of the projects and is also a reflection of the user-centred design approach. Students have utilised strategies such as modularity, transformation, and multi-purpose use to ensure flexibility in their designs. This not only adds an aesthetic dimension but also a functional one, enabling them to develop solutions that can quickly respond to users' changing needs. For example, an office set that allows for different arrangements helps users optimise their workspaces according to their personal preferences.
- Creative approaches in projects encourage stepping outside traditional design patterns. Drawing inspiration from different art movements (deconstructivism, De Stijl, etc.) allows students to combine aesthetics and functionality in their designs. Such creative processes enable students to achieve originality in design while also developing their innovative thinking skills. For example, projects inspired by the deconstructivism movement encourage the creation of abstract and dynamic structures that go beyond ordinary forms.
- The choice of materials used in projects has a significant impact on the functionality and aesthetics of the design. The use of materials such as plexiglass, MDF and concrete offers different experiences in terms of both durability and aesthetics. This variety of materials increases students' opportunities to experiment and apply different techniques in their design processes. For example, the lightness and transparency of plexiglass give designs a modern look, while concrete emphasises durability and minimalist aesthetics. Material choices are elements that directly affect the overall perception of projects and the user experience.
- Modular design is at the forefront of most projects. Modular structures allow users to personalise designs according to their needs. This enriches the user experience while also increasing the flexibility of the design. For example, the ability to combine the modules of an office set in different colours and shapes allows users to personalise their own spaces. This strengthens the interaction between the user and the design while also increasing the functionality of the design.

Projects reflect the dynamic and interactive nature of the design process, while also providing a platform for students to experience different design approaches. Studio classes provide an important ground for students to develop their ideas, receive criticism, and revise

their designs based on this feedback. This process enables students to become more flexible and adaptive in their design practice, enhancing their professional competence.

Ultimately, the combination of elements such as flexibility, creativity, material use, and modularity offers students a comprehensive learning experience. The convergence of these elements helps students develop more conscious, creative, and user-centred approaches in their design processes. Thus, a solid foundation is established for future designers to produce rich and flexible solutions that are both aesthetically and functionally appealing. Through such projects, design education not only equips students with technical skills but also encourages them to think critically and develop innovative solutions.

CONCLUSION

This study emphasised the importance of integrating the concept of flexibility into design processes, offering students the opportunity to develop creative and functional solutions. The office set design studio project, conducted within the framework of flexible design principles, provided an important platform for students to develop different perspectives and experience contemporary design approaches.

The findings of the study demonstrate how flexibility parameters (modularity, add-on capability, convertibility, functional diversity, lightness/portability, foldability, stackability, and dimensional flexibility) are applied in projects and reveal how these elements support a user-centred design approach. The creative approaches used by students in their designs have succeeded in combining aesthetics and functionality by breaking away from traditional patterns. In particular, the prominence of the modular design approach allows users to personalise the designs according to their own needs, enriching the user experience while increasing the flexibility of the design. The choice of materials in the projects also plays an important role. The use of various materials such as plexiglass, MDF and concrete offers different experiences in terms of both durability and aesthetics, increasing the students' opportunities to experiment and apply different techniques in their design processes.

The studio process provides a critical platform for students to develop their ideas, receive critiques, and revise their designs based on this feedback. This process enables students to become more flexible and adaptive in their design practice, enhancing their professional competence. Furthermore, the fact that studio work is based on a

hands-on learning approach enables students to put their theoretical knowledge into practice and thus develop a deeper understanding.

This study demonstrates that the combination of flexibility and creativity forms a basis that enables future designers to produce rich and flexible solutions, both aesthetically and functionally. Through such projects, design education not only equips students with technical skills but also reinforces their ability to think critically and develop innovative solutions. Furthermore, the importance and application areas of flexible design are emerging as elements that deserve increasing attention in modern design practice. In the future, the application of flexible design principles in more areas will contribute to the training of designers who can produce sustainable and aesthetic solutions that respond quickly to users' changing needs. In this context, the concept of flexibility has gained importance not only in furniture or office set design but also across all design disciplines. Consequently, this study demonstrates that flexible design is an indispensable part of contemporary design understanding and that adopting this approach in design education will equip future designers to become more capable and innovative individuals.

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THE ROLE OF SOCIAL DESIGN IN INTERIOR ARCHITECTURE

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ABSTRACT

Interior architecture is a discipline that designs to make human life easier, despite being perceived as a field focused on luxury consumption. The purpose of this study is to identify the ground on which interior architecture is based. Through definitions, it seeks to explain the responsibilities of the profession in detail. These definitions will make room for a discussion of our profession's ethical codes and social responsibility. The objectives of this study are to; (1) explore social responsibility in the context of interior architecture, (2) define social design, (3) highlight its relevance to interior architecture, and (4) discuss the principles of social design through the lens of interior architecture's professional responsibilities using the first three networks. This approach is expected to provide a key framework for defining the interior architecture profession. This research examines studies related to social design practice and the responsibilities of designers. Furthermore, it opens up a discussion about the social responsibilities inherent in the field of interior architecture through the defined categories. The connection of interior architecture and social design practice can be identified through basic concepts. These concepts presented help to define professional responsibility in the discipline of interior architecture.

Keywords: Social Design, Interior Architecture, Interiors' Responsibility, Designers' Responsibility, Ethical Codes

INTRODUCTION

Movements centered on humanitarian aid have become a mission that must be positioned at the core of societies today. In order to make the world more livable and to leave behind a cleaner future, this movement should be integrated into the daily lives of all people, not only a certain group or class. It represents a way of thinking and an essential consideration in every kind of activity. Humanitarian aid based initiatives have an infrastructure that can interact with almost every discipline. It emerges as a necessary and contemporary field of study, particularly within graduate programs worldwide.

Climate change, women's rights, income inequality, socioeconomic disparities, natural disasters, and humanitarian crises can be considered the main subjects of humanitarian aid efforts; however, any theme of assistance centered on the human being also carries the potential to be included within this scope (Chun & Brisson, 2015, p.9; Koskinen, 2016, p.18). The formulation of humanitarian aid oriented policies should be developed in collaboration with the disciplines working in the field.

Numerous collaborative platforms bringing together practitioners in the field continue to operate. Within the scope of humanitarian aid and design, research groups aiming to improve and develop society have mobilized by bringing together architects, designers, and planners. One example of such initiatives is ADPSR, founded in the United States in the 1980s (ADPRS, n.d.). It is observed that the identity of the architect is often at the forefront when examining platforms that adopt a participatory approach to foster community development and work toward a better future (Min Soo Chun & Brisson, 2015, p.9). In addition to architectural identity, landscape architecture (Project for Public Spaces, n.d.) and industrial designers, who stand out with their design expertise, also have a presence in the field. On the other hand, interior architecture, as a discipline of spatial design, is an important field represented in humanitarian design research. However, it has been observed that specific emphasis on the identity of interior architects is largely absent in the literature.

Humanitarian design, informed by knowledge of sustainability, should aim at proposing solutions to challenges arising from rapid global urbanization and future-oriented issues (Chun & Brisson, 2015, p.21). This practice, which uses design as a tool to improve human life, is defined by various terms such as humanitarian design, social design, and others (Veiga & Almendra, 2014). Humanitarian design, described under many terms including social design, socially responsive design, and socially responsible design, constitutes a broad practice that spans multiple

disciplines (Tromp & Vial, 2023, p.211; Veiga & Almendra, 2014). Social design will be used as an umbrella term, encompassing humanitarian design. Within the scope of this study, clarifying the terminology of the research practice is considered valuable for academic inquiry. For interior architecture, which addresses all types of human-occupied spaces, social design is an essential topic.

This study aims to examine social design and to discuss the responsibility of the designer. Defined by various concepts such as humanitarian design, social design, and socially responsible design, this field encompasses a broad research and practice framework (Chun & Brisson, 2015; Tromp & Vial, 2023; Veiga & Almendra, 2014). The study considers clarifying this terminology as the first step. Subsequently, the relationship of these concepts with the discipline of interior architecture will be discussed. In this context, key concepts and areas emerging from social design research will undergo content analysis, and subcategories that can be integrated into interior architecture practice will be identified and evaluated. Through this intersection, the study aims to explore the social responsibility of interior architecture.

SOCIAL DESIGN

Social design defines a very broad research and design pratice, and experts working in the field have different definitions on it. The solutions of humanitarian problems have led to different working practices, which has expanded the scope of social design (Koskinen, 2016, p.18). Social uses as an umbrella term to cover all kind of humanitarian and public design practices. Main focus of social design is social problems. But social problems' range is very broad and can led to different research area (Janzer & Weinstein, 2014, p.328). Based on this, discussing the research area and adressed problems are important for this paper.

In the current century, there has been a notable increase in studies related to interior architecture, social responsibility, and professional ethics. As research and practices that emphasize the social aspects of design have evolved, interior architects in this field have started to engage in discussions about the role of social design within their profession. The definition of social design is important and valuable in terms of the connection to be established with interior architecture. Social design is a practice that includes humanitarian-based design research and has a wide terminology in its field (Tromp & Vial, 2023).

Papanek, who emphasizes the importance of the social and individual responsibility of the designer in practice, is one of the greatest advocates of considering social and environmental factors in design.

Papanek examines the neglected areas in design under six categories: third world countries and needy people; design of educational and teaching tools for people with disabilities; designs required for the medical world; designs for experimental research (laboratory, etc.); designs that support human life for extreme environments; and designs of groundbreaking concepts that can be adapted to the present day from vehicles that have reached the end of their use (Papanek, 1984). It is possible to adapt these areas that Papanek put forward as an industrial designer to interior architecture. At this point, the sub-areas of social design and their reflections on interior architecture become clear.

Whiteley, similar to Papanek, emphasizes that we are surrounded by an excessive number of consumer- and market-based products and designs, while drawing attention to the designer's responsibility. As an important researcher in social design, Whiteley invites us to think about the designer's responsibility to society before the client, values, and the role of the designer in society. He emphasizes that ethical codes need to be clarified in order to discuss these concepts in design disciplines (Whiteley, 1993). Although the IFI Interiors Declaration in 2011 aimed to reveal these concepts, it should be examined how much they are adopted today.

Another prominent name in the field of social design is Margolin. Emphasizing that design is seen as an artistic practice for luxury products, he argues that there is a lack of awareness of how a designer can improve human life. While giving clues about the path a socially responsible designer should follow, he mentions the importance of training social designers through interdisciplinary programs in education and passing on this awareness to our young colleagues while they are students (Margolin & Margolin, 2002).

Authors and scholars such as Papanek, Whiteley, and Margolin, who are pioneers in the field of social design, have discussed the significance of social design and the ways in which it exists within society. They have brought forward the sense of responsibility that designers, who produce for a consumer society, should possess, and propose social-led design or a social model as an alternative to consumer-led or market models. Since the 21st century, social design has emerged as a recognized field of practice within academia, designers, and practitioners. Today, a wide range of terms and diverse approaches related to social design can be observed.

A study that argues the core of social design lies in enhancing the common good emphasizes both what social design is and how divergences occur in the pursuit of this goal. By examining social design

practices with different motivations, the study proposes a framework for how they can be categorized. Accordingly, five categories are identified: care-driven projects (1), which target disadvantaged groups; responsiveness-driven projects (2), which aim to improve institutional culture and governance; political progress-driven design projects (3); social capital-driven design projects (4), which focus on relationships and communities; and resilience-driven design projects (5), which emphasize creating a sustainable and better future for all (Tromp & Vial, 2023, pp.221-223). Researchers are attempting to better understand and classify the subfields of social design. Designers' research to define social design practice continues.

A study conducted to resolve the terminological confusion in the field of social design and to reveal the criteria behind such classifications examines social design practices around the world and categorizes them. At this point, social design practices are grouped into three main categories based on the type of problem addressed and the primary purpose: survival projects (1), which deal with human survival and fundamental rights; citizenship projects (2), which seek to address systematic challenges in social issues; and policy projects (3), which shape decision-making processes that directly influence systems. The study proposes the term social design as an umbrella concept encompassing these practices (Veiga & Almendra, 2014).

Koskinen (2016) seeks to reveal how the aesthetic language is addressed within the practice of social design. Based on the purpose, philosophy, and social impact of projects, he puts forward three different conceptions of aesthetics in social design. The 21st-century approach to social design highlights that design is nourished not so much by objects as by the social relations and processes it establishes. In this respect, the aesthetic language of design also develops in ways that adapt to social design. When examining the relationship between aesthetics and social design, three approaches emerge: Agonistic Aesthetics (1), which puts forward striking and critical designs that aim to provoke and stimulate debate; Convivial Aesthetics (2), which seeks to create new forms of community interaction that emphasize togetherness and warmth; and Conceptual Aesthetics (3), which deliberately withdraws from aesthetics in order to discover existing aesthetic approaches and employ them for improvement (Koskinen, 2016, pp. 20–26). These aesthetic approaches also define the design strategies employed in projects produced within the field of social design.

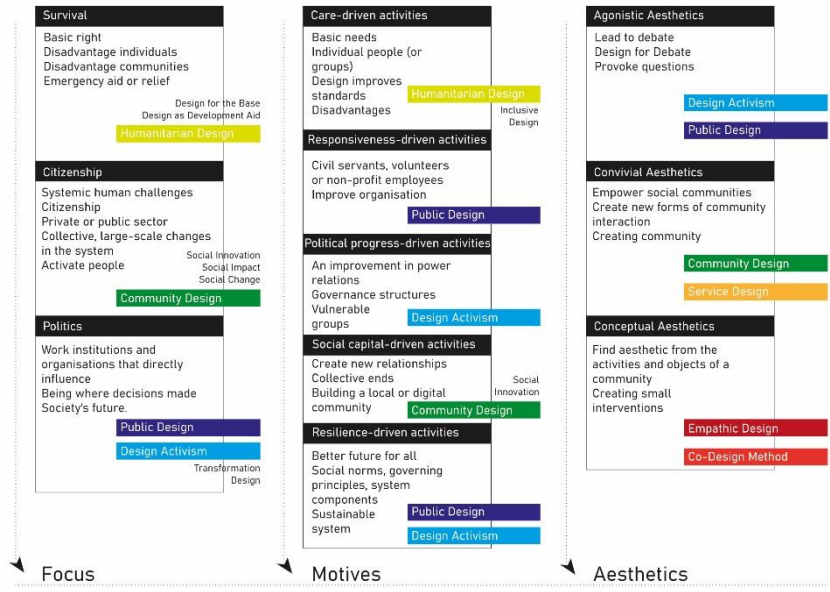


Figure 1. Focus, Movites and Aesthetics of Social Design

When examining the research that stands out in the field of social design, it is observed that especially in the 21st century, projects have been categorized based on various aspects such as their focus, motives, goals, and the aesthetic values in design (Figure 1). Public design and design activism, which are practices of social design, are projects carried out with responsiveness-driven, political progress-driven, or resilience-driven motives, and include politics practices aiming for a better future. Community design projects are citizenship-focused practices that target social innovation, created through social capital-driven motives and convivial aesthetics. Humanitarian design projects are survival-focused, care-driven initiatives. In this sense, the different categories established aim to eliminate the terminological confusion existing in the field. It is also evident how diverse and multidirectional the projects emerging under the umbrella of social design can be. Of course, this should not be considered a rigid classification; it should be remembered that a survival-focused project may also carry an agonistic aesthetic aimed at resonating within society. These classifications are illuminating in helping us better understand the content of social design.

Public design, design activism, community design, service design, humanitarian design all are working field defined under social design. Service Design guides designers to engage with social processes, while Community Design focuses on rooting design within communities. Public

Design, on the other hand, works with clients such as local communities, NGOs, cities, and government organizations (Koskinen, 2016, p.18). Design for Social Innovation and Design for Social Impact are two design fields that highlight social innovation, which is important for social design (Chen, Chang, Hummels and Koskinen, 2016, p.2; Tromp & Vial, 2023, p.212; Veiga & Almendra, 2014). Transformation Design discusses redesigning public services and pushes the boundaries of design (Tromp & Vial, 2023, p.212), whereas Transition Design encourages designers to commit to long-term visions and create systemic designs for a better future (Tromp & Vial, 2023, p.223). Design for the Base or Bottom of the Pyramid (BoP), Humanitarian Design and Inclusive Design focuses on basic needs of disadvantaged groups in developing countries, primarily addressing care-driven activities (Tromp & Vial 2023, p.221; Veiga & Almendra, 2014).

Many of these terms overlap and can be used in different contexts to describe similar practices. Because the field is always evolving, new terms continue to emerge. As we can see, all these areas of work focus on public welfare or the common good, while addressing human needs and improving the quality of life. Of course, motives and goals of design depend on the designer's perspective of society. Designers do not merely create the physical properties of an object or space; through their work, they also shape cultural and social structures. At this point, it is useful to examine our discipline and its ethical codes.

PRACTICE OF INTERIOR ARCHITECTURE

The concepts of social design, the designer's perspective, and the ethical codes within design disciplines have been discussed since the late 20th century and continue to be a topic of debate today. In this century, interior architects and designers have also started to explore and examine these concepts. Interior architecture is associated with the field of social design; the number of interior architects working in this field is increasing.

Interior architecture is one of the primarly research areas for creating a livable environment. Because of its scale, interior architecture differs from other architecture and design disciplines, yet there are overlapping boundaries at certain points. Studies have been carried out since the last century to define our professional field (Darbandi, Imani & Rahimzadeh, 2023). In 2011, as a result of a consensus organized with the participation of leading experts in the field, the International Federation of Interior Architects/Designers (IFI) Interiors Declaration (IFI ID) was created. Through this document, the definition of interiors was presented under seven concepts (Figure 2) (Demirbaş & Demirbaş, 2023; IFI, 2011).

The document in question is generally a summary that reveals the values, professional ethics and responsibilities in the field of interior architecture. Seven defining characteristics of our discipline are addressed in the declaration (Figure 2). According to public perspective, interior architecture is a profession focused on luxury consumption. However, as interior architecture is explored further in the academic world, it becomes clear how diversified the professional field is. In interior architecture, it is essential to define and detail the social responsibility of our discipline; its necessity and significance must be clearly stated. The text in question also outlines the ethical behavior expected of an interior designer or architect. It highlights the profession's ethical codes, the interior's responsibility, and the designer's responsibility.

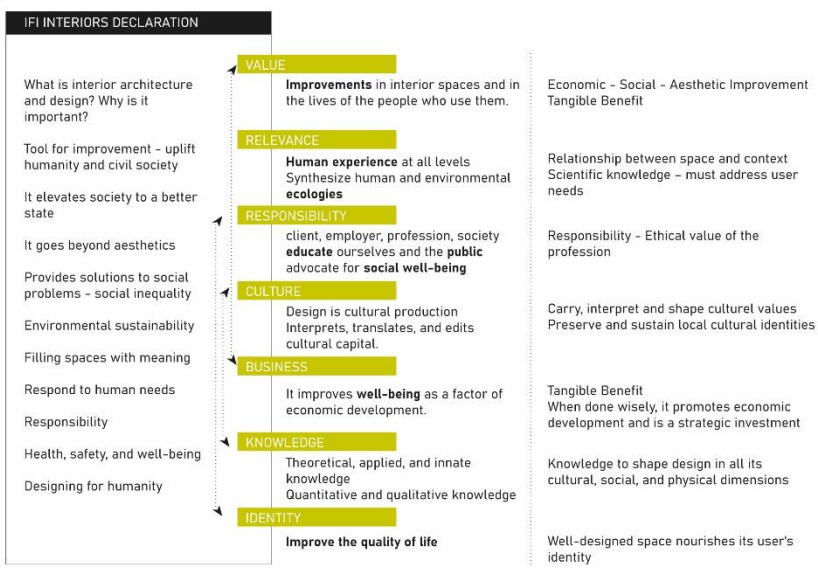


Figure 2. IFI Interiors Declaration - Defining characteristic

It is emphasized that the professional legitimacy of a field depends on its contribution to social benefit. It is debated the social value of Interior design / architecture is creating interior environments that contribute to human well-being and life quality (Anderson, Honey & Dudek, 2007). Today, interior architecture must emphasize its social necessity to society. In this way, the role and importance of our discipline in human life will be better understood. Around the world, there are many people exposed to various emergencies and seeking living spaces. Clarifying this relationship will make it possible to create a more livable environment for these people. A designer is responsible for what they design, what it signifies in society, and the impact it creates (Grant & Fox,

1992, p.77). When we examine the ethical codes of interior architecture and interior design, we see that a set of rules has been established to regulate the sense of responsibility towards society, clients, colleagues, and the profession. In addition to IFI, The Society of British & International Interior Design (SBID), the American Society of Interior Designers (ASID), and the International Interior Design Association (IIDA) have also declared ethical codes for the profession. When IFI addresses interior architecture and interior designers in a general framework, ASID, IIDA, and SBID primarily focus on the field of interior design.

When examining the defined ethical codes of the profession, it is observed that the definition of responsibility is articulated very strongly as a priority. This definition of responsibility is established toward society, clients, colleagues, professional practice, and employers. An emphasis on environment and sustainability is also made, and disciplinary actions to be taken in case professionals act improperly are specified (Table 1).

Table 1. Ethical Codes of Interior Design (ASID, n.d.; IIDA Oregon Chapter, n.d.; SBID, n.d.)

Theme / Principle	ASID (USA)	IIDA (USA/International)	SBID (UK/International)
General Purpose / Preamble	Protect public health, safety, and welfare; uphold the profession and society	Ensure design practice is ethical, professional, and responsible; serve the public good	Professionalism, transparency, honesty; responsibility to society, clients, and environment
Responsibility to the Public	Compliance with laws; prioritize health–safety–welfare; ban on misleading advertising; ban on bribery	Serve the public interest; maintain dignity of the profession	Prioritize public health and safety; anti-discrimination; sustainability
Responsibility to Clients	Clear contracts; confidentiality; honesty; financial responsibility; competency	Confidentiality; honesty; avoid conflicts of interest; competency	Fair dealings; disclosure of conflicts of interest; trust-based service
Responsibility to Colleagues / Other Designers	Do not harm reputations; fair competition; knowledge sharing	Respect colleagues; professional collaboration; honest representation	Respect peers; ban on unfair competition; collaboration encouraged
Responsibility to the Profession	Continuous learning; knowledge sharing; uphold profession's reputation	Contribute to professional development; commitment to IIDA's mission	Raise professional standards; continuing education; support SBID's values
Responsibility to Employers	Protect confidential information; do not remove materials without consent	Loyalty to employer; confidentiality	Professionalism in employer relations; avoid conflicts of interest
Environment / Sustainability	Implicit via health–safety focus	Limited emphasis	Explicit commitment to sustainability and environmental responsibility
Enforcement / Disciplinary Process	Detailed complaint and disciplinary procedures	General membership and disciplinary rules apply	Ethics committee and disciplinary mechanisms in place
Key Highlights	Strong focus on health–safety–welfare and detailed complaint procedure	Concise emphasis on professionalism and ethics	Clear emphasis on sustainability, diversity, and inclusion

It is evident that frequent references are made to health, safety, and wellness, all addressed under responsibility. IIDA has emphasized professionalism, ethics, and confidentiality, while SBID, in addition to these, has also addressed sustainability, diversity, and inclusivity. ASID, on the other hand, has approached the subject in more detail compared to the others, specifying the areas of responsibility under separate

headings (ASID, n.d.; IIDA Oregon Chapter, n.d.; SBID, n.d.) (Table 1). Building on this, it is emphasized that the disciplines of interior architecture and interior design are responsible for implementing practices that, by prioritizing the public good, enhance well-being and wellness at both the individual and societal levels.

IFI ID emphasizes "producing measurable outcomes and improvements in interior spaces and in the lives of the people who use them" for our profession. At the same time, the principles have been defined as both the purpose and the means of finding the values, responsibilities, and identity of our profession. The impact on human life is further stated as "Interior designers and interior architects determine the relationship of people to spaces based on psychological and physical parameters, to improve the quality of life." (IFI, 2011).

Interior architecture goes beyond producing visually pleasing spaces, and is particularly significant for the efficiency of human activities. It makes the necessary adjustments to ensure livability by influencing user health, satisfaction, and productivity within space. Acoustics, air quality, safety, and spatial adequacy are parameters that interior architecture intervenes in when considering environmental quality in interiors (Saleh, 2011, p.57).

Although shelter is a priority in the field of humanitarian aid, it has been noted that the number of specialists in the field remains limited (Davis, 2011, p.194). Moreover, when examining the platforms operating in this field, engineers tend to take the lead, with interior architects sidelined and even architects having relatively little influence (Lepere, 2020, p.42). In the area of emergency and shelter, which is a subset of social design, the livability of spaces is crucial. However, even architects are not sufficiently employed in this field, and support and efforts largely remain at the engineering level. Even though architects are brought to the forefront in literature and on humanitarian aid platforms, in practice engineers often take the lead.

Interior architecture is not only about creating aesthetically pleasing spaces for luxury consumption, but is fundamentally related to improving human quality of life. In the context of emergencies and shelter, designs that support the human recovery process are essential. Lighting, materials, color, the relationship between private and public spaces, accessibility according to different age groups and physical conditions, hygiene, food, water, clothing, and other necessities should be designed not only at a basic needs level, but with a depth that engages human experiences and behaviors. Such a level of detail can have a significant impact on improving human life. Since interior architecture

focuses on the human, perceiving it from the human scale and perspective, it has the potential and purpose to establish a direct relationship with the field of social design.

Globally, interior architecture plays a role not only in shelter but in every type of space inhabited by humans, serving as a factor that can enhance people's quality of life. Therefore, social design is inherently an approach embedded within the discipline of interior architecture, since the core concern of interior architecture is the human being and their well-being. However, this relationship is often overlooked due to the public perception of interior architecture. As a result, interior architecture does not find recognition under its own name within the field of social design.

Design used to address and solve social problems is referred to as social design (Janzer & Weinstein, 2014, p.328). For interior architecture, which focuses on design problems at the human scale, social problems are naturally included among these issues, but there is no need to separate and categorize them. Emphasizing these points is expected to clarify the relationship between social design and interior architecture.

METHODOLOGY

This research examines studies related to social design practice and the responsibilities of designers. The focus has been on significant designers' research, emphasizing the connection between these ideas and the practice of interior architecture. The aim is to identify key areas and concepts within social design practice by fostering discussion around the examined ideas. The research analyzes various categories and areas found in these studies, revealing the intersections between social design and interior architecture. Furthermore, it opens up a discussion about the social responsibilities inherent in the field of interior architecture through the defined categories.

This research aims to; (1) detail the concept of social responsibility in the discipline of interior architecture, (2) define the social design, (3) emphasize the importance of social design in the field of interior architecture, (4) discuss the foundations of social design with the perception of responsibility in interior architecture through the first three networks. It is believed that this approach will lead to a significant defining factor in describing our profession.

The connection of interior architecture and social design practice can be identified through basic concepts. These concepts presented help to define professional responsibility in the discipline of interior architecture. Determining social design terminology is enlightening for

both academic research and design practices. One of the aims of this study is to support social design research in the field of interior architecture. Also, this research argues that social design should find its place as one of the priority research areas for interior architecture. The research opens up social design terminology and its priority subfields for discussion.

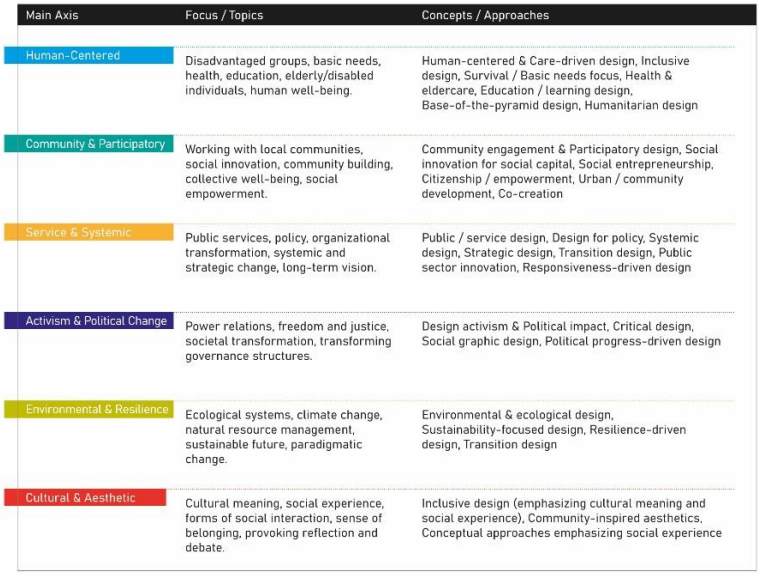
FINDINGS

Social design is a broad field of practice that has existed since the second half of the last century, though it has gained recognition by name mainly in this century. Its primary aim develops around promoting the well-being of all and the common good, addressing problem areas such as inequality, injustice, poverty, health, education, and marginalization. As a design approach that targets the welfare of society and everyone, it employs methods in which people can actively participate, such as workshops, co-creation, and action research, with participatory design being central. While social design practices have yielded successful outcomes in small local communities, they tend to remain limited on a larger scale and encounter challenges in implementation. Since social design has the capacity to overlap and collaborate with all disciplines, it may face difficulties in terms of theoretical framing and analytical tools. Researchers wishing to work in the field of social design need to be inclined toward interdisciplinary collaboration, willing to understand human behavior, and knowledgeable about social needs (Table 2).

Table 2. Key features of Social Design

Social Design – Key Features	
Category	Key Features
Purpose / Focus	Common good, public welfare, human needs, societal benefit
Problem Areas	Injustice, poverty, inequality, health, education, social cohesion, marginalization
Methodologies	Co-creation, Participatory design, Social innovation, Action research, Workshops, Prototyping, Design thinking
Limitations	Focused on small communities, Limited in large-scale structures, Theoretical fragmentation, Lack of evaluation tools
Education / Competencies	Knowledge of social needs and policies, Understanding of human behavior, Ability to work in interdisciplinary teams

The main research areas of social design can be explained under six categories. These are human-centered, community and participatory, service and systemic, activism and political change, environmental and resilience, and cultural and aesthetic based design projects. All sub-classifications in the field of social design fall under these six main axes. This is useful for viewing the research areas of social design in a unified framework (Figure 3).



Main Axis	Focus / Topics	Concepts / Approaches
Human-Centered	Disadvantaged groups, basic needs, health, education, elderly/disabled individuals, human well-being.	Human-centered & Care-driven design, Inclusive design, Survival / Basic needs focus, Health & eldercare, Education / learning design, Base-of-the-pyramid design, Humanitarian design
Community & Participatory	Working with local communities, social innovation, community building, collective well-being, social empowerment.	Community engagement & Participatory design, Social innovation for social capital, Social entrepreneurship, Citizenship / empowerment, Urban / community development, Co-creation
Service & Systemic	Public services, policy, organizational transformation, systemic and strategic change, long-term vision.	Public / service design, Design for policy, Systemic design, Strategic design, Transition design, Public sector innovation, Responsiveness-driven design
Activism & Political Change	Power relations, freedom and justice, societal transformation, transforming governance structures.	Design activism & Political impact, Critical design, Social graphic design, Political progress-driven design
Environmental & Resilience	Ecological systems, climate change, natural resource management, sustainable future, paradigmatic change.	Environmental & ecological design, Sustainability-focused design, Resilience-driven design, Transition design
Cultural & Aesthetic	Cultural meaning, social experience, forms of social interaction, sense of belonging, provoking reflection and debate.	Inclusive design (emphasizing cultural meaning and social experience), Community-inspired aesthetics, Conceptual approaches emphasizing social experience

Figure 3. Research Areas of Social Design

Human-centered design prioritizes the needs of disadvantaged groups and inclusive solutions, while community and participatory design focuses on collaboration with local communities and focusing collective well-being. Service and systemic design addresses public services, policy, and organizational transformation, whereas activism and political design supports social justice and societal change. Environmental and resilience-focused design emphasizes ecological systems and sustainability, and cultural and aesthetic design aims to provoke discussion through social interaction and a sense of belonging. This classification provides a framework summarizing the scope and diverse motivations of social design. Although six main axes have been identified within the scope of the study, these categories have been introduced to facilitate the understanding of social design. Social design is a practice that can be applied in any problem-solving process aimed at improving human life.

IFI has published a declaration that encompasses interior design and interior architecture professionals worldwide. Within the scope of the study, ASID, IIDA, and SBID define the prominent ethical codes in the field of interior design. However, when examined in general, it is observed that the ethical codes highlighted within the profession show significant similarities. These are;

- Well-being / Health / Safety – well-being, health, safety, comfort
- Humanity / People / Society – humanity, people, society, community, public service
- Trust / Integrity / Honesty – trust, integrity, honesty, transparency
- Equity / Anti-discrimination / Inclusion – equity, anti-discrimination, inclusion, fairness, diversity
- Collaboration / Respect / Knowledge-sharing – collaboration, respect, knowledge-sharing, peer support
- Sustainability / Environment / Responsibility – sustainability, environment, responsibility, eco-conscious design
- Learning / Growth / Professionalism – learning, growth, continuous improvement, professional standards
- Accountability / Ethics / Transparency – accountability, ethics, ethical practice, compliance
- Culture / Identity– culture, identity, heritage, local context, human-centered design
- Relevance– relevance, context, user-centered design, adaptability
- Business– business, professionalism, ethics in practice, strategic planning
- Knowledge– knowledge, education, research, innovation, interdisciplinary collaboration

Based on the definition by Veiga and Almendra (2014), social design is "…the practice which uses design as a tool to improve human life." According to IFI (2011), "Interior designers and interior architects determine the relationship of people to spaces based on psychological and physical parameters, to improve the quality of life." At its core, every interior architect should view society from the perspective of a social designer.

CONCLUSION

This study aims to explore the place of social design within the discipline of interior architecture. Social design, understood as an umbrella term encompassing various human-centered aid projects, is elaborated in this research to provide a clearer understanding of its different tendencies. Fundamentally, what stands out is that social design is a

design practice that addresses socially oriented problems with the aim of promoting the common good and collective well-being.

The second part of the research elaborates on the practice of interior architecture. It conveys the ethical values that are prominent in the interior architecture profession. Interior architecture is a field focused on improving human life; it is not limited to aesthetic values but aims beyond, targeting both individual and societal benefits. The scope of professional responsibility extends from clients to employers, and from colleagues to society. When these responsibilities are detailed, it becomes clear that interior architecture aims not only to enhance individual experiences but also to contribute to societal well-being, to recognize and integrate the needs of disadvantaged groups into spaces, and to provide contributions at different levels of knowledge, from construction to materials, with an emphasis on environmental sustainability. In summary, the social responsibility of interior architecture is not merely to design spaces, but to safeguard people, society, culture, and the environment while promoting the common good. From this perspective, traces of social design principles can be observed at the core of interior architecture (Figure 4). Figure 4 presents the key research areas of social design alongside the principles prioritized in the interior architecture profession. A comparison of the two diagrams reveals that interior architecture and social design are guided by closely aligned principles.

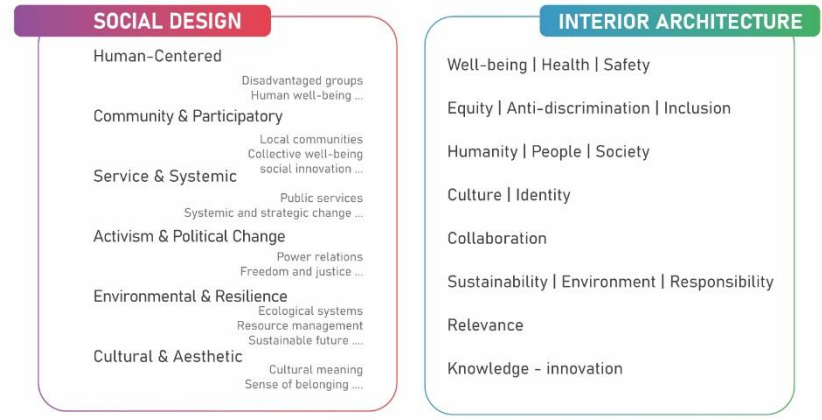


Figure 4. Feauture of Social Design and Focuses of Interior Architecture

Every design action carries traces of social design. This is because a designer does not turn away from problems; rather, they focus on improvement through a problem-solving mindset. At a more specific level, interior architecture approaches space from a human scale and

works to enhance health, well-being, and quality of life. Examining the profession's defined ethical codes reveals that this emphasis on responsibility is central. Therefore, it would not be inaccurate to say that the components of social design are embedded in the core of interior architecture. At its core, every interior architect should perceive society through the lens of a social designer, making this perspective a priority in their practice.

Design is inherently social. At least half of contemporary design practices are directly related to social design. This study argues that making the perception of social design within our discipline visible will help the profession gain greater recognition from society. The social design perspective is often not emphasized because it is considered a fundamental part of our profession. However, emphasizing it can significantly alter society's perception of the importance and necessity of our field. It is important to start emphasizing this during education. This helps young designers develop a social perspective as they move into their professional careers.

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TECHNOLOGY / MATERIAL / SUSTAINABILITY / REUSE

AN APPROACH FOR VISUAL COMFORT AND ENERGY PERFORMANCE ANALYSES BASED ON LIGHTING DESIGN PARAMETRS: AN EXAMPLE OF AN OFFICE SPACE ON A UNIVERSITY CAMPUS

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ABSTRACT

The shortage of fossil energy resources and the increasing cost of energy have made the energy-efficient design of buildings a key issue for designers. Lighting, which is one of the important elements of architecture in providing the visual comfort conditions of the space, plays a major role in the energy performance of the building. This study presents an approach that considers the EN 15193-1 + A1 standard to estimate lighting energy performance in offices. For performance estimation, a two-person office room on the campus of Karadeniz Technical University was selected with the dimensions of 2.80x6.90x3 meter that 60% transparency rates. The study created scenarios consisting of variations in window shape, light transmittance of the glass, solar control elements for natural lighting, as well as different lamp types and control systems for artificial lighting. The results according to the proposed energy calculation method showed that the variables introduced in the integrated lighting scenarios affect the annual lighting energy requirements at different levels. The analysis showed that using LED lamps has the most significant effect on energy consumption, providing up to 50-60 % energy savings compared to fluorescent lamps. The automatic control system saved almost 10% of energy compared to the manual option. Among the variables in the natural lighting system, solar control had %8-9 impact on the total amount of lighting energy used throughout the year. Taking the window shape and glass light transmittance parameters into account, it was found that, although the annual lighting energy requirements differed between the alternatives, these differences were minimal.

Keywords: Lighting Design, Office Lighting, Visual Comfort, Energy Performance, EN 15193-1.

INTRODUCTION

The issue of energy efficiency has recently become a key concern due to rising energy demand and costs. As in any other field, the issue of efficient energy use in buildings continues to be topical. Lighting is one of the most important elements of architecture when it comes to creating visual comfort in spaces, and it significantly affects a building's energy consumption. Due to the large amount of energy consumed by lighting in the world and in our country, energy use at appropriate levels is an issue that should be given importance, especially in volumes that are used for long periods of time and throughout the day, such as office spaces. Effective use of lighting energy in buildings is an important part of saving energy in buildings. By using effective methods in lighting, building operating costs can be reduced by 10% and energy savings of more than 30% can be achieved (Bodart & Herde, 2002; Dubois & Blomsterbeg, 2011). Energy savings in lighting can be achieved by creating optimal conditions for functionality without compromising on quality. Using efficient artificial lighting elements is important for achieving good lighting. The level of lighting required to provide visual comfort can be achieved using correct and appropriate lighting elements that allow for lower energy consumption (Chwe et al, 2017; Uygun et al, 2020; Rockcastle & Mahic, 2024). The efficiency of indoor daylight can be increased through various design choices, which can help to increase energy efficiency and reduce the installation load of the artificial lighting system. In this context, the lighting design of sustainable buildings and the renovation of existing buildings involve the appropriate selection, analysis and use of natural and artificial lighting products (Katzev, 1992). Offices are building types that are actively used during daylight hours and should be carefully designed in terms of the health, comfort and productivity of the occupants. For this reason, the design of lighting systems in offices should take into account both visual comfort conditions and energy-efficient design criteria that are functionally and operationally appropriate. In order to provide visual comfort, the required lighting level can be attained thorough the use of precise and appropriate lighting elements that facilitate less energy consumption (Vischer, 1996; DiLaura et al, 2011). This will contribute to the national economy and improve the quality of work (CIE, 2001).

EU countries have carried out various studies to determine the energy performance of buildings and in 2002 the Energy Performance of Buildings Regulation (2002/91/EC) was published. The purpose of this regulation is to introduce a common methodology for determining the energy performance of buildings. Following this regulation, EN 15193 Energy Performance of Buildings - Lighting Energy Requirements was developed for the calculation of lighting energy requirements in

buildings. The new version of EN 15193-1 + A1, updated in 2021, was approved and published as a Turkish standard at the meeting of the Technical Committee of the Turkish Standards Institute and entered into force as TS EN 15193-1 + A1. The standard sets out a methodology for determining the lighting energy requirements of buildings. This method can be used for evaluation purposes when designing or renovating buildings. The lighting energy of a building or volume can be calculated using different variables, such as lighting systems, lamps, control systems and the characteristics of openings and façade systems, as well as

the geographical location (Energy performance of buildings EU Directive, 2010; European Committee for Standardization, 2021; Institute of Turkish Standards, 2021). There are studies in the literature based on the standard's methodology of estimating the annual energy consumption for lighting, defining the main scope of the standard, highlighting its limitations and proposing improvements (Erkin & Onaygil, 2014; Yılmaz & Yener, 2015; Zinzia & Mangione; 2015; Aghemo et al, 2016). A study performed by Akimov et al (2015) provided an assessment of the EN 15193-1 standard's energy requirements calculation against DAYSIM simulation tool considering the impact of the following factors: window-to-wall ratio, presence of side openings, glazing transmittance, distribution of windows, overhang length and space geometry. However, this study excluded the artificial lighting systems and the application of control systems. Lo Verso & Pellegrino (2019) conducted a study that quantified the energy savings resulting from four types of daylight-linked controls and their combination with an occupancy auto-off control, as specified in EN 15193-1. The results showed that target savings of 20% and 30%, respectively, can be achieved by using the photodimming and occupancy controls included in the standard. Another study emphasized the importance of building automation and control systems in evaluating the energy and environmental performance of specific lighting control systems. Considering the whole monitored annual electric energy consumption, the energy savings varied from 17% to 32%. (Aghemo et al, 2014).

Now that the required luminous flux values can be achieved with rapidly developing LED technology, the use of LED panel luminaires for retrofitting purposes, as an alternative to other luminaires previously widely used in office lighting, has been investigated comparatively. These studies have shown that LED panels are favourable in terms of energy savings. (Erkin et al, 2015; Küçükkaya & Alakavuk, 2019; Manav et al, 2013). Therefore, LED systems are significant in terms of both energy and economic savings for buildings. (Fantozzi et al, 2017; Doulos et al, 2019). A study was carried out in Italy in which the lighting energy requirements of nine different building types were evaluated according

to the EN 15193-1 standard, and LENI values were calculated. The results showed that converting from an artificial fluorescent lighting source to an LED system had the greatest influence on the LENI values (Pompei et al, 2022). Despite all these studies, the analysis of the impact of all parameters on energy performance remains deficient in the literature. A comprehensive overview that considers both artificial lighting and daylight parameters is essential for more detailed energy analyses.

In this frame, the study presented in this paper is aimed at estimating, through the analytical calculation method defined in the EN 15193+ A1:2021 (Energy Performance of Buildings – Lighting Energy Requirements), the differences in the lighting energy performance that can be obtained using different artificial and natural lighting scenarios. In order to evaluate how lighting features might affect energy savings, the analyses was carried out for a two-person office room on the campus of Karadeniz Technical University in Trabzon, Turkey. In the study created scenarios differ in geometry of the openings, light transmittance of the glass, presence of solar control devices for day lighting systems, and different lamp type and control systems for the artificial lighting systems. The results obtained from the calculations were evaluated comparatively, and the effectiveness of the alternatives was discussed.

METHODOLGY

Figure1 describes the workflow of the applied to this study and summarizes the adopted steps. Both the architectural data and lighting requirements (level of illuminance required for activity, the type of activity, etc.) represents a key role for the final energy performance of the volumes as highlighted in the literature.

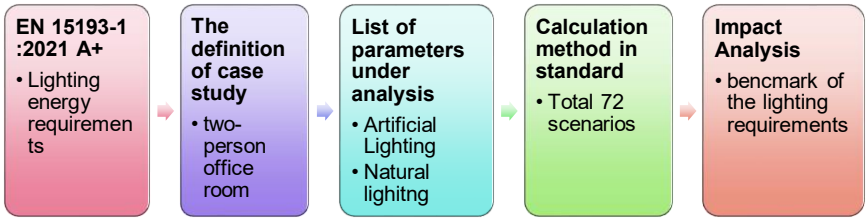


Figure 1. Workflow of the methodology applied to this work.

Overview of the standard EN- 15193-1+A1

The standard allows the lighting energy requirement of buildings to be determined according to the daylighting efficiency provided in the space depending on the lighting installed power. Accordingly, the

standard's calculation procedure can be divided into the following steps.

- Definition of the geometry and use
- Estimation of the installed electric power
- Definition of the luminaries control system
- Daylight availability depending on location, orientation, openings geometry, shading systems and glazing properties.

According to the calculation method defined in the EN 1593-1 + A1 standard, the annual amount of energy consumed for lighting in any volume or section of a building can be calculated using Equation 1 below.

$$\boldsymbol{WL,t} = \{(Pn\ x\ Fc)\ x\ Fo\ [(tD\ x\ FD) + tN)]\} / 1000\ (kWh) \qquad (1)$$

WL,t : Annual lighting energy requirement (kWh)
Pn : Total installed lighting power of all lamps for a volume or section (W)
Fc : Constant illuminance factor
tD : Daylight hours utilization (h)
Fo : Usage dependent factor
FD : Daylight dependency factor
tN : Use outside daylight hours (h)
The main parameter is the lighting energy WL,t required to provide a zone of the building with adequate illumination. The daylight factor (FD) in the method expresses the reduction in lighting energy demand during daylight hours when the volumes benefit from daylight. This value is determined as a function of the daylight factor (FD, S) and daylight control (FD, C) values. In order to determine the daylight factor, various indices have to be calculated. The daylight factor for the window opening is calculated by taking into account the window dimensions, the volume dimensions, the presence of obstacles in front of the window, and according to this value, the daylighting effect is classified as "strong, medium, weak, none". It is a tabular value in the standard. The value of the daylight-dependent artificial lighting control (FD, C) is another factor that influences the daylight-dependent factor (FD). It is the coefficient indicating the energy efficiency of the artificial lighting control system. FD, C values are included in the calculations depending on whether the artificial lighting control system is manual, automatic or daylight-based (Yener, 2011; Yener et al, 2019). As a result, the FD (Daylight dependency factor) value is calculated according to Equation 2:

$$\boldsymbol{FD} = 1 - (F\,D,S\ x\ F\,D,C). \qquad (2)$$

Definition of the Case

Within the scope of this study, an office room in the Faculty of Architecture at Karadeniz Technical University Campus was selected for case study purposes. The office room is located on the first floor of the building. The dimension of the space is 2.80 x 7.70 m and the floor height is 3.03 m. The transparent surfaces used on the facade are double-glazed. The light transmittance coefficient of the window glass is determined to be 78%. Obstacles around the building have been disregarded. Vertical slatted blinds are present on the windows as a sun control element. The light reflectance coefficients of the interior surfaces of the volume have been determined to be 50% on the walls, 80% on the ceiling, and 20% on the floor, in accordance with the EN 12464 standard. The floor plan of first floor and an image of the building are shown in Figure 2.

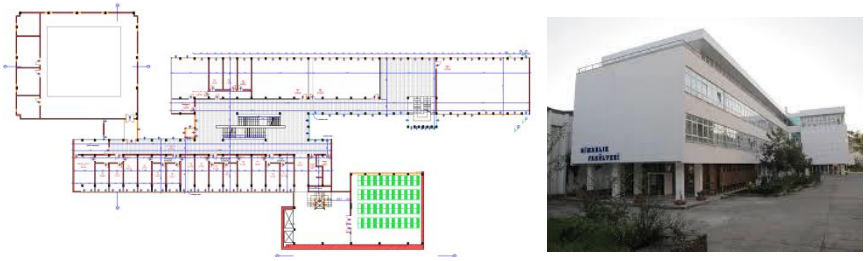


Figure 2. The floor plan of the first floor of the building and building image

Determination of Artificial Lighting

The standard EN 1593-1 + A1 makes it possible to determine a building's lighting energy requirements based on the installed lighting wattage and the design of the natural lighting system. The first question asked in energy calculations to improve user performance and productivity in offices is whether artificial lighting provides adequate visual comfort conditions in office buildings. The values to be provided in terms of visual comfort conditions were determined with reference to EN 12464-1 standard (Table1). Accordingly, it is known that the required illuminance level in office spaces should be 500 lx, the glare index UGR value for artificial lighting elements should be maximum19, and the illuminance distribution should be minimum 0.6.

Table 1. Recommended lighting conditions in accordance with EN 12464-1

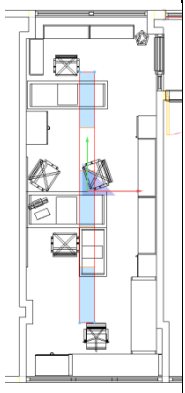
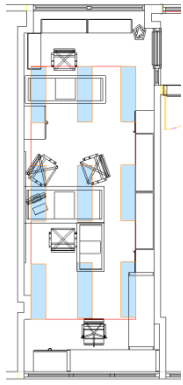
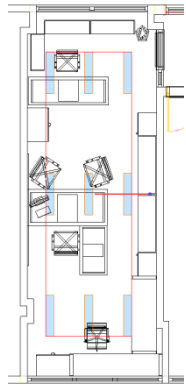
Type of work	$E_{average}$ (lm/m²)	U_o (E_{min}/$E_{average}$)	UGR
Computer-aided work units (CAD WorkStations)	≥ 500	≥ 0,6	≤19

The office room under examination has been modeled in the Dialux evo simulation program. Table 2 shows the artificial lighting features of the space and the image of the model. In the current situation, artificial lighting elements consist of ceiling-mounted fixtures with 2X18W lamp power, fluorescent tubes. As a recommendation for the current lighting scenario (Scenario 1), alternative lighting scenarios involving different lighting product selections and placement configurations have been developed within the scope of this study. Scenario 2 is achieved by developing the existing lighting device through increased usage. The other scenarios were developed with products recommended for visual comfort, featuring microprismatic reflectors in the form of direct, surface-mounted lighting, in line with the data obtained in Gül's (2023) previous study. The lighting schemes of the developed scenarios are shown in Table 3.

Table 2. Information related to the office space

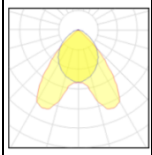
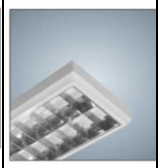
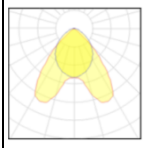
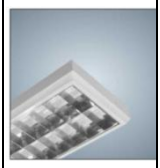
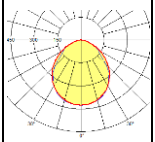
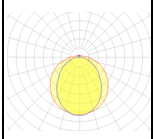
Office type	Cellular Ofice (2 person)
Area	21.46 m^2
Transparent surface area	2.40x 2.80 m
Lamp power and lamp type	2X 18W – flourescent
Lighting device type	Direct lighting –surface mounted
Image of the space	

Table 3. Lighting arrangements in the created scenarios

Scenario 1	Scenario 2	Scenario 3	Scenario 4
			

The artificial lighting calculations for the developed scenarios were performed using the Dialux evo programme. The average illuminance level, illuminance distribution and glare values were determined for each scenario. Information about the products used and the simulation results are provided in Table 4. It is important to ensure that the minimum and the maximum values specified as references in the EN 12464 standard are met in the space in order to ensure visual comfort. In this context, it was observed that the required values were achieved with the products used in scenario 3 and 4. These products were included in the energy calculations for the integrated lighting scenarios.

Table 4. Calculation results

	Light intensity distributions	Image of the device	Luminaries model name	System flux (lumen)	Lamp power (watt)	Lamp type	Illuminance level	Uniformity ≥0,6 U_o	Glare ≤19 UGR
Scenario 1			OSRAM	2500	36	Fluorescent	250	0.40	20.1
Scenario 2			OSRAM	2500	36	Fluorescent	450	0.51	19
Scenario 3			ZUMTOBEL M levo EA	3540	30	LED	532	0.70	16.2
Scenario 4			RIDİ WL 221P	2688	45	Fluorescent	500	0.62	17.5

Development of Integrated Lighting Scenarios

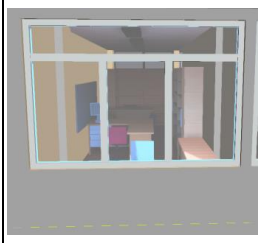
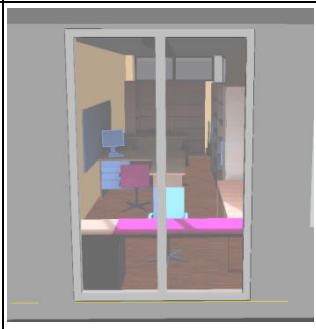
This part of the study includes the process of optimal integration of artificial and natural lighting systems for the office space. The natural lighting variables were determined in accordance with the design parameters that affect illuminance and light distribution in the offices. Natural lighting scenarios for the office volume, assumed to be free of external obstructions, were developed based on the variables of window type, light transmittance of the glass, and solar control element.

Window; the variation of this parameter was conducted by using a different type of window with the same glass area but different position on the same façade.

Light transmittance; the single, double (the existing glazing) and triple glazing were calculated with a visible transmittance of 0.90, 0.78 and 0.65 respectively.

Solar Shading; in the existing situation there is internal shading that is a vertical blind represents the simplest type of manual shading. The variation of this parameter was conducted by using external horizontal shading. The design of the external shading element is based on the day and time of day when the sun's rays reach Trabzon at their steepest angle. For this purpose, data on the angle of incidence of the sun's rays on the Earth's surface in Trabzon on 21 June at 12:00 were taken from the Solar Physics Department of the Kandilli Observatory in İstanbul. In line with the data obtained, the profile angle was determined as 72◦C on the dates when shading was required for Trabzon Province. As a result of the drawings made according to this profile angle, the size of the horizontal shading element was decided as 57.5 cm. The alternatives created for natural lighting are presented in Table 5.

Table 5. The alternatives created for natural lighting

	Window type	Light transmittance (VT)	Solar shading
Office room Existing variations	**Dimension:280w x195h** 	1.Double glazing- (VT) : 0.78	Vertical blind 
Alternatives	 **Dimension: 195w x 280h**	2.Low-e glass-triple glazing (VT): 0.65 3.Clear glass- (VT): 0.90	External horizontal concrete shelf 

In the EN 15193-1 + A1: 2021 standard, the lighting control systems in buildings play an important role in determining energy consumption. Whether the lighting control of a volume is designed to be automatic or manual has a decisive influence on the calculations. Different types of lighting controls are considered in the calculation method of the standard. These are occupancy dependent control system, constant illuminance control system and daylight-responsive control system.

In this study daylight responsive control alternatives were created for energy analysis. First one is the automated on/off system: the electric lighting is automatically switched off when the maintained illuminance is achieved by the daylight and the electric lighting is switched on again automatically when the illuminance is no longer achieved by daylight. The second one is the automated turn on/off in stages: the electric lighting is switched off in stages until the illuminance is achieved by daylight and switched on again in stages. In this context, the integrated lighting scenarios determined by the optimum integration of artificial

and natural lighting systems according to the specified standard are shown in Table 6.

Table 6. The integrated lighting scenarios

Artificial Lighting		Natural Lighting		
Control Systems	Lamp type Lamppower (watt)	Window shape (wxh)	Light Transmittance (VT)	Solar Control
1.Manual	1.30W- LED	1.280wx195h	1.Low-e glass - 0.65	1.Interior blinds
2.Daylightresponsive control-auto on/off	2.45W-Fluorescent	2.195wx280h	2.Double glazing-0.78	2.Concrete shelf
3.Daylightresponsive control- auto turn on/off in stages			3.Clear glass-0.90	

Calculation of Lighting Energy Requirements

This section of the study focuses on the energy calculation process developed for office spaces. The EN 15193-1+A1:2021 standard takes into account the design parameters of the natural and built environment parameters related to building users, the hours of use of the building, and the characteristics of its artificial and natural lighting systems. Calculations were performed for each scenario using Equation (1), which was introduced in the overview of the standard.

Calculation of Total Installed Lighting Power (Pn): Visual comfort assessments of the artificial lighting alternatives created within the scope of the study are presented in Table 2. One of these devices is Zumtobel Mlevo EA model with 30W LED light source and the other is RIDI WL 221P model with 45W fluorescent light source. The installed power (in Watts) for devices with two different power outputs (Pn1 and Pn2) was calculated for each volume. Accordingly, the total installed power values were calculated as follows: Volume 1: Pn 1 = 180 W, Pn 2 = 405 W.

Calculation of Constant Illuminance Factor (FC): This value relates to the consumption of total installed lighting power in a volume due to constant illuminance control, and is taken into account in dimmable lighting systems. As dimmable lighting control is not considered here, the constant illuminance factor (FC) is assumed to be 1 (no effect).

Relationship between day lengths and working hours Calculation of tD and tN values: According to the calculation method, the annual tD and

tN values depending on the building usage hours can be selected from the table prepared according to the building typologies in the Standard. Since the building typology selected in this study is office, (tD) annual daytime use is determined as 2250 (tN) annual non-daytime use is determined as 250.

Calculation of the Usage Dependent Factor (Fo): The utilization-dependent value is calculated by taking into account the lighting control factor and the utilization rates of the spaces. Accordingly, the absence factor (FA) values indicating the rate at which spaces are unused and the use factor (Fo) values are determined using the table associated with the lighting control system assumed to be in the space. The two-person office developed in volume of the study has an FA value of 0.30, as specified in the table in the standard.. The (Fo) values for the volume were selected as 0.900 for manual control and 0.800 for automatic control.

Calculation of Daylight Dependency Factor (FD): The daylight dependency factor depends on the control characteristics of the lighting systems and the daylight factor. As mentioned before, the daylight factor varies according to the geographical location's latitude and longitude values, the daylight factor class, and the desired average illuminance level. In this study, calculations were made in line with the latitude and longitude values of Trabzon Province (41° 0′ 19″ North, 39° 43′ 4″ East) and the outdoor illuminance values obtained from the data compiled as Typical Meteorological Year for Trabzon Province. The desired average illuminance level for office spaces was determined as 500 lux. The daylight supply factor (F D, S) and daylight-dependent lighting control (F D, C) for each volume were calculated using the variables determined for each scenario. As a result, the FD (Daylight dependency factor) value is calculated according to Equation 2 to be used in Equation 1.

RESULTS AND DISCUSSION

Analysis of the results obtained using the proposed energy calculation method showed that the variables introduced in the integrated lighting scenarios affected the annual lighting energy requirements at different levels. Table 7 shows the significant correlations between lighting energy requirements and lamp type, control systems, window type, glass light transmittance and solar control element parameters in the office space. Analysis of the results showed that the artificial lighting system is the parameter that most significantly affects total annual lighting energy. The second parameter affecting the total annual lighting energy the most was the presence of the control system. The correlations between

energy consumption and natural light parameters were not significant. The type of solar control element, window shape and light transmittance of the glass had a lesser effect on total annual lighting energy consumption.

Table 7. Correlations between integrated lighting scenarios and total annual lighting energy

Artificial lighting parameters	Correlation (r) Significance (p)	Annual Lighting Energy Requirement (KWH)
Lamp type	r	.901**
	p	.000
Control Systems	r	-209*
	p	.012
Natural Lighting Parameters	Correlation Significance	
Window Type	r	-.018
	p	.838
Light Transmittance (VT)	r	-.044
	p	.716
Solar Control	r	.049
	p	.311
p<0.01	p< 0.05	

The annual lighting energy requirement values were calculated based on the lamp type and control systems, window type, the light transmittance and solar control element parameters introduced in the integrated lighting scenarios. These values were then compared for the office volume. Figure 3 show that, the greatest difference between the options was between LED and fluorescent light sources. When artificial lighting was designed using LED lamps, 60% energy savings were achieved compared to using fluorescent lamps. Taking into account the differences between the control systems, compared to Manuel system, 20% energy saving was achieved when the control system was arranged as daylight responsive control - auto turn on/off in stages. Also, daylight responsive control - auto on/off system provided 10% energy savings compared to the manual system. It was observed that energy consumption increased %9 in cases where the shading element was interior blind instead of concrete exterior shelf. Taking into account the parameters of window type and glass light transmittance, it was seen that, although there were changes in annual lighting energy requirements between the alternatives, the differences were very low.

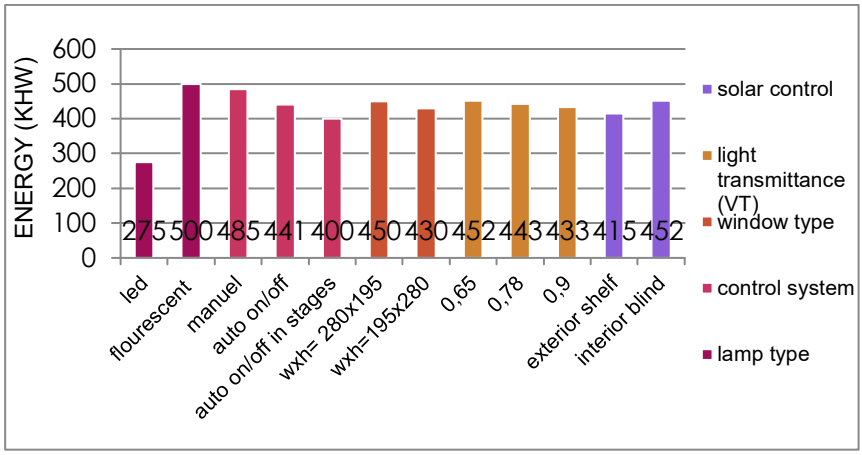


Figure 3. Total annual lighting energy requirements of the alternatives for the office

CONCLUSION

Due to increasing energy needs and costs, it is now more important than ever to consider energy efficiency when designing lighting systems. The effective use of lighting energy in buildings is crucial for achieving energy savings. For this reason, lighting systems, whether natural or artificial, should be designed to keep energy consumption at an optimum level in spaces that are used for long periods throughout the day, such as offices. In this context, an application has been realized for the conditions of Trabzon Province of Turkey. The process included the optimum combination of artificial and natural lighting systems for a two-person office room on the campus of Karadeniz Technical University in Trabzon. Lighting energy requirements for artificial and natural lighting scenarios were calculated and energy performance was evaluated. The visual comfort conditions were considered when determining the artificial lighting alternatives. The visual comfort performance of the alternatives was evaluated based on the suitability of the illuminance and uniformity levels provided by the artificial lighting system, as well as the level of glare value (UGR). For the visual comfort conditions, the data obtained from the specified criteria were evaluated within the scope EN 12164-1 standard about the artificial lighting requirements in working areas.

The calculation method proposed in the EN 15193-1+A1:2021 standard was used for the energy performance evaluations of the natural and artificial lighting design parameters. This method takes into account parameters related to users of the buildings, usage hours and the

characteristics of the artificial and natural lighting systems. A table showing the correlation values was created in line with the data obtained using the energy calculation method proposed in the study. This illustrates the impact of the variables introduced in the integrated lighting scenarios on the annual lighting energy requirements.

When the results were analyzed, it was seen that the artificial lighting system had the greatest impact on the total annual lighting energy. Increasing energy efficiency by minimizing lighting energy consumption and reducing the installation load of the artificial lighting system is possible through various design decisions that increase indoor daylight efficiency. When artificial lighting was designed using LED lamps, %50 energy savings were achieved compared to using fluorescent lamps. The use of control systems has been found to be effective in energy savings. The daylight-responsive control systems used in this study increased energy efficiency compared to manual operation.

In the scenarios created in the study, data were obtained on how the total energy load could be reduced with natural lighting variables, which is an important consideration in the context of energy efficiency and sustainability. It was seen that there was not a significant correlation between natural light variables and energy. Among daylight variables, the change in solar control elements had the most significant impact on energy. The window shape and the light transmittance of the glass had the lowest impact on the total annual lighting energy. The data obtained from these evaluations provides an approach to visual comfort and optimum energy use in offices. It is intended for use in creating appropriate lighting design options or improving lighting schemes.

Finally, this study gives a contribution to the latter, providing reliable and comprehensive targets, calculated with the standard. Since, the latitude and the orientation of the building were not considered in this study, future developments could expand this research providing lighting benchmarks on of each urban settlement.

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A SYSTEMATIC REVIEW OF COMPUTATIONAL TOOLS USED IN URBAN HEAT ISLAND EFFECT RESEARCH

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ABSTRACT

The Urban Heat Island (UHI) effect, a growing concern in urban areas due to rapid urbanization and climate change, poses significant challenges to sustainability and public health. In response, computational tools have emerged as essential resources for simulating urban microclimates and evaluating UHI mitigation strategies. This study employs the PRISMA methodology to systematically review computational tools used in UHI research. From an initial pool of 245 Scopus-indexed articles, 55 studies published between 2014 and 2024 were selected for in-depth analysis. ENVI-met emerged as the most frequently used tool (65.45%), demonstrating strong capabilities for micro-scale UHI modeling, particularly in assessing vegetation effects and pedestrian thermal comfort. Many studies also employed multi-model integration, combining ENVI-met with CFD tools or urban canopy models to enhance spatial and temporal analyses. Notably, the reviewed studies employed these tools to evaluate various mitigation strategies, including green infrastructure, high-albedo materials, and water-sensitive urban design. The findings emphasize that no single tool is universally optimal for UHI mitigation, and tool selection should be strategy-specific and scale-dependent. By systematically evaluating computational tools and their integration potential, this study provides actionable insights for urban planners, policymakers, and researchers in developing evidence-based, climate-resilient urban environments. The review contributes to the growing body of knowledge supporting sustainable urban planning through advanced simulation-based decision-making frameworks.

Keywords: Urban Heat Island; Computational Tools; PRISMA Methodology; Heat Mitigation Strategies; Sustainable Urban Planning.

INTRODUCTION

In recent decades, the rapid growth of urban populations and urbanization has heightened the urban heat island (UHI) effect, which has become one of the most pressing environmental challenges (Tanoori et al., 2024). This effect occurs when urban areas become significantly warmer than their rural counterparts, leading to various environmental issues such as increased energy use, air pollution, and health problems related to heat, all of which threaten urban sustainability (Kotharkar et al., 2020; Chatterjee et al., 2019). The UHI effect is a critical issue for cities worldwide, making it vital to understand its causes, impacts, and possible solutions to enhance urban livability and promote sustainable development (Battista et al., 2022). Consequently, effectively addressing UHI effects has become a key focus in sustainable urban planning (Yue et al., 2024; Li et al., 2024; Battista et al., 2023).

Several strategies have been investigated to lessen the impact of Urban Heat Island (UHI) effects. One effective method is the addition of urban green spaces. These areas provide shade, absorb heat, and promote evaporation, which together help to lower surface temperatures in cities. The cooling benefits of these green spaces vary based on factors such as their size and density (Xu & Rui, 2024). Vegetation on impervious surfaces can significantly reduce Land Surface Temperature (LST) compared to areas with less greenery (Wu et al., 2024). Water bodies also play a crucial role in cooling urban areas (Jang et al., 2024). Designs that are sensitive to water not only help lower surface temperatures but also address urban flooding challenges (Probst et al., 2022). Another approach is to use light-colored materials for covering impervious surfaces like roofs and roads. These materials have a higher albedo, meaning they reflect more sunlight and absorb less heat than darker surfaces, thus helping to mitigate UHI effects (Shi et al., 2023). Beyond these strategies, there are additional methods to combat UHI. For example, green roofs and walls effectively integrate vegetation into buildings, helping to reduce temperature increases in urban settings (Susca et al., 2024). Furthermore, urban ventilation corridors link parks, waterways, and green spaces, enhancing airflow and cooling. These corridors are typically characterized by minimal airflow resistance, allowing air to circulate freely through urban areas (Wang et al., 2020), which contributes to lowering overall urban temperatures (Fang & Zhao, 2022).

Computational tools have become essential in the development, testing, and implementation of strategies to mitigate urban heat islands (UHI) by simulating various scenarios and predicting their effects on

urban microclimates (Aydin et al., 2024; Stavrakakis et al., 2021). This study aims to review the use of computational tools in UHI research.

METHODOLOGY

In this study, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology is adopted. Scopus, recognized as the largest scientific knowledge base (Rahman et al., 2023; Barros Moreira de Carvalho & Bueno da Silva, 2023), served as the primary source for identifying relevant studies, ensuring a broad and reliable dataset. The references were gathered, stored, and organized using Mendeley, a reference management software. Mendeley's organizational capabilities enabled systematic tracking of the articles for further evaluation and facilitated efficient citation management (Ali et al., 2023).

The keywords for the literature search included: Urban heat island AND mitigation strategies OR cooling strategies OR heat mitigation AND simulation OR Geographic Information Systems (GIS) OR remote sensing OR Artificial Intelligence OR climate modeling OR numerical modeling OR urban heat mapping OR prediction models AND urban microclimate. This initial search yielded 245 documents. To capture the latest advancements, the search focused on studies published between 2014 and December 31, 2024. Additionally, the search was limited to studies categorized under Environmental Science and Computer Science and restricted to peer-reviewed journal articles. This refined approach resulted in 89 documents. A systematic filtering and screening process was then applied to refine the dataset further (Figure 1). This process involved two key stages: title and abstract screening, followed by a full-text eligibility check. During the title and abstract screening, 4 articles were excluded as they did not constitute empirical research. Consequently, 85 articles were selected for full-text review. The full-text screening further refined the selection, focusing on studies that systematically analyzed computational tools used in UHI mitigation, particularly in simulations and the implementation of mitigation strategies.

Out of the 85 studies, 30 were excluded during the full-text review for the following reasons: not implementing mitigation strategies or scenarios and instead focusing on analyzing the current situation; a narrow focus on courtyard dynamics; a lack of broader urban-scale applications; or a concentration on building-level energy impacts rather than urban-scale mitigation efforts. These exclusions were due to the studies not meeting the criteria for evaluating or implementing UHI mitigation strategies. Ultimately, 55 studies met the inclusion criteria and were

selected for detailed analysis. These articles were thoroughly evaluated and examined.

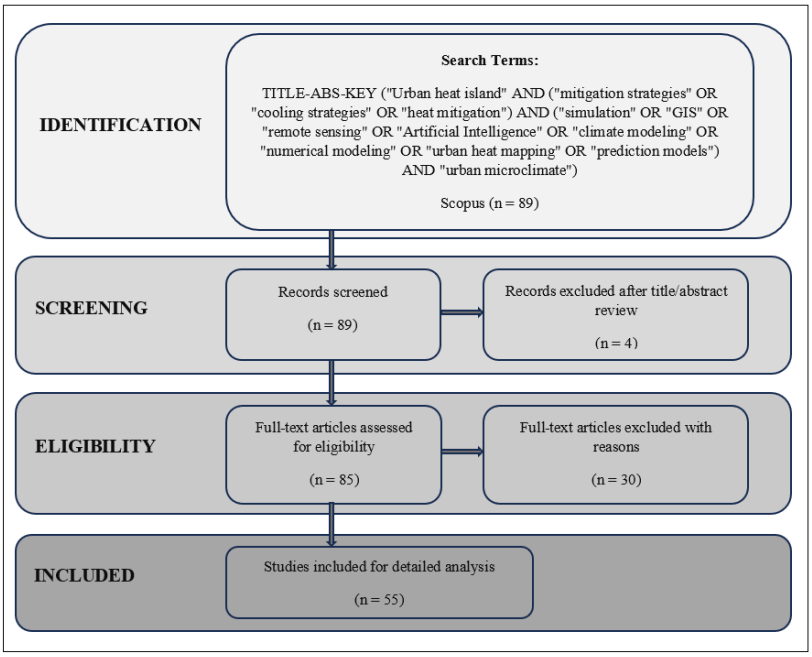


Figure 1. Reviewed studies selection procedure.

FINDINGS

The studies examined are categorized based on their focus on different mitigation strategies, and the computational tools used to model these effects are highlighted. As shown in Table 1, each study is associated with specific UHI mitigation strategies and the corresponding computational tools that have been applied to evaluate their impact. The findings have been listed below.

- ENVI-met emerged as the most frequently employed, appearing in 65.45% of the reviewed studies, due to its strong capabilities in micro-scale modeling, particularly in assessing vegetation interactions, pedestrian thermal comfort, and localized cooling strategies.
- CFD tools, such as ANSYS Fluent, excel in wind flow modeling, urban ventilation analysis, and vegetation-induced cooling, making them valuable for street- and district-scale assessments.
- GIS-integrated tools, including QGIS, ArcGIS, SOLWEIG, and UMEP, facilitate large-scale spatial analysis, helping researchers map

land surface temperatures, urban greening potential, and heat exposure patterns.

- Urban canopy models (BEM-UCM, TEB-ISBA, UWG) enable city-wide UHI simulations, offering insights into how urban morphology and anthropogenic heat influence urban climates.

Table 1. Categorization of Studies Based on UHI Mitigation Strategies and Corresponding Computational Tools.

Main Category	Study	Computational Tools Used	Mitigation Strategies/Scenarios
Urban Greening Strategies	(Flohr et al., 2024)	SOLWEIG's QGIS Plugin	Baseline (2010), Future Climate (2050 projection), Future Loss (24% tree cover decline), 50% Tree Cover, 60% Tree Cover.
	(Abdelmejeed & Gruehn, 2024a)	ENVI-met (Version 4.4.5)	Greenery coverage (35% & 50%), street alignment, height-to-width ratios.
	(Kim et al., 2024)	ENVI-met 5.0.3/RayMan Pro 2.1/Biomet	Linear Park extension, tree-grass-water ratio adjustments, park orientation to wind.
	(Abdelmejeed & Gruehn, 2024b)	ENVI-met (V5.6.1)	Current vs. increased tree density, interaction with urban geometries.
	(Ananyeva & Emmanuel, 2023)	ArcGIS Pro/ENVI-met v4.4.5/LEONARDO/BIO-met v4.4.5	Street trees, alternative species, +20% & +50% trees, grass/shrubs, green roofs.
	(La Rosa & Li, 2023)	Urban Multi-scale Environmental Predictor (UMEP) Model, specifically its SOLWEIG module/QGIS	Tree planting in public and private areas, targeting high Tmrt (Mean Radiant Temperature) zones.
	(Ge et al., 2023)	ENVI-met/EnergyPlus/Grasshopper Platform with Ladybug & Honeybee Plug-ins	Low-rise scattered greenery, high-rise centralized greenery, high-rise scattered greenery.
	(Zeeshan et al., 2023)	ANSYS FLUENT (Version 16.2)/Pointwise V18.1/QGIS 2.18	Tree species selection, canopy morphology, leaf area density.
	(Dong et al., 2023)	ENVI-met 5.1.1/EnergyPlus 22.2.0/Grasshopp	Tree species selection, 21% tree coverage, different Local Climate Zones (LCZs).

		er (Ladybug Tool Plug-in)	
	(Abdelmejeed & Gruehn, 2023)	ENVI-met V5.1	Tree Density Scenarios (0%, 20%, 50%)
	(Erell & Zhou, 2022)	CAT Model (Canyon Air Temperature Model)/EnergyPlus with ENERGYui interface/R software/ArcGIS 10.6	Increased vegetation (50% cover), current condition (12%), and no vegetation.
	(Teichmann et al., 2022)	uhiSolver v2106-0.21	Vertical greenery systems (living walls) and a green pergola for shading.
	(Abu Ali et al., 2021)	ENVI-met	Landscaping with trees (Poinciana, Ghaf, Temple trees), grass-only, and no vegetation.
	(Ouyang et al., 2020)	ENVI-met Version 4.3	Tree coverage ratios (TCR) in low-, mid-, and high-density areas, with greenery coverage ranging from 2% to 56%.
	(Petri et al., 2019)	ENVI-met	Tree removal, strategic tree planting in streets, i-Tree recommended planting in parks.
	(Ebrahimnejad et al., 2017)	ENVI-met	Intensive and extensive green roofs on the Nature Bridge.
	(Alves & Lopes, 2017)	Surfer 13 for: Semi-variogram analysis - Kriging interpolation of UHI intensities	Increasing normalized difference vegetation index (NDVI) by 20%, 40%, 60%, 80%, and 100%.
Water-Based Cooling Strategies	(Fei et al., 2022)	ENVI-met	Water widths (40–100 m), green space layouts, riverbank geometry, platform integration.
	(Ulpiani et al., 2019)	LabVIEW/ANSYS Fluent	Fuzzy logic-controlled water nebulization vs. traditional on-off control.
	(Daniel et al., 2018)	Town Energy Balance (TEB)/Interaction Soil Biosphere Atmosphere (ISBA) Model: Simulated urban microclimate and evapotranspiration	Vegetation watering (unrestricted, realistic), pavement watering, combined watering.

		processes/NEDUM-2D Model	
High-Albedo and Reflective Materials	(Donthu et al., 2024)	EnviBatE Microclimate Simulation Tool, Integrated with SOLENE and QUIC-URB for detailed microclimate simulations.	Cool roofs (albedo 0.8), cool roads (albedo 0.6), cool walls (albedo 0.8).
	(Giorio & Paparella, 2023)	ENVI-met 5.1.1/Grasshopper Plugins (Ladybug, Honeybee, Dragonfly, and Urbano plug-ins)	Cool pavements (white topping, colored asphalt, permeable concrete blocks).
Green Infrastructure-Based UHI Mitigation	(Maggiotto, 2022)	ENVI-met 4.0	Soil moisture management using irrigation (critical crop humidity vs. field capacity).
	(Perera et al., 2022)	ENVI-met version 4.4.5	Green belts, roadside and curbside vegetation.
Hybrid and Combined Strategies	(Elnabawi & Saber, 2023)	DesignBuilder/ENVI-met 5	Cool roofs, green roofs, light-colored gravel roofs.
	(Sayad et al., 2023)	ENVI-Met	Urban greening (trees) and water bodies, tested individually and combined.
	(Zheng et al., 2023)	Core Software (Building Energy Model (BEM), Urban Canopy Model (UCM))/Additional Tools (Energy Plus, UTCI Universal Thermal Climate Index),	Street orientation, window-to-wall ratio, Building-Integrated Photovoltaics glazing, reflective materials, roadside trees.
	(Cho et al., 2023)	Agisoft Metashape 1.8.1/ArcGIS/Urban Multi-Scale Environmental Predictor (UMEP)	Urban Green Spaces (UGSs), Ground-Based Albedo Modification (GBAM), Shadow Zones.
	(Zeeshan & Ali, 2022)	ANSYS Fluent 16.2	Cool materials, vegetation, water bodies, combined measures.
	(Pezzuto et al., 2022)	ENVI-Met/Urban Weather Generator (UWG)	Vegetation cover (0%, 20%, 60%), high-albedo surfaces, combined strategies.

	(Zheng et al., 2022)	ENVI-Met (version 5.0.1)	Cool pavements, cool roofs, increased vegetation, integrated strategies.
	(Teshnehdel et al., 2022)	ENVI-met Version 4/RayMan Model	Trees, water bodies, pavement types, and combined strategies.
	(Tan et al., 2022)	ENVI-met Version 4	3-m and 6-m building setbacks, roadside tree planting.
	(Cortês et al., 2022)	ANSYS Workbench 2019 R3/DesignBuilder	Cork-based living walls with evaporative cooling and shading effects.
	(Ciacci et al., 2022)	ENVI-met	Cool pavements, tree planting, and green walls applied to an industrial district.
	(Tamaskani Esfehankalateh et al., 2021)	ENVI-met (Version 4.4.5)	Tree coverage (20–60%), Leaf Area Density (LAD), and surface albedo modifications.
	(Detommaso et al., 2021)	ENVI-met	Cool Scenario (high-albedo materials) and Green Saturation Scenario (green roofs, trees, grass).
	(Jia & Wang, 2021)	ENVI-met/AnyLogic	Extensive and intensive green roofs, green façades, street trees, cool pavements, and permeable pavements.
	(Wang et al., 2021)	ENVI-met	Green infrastructure scenarios: grove and street trees (10% GS), green roofs (10% GR), and combined strategies (20% GS+GR).
	(Loibl et al., 2021)	Ladybug and Honeybee plug-ins for Grasshopper/Arc GIS/STAR-CCM+	Green roofs, green facades, street trees, vertical densification, shading systems, cross-ventilation.
	(Mosca et al., 2021)	ENVI-met (Version 4.4.5)	Trees, grass, green facades, green roofs, shrubs, shelters with climbing plants, high-albedo pavements, water mirrors/ponds.
	(Zhang et al., 2019)	ANSYS Fluent	Vegetation layouts (small units, centralized, between buildings), wind corridors, elevated spaces.
	(Makido et al., 2019)	ENVI-met	Green roofs, increased albedo (roads and roofs), added vegetation, combined strategy.
	(Chatterjee et al., 2019)	ENVI-met V 4.0	Cool pavements, cool roofs, urban vegetation, combined mitigation (Cool City).

	(Straka & Sodoudi, 2019)	MUKLIMO_3	White coating, green roofs, hybrid strategies, vertical & horizontal compactness.
	(Herath et al., 2018)	ENVI-met (Version 4)	Trees along curbsides, 100% and 50% green roofs, 50% green walls, combined strategy.
	(Jiang et al., 2018)	ENVI-met	Riparian green corridors, high-albedo materials, green patches, rooftop vegetation, east-west and north-south vegetation corridors.
	(Tsiros et al., 2018)	ENVI-met 3.1	Vegetation (dense trees, grass), courtyard shading, semi-open spaces (galleries), ground materials.
	(Taleghani et al., 2016)	ENVI-met/RayMan model	Green Roofs, Cool Roofs, Cool Pavements, Additional Trees
	(Djedjig et al., 2016)	TRNSYS (Transient System Simulation Tool)	Green Walls, Green Roofs, Street Canyon, Configurations (narrow, wide, secluded)
	(Perini & Magliocco, 2014)	ENVI-met 3.1	Green areas (trees, shrubs, grass), Green roofs, No green, green A (moderate vegetation), and green B (higher vegetation), Urban configurations with varying densities and heights
	(Saneinejad et al., 2014)	ANSYS-Fluent 12.0 - BE-HAM (Building Envelope Heat and Moisture Model)/Radiation (RAD) model	Evaporative cooling (water-saturated urban surfaces), High albedo surfaces, Shading (global shading device reducing solar radiation intensity by 50%)
	(Ambrosini et al., 2014)	ENVI-met (v3.1)	Standard albedo values (roof: 0.3, walls: 0.2), High-reflectance roofs (albedo: 0.9), Green roofs (50 cm grass layer) with standard albedo values for walls
Energy-Efficient Strategies	(Heusinger et al., 2023)	ENVI-met (Version 5.0.3)	Building retrofitting: No insulation, KfW 40, KfW 100 energy efficiency standards.
Urban Morphology Strategies	(Nice et al., 2022)	VTUF-3D (Vegetation-Terrain Urban Fluxes in 3D)	Modifying land cover fractions (grass, trees, streets, buildings) and adjusting heights (buildings up to 50 m, vegetation up to 20 m).

CONCLUSION

This systematic review underscores the pivotal role of computational tools in mitigating the urban heat island (UHI) effect, a growing environmental challenge exacerbated by rapid urbanization and climate change. By analyzing 55 selected studies from a broader pool of 245 articles, this research provides a structured evaluation of how various computational tools model urban microclimates and assess mitigation strategies. A key takeaway from this study is that no single computational tool is universally optimal for all UHI mitigation analyses. Tool selection should be strategy-specific and context-dependent.

Despite the valuable insights provided, this study has certain limitations. Although this review exclusively relies on Scopus-indexed literature, which may have excluded relevant studies from other databases such as Web of Science, Google Scholar, or PubMed, the inclusion of 55 studies provides a robust and representative dataset for analyzing computational approaches in UHI mitigation. Expanding future systematic reviews to incorporate multiple databases could further enhance the comprehensiveness of the findings.

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INVESTIGATING THE PRIORITIES OF ARCHITECTURE THROUGH VERNACULAR DESIGN: A STUDY OF BLACK HAIR TENTS

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ABSTRACT

The study of vernacular typologies, as in this case of black hair tents by nomadic communities across Northern Africa, Western and Central Asia, lays fundamental insights to distil priorities in architecture. Focusing on examples from Türkiye and Iran, this paper explores how these mobile structures embody various strategies to endorse human comfort and socio-environmental feasibility like climatic intelligence, material circularity, and cultural continuity. Constructed from goat hair textiles, black tents adapt to extreme environments using passive strategies for ventilation and insulation, offering a low-tech yet highly effective response to environmental and social needs. Their modular design, regional typologies, and production methods reflect a sophisticated ordering of priorities that challenges dominant architectural paradigms based on permanence, standardisation, and technological complexity.

Drawing on interdisciplinary methods, including field observations, material studies, and historical analysis, the relevance of these structures for contemporary discourse on sustainable architecture is highlighted.

And the argument that black hair tents prioritise mobility, adaptability, and cultural cohesion offers insight into alternative design strategies in the face of climate change and resource scarcity. Beyond technical performance, these tents serve as spatial expressions of identity, community, and resilience. In conclusion, vernacular practices such as black hair tents should not be viewed as obsolete but as foundational resources for rethinking priorities in architecture today.

Keywords: Vernacular Architecture; Black Tents; Nomads; Passive Cooling; Sustainability

INTRODUCTION

When investigating through the vernacular lens, the perception of possible priorities in architecture cannot be avoided. In understanding black hair tents in their context of use, a compelling example emerges, displaying how architectural knowledge develops through material logic, social necessity, and climatic responsiveness. Far from being static artifacts, the tents represent a dynamic, resilient architectural practice shaped by extreme conditions, cyclical mobility, and communal use. Constructed from coarse goat hair and adapted over centuries to diverse environmental and cultural contexts, these mobile structures are traditionally used by nomadic communities in Northern Africa, Western and Central Asia.

Black hair tents are not merely ethnographic objects but also sophisticated spatial and material systems. Their architectural configuration responds precisely to a hierarchy of needs: mobility is embedded in the modular assembly of woven panels; thermal regulation is achieved through the material's hygroscopic behaviour and porosity; and cultural identity is maintained through regional typologies, construction rituals, and spatial orientation. The performance under harsh climatic exposure challenges conventional assumptions about the limitations of low-tech or vernacular solutions.



Figure 1. Thermal regulation effect on a black hair tent surface after rain, Sopron/ Hungary, 2011, Photographer: Peter Trachsel

Against this background, the study draws on historical analysis, material science, and field-based ethnography to explore how black hair tents articulate architectural priorities without abstraction. They prioritise adaptation over permanence, local knowledge over industrial standardisation, and collective maintenance over individual authorship. In doing so, they present an alternative model of architectural practice where climatic functionality, material circularity, and social cohesion are not negotiable add-ons but foundational elements.

In dialogue with the broader theme of "Priorities in/of Architecture," this investigation engages key questions: if architecture has priorities, are they expressed in response to environment, to mobility, or to shared cultural life? If not, has architectural discourse lost connection with the very conditions it once evolved from? By focusing on a vernacular typology tested over thousands of years, this paper argues that architectural priorities are neither fixed nor universal, but historically situated, materially specific, and inseparable from the socio-environmental systems in which they operate.

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Black hair tents, also known as black tents, are defined as vernacular architectural designs used by various nomadic peoples. Traditionally constructed from coarse goat hair weaves, they have been adapted to extreme climates across Northern Africa, Western Asia, and parts of Central Asia for about 3,500 years. The tents' ability to provide climatic protection, despite their dark fabric, has recently attracted increased attention in architectural and environmental research.

Few scriptures hint at the early use of these structures. Biblical references such as Exodus 26:7–14 and Assyrian reliefs from the 7th century BCE

(Faegre, 1979; Klengel, 1971) not only offer crucial insights but also highlight the early significance of these dwellings. From the mid-20th century onward, scholarly publications on black hair tents increased, though often marked by disciplinary fragmentation, regional bias in early literature, and limited scientific integration in narrative travel writing. Nonetheless, several monographs, such as those by Feilberg (1944) and Faegre (1979), offered in-depth and qualitatively rich studies. Despite this, empirical research on thermal performance and material ecology remained scarce until the early 21st century. As most research has emerged from anthropological or ethnographic contexts, architectural dimensions are frequently sidelined, with studies typically focused on social organisation and migratory practices. A more comprehensive understanding of black hair tents requires expanding beyond English-language sources. Feilberg's early work (1944) in French, for instance, maps the global distribution of black hair tent types. Likewise, a case study of Heidari and Ainifar (2011), the first thermal analysis of a traditional Iranian tent using Fanger's comfort model, is published in Farsi.

Although largely overlooked in contemporary architectural discourse, black hair tents have influenced modern lightweight membrane structures. Philip Drew (1997) highlighted their structural complexity, drawing connections to contemporary design through examples from Saudi Arabia and Northern Africa. Other studies have focused more directly on the vernacular forms themselves. For instance, environmental load analysis on Iranian tents by Hassas (2021), or Bakhtyari tent architecture including a sun-path and climate data analysis by Sourani (2018). Such findings reveal the performative logic embedded in material geometry and assembly, evidencing a nuanced vernacular understanding of airflow and heat regulation.

Among other regions, a broad typological range is documented in Türkiye and Iran, where diverse nomadic groups have employed these mobile structures for centuries. This essay focuses on the shelters of the Yörük in Türkiye and the Qashqai in Iran. Black hair tents in these regions exhibit regional adaptation in weaving patterns, fibre combinations, and spatial layouts in response to environmental parameters. To understand these responses an investigation from micro and macro scale is necessary. E.g. the kemp fibres of black goat hair are hollow, translucent, and thermally responsive, suggesting high spectral interaction in the ultraviolet and infrared ranges (Meredith, Tobias, & Ralston, 2004). The fibre's performance is shaped not only by its biological properties but also by its weave density, spinning method, and exposure to environmental humidity, each influencing heat retention, radiation, and airflow.

In search for why black hair tents remain inexplicably cooler in hot climates than other designs (Qobrosi 2013), one proposed explanation may be that the black fabric absorbs solar radiation, heats up, and warms the surrounding air, which then rises before significantly affecting the tent's interior. This upward movement creates a convective flow that draws cooler air, effectively ventilating the structure (Attia 2014; Heidari & Ainifar, 2011). Early studies suggest that the cooling effect becomes evident when analysed through Fanger's comfort variables and metrics related to human thermal perception (ibid.). However, critical parameters remain insufficiently assessed, limiting the potential for accurate computer modelling or for reproducing the effect in other architectural contexts.

Completely apart from these findings, the need for textile passive cooling structures is reflected in contemporary research in environmental design focusing on high-reflectivity materials and nanostructured passive cooling textiles. These approaches, while effective in controlled laboratory settings, involve resource-intensive production due to special metal coatings with cost-intensive weaving machines to reach homogenous surfaces on nano-level. (Hossain, Shahid, Limon, Hossain, & Mahmud, 2024) Adaptability, like allowing open-pored membranes or coarser structures, is not available in that spectrum. In contrast, black hair tents achieve similar thermal modulation through absorptive strategies, where heated textiles initiate air convection and drive interior ventilation without synthetic coatings or additional energy inputs (Attia, 2014; Heidari & Ainifar, 2011). This radiative-convective mechanism positions the tent as a low-tech analogue that is easy to achieve in contrast to modern climate-responsive textiles.

Within architectural theory, black hair tents challenge the dominance of high-tech approaches to environmental control. Their absorptive, convective cooling strategy demonstrates how form, material, and microclimatic interaction can achieve effective ecological design with minimal technology. Environmentally, they reflect circular principles, like biodegradability, low embodied energy, and local adaptability, positioning them as valuable references for material intelligence in architecture (Pfeifer, 2015). Bridging ethnographic knowledge and scientific inquiry, they point toward hybrid frameworks where vernacular practices inform resilient, low-carbon futures.

CASE STUDY: BLACK HAIR TENTS IN TÜRKIYE

Black hair tents exemplify the architectural tradition developed for centuries by Yörük communities who lived a nomadic life in the rural mountainous regions of southern and southwestern Turkey, particularly in Mersin, Antalya, Isparta, Burdur, Muğla, Aydın, and İzmir (İnalcık, 2014). These tents are not merely temporary shelters but also architectural works that reflect the Yörük people's cultural values, lifestyles, and environmental adaptations. Black hair tents stand out as a sustainable nomadic lifestyle due to their portability, ease of assembly, use of materials obtained from their animals, and adaptability to climate. The ventilation and thermal control features of black hair tents are particularly well-suited to the challenging geography and variable climates of southern a-nd southwestern Anatolia. Today, black hair tents remain a part of the diminishing and changing, yet continuing, ecological life of Anatolian Yörüks (Pfeifer, 2015).



Figure 2. Yörük tent of the families Şimşek and Şurgun, Ahmetli Köy, Torbalı/ Türkiye, 2005, Photographer: Kristina Pfeifer

Eröz categorizes Yörük tents into three types: black tent (hair tent, sackcloth tent), felt house (*alaçık, alıcık*), and round house (*topak* house, *bekdik* tent, *derim* house). A felt house is a tunnel-shaped tent made of juniper or pine sticks, covered with sackcloth or felt. A round house is constructed with wooden elements into a hoop shape to form a dome and covering them with white felt. A circular wooden element is used at the top to create the dome shape, and the top can also be open (Eröz, 1991; Kumtepe, 2016; Ak, 2019). The black hair tent is the most common tent type in southern and southwestern Anatolia and is the example investigated in this study. Eröz attributes the use of sheep felt, the covering material of the round house, to sheep husbandry on the vast

plains of Central Asia. However, because raising goats rather than sheep is more convenient in the steep rocky terrain of Anatolia, black hair tents are common there (Eröz, 1991). Goat hair, the primary material used in the construction of black hair tents, is the primary source of shelter for Anatolian nomads, whose hairs are used in addition to their meat and milk, which are their main sources of income. Migrating to cooler plateaus (*yayla*) in the summer, the nomads tend their animals at higher elevations during the warmer seasons and then returning to their winter quarters in the winter. During this constant movement, during which they travel long and challenging routes with their animals, black hair tents are preferred for their lightness, ease of transport, ease of setup and disassembly, and thermal properties adapted to the climate.

Black hair tents, like other tents, have wooden poles (*direk*). The wooden poles, preferably made of poplar tree, can be 3, 4, 5 in number, or more. Depending on the size of the tent, woven pieces of hair are prepared, and both the roof (tent-*çadır*) and sides (cover-*kapak*) are covered with them. The woven pieces, covered over the poles, are stretched and secured to the ground with ropes (*bağ*) and stakes (*kazık*). During the tent setup, woven pieces measuring approximately 64–95 centimetres in width and 4.5–8 metres in length (Pfeifer, 2015) are first laid out on the ground and stretched taut using stakes (Eröz (1991) states it as 70–100 centimetres wide and 4–8 metres long.). These pieces are then sewn together to form the roof of the tent. During the roof preparation, wooden bowls (*çanak*) that serve as sockets for the posts, as well as wooden stay-fasteners (*bakara*) for tying the ropes, are also sewn onto the tent. The ropes (or link-up) used in the tensioning and erecting process are also made from goat hair. The prepared tent roof is turned upside down and laid on the ground; as it is stretched and fixed to the ground with guy ropes, it is simultaneously raised on the poles. Once the tent roof is erected in this manner, the side pieces are sewn onto the roof, and rugs are laid inside the tent. The tent is dismantled in the reverse order, and folded for transport without unravelling or re-sewing the fabric pieces (Eröz, 1991; Pfeifer, 2015).



Figure 3. Sewing of a new Yörük tent by the families Şimşek and Şurgun, Ahmetli Köy, Torbalı/ Türkiye, 2007, Photographer: Kristina Pfeifer

Tents are generally set up on relatively elevated spots, avoiding low-lying areas, so that the herds can be easily observed. In winter, the entrance of the tent is oriented to the south to maximize exposure to sunlight, while in summer it faces north to benefit from the cooling northeasterly breeze. Tents are set up in close proximity to one another, provided they belong to members of the same family (Eröz, 1991; Genç and Şimşek Tolacı, 2019, Ak, 2022). The tent is designed to meet all daily needs. A hearth for heating and cooking is positioned near the entrance. Sitting and sleeping activities are also carried out inside the tent. Food is stored in sacks on stones in one corner of the tent to avoid ground moisture. The tent owner and guests have separate seating areas (*sedir*). Mattresses (*döşek*) used for sleeping are collected and put away to one side of the tent during the day. Only the toilet is built outside the tent (Eröz, 1991; Pfeifer, 2015). The soot produced by lighting a fire inside the tent fills the gaps between the woven hairs, creating an insulating layer from the inside; at the same time, the hairs swell when exposed to rain, eventually becoming waterproof. Although the black hair tents are black in colour, their porous structure provides good thermal performance in hot weather, and the inside of the tent remains noticeably cooler than the outside (Pfeifer, 2015). While the fabrics of the tent were once woven on traditional looms with hand, usually by women labour, today, with modern technology, they are machine-woven in factories, and traditional production is gradually decreasing (Üner and Başaran, 2017; Aktaş, 2019). However, the rainwater permeability protection performance of hand-woven fabrics cannot be achieved in machine-woven fabrics due to both the difference in fabric density in the knitting technique and the inclusion of polyester in the hair material.

Unfortunately, due to challenging economic conditions, the decline of local livestock, forced resettlement policies, the opening of rural areas to construction, and the construction of new roads along migration routes of the nomads, *yörüklük*, a sustainable way of life in Anatolia, is gradually diminishing. For this study, the few remaining families who continue their nomadic activities in the areas of Ahmetli/Torbalı/İzmir, Başaran/Kuyucak/Aydın, and Kocabaş/Honaz/Denizli were visited in October and April 2025. During these visits, the weaving and construction practices of the black hair tent were examined, and daily life was observed at the Yörük festival. Throughout this process, the research team was treated with warm hospitality. Daily life is functionally divided between the spatial arrangement within the tent and the surrounding open spaces. Women undertake both domestic duties and production activities such as weaving, while men generally manage the herds. This way of life has become more visible in recent years through Yörük festivals. Yörük festivals allow Yörük people to both reproduce their cultural identity and promote this lifestyle to the wider community. The black hair tents set up during festivals, the traditional dishes prepared (*gözleme, keşkek, yayık ayran*), and the music and dance performances represent not only a presentation of folklore but also an active connection to the past. Although the number of elders who know how to weave and set up tents has diminished, the tradition of gathering and sharing in tents continues as a heritage. Although many of them have now settled in villages, nomadic families who gather monthly in this way maintain both their social ties and the practices of traditional nomadic life.

CASE STUDY: BLACK HAIR TENTS IN IRAN

Iran, a country with a long and rich historical background, is distinguished by its four distinct seasons and a wide diversity of climatic conditions. The northwest has a mountainous climate, the northern regions enjoy a temperate and humid climate, the central areas experience hot and arid conditions, and the southern and southeastern regions are characterized by a hot and humid climate. The geographical domain of nomadic communities, along with the locations where black tents are erected, spans a substantial portion of the country's provinces. Iran is among the few countries where nomadic black tents have been established across a broad range of climatic zones, adapting effectively to diverse environmental conditions. Serving as year-round dwellings, these tents can be slightly modified to suit the climatic and seasonal variations of each region (Molaei Heshjin, 2021). Beyond meeting essential living needs, they also embody cultural and artistic dimensions, representing an authentic and innovative example of indigenous technology in environmental adaptation.



Figure 4. Black tent of nomads around the city of Sang-e-Sar, Semnan Province, Iran, 2022, Photographer: Einollah Azmoudeh

Iranian nomadic black tents, constructed using locally sourced and recyclable materials such as goat hair, impose minimal pollution and energy consumption on the environment and are built in complete harmony with the climate. The outer covering of these structures is made of dark strips woven from goat hair, which possesses unique properties in relation to moisture and temperature. Goat hair exhibits moisture-dependent elasticity: in rainy and humid conditions, the fibres contract, closing the tent's weave and preventing raindrops from penetrating inside; in hot and dry weather, the fibres expand, reopening the gaps to allow natural ventilation and airflow (Kiani, 1998). In fact, the tent covering is designed in such a way that, in the event of rainfall, as long as the inner surface is not touched by hand, water infiltration is prevented (Heidari, 2009). This natural, intelligent mechanism provides ventilation and thermal comfort without the need for artificial energy. In addition to this capability, black tents are highly flexible in terms of relocation and seasonal adaptation, and they are erected with minimal disturbance to the land and surrounding environment. The use of renewable resources, the optimal utilization of environmental factors such as light, heat, wind, and natural ventilation, and adherence to indigenous design patterns make these structures a valuable example of the integration of culture, art, and functionality in sustainable architecture.

In addition to the technical properties of goat hair, one of the main reasons for its use in the construction of black tents is its abundance and easy accessibility in Iran. Almost every nomadic family keeps several goats, ensuring a constant and sufficient supply of goat hair. Since self-sufficiency is a fundamental principle of nomadic life in Iran, the

processes of spinning, twisting, and weaving the strips for black tents are carried out by nomadic women and girls. Throughout the year, women gradually weave the strips of the black tent from yarn made of goat hair and, by joining these strips together, create a complete and functional structure. On average, weaving each strip takes approximately 10 to 12 hours, and the useful lifespan of a black tent is estimated to be between 6 and 10 years. The size of the tent is directly related to the social status of the household head and the number of family members, with larger tents typically belonging to larger families or those with higher social standing (Rouhi, 2016: 11–12). This entirely local and community-based process is an example of self-sufficiency in nomadic life, in which all stages of material preparation and construction are completed without relying on external resources. Such a method is not only economically sustainable but also consistent with the principles of sustainable architecture, as it uses local and renewable resources, reduces dependence on energy and industrial materials, and preserves traditional skills, thereby both protecting the environment and ensuring the continuity of the community's cultural heritage.



Figure 5. Interior of a nomadic black tent near the city of Sang-e-Sar, Semnan Province, Iran, 2022, Photographer: Einollah Azmoudeh

The most important consideration in selecting a suitable location for erecting black tents is assessing the potential risk of flooding and the path of nearby rivers, as well as taking into account the prevailing and disruptive wind directions to prevent the tent from toppling. In summer, black tents are typically positioned with their backs to the sun and facing favourable winds to maximize the benefits of shade and cool airflow. This orientation not only ensures thermal comfort for the inhabitants but also holds significant importance from a sustainability perspective. The intelligent selection of location and orientation based on climatic

conditions can play a decisive role in reducing energy consumption and enhancing environmental efficiency. Observing these principles in the design and construction of Iranian black tents exemplifies the harmony of vernacular architecture with the environment and the application of sustainable practices in traditional structures.

The orientation of black tents also varies according to the season and geographical conditions. In summer pastures (*yaylaq*), due to mountainous terrain and the late arrival of sunlight in valleys, tent entrances are usually placed facing east to benefit from the morning sun and its warmth. In winter pastures (*qishlaq*), the orientation is chosen based on the region's geographical features to provide maximum protection from unfavourable winds and to make the best use of sunlight and warmth,- or shade and coolness-, depending on the climatic needs. These principles not only ensure the thermal comfort of the residents but also play an important role in sustainable architecture by reducing energy demands and enhancing climatic adaptability (Rouhi, 2016).

Overall, Iranian nomadic black tents represent an outstanding example of sustainable vernacular architecture that has successfully adapted to the diverse climatic conditions of this land over centuries. The use of local and renewable materials such as goat hair with its unique technical properties for providing thermal comfort and natural ventilation, combined with a fully local and community-based production process, has enabled these structures to reduce dependence on external resources while exerting minimal negative impact on the environment. The intelligent approach to site selection and tent orientation, based on seasonal changes, geographical conditions, and prevailing winds, ensures thermal comfort for residents without the need for artificial energy and minimizes energy consumption. These features, along with portability, long durability, and a deep connection to nomadic culture and identity, make black tents a valuable model for contemporary sustainable architecture that can inspire the design of climate-responsive, environmentally low-impact structures in today's world.

APPLICATION IN CONTEMPORARY ARCHITECTURAL PRACTICE

Contemporary architectural practice is subject to a whole host of rules and regulations that apply to buildings and the materials used in their construction. Among this author team, one author runs her own practice in Vienna, Austria. The following restrictions are based on her practical experience.

Let's first take a look at the possible applications.

The black tent has its origins in a long tradition of nomadic peoples and is/was optimised for their way of life. The material comes from goats – goat hair – and is not the more valuable cashmere, but the coarser part of the hair. It could be spun on the go; even the panels are measured so that they can be easily transported after being folded in a specific way. We will not find such a perfect application, refined over thousands of years, in contemporary architecture, or will we?

Attempt at a possible classification of areas of application:

A) On the one hand, we can ask ourselves how we can transfer this fabric to modern architecture, with the buildings of our cities in mind. So, we ask ourselves, what function could such a fabric take on, or how do we want to use it skilfully?

B) But we can also ask ourselves where we might need black tents today, as they are, in their perfection and adaptation to the corresponding climate zones.

C) We can ask ourselves where we can use black tents for tasks that do not have such strict regulations and, in this context, look for temporary applications, for example.

ad A)

The textile traditionally used in black tents demonstrates characteristics that are highly relevant for contemporary urban architecture. Its breathable structure and climate-responsive behaviour - tightening when dry and loosening when humid - enable passive regulation of indoor environments. In dense urban settings, where thermal stress and limited ventilation are prevalent, such materials could be integrated into façade systems, rooftop shading, or modular envelope components to enhance thermal comfort and reduce energy demand. Recent developments in textile technology, such as the incorporation of conductive fibres and environmental sensors, further expand the potential of these materials by enabling adaptive responses to changing microclimatic conditions (Stoppa & Chiolerio, 2014). These innovations can be implemented without compromising the textile's lightweight and flexible nature.

ad B)

Black tents have long served nomadic communities in arid regions as climate-responsive shelters. Their coarse black fabric absorbs heat,

creating convection currents that ventilate the interior during the day, while retaining warmth at night (Ranjbar & Mahmoudi, 2020). These tents are not only technically efficient but also culturally rich: they embody mobility, resilience, and a deep connection to landscape and identity.

In contemporary contexts, black tents could offer low-tech, adaptable solutions for temporary settlements - especially in refugee camps where climatic extremes and social dislocation converge. Their modularity and breathable structure support both thermal comfort and rapid deployment. Moreover, their spatial organization - often separating public and private zones - can foster dignity and familiarity for displaced persons, helping to recreate a sense of home and cultural continuity (Dalal, 2017).

Importantly, black tents can serve as identity-forming spaces. As Mull (2016) emphasizes, architecture for displaced communities must go beyond utility to support dignity, belonging, and cultural expression. In this sense, black tents are not just shelters but vessels of memory and social practice - spaces where hospitality, storytelling, and ritual unfold. Reconsidering their relevance today invites us to explore low-tech, culturally embedded solutions to global challenges, and to rethink the aesthetics and ethics of shelter in times of transition.

ad C)

Black tents offer a compelling alternative in contexts where architectural regulation is minimal and flexibility is paramount. Their lightweight, modular nature makes them ideal for temporary uses such as pop-up cultural events, educational workshops, mobile exhibitions, or community-based interventions. These structures can be deployed quickly, adapted to diverse environments, and dismantled without leaving a trace - qualities that align with the ethos of ephemeral architecture (Zaguła, 2022).

In urban settings, black tents could activate underused public spaces, offering shelter for informal gatherings, artistic performances, or participatory design processes. Their symbolic and spatial qualities - rooted in nomadic traditions - can foster a sense of belonging and identity, especially in transitional or experimental contexts (Al-Musawi & Ali, 2024). Unlike permanent buildings, these tents do not require extensive permitting or infrastructure, making them accessible tools for grassroots initiatives and low-budget cultural programming.

Moreover, temporary tent structures have proven effective in creating dynamic, inclusive environments that respond to immediate needs while encouraging interaction and creativity (Shelter Structures, 2024). Their

adaptability allows for reconfiguration based on site-specific conditions, user input, and evolving programmatic demands. In this way, black tents become not only shelters but platforms for dialogue, experimentation, and community engagement.

But what are the challenges and potentials of material translation, circularity, and integration into building codes?

The material, as a natural product, is readily available and inherently meets many criteria of circular construction. However, its use in large-scale building projects is limited. Translating such materials into industrialized processes remains a separate field of research. While small-scale structures benefit from its ecological and flexible properties, integration into building codes is challenging due to complex approval procedures. For small producers, this often becomes a structural barrier - potentially addressable through collective representation in associations that could support certification and regulatory adaptation.

CONCLUSION

This study has demonstrated that black hair tents, far from being primitive or obsolete, represent highly sophisticated examples of climate-responsive, culturally embedded architecture. Their material logic, climatic adaptability, and socio-spatial organisation reflect a system of priorities that differ markedly from dominant paradigms in contemporary practice. Instead of permanence, these structures prioritise mobility; instead of synthetic innovation, they rely on refined traditional knowledge; instead of high-tech infrastructure, they embody ecological intelligence through low-tech means.

Both case studies on black hair tents in Türkiye and in Iran exemplify regionally nuanced adaptations to topography, microclimate, and social structures. They not only meet physiological and environmental needs, such as ventilation, solar regulation, and water resistance, but also sustain intangible cultural values through their production methods, spatial rituals, and collective memory. Their continued use and symbolic presence in cultural festivals underscore their dual function as both functional shelters and markers of identity.

The findings point to critical lessons for contemporary architecture, particularly in the context of climate change and material scarcity. Black hair tents challenge the field to reassess assumptions about innovation, permanence, and sustainability. They encourage renewed attention to the circular use of materials, to passive strategies for climate adaptation, and to the socio-cultural dimensions of design. These areas are often neglected in standardised or techno-centric approaches.

Further research is needed to explore the thermal behaviour in controlled experiments, to assess the scalability of the material principles, and to integrate the performative logic into building codes and architectural education. Rather than mimicking form, such inquiry should focus on understanding and translating underlying priorities.

By positioning vernacular design within architectural discourse not as an exception but as a foundational practice, this study contributes to redefining what architecture prioritises - and why - in times of socio-environmental and societal transformation.

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THE IMPACT OF WINDOW-TO-WALL RATIO IN THE EARLY DESIGN STAGE: A COMPARATIVE STUDY ON EDUCATIONAL BUILDINGS

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ABSTRACT

The aim of this study is to reveal daylighting performance, an important criterion in guiding architectural decisions during the early design phase. Within this scope, a typical primary school classroom under Istanbul conditions was examined, and daylight performance was evaluated based on two key parameters: window-to-floor area ratio and façade orientation. Analyses were conducted in the Rhino–Grasshopper environment using the Honeybee plugin, with the EPW file for Istanbul used as the fixed climate data in the simulations. Daylight performance was measured using internationally recognized metrics: Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), and Useful Daylight Illuminance (UDI). In the first phase, scenarios with the existing window ratio (10.4%), the ratio corresponding to the MEB standard (25%), and an increased ratio (30%) were compared; it was observed that the increase in window area positively affected daylight performance but also raised the risk of excessive glare. In the second phase, the window ratio was fixed at 25%, and the classroom was placed in four different orientations to examine the effects of orientation. The findings indicated that façade orientation is decisive in daylight distribution, with balanced lighting conditions achieved on the north façade, while the south façade exhibited high illuminance along with an increased glare risk. As a result, it was determined that window ratio and orientation decisions play a critical role in daylight performance during the early design process; evaluating these parameters together is a fundamental requirement for ensuring visual comfort in educational buildings.

Keywords: Early Design Phase, Daylight Performance, Window-to-Floor Area Ratio, Orientation, Sda, Ase, Udi

INTRODUCTION

Daylight is considered not only a source of illumination but also a fundamental design component that provides multifaceted contributions in terms of energy efficiency, user health, psychological comfort, and spatial aesthetics (Gagne, 2011). Natural light is known to reduce stress levels, alleviate symptoms of depression and anxiety, and improve sleep patterns (Zolfaghari & Jones, 2022). At the same time, it positively influences mood by increasing serotonin levels and contributes to the regulation of biological rhythms by controlling melatonin secretion. In this context, daylight has a direct impact on productivity, learning capacity, and overall health (Rashid & Zimring, 2008).

In sustainable design approaches, daylight contributes to reducing energy consumption and carbon emissions by decreasing the need for artificial lighting. Reducing the demand for artificial lighting, which accounts for approximately 40% of a building's total energy use, is achievable through effective daylight strategies (Acosta et al., 2016; Ngarambe et al., 2022). Decisions made during the early design process play a critical role in integrating daylight into the building; however, this phase often focuses primarily on the building's overall form and functionality, while climatic factors and façade design are frequently overlooked (Lin & Tsay, 2021; Alagöz, 2020). Yet, early decisions that define building geometry and façade layout have long-term effects on daylight performance and spatial quality (Kazanasmaz et al., 2016).

Research on educational buildings has shown that daylight directly affects student performance (Ashrafian & Moazzen, 2019; Çelik & Ünver, 2019; Liu et al., 2022). Classrooms receiving natural light have been found to enhance learning outcomes and positively influence students' growth, immune system, and visual development (Heschong et al., 2002). However, in Turkey, school buildings constructed based on standard typologies often do not adequately consider climatic data, resulting in insufficient natural lighting; this increases reliance on artificial lighting, raising energy consumption and limiting visual comfort. Since students spend a significant portion of their day at school, the spatial quality of educational buildings plays a critical role in the learning process (Kutlu Güvenkaya & Küçükdoğu, 2009). Particularly in primary schools, maintaining motivation, supporting academic success, and ensuring healthy developmental processes are directly linked to the conditions of the space. Therefore, ensuring spatial, visual, acoustic, and thermal comfort in classrooms positively affects students' attention and health, while ergonomic design principles emerge as a key factor supporting learning efficiency (Tapkı & Canbay Türkyılmaz, 2018).

The Ministry of National Education (MEB) has developed spatial standards for educational buildings. According to the MEB Minimum Design Standards Guide for Educational Buildings (2015), the window-to-floor area ratio in classrooms should be at least 25% and can be increased up to 50% depending on the climatic region. It is also emphasized that classrooms should be planned so that daylight comes from the student's left side, and that furniture layout and door openings should be designed according to this principle. Windows should start at a minimum height of 90 cm from the floor, with window handles positioned at 140 cm; safety details preventing falls must be included on opening sashes. The sash widths should not exceed 80–85 cm, should allow for double-axis operation, and top-hung (vasistas) windows should be planned at the upper level, with at least two units arranged per classroom. Primary and secondary school classrooms are recommended to consist of three openings spaced 2.60 m apart, with a total width of 7 m. Additionally, the use of high light-transmitting glass is mandatory, as dark-colored glass reduces the amount of daylight entering the interior, weakens the visual connection of users with the outside environment, and can cause misleading effects on time perception. Therefore, the MEB Construction and Real Estate Department (2015) specifies that the light transmittance coefficient of window glass should be 0.60. These criteria aim not only to increase daylight levels but also to ensure a balanced consideration of safety, visual comfort, and pedagogical requirements.

In this study, daylight performance was examined using a classroom model designed according to the criteria specified in the Ministry of National Education's Minimum Design Standards for Educational Buildings, with a window-to-floor area ratio of at least 25%. Analyses were conducted for four different orientations to reveal the effects of orientation on daylight distribution. Subsequently, the window ratio was gradually increased to evaluate the impact of transparent surface dimensions on interior illuminance levels. Additionally, comparisons made by positioning windows at different heights along the vertical axis demonstrated that window placement is a determining factor in natural lighting performance. Within this scope, the study aims to reveal the long-term effects of decisions made during the early design phase on spatial quality and visual comfort.

1.1 Factors Affecting Natural Lighting

In order to accurately evaluate natural lighting performance, it is necessary to identify the key factors that determine the daylight entering an interior space. These factors are generally categorized into two main groups: those arising from natural conditions and those that can be controlled or influenced through design.

Natural Factors

Among the factors affecting natural lighting, uncontrollable natural factors play a decisive role. Daylight provided by natural sources varies according to the latitude and longitude of the space, the structure of the atmosphere, and the time (Kutlu Güvenkaya & Küçükdoğu, 2009). In this context, geographical location, climate conditions, and surrounding built environment are among the most fundamental elements. Geographical location is one of the primary factors shaping daylight levels in different regions; in northern cities, low solar angles in winter can cause glare issues, while cities with a Mediterranean climate receive more daylight due to clear skies (VELUX Knowledge Centre for Daylight, 2014). Climatic characteristics also have a critical impact on facade design; wider openings are preferred in cold regions, while shading strategies are applied in hot regions to reduce excessive heat gain (Lechner, 2014; cited in Çiftçi, 2023). Additionally, the surrounding built environment is considered a significant factor limiting daylight access (Duraler & Yener, 2016). The height of neighboring buildings and the distances between them determine the amount of daylight entering the interior through obstruction angles, directly affecting illumination levels (Murt, 2006). Furthermore, the topographical features of the building establish a direct relationship between natural ventilation and effective daylight use, making it a key parameter to consider for the continuity of spatial comfort (Özen & Sümengen, 2022).

Design-ContolledFactors

The design-controlled parameters affecting daylight performance include the opaque–transparent surface ratio, building geometry, building orientation, location and characteristics of transparent surfaces, volume dimensions, reflectance values of interior surfaces, as well as shading devices and solar control systems. Each parameter directly influences the entry and distribution of daylight within the interior space and its effects on the occupants.

Among these factors, the opaque–transparent surface ratio is a critical parameter that directly affects daylight performance. Increasing the transparency ratio on façades facilitates the penetration of natural light into interior spaces; however, it can also lead to excessive glare, heat gain, and visual comfort issues. A study conducted in Vancouver, Canada, found that an increase in the window-to-wall ratio (WWR) directly raised energy consumption, while positioning windows at mid-height provided a more balanced energy performance (Kim et al., 2016). Furthermore, as the depth of the space increases, it becomes more difficult for natural light to reach the rear areas. Therefore, the size and location of transparent surfaces should be properly determined. Openings placed higher allow light to penetrate deeper into the space, while horizontal openings distribute light over a wider area, providing more uniform illumination (Mokhtari et al., 2023).

Building geometry also plays a critical role in daylight utilization. Atrium or courtyard plan solutions allow more natural light to reach interior spaces (Kutlu, 2019). Building orientation is also decisive for energy efficiency and occupant comfort; in particular, south-facing façades receive more light throughout the day, providing an advantage for natural illumination (Yüksek et al., 2015).

The type of glass, its transmittance rate, frame thickness, and the level of dirt on the glass are also among the factors that determine the amount of light entering interior spaces (Yücel, 2019; Taşoluk, 2014). Here, the 60% light transmittance criterion specified by the Ministry of National Education (MEB, 2015) is considered a guiding standard. The reflectance properties of interior surfaces are also important for visual comfort; light-colored surfaces contribute to the uniform distribution of light, whereas dark surfaces absorb it (Çiftçi, 2023; Mandala, 2019).

Finally, shading elements and solar control systems are used both to reduce glare and to achieve energy savings (Cerutti, 2020; Erkan, 2024). Properly designed shading strategies prevent excessive light gain, enhance visual comfort, and provide balanced lighting within spaces.

1.2 The Importance of the Early Design Phase

Architectural design is a multi-layered and holistic process, spanning from conceptual development to implementation. The early design phase of this process refers to a stage in which the design problem is not yet fully defined, the program of requirements is limited, and uncertainties are high (Gerber & Lin, 2012). During this phase, where initial ideas are formed and different design alternatives are explored, fundamental decisions regarding spatial organization, building orientation, façade arrangement, and opaque–transparent surface

ratios are made; these decisions have long-term impacts on the building's sustainability, energy performance, and visual comfort (Canbay Türkyılmaz, 2010; Lin & Tsay, 2021).

As previously emphasized, decisions made during the early design phase play a decisive role in daylight performance. Interventions at this stage guide the overall quality of the project and prevent potential environmental or functional problems in later phases. Indeed, this phase represents a critical period in which the impact of design decisions is highest while costs remain lowest (Marsh, 2009; cited in Arpacıoğlu, 2010). Therefore, assessing natural lighting and related visual comfort parameters at an early stage has become a strategic necessity, enabling designers to make informed and sustainable decisions (Arpacıoğlu, 2010; Attia et al., 2012).

1.3 Studies on Daylight Performance in Primary School Buildings

When studies on daylight performance in primary school buildings are examined, it is observed that façade orientation, window-to-floor area ratio, surface reflectance, and shading strategies are the prominent factors. The key findings in the literature are summarized below and presented in Table 1.

Table 1. Studies on Daylight Performance in Primary School Buildings

Author(s), Year	Study Topic / Objective	Method / Tools	Examined Parameters	Performance Metrics
Kutlu Güvenkaya & Küçükdoğu, 2009	Determination of appropriate façade arrangements according to orientations in primary school classrooms within the context of energy-efficient design	Radiance insimulation Istanbul data	Facade orientation, window transparency ratio, fixed/movable shading	Daylight illuminance level, artificial lighting energy load
Köknel Yener, Kutlu Güvenkaya & Şener, 2009	Evaluation of visual comfort under natural and artificial lighting conditions in primary school classrooms in Istanbul	On-site measurements, field analysis, CIE & CIBSE standards	Facade orientation, window size, glass transmittance, interior surface reflectance, artificial lighting layout	Illuminance level, uniformity, glare

Aydın Yağmur & Sözen, 2016	Evaluation of visual comfort parameters and the effects of interior surfaces in classrooms	Radiance-based simulation, classroom model	Interior surface colors and reflectance values, window location and size	Daylight factor (DF), illuminance level, glare
Duraler & Yener, 2016	Analysis of daylight performance in typical primary school classrooms according to MEB standards and development of design alternatives	Dialux Evo simulation, Istanbul conditions	Window-to-floor ratio, orientation, glass transmittance, surface reflectance, shading, and light shelf	DF, average illuminance, uniformity, glare
Tapkı & Canbay Türkyılmaz, 2018	Comparison of the ergonomics and comfort conditions of two primary school buildings	On-site observation, measurements, MEB standards	Spatial dimensions, fixture elements, visual/auditory/thermal comfort	Area per person, noise, temperature, illuminance
Çelik & Ünver, 2019	Evaluation of Visual Comfort and Energy Performance of an Elementary School Building in the Context of MEB 2015 Standards	Dialux Simulation, MEB 2015, TS EN 12464-1	Facade Orientation, Classroom Type, Window Ratio, Surface Reflectances	Illuminance Level, DF (Daylight Factor), Glare, Uniformity, Energy Consumption
Ashrafian & Moazzen, 2019	Evaluation of daylight performance and energy consumption in primary school classrooms in Eskişehir	DIALux Evo, DesignBuilder, EnergyPlus	Facade transparency ratios (20–50%), orientation, glass properties	Daylight level, visual comfort, energy consumption
Arpacıoğlu, Çalışkan, Şahin & Ödevci, 2020	Development of a conceptual design support model to enhance daylight effectiveness	Literature, standards, expert opinions, example school building	Window-to-floor ratio, volume dimensions, surface reflectance, orientation, shading	DF, GDF, DGI/DGP, DAR, illuminance level

Nas, 2021	Evaluation of the existing lighting design at Cibali Primary School	On-site measurements, simulation, comparison with standards	Facade orientation, window dimensions, existing lighting layout, use of curtains	Illuminance level, uniformity, glare
Özen & Sümengen, 2022	Evaluation of typical classroom buildings in different climate regions of Turkey according to TS EN 17037	VELUX Daylight Visualizer, TS EN 17037	Climate zones, window-to-floor ratio, orientation, glass transmittance	Illuminance level, DF, performance classification
Bircan, 2023	Evaluation of typical primary school projects according to TS EN 17037 standard	Dialux Evo simulation, Istanbul conditions	Orientation, window-to-floor ratio, façade openings	Illuminance level, daylight sufficiency ratio

Research on daylight performance in primary school buildings indicates that parameters such as façade orientation, window size, surface reflectance, and compliance with standards are critical for visual comfort and energy consumption. Kutlu Güvenkaya & Küçükdoğu (2009) examined the impact of façade orientation and shading strategies on classroom lighting performance, showing that movable shading devices improve energy efficiency and that south-facing façades are advantageous. Duraler & Yener (2016) highlighted that light shelves and shading elements provide more uniform illuminance on south façades, while east and west façades exhibit imbalances. Focusing on different climate regions, Özen & Sümengen (2022) found that daylight performance varies between cities, with Antalya showing high values and Istanbul, Ankara, and Diyarbakır showing lower values. Similarly, Bircan (2023) noted that in the analysis of typical projects under the TS EN 17037 standard, façade openings and orientation play a critical role in daylight adequacy.

Studies on window size and ratios indicate that, according to field measurements, Köknel Yener, Kutlu Güvenkaya & Şener (2009) demonstrated the direct effect of window dimensions and glass transmittance on visual comfort. Çelik & Ünver (2019), within the context of the MEB 2015 standards, observed deficiencies in north-facing façades, whereas south-facing façades met the required illuminance levels and reduced energy consumption by 15–20%. Furthermore, Özen & Sümengen (2022) reported that increasing the window-to-floor ratio

from 21% to 25% improves performance across all climate regions. Bircan (2023) also showed that window ratios tested in the 20–30% range yield different results depending on orientation, and that façade openings and orientation are critical for daylight adequacy under the TS EN 17037 standard. Ashrafian & Moazzen (2019), in their study in Eskişehir, found that a façade transparency ratio of 40–50% enhances visual comfort and reduces electricity consumption by 15–18%.

Studies focusing on interior surface colors and reflectance values indicate that Aydın Yağmur & Sözen (2016) reported light-colored surfaces increase the daylight factor and provide more uniform light distribution, whereas dark surfaces raise the risk of glare. Similarly, Çelik & Ünver (2019) demonstrated that interior surface reflectance is a determining factor for both visual comfort and energy performance.

Field studies on existing school buildings clearly highlight the limitations of typical projects. Nas (2021), in measurements conducted at Cibali Primary School, noted that illuminance levels in most classrooms fell below the standards and could be improved through adjustments in curtain usage and lighting fixtures. Tapkı & Canbay Türkyılmaz (2018) compared schools built with typical projects to buildings with original designs, emphasizing that typical projects offer limited spatial flexibility and furnishings are not suitable for children's anthropometry, whereas original designs achieve higher comfort conditions.

Research on design support models shows that Arpacıoğlu, Çalışkan, Şahin & Ödevci (2020) proposed a method systematically evaluating window ratio, surface reflectance, orientation, and shading parameters. This model aims to guide designers at an early stage and indicates that standards alone are insufficient; climatic conditions and user needs must also be taken into account.

2. METHOD

The study examined a typical four-classroom primary school model, assumed to be located in Istanbul. Analyses were conducted in the Rhino Grasshopper environment, using the Honeybee plugin for climate-based daylight simulations. The climate data used was the EPW (EnergyPlus Weather) file for Istanbul, considered constant throughout the simulations.

The study was designed in two stages. In the first stage, the existing window-to-floor area ratio (10.4%) was considered and increased to 25% and 30% in accordance with the Ministry of National Education's Minimum Design Standards for Educational Buildings. In this stage, orientation was kept constant, and only the effect of changing the

transparent surface ratio on daylight performance was investigated. In the second stage, the window ratio was fixed at 25%, and the classroom model was placed in four different orientations (north, south, east, west) to evaluate the effect of orientation on daylight performance.

Certain parameters were kept constant across all scenarios. These fixed parameters were as follows:

- Classroom geometry,
- Interior surface material reflectance values (ceiling 0.80; walls 0.60; floor 0.10,
- Furniture layout,
- Work plane height (0.85 m) and grid boundaries (0.50 m inward from walls).

Thus, only the glazed surface ratio and orientation were considered as variables, and performance differences were compared based on these parameters.
In the evaluations, three internationally recognized climate-based daylight metrics were used: Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), and Useful Daylight Illuminance (UDI). While sDA measures the percentage of the space that receives sufficient natural light throughout the year, ASE indicates the risk of excessive direct sunlight and glare. To comprehensively assess daylight performance, it is recommended to report ASE and sDA values together; this allows for an effective evaluation of both adequate natural light penetration and excessive direct sunlight exposure (Talaei & Sangin, 2024). Moreover, climate serves as a fundamental data source for Climate-Based Daylight Modeling (CBDM) methods used to evaluate building performance in daylight design. Using these metrics, the existing conditions were compared with proposed scenarios, and the visual comfort conditions and daylight performance of the classrooms were thoroughly analyzed.

The analyses were conducted on the classroom marked in green in the typical primary school plan (Figure 1).

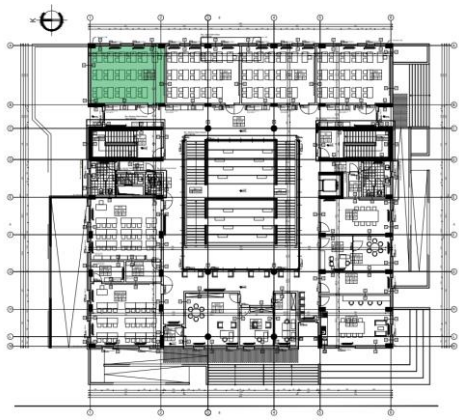


Figure 1. Typical primary school plan and the classroom selected for daylight analysis (green area)

Effect of Window-to-Classroom Area Ratio on Daylight Performance

One of the most important design parameters affecting daylight performance in classrooms is the window-to-classroom floor area ratio. This ratio determines the amount of natural light entering the interior while also playing a critical role in visual comfort and energy efficiency. In the current situation, the window-to-classroom area ratio in the examined classroom is calculated as 10.4%, which is below the 25% minimum requirement specified in the Ministry of National Education's (MEB) Minimum Design Standards for Educational Buildings. Therefore, in this study, the window ratio was increased to create different scenarios, and its impact on performance was investigated.

Table 2 presents the plan and section views of the classrooms, showing three scenarios representing the current situation (10.4%), the MEB Minimum Design Guide (25%), and the improved situation (30%). In the current situation, there are three narrow window openings on the façade; in the 25% scenario, the openings are enlarged; and in the 30% scenario, a single large opening on the façade is preferred.

Table 2. Scenarios Created Based on the Window-to-Classroom Floor Area Ratio in Classrooms

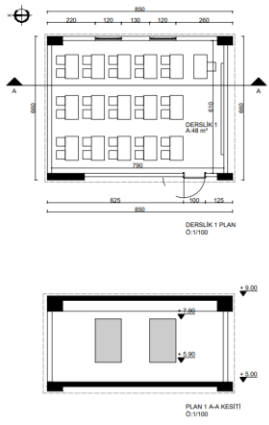
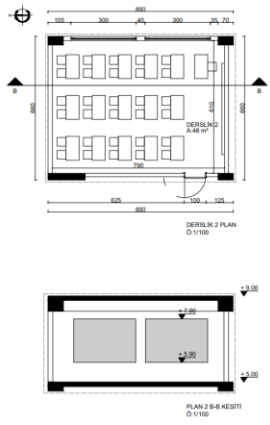
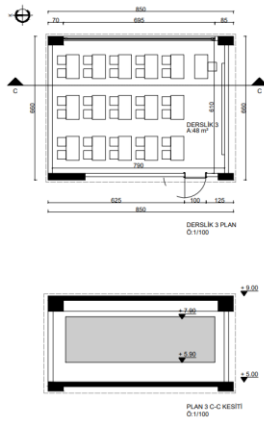
Existing Condition 10.4%	MEB Standard 25%	Improved Condition 30%
		

Table 3 summarizes the dimensional characteristics of the three different scenarios. In the existing condition, the window width is 1.20 m, with two openings, resulting in a total ratio of 10.4%. In the scenario complying with the MEB standard, the width is increased to 2.85 m, while the number of windows remains two. In the improved scenario, a single window is designed on the façade, with a width of 6.85 m, reaching a total ratio of 30%. In all scenarios, the window height is approximately 2.00 m, the parapet height remains 0.90 m, and the orientation is evaluated based on the east façade.

Table 3. Window characteristics according to different window-to-classroom area ratios

Window Properties	Current Condition %10.4	MEB Standard %25	Improved Condition %30
Width	1.20 m	2.85 m	6.85 m
Height	2.00 m	2.00 m	2.10 m
Number of windows	2	2	1
Parapet height	0.90 m	0.90 m	0.90 m
Window orientation	East	East	East

With this setup, all other parameters (classroom geometry, surface reflectance coefficients, furniture layout, working plane height) were kept constant, ensuring that performance differences were solely due to changes in window area. In this way, the impact of increased transparent surface area on daylight performance metrics such as sDA, ASE, and UDI became directly comparable.

Effect of Orientation on Daylight Performance

In the initial stage, different scenarios of window area/classroom area ratio were evaluated; models were created for the current condition (10.4%), the standard value (25%), and the increased ratio (30%). In these scenarios, orientation was kept constant, and the only variable parameter was the window area.

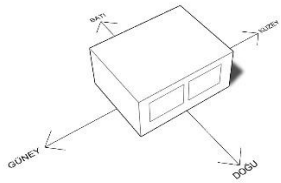


Figure 3. Classroom model according to four different orientations.

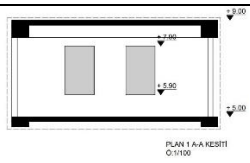
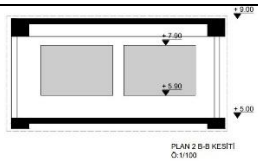
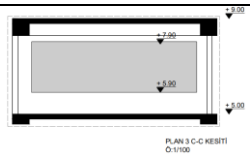
In the second phase, the window ratio of 25%, which is in accordance with the Ministry of National Education (MEB) standard, was fixed, and the classroom model was placed in four different orientations (north, south, east, west). In this setup, the spatial geometry, interior surface reflectance coefficients, parapet height, window sizes, and furniture arrangement were kept as fixed parameters; the only variable parameter was the orientation (Figure 3).

3. RESULTS

In this section, the daylight simulation results for the scenarios defined in the previous section are presented. The effects of the window-to-room area ratio and facade orientation are evaluated, and the performance outputs obtained are compared using the sDA, ASE, and UDI metrics.

Firstly, the daylight simulation results for the current situation (10.4%), the situation in accordance with the MEB standard (25%), and the improved situation (30%) are assessed. In Table 4, the sections and performance values for the three scenarios are shown.

Table 4. sDA, ASE, and UDI values according to different window ratio scenarios

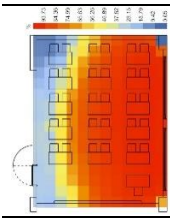
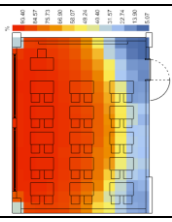
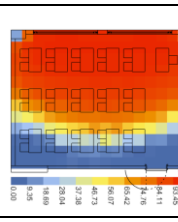
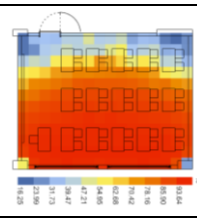
Current Condition %10.4	MEB Standard %25	Improved Condition %30
		
sDA: 30.72	sDA: 74.47	sDA: 83.33
ASE: 11.46	ASE: 41.15	ASE: 47.4
UDI: 66.15	UDI: 79.58	UDI: 77.7

According to the results, it is observed that the increase in the window ratio has a direct and significant effect on spatial daylight autonomy (sDA). In the current situation, the sDA value is calculated as 30.72%. With a window ratio of 25%, this increases to 74.47%, and with a window ratio of 30%, it rises to 83.33%. This increase indicates that as the window area expands, a larger portion of the classroom is illuminated by daylight.

In contrast, the annual sunlight exposure (ASE) values also increase along with the window ratio. The ASE value in the current situation is 11.46%, which increases to 41.15% with a window ratio of 25%, and to 47.40% with a window ratio of 30%. This finding suggests that while increasing the window area improves the amount of natural light, it may also increase the risk of glare and excessive solar exposure.

In the second phase of the study, the window-to-room area ratio was fixed at 25%, and the classroom model was placed in four different orientations (east, west, north, south). The daylight distribution maps, along with the sDA, ASE, and UDI values for these scenarios, are presented in Table 5.

Table 5. sDA, ASE, and UDI values obtained according to the orientation scenarios.

East	West	North	South
			
sDA: 74.47	sDA: 72.39	sDA: 67.18	sDA: 78.64
ASE: 41.15	ASE: 31.25	ASE: 0	ASE: 58.33
UDI: 79.58	UDI: 80.22	UDI: 86.51	UDI: 74.57

The results show that facade orientation has a decisive impact on daylight performance. On the north facade, the sDA value was found to be 67.18%, lower than other orientations, but the ASE value was calculated to be 0%, indicating that the risk of excessive solar exposure is eliminated. On the south facade, the sDA value reached 78.64%, while the ASE value rose to 58.33%, marking the highest level, and the glare risk increased. The east and west facades provided similar sDA results (74.47% and 72.39%, respectively), but due to the sun's effect during morning and evening hours, the ASE values were 41.15% and 31.25%, respectively.When examining the UDI values, the north orientation showed the most balanced distribution at 86.51%. The east and west orientations had values in the 79-80% range, while the south orientation dropped to 74.57%. These results suggest that the north orientation offers a balanced and comfortable daylight distribution, whereas the south orientation, with higher light levels, increases the risk of glare.

4. CONCULSION

In this study, the daylight performance of a typical elementary school classroom in Istanbul conditions was evaluated based on two main parameters: window-to-room area ratio and facade orientation. The simulation results revealed that increasing the window area ratio directly impacts daylight performance. The current window ratio of 10.4% was found to be insufficient, while a ratio of 25% led to a significant improvement in sDA and UDI values, while maintaining an acceptable ASE level. In contrast, a window ratio of 30% resulted in a rise in ASE values, indicating a risk of excessive solar exposure and glare. These

findings suggest that the 25% window ratio, corresponding to the MEB standard, is an appropriate solution.

Orientation analysis revealed that the daylight performance of classrooms varies significantly depending on the facade. The north orientation provided balanced daylight with a low ASE value, while the south orientation offered advantages with a high sDA value but also increased the risk of excessive solar exposure. The east and west orientations, while performing acceptably, showed imbalances during certain hours of the day.

Overall, it is recommended that the window ratio be kept at 25% to improve natural lighting performance in classrooms, that facade orientation be considered in design decisions, and that shading solutions be incorporated where necessary.

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TOWARDS REGENERATION: IMPROVING HEALTH AND WELLBEING WITHIN EXSISTING BUILT ENVIRONMENT

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ABSTRACT

The current sustainable paradigm, which is primarily focused on "doing less harm" or "patch fixes," is insufficient to address extreme global challenges and the depletion of resources. The world relies on degenerative linear systems, necessitating a drastic shift towards positive outcome systems and regenerative development. Regenerative development offers solutions by centering human health and wellbeing as much as planetary wellbeing, aiming to reverse environmental decay. This conference paper's aim is to analyze the wellbeing component in relation to physical, intellectual, and emotional dimensions to reach positive outcomes within architectural implementations, thereby supporting regenerative potentials.

Wellness Correlation Chart which combines Zari and Storey's three dimensions of wellbeing (Physical, Intellectual, and Emotional) with key variables from the Well Certification framework and the 14 Patterns of Biophilic Design was developed to provide a comprehensive framework to identify how architectural elements and design features contribute to specific dimensions of wellbeing, in addition to existing qualitative and quantitative assessment tools. The Wellness Correlation Chart was applied to the Ecological Building – Gaziantep Municipality, a structure with LEED Platinum and Enerphit certification.

This article aims to offer an understanding towards health and wellbeing nourishment by means of regeneration within architecture; and emphasize the qualities for common use in the existing building stock. The more intangible qualities can be depicted, the more multilayered structure of wellbeing can be achieved, which enables a deeper X factor. Therefore, positive impact systems can be implemented in existing built environment; and health and wellbeing nourishment can be prioritized.

Keywords: Regenerative Development, Wellbeing, Degeneration, Regeneration, Liveability

INTRODUCTION: THE NEED FOR POSITIVE OUTCOME SYSTEMS

Our world is at the edge of a transformation regarding the depletion of resources. Due to the recent collective awareness, sustainable paradigm made sure to comprehend the fact that consumption cannot continue as it is and the global initiatives accelerated the widespread influence of this knowledge. Nevertheles, the methodologies are primarily focused on "doing less harm" or "patch fixes" are no longer sufficient to address and/or compensate for extreme global challenges such as climate change, pandemics, earthquakes. Rather than the current "business-as-usual" approach and sparsely implemented eco-efficient practices, another degree of understanding of the need for positive impact systems should come to light.

Today's world relies on degenerative linear systems which default in mainstream systems of everyday life. However, there is a need for a drastic change for the benefit of long-term sustainability towards positive outcome systems. The world is processing a state which requires sudden changes in the existing patterns into adaptable systems that are capable of not only minimizing the degenerative effects of the existing formations but also providing for regeneration. There, whilst sustainable paradigm can be considered to be mainstream, it is insufficient to meet the needs of current problematic of environmental decay. In other words, the precautions taken for degeneration are not enough to cope with the extremes. There is a need for change of systems towards positive impact and Beijing's post pandemic and pre pandemic air quality have become the topic of many news and point out the fact that the problems are indeed anthropocentric.



Figure 1. A photograph displaying Beijing's post pandemic and pre pandemic air quality.

Even though, this acknowledged fact of environmental challenges are being researched and studied with respect to various fields such as engineering, architecture or medicine, when the pandemic taken into consideration, threats have become more severe and precautions become insufficient. Because, it have brought out the fact that, our living systems and structures turned into overpopulated areas with unconscious decision mechanism55 and this is unacceptable in order to sustain any level of livable environment in the future in terms of health and wellbeing of our world and us. As it is stated by Zari M. Peterson in her conference paper *Factor X – Wellbeing as a key component of regeneration of green buildings,* "human well-being and planetary well-being are intricately interwoven"(Storey, J. B., Zari, M.P.,2006).

Regenerative development is able to offer solutions as it centers human health and wellbeing as much as planetary wellbeing. It emphasizes the need for positive outcome systems and reversing environmental decay so as to target long-term benefits. John Tillman Lyle defines the existing reductionist systems within industrial one way flows as degenerative systems (Lyle,1994). Moreover, he believed that these degenerative systems as finite and they are no longer available to maintain themselves; and the sustainable systems that are in use are concerned about limiting the impact, which is not enough for both the environmental and social decay. He "defines regenerative design as the replacement of linear systems of throughput flows with 'cyclical flows at sources, consumption centers, and sinks"(Lyle, 1994) and the plain definition of regenerative design can be given as to create with the intentions to restore environmental decay and seek the ways for positive outcomes instead of less impact and considering systems as a whole in terms of human's wellbeing and health as well as nature's, therefore aiming a co-existence with co-evolutionary systems (Mang, Reed, 2012).

Furthermore, regenerative thinking and regenerative development not only offer a holistic approach through circular systems that aim to eliminate or even reverse degeneration but also helps to regain state of 'regenesis' within built environment. While the shift towards regenerative development occurs, a shift in mindsets is required as well. Nevertheless, this is a very difficult transformation from business as usual and requires effort. "In the absence of tangible regenerative design concepts, the intersections in bio-inspired design, which seeks to improve both the ecological and psychological suitability of the built environment, could be a crucial component of creating comprehensive regenerative architecture" (Zari, 2009).

Therefore, this conference paper's aim is to analyze the wellbeing component in relation to physical, intellectual and emotional

dimensions so as to reach for positive outcomes within architectural implementations in order to shed light to regenerative potentials in an effort to support wellbeing.

Priorities in Architecture and Design: Towards Enhancing Health and Well-being

The subjectified term of this conference, priority, should be defined in order to comprehensively address the given problematic of the need for positive outcome systems. Construction industry and architecture have become two different ends of the same work of curatory our living space, our habitat: the built-environment. As they take the subject of this formation of one's living space from different point of view due to their prioritization of different variants, the built environment and the construction sector play a significant role in the aforementioned degeneration. Throughout the life cycle of buildings—from raw material extraction, processing, construction, operation, and maintenance, through to demolition—negative environmental impacts result from pollutants, energy and water use, land degradation, and waste production. Sustainable paradigm targets to decrease these harmful effects by means of reconsideration of existing systems and carefully curating the demand and supply chains. Nevertheless, it is argued that existing sustainability approaches, with their motto of "doing less harm," are insufficient. In this context, regenerative development offers holistic thinking that helps the built environment regain its state of 'regenesis' should come to fore and trigger a reconsideration of the existing systems. Moreover, architecture should play a crucial role in prioritizing regeneration instead of degeneration. "Sustainability in architecture is thought in terms of resource efficiency, pollution reduction, and mitigating impact on natural ecosystems. It can be argued however that human well-being and planetary well-being are intricately interwoven" (Storey, Zar, 2006).

The Link Between Health, Well-being, and the Built Environment

When people experience belonging and the desire to be in that particular place, that linkage is what makes a building an object of architecture. One of the forefront regenerative practitioners Maibritt Pedersen Zari and her colleague John B Storey, defines this situation of being subjected to desirability as *the X factor*, "that makes some places a delight to be in where people feel alive, vibrant, stimulated, refreshed and, where absent, makes other places others unpleasant, disturbing, disquieting, where people feel unhappy or uncomfortable while others generates no feelings at all. Places that create feelings of negativity or indifference diminish us as human beings and demonstrate a crucial failure on the part of the design team. Factor 'X' is about creating

environments that enhance a user's holistic sense of well-being" (Storey, J. B., Zari, M.P.,2006). Zari M. Petersan and John B. Storey explains the relationship of wellbeing and architecture within 3 dimensions, which are physical wellbeing, intellectual wellbeing and emotional wellbeing as shown in Figure 2.



Figure 2. Health and well-being dimensions: physical, intellectual, and emotional well-being.

The concepts of health and well-being are inseparable components of the built environment. Once a building becomes an architectural object, the interaction between its users and the building begins, and this interaction directly impacts people's well-being. However, the architecture sector often prioritizes quantitative factors while overlooking qualitative factors such as creating livable and relatable environments (Zari, 2006). This leads to the emergence of soulless and alienated environments where people cannot develop a sense of belonging. Maibritt Pedersen Zari and John B. Storey define this situation as the "X Factor," which encompasses the qualities that make people feel alive, vibrant, stimulated, and refreshed in a place, or, conversely, displeased, uncomfortable, or indifferent.

The absence of this X Factor signifies a disconnection from the environment which results in an influence on one's health and wellbeing. Health and wellbeing nourishment plays an essential role in the transition of positive outcome systems. Moreover, it is one of the describable and observable variant within built-environment that can provide for data of

this afore mentioned transition. The usage of degenerative systems threatens not only environmental health but also the health and well-being of both people and ecosystems (Zari, 2006).

Transition Towards Positive Outcome Systems

Despite regenerative development being a rooted field of study, its borders are vague because of its comprehensive structure. Although there are theoretical foundations of the subject, the application is still very limited to detached settlements. The challenge is to adapt the principles and systems within them to achieve positive impact in existing built-environments. With regard to these needs, employing the existing theoretical framework and mindsets which can work with, and support regenerative development can be a solution. In other words, "in the absence of tangible regenerative design concepts, the intersections in bio-inspired design, which seeks to improve both the ecological and psychological suitability of the built environment" (Zari, 2009) can offer the desired transition within the existing built environment. Moreover, the transition towards positive outcome systems requires a smooth setting by not only replacing existing degenerative systems but also intervening the existing systems and manipulating them to cooperate towards regeneration. By replacing the degenerative patterns and systems could result in positive outcomes with careful interventions by providing a transition through existing systems. However, this kind of intervention requires careful large scale planning rather than a one-time application that provides patch solution.

To elaborate, it can be inferred that building certification systems comprehensively integrate different divisions of sustainability into their evaluation (Bura, Narkhede, 2021) and the result is calculated as a percentage of earned credit points. In general, key characteristics of the systems can be categorized as environmental benefits concerning resources such as energy, materials, water, and land; economic dimensions related to cost monitoring, economic efficiency calculations, and the life cycle cost analysis; regulations including building certification, national and international building regulations and codes; and social dimensions as in promoting physical health with material choices, thermal considerations etc., in which building certification systems have to rigorously implement. Nevertheless, widespread qualitative certification systems such as Leed, Breeam cannot deeply incorporate with every social aspect within their evaluation. When creating regenerative systems, more than one evaluation medium is required in order to procure the results diversely.

Therefore, a combination in the existing systems and tools within sustainability, qualitative and quantitative assessment methods are offered for the continuation of eco-efficient systems. From a regenerative development perspective, not only one system is enough, but also the usage of multiple systems is necessary to comprehensively capture both tangible and intangible aspects of wellbeing. Since, most aspects of sustainable assessments and certification systems are short in terms of quality assessment resulting in intangible concepts such as wellbeing.

Tangible Enhancements Towards Wellbeing Nourishment

As business-as-usual proceeds from eco efficient practices to net-zero impacts, the report stated that net-zero will be indifferent from previous approaches if not supported or even transformed into positive outcome systems. Action plans of New Zeeland Government is originated in 2009, emphasize the need for a change towards regenerative practices as "the current move to eco-efficiency practices is an important first step towards achieving a short-term sustainable built environment, but it is not sustainable in the long term" (New Zealand Report, 2009). The reports offer a three stage transition towards regenerative development emphasizing, eco-efficient, restorative and regenerative approaches in order to provide transition in short term, midterm and long terms goals. The importance of these reports to this study is that their methodology of using the built environment as the medium to replace the degenerative systems and making use of green building infrastructure to add on regenerative features. Gradually, business-as-usual systems are to be replaced by regenerative systems aiming for positive impact, and this study targets to depict wellbeing elements and support wellbeing nourishment. (New Zealand Report, 2009).

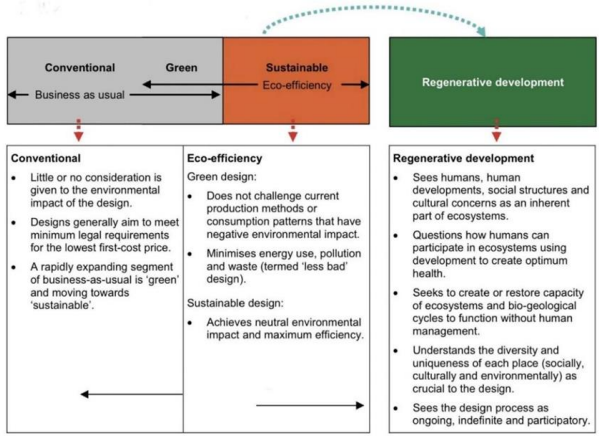


Figure 3: Business as usual to regenerative development comparison chart towards a regenerative future, directly quoted from New Zealand Governmental report, 2009.

This study is focused on health and wellbeing components within regenerative systems and aims to detect health and wellbeing quality of the subjected case study so as to depict in which dimensions the buildings can be supported. To make this evaluation, patterns of Biophilic Design, Well Certification and Zari's Wellbeing dimensions are combined and cross-referenced under Wellness Correlation Chart.

Firstly, Terrapin Bright Green is an environmental consulting company which has conducted extensive interdisciplinary research and used empirical evidence to create the "14 Biophilic Patterns", which serve for improving health and wellbeing. There are three classifications and 14 patterns within. First classification is Nature in Space. It defines 7 patterns; which are Visual connection to nature, Non-visual connections with nature, Non-Rhythmic Sensory Stimuli, Thermal & Airflow Variability, Presence of Water, Dynamic & Diffuse Light and Connection with Natural Systems. Second classification is Nature Analogues and it consists of 3 patterns which are Biomorphic Forms & Patterns, Material Connection with Nature and Complexity & Order. Third classification is Nature of the Space. It is defined with 3 patterns which are Prospect, Refuge, Mystery and Risk/Peril as an identifiable threat coupled with a reliable safeguard.

Bio-inspired design, particularly Biophilic Design, is crucial for achieving regenerative outcomes and tangible enhancements in health and wellbeing. Biophilic design focuses on "bringing buildings 'alive'" and re-establishing human connections with nature within built environments.

Biophilic principles incorporation with health and wellbeing dwell on three stages thinking in terms of applying rules of nature to human systems; feeling in terms of cultivating a different set of qualities internally; and connecting in terms of Working together to weave a new culture of progress into the world (Zari, 2009) These criteria offer a series of spiritual connections directly to the wellbeing. It offers specific principles and patterns that support health and wellbeing by mitigating stressors such as visual connection to nature and enhancing qualities like creativity, memory, and relaxation. These patterns, when incorporated into design, lead to inspirational, restorative, and healthy spaces that are integrated with the urban ecosystem to demonstrate how biophilic features enhance livelihood and user interaction, prompting the X Factor. Biophilic principles can be widely applied in landscapes, interiors, and even art objects to create meaningful connections.

Secondly, the Well certificate consist of eleven variables and their components. The variables are air, water, nourishment, light, movement, thermal comfort, sound, materials, mind, community and innovation. This framework evaluates well-being in the built environment across eleven variables, each connected to physical, intellectual, and/or emotional dimensions of health. For example, "Air" and "Light" are directly linked to physical wellbeing, while "Mind" and "Community" variables engage intellectual and emotional aspects through sensory design, mental health promotion, and civic engagement.

Lastly, Zari M. Petersan and John B. Storey propose that wellbeing in architecture can be understood through three dimensions: Physical, Intellectual, and Emotional Components. Physical Wellbeing relates to materialistic aspects and physical comfort. It encompasses elements like lighting, clean air quality, temperature, humidity, and their impact on decreasing stress levels and promoting physical health refurbishment. Intellectual Wellbeing is connected to how people interact with their surroundings through their senses and receive sensory feedback. It includes aspects like personalization of the environment, sensory engagements such as smells, textures and connection to nature. Emotional Wellbeing involves spiritual and deep connections with a place. It includes cultural connections, harmonization with nature, metaphors, beliefs, and moral norms, which contribute to mood creation, modification, and a sense of restorative design.

New Collective Methodology: Wellness Correlation Chart for Enhancing Wellbeing

The table is based on the keywords gathered from Wellness definition of Zari in the X Factor referring Physical, Intellectual and Emotional in terms of the key variables of Wellness Chart and Patterns of Biphilic design. It sums up the keywords driven from patterns and certification by re-interpreting their correlation whether they serve physical wellbeing, intellectual wellbeing or emotional wellbeing with a direct or indirect relationship. It aims to give collective information about which type of improvement or consideration reflects on which level of wellbeing.

The study proposes a Wellness Correlation Chart as a new collective methodology. It aims to illustrate how different architectural elements, design features, and interventions contribute to specific dimensions of wellbeing. The chart is not intended for point-based scoring but to identify the type of wellbeing nourishment provided. It clarifies whether a given feature such as thermal comfort, natural light, material choices, or engagement with natural systems primarily reinforces physical, intellectual, or emotional wellbeing, or a combination. By utilizing this comprehensive framework, the aim is to ensure that interventions in the built environment move beyond basic sustainability to actively nourish health and wellbeing across all three dimensions, ultimately moving towards a state of "regenesis".

New Collective Methodology for 3 Dimensions of Wellbeing Case study: Ecological Building – Gaziantep Municipality

For the sake of implementing the evaluation criteria on an existing building, an example from turkey is chosen concerning its qualifications such existing certification and technical systems. The chart indicated the direct and indirect relationships of key terms with each other and illustrates how many of them are present in this case. For some dimensions, it is possible to add up to existing setting and provide for more connection. However, some dimensions such as risk and peril, mystery etc. should be present in mind from pre-design stages.

Ecologic house by Gaziantep Municipality is a promotional and informational building providing public services, which is used for activities related to energy criteria and energy efficiency. The building also has LEED Platinum certification and Enerphit certification in 2015. Main features of the building include green roof, and water collecting systems as well as pv panels located on the parking site with which building harvests more electricity than its using. Therefore, exes energy is distributed to the city's electrical system. Building envelop is mainly a closed concrete shell which is supported by insulation and isolation

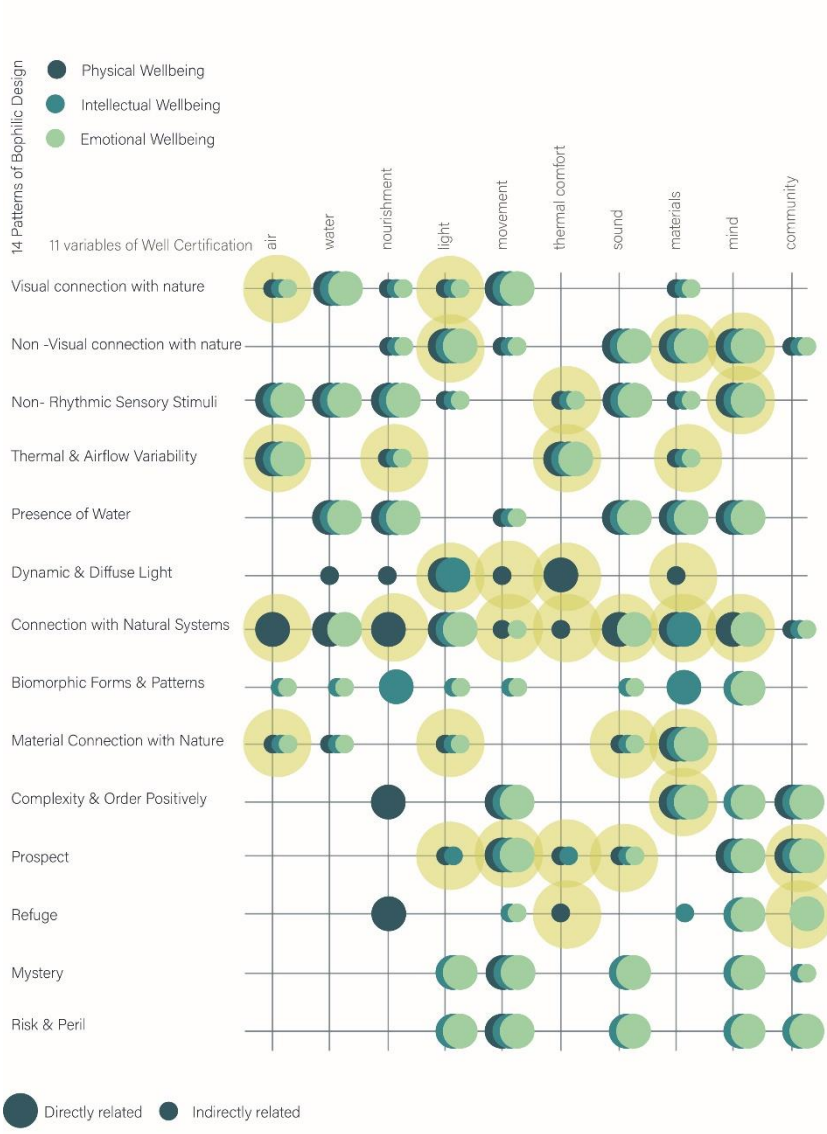
layers in order to achieve maximum passive reliance. With the green roof implementation, roof thermal insulation is provided. Thus, the more green features building has, the more features can provide for thermal capacities. The used windows have insulated frame systems as well as a three layer glass envelope PVC windows provide for natural lighting. To elaborate on technical systems, the building employs Canadian Well system design in order to supply for heat recovery and clean air feature with a sustainable system up to %85. Therefore, there is a clean air circulation in the building for 24 hours and 7 day with high thermal comfort. Moreover, the building has a greywater treatment system and rainwater storage system. Soil-based ventilation, heat balance system and water-based cooling system. Indoor climate is provided by water source electrical heat pump. Compact architectural design enables adjacent public transport and pedestrian transport paths to be used.

As an interesting method related to the project, it is common to use shading features on the southern sides of the hot climate regions and Gaziantep has a high sun exposure as it is located in the southern Anatolia region of Turkey. Nevertheless, building designers decided to create a surrounding garden with existing trees in order to supply the required shading rather than an extra structure. Besides, the project uses endemic plants in order to support and preserve biodiversity in the area.

Ecological Building serves for public usage, which limits the time interval that the building is being used to day time. Therefore, the building interacts with its users in morning, noon and afternoon but no necessarily the night time. The surrounding of the building is designed to offer diverse experiences such as natural path ways to explore, refuge places to calmly spent time, planting areas to interact with nature and a parking lot including photovoltaic shading panels. Moreover, the interior of Ecological Building offer a thermally comfort space with mechanized airflows within buildings closed envelop. As mentioned, building is located in a hot climate zone that the temperatures can go really high. Therefore, in order to prevent the disturbance and overheating in summer, the building have minimal windows that are located at the interior edge of the building's massive walls; and supported with reflective surfaces.

With respect to the qualities that are mentioned above, the Wellness Correlation Chart of Gaziantep Ecological Building is prepared. To explain, the building interacts with the nature positively, display different types of light and shade, provide refuge places and have planned surrounding area which offers a kind of prospect quality. Nevertheless, the material usage within the building does not display neither natural

qualities nor biomorphic forms, as well as no mystery or risk and peril elements.



The table displays 31 physical wellbeing endorsing indicators, 23 intellectual wellbeing indicators and 22 emotional wellbeing indicators which are present in the given project. Although, this project positively interacts with its users that improves their physical wellbeing, it can possess more intellectual and emotional wellbeing indicators.

CONCLUSION

To conclude this study regards regenerative development and design from health and wellbeing point of view. Therefore, concept of wellbeing in terms of it components physical, intellectual and emotional aspects from Zari's The X Factor Wellbeing table are correlated with two evaluation mechanism which are Well Certificate and Biophilic Design Principles in order to offer a system to read regenerative possibilities. The Wellness Correlation Chart enables the information of physical features as well as spiritual elements to be related with a kind of wellbeing quality related to the architectural elements; and the features directly related to the wellness indicators are present in the case study. To explain, the architectural implications such as the design features, handling of the project, management of project and having multidisciplinary project teams all enable diverse qualities within projects, which interact with their users. These interactions enable the establishment of the X Factor within the projects; and them to become susceptible to both human and nature wellbeing. The structures do not become element of architecture until after they start their interaction and communication with people. This relationship can have positive or negative outcomes on people as well as the existing ecosystem. In terms of wellbeing, prioritizing the X Factor within designs, should become the key of health and wellbeing improvement within architectural implementations to create fully healthy projects resulting livable environments concerning not also pre-occupancy period or construction but also post-occupancy user feedbacks.

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2. *Passive House Database ID of Gaziantep Municipality Building is 4976 and the main frame information of characteristics of project can be found in this video https://youtu.be/wAjE8AvEewY.*

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Figure-1: https://www.bostonglobe.com/news/science/2018/10/18/harvard-researchers-say-they-may-have-solved-mystery-beijing-air-pollution-woes/o42Mw9OJptk8d3N14av8mO/story.html

ADAPTIVE REUSE OF OFFICE BUILDINGS AS RESIDENTIAL SPACES: PRIORITIES AND APPROACHES IN GLOBAL CONTEXT

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ABSTRACT

Adaptive reuse of buildings contributes to more sustainable environments by extending the life cycle of existing buildings. Office-to-residential conversion has emerged as a promising strategy in response to rising office vacancy rates driven by changing work patterns, economic shifts, and environmental concerns. However, its implementation remains complex due to regulatory and financial barriers. Therefore, it was aimed in this study to investigate how five developed countries -Germany, France, the United Kingdom, the United States of America and Australia- approached office-to-residential conversions through national and municipal level policies. The methodology involved a comparative analysis of policy reports, legislative frameworks, incentive programs, and planning strategies, supported by selected case studies. Findings show that each country employs distinct tools: Germany integrates vacancy activation with urban regeneration; the City of Paris uses design competitions and sustainability criteria; the United Kingdom promotes conversions through extended permitted development rights; the United States combines federal and local incentives; and Melbourne, Australia emphasizes climate-responsive design at the city scale. The study revealed some challenges at the building scale as well, such as daylight access, natural ventilation, and circulation constraints. Ultimately, it was shown how adaptive reuse is a multifaceted process, shaped by context-specific governance, design, and policy approaches. Additionally, best practices and implementation barriers were highlighted for offering insight into how adaptive reuse can support long-term urban resilience and sustainable development.

Keywords: Adaptive Reuse, Office Conversion, Residential Use, Governmental and Municipal Policies, Use Performance.

INTRODUCTION

Adaptive reuse of buildings is a measure that can contribute to reaching more sustainable environments in terms of resource consumption. It is the process of giving a building a new and efficient identity and function when it is no longer suitable for its original purpose, providing an efficient identity that better serves the periodic needs, and thus, it extends the building's lifespan (Douglas, 2006; Velthuis & Spennemann, 2007). In this context, the adaptive reuse of offices for housing prompts as a solution in times when a significant portion of office buildings remain vacant due to changing market demands, evolving work culture, technological advancements, economic shifts, etc. regarding sustainable urban development as well as environmental sustainability (Geraedts & van der Voordt, 2003). Even though the adaptive reuse of office buildings into housing can be recognized as a viable strategy to address these challenges, its implementation remains complex due to financial feasibility concerns and regulatory barriers (New York City Department of City Planning [NYC DPC], 2023). Additionally, as listed by Wang and Zeng (2010), the cultural, economic, architectural, environmental, social, and sustainability factors that cause adaptive reuse preferences differ from country to country and city to city. Each of these factors can influence the adaptive reuse processes based on the local context and the needs of the community. Therefore, the feasibility and success of such conversions depend on various regulatory, economic, and social factors that vary across different national and local contexts.

Numerous academic research studies have analysed the conversion of offices into residences. In addition to these research studies, there are also projects, investments and conversion studies carried out by various countries and city administrations around the world to evaluate the building stock in the regions they rule. The literature shows that adaptive reuse processes depend on a combination of public policies, economic incentives, and innovative design approaches, and this varies by location. While some cities have actively promoted adaptive reuse through legislative changes and financial incentives, others have faced difficulties due to outdated zoning laws, inflexible building codes, or community opposition (Die Bundesregierung, 2024). All of the documents reviewed were published after 2015, which indicates that the issue remains highly contemporary and actively discussed in the countries under consideration.

This research aimed to determine the scope of adaptive reuse efforts in developed countries, focusing on government and municipal level initiatives. It covered a comparative analysis of policy reports, legislative documents, and urban planning strategies from Germany, France, the

United Kingdom, the United States and Australia. By analysing official reports, incentive programs, and regulatory frameworks, the research aimed to identify commonalities and divergences in how these nations approach office-to-residential conversions; in addition to trends, challenges, and best practices. Additionally, selected case studies from each country were examined to assess the real-world application and impact of adaptive reuse policies.

METHODOLOGY OF THE STUDY

This research is based on a qualitative document analysis conducted to understand how policies and practices for the adaptive reuse of office buildings as housing are developed in different national contexts. The study was carried out through a systematic review of current strategy documents, guidance materials, planning texts, and legislative regulations, particularly those published by public institutions and local governments.

The direction of the research was shaped by the diversity of policies on office-to-residential conversion in the countries planned for investigation (i.e., developed countries) and the availability of accessible and reliable open-source materials in the field of adaptive reuse. The process began in Spring 2025 with preliminary readings of credible English-language press sources and official news bulletins, without any limitation in publishing year. When news related to office-to-residential conversion was identified in a specific country or city, attention shifted to open online sources in the local language of that country, provided by official institutions.

Considering data accessibility, the ability to overcome language barriers, and the density of official documents, the research was conducted for data from the United States of America, Germany, France, the United Kingdom, and Australia, in that order. The data collection process was carried out through systematic online open-source searches. For each country, the official websites of relevant ministries, metropolitan municipalities, and urban planning authorities were systematically reviewed. Within this scope, strategy documents, implementation guides, action plans, legislative texts, and publicly available policy documents published by local governments were examined. In addition, reliable press sources and official bulletins were evaluated to track current developments and approaches.

The collected documents underwent preliminary screening based on content validity, institutional authority, and currency. Documents that directly refer to office-to-residential conversion, and prepared by official

institutions, were included in the analysis. The main criterion in the selection process was the extent to which the documents addressed legal, administrative, economic, spatial, and design-related aspects of the conversion process. Documents that remained within the general framework of urban planning or referred to the conversion theme only indirectly were excluded.

In the qualitative content analysis on the documents, it was aimed to systematically examine how conversion policies are shaped around themes such as legal regulations, incentive systems, implementation guidelines, and design standards. In the thematic coding process, the classification from 'The New Transformation Meter' developed by Rob P. Geraedts and Theo van der Voordt (2003, 2007) was used as the analytical framework. This structure allowed the contents of different documents to be comparatively evaluated under common thematic categories.

FINDINGS ON ADAPTIVE REUSE STRATEGIES

As urban centres continue to grapple with housing shortages and the urgent need to address climate change, adaptive reuse emerges as a strategic approach to repurposing existing building stock for the benefit of current and future generations. The adaptive reuse of office buildings into housing offers a unique opportunity to reduce resource consumption, limit urban sprawl, and promote sustainable development. However, the nature of such interventions varies significantly across city-, neighbourhood-, and building-scales, reflecting the influence of local governance models, planning traditions, and socioeconomic conditions.

It is found similarly in this study that national and municipal authorities adopt multi-scalar approaches to office-to-residential adaptive reuse. At the city scale, strategies often focus on regional regeneration, optimizing the use of accessible urban areas, and balancing residential density across districts. At the neighbourhood scale, policies emphasize the improvement of local amenities, the preservation of social cohesion, and the integration of mixed-use functions. At the building scale, technical adaptability, daylight access, natural ventilation, and circulation patterns emerge as key determinants of feasibility. In the following subsections, these varying approaches are analysed for each scale separately to provide insight into how different governance structures address the challenges of office-to-residential conversions and identify transferable lessons for future urban regeneration initiatives.

Strategies and Approaches Implemented at City Scale

At the city scale, office-to-residential adaptive reuse policies often function as part of broader urban regeneration strategies, linking the transformation of individual buildings to citywide objectives such as balanced residential density, climate adaptation, and infrastructure optimization. Cities operate as the primary arena where planning, zoning, and investment decisions converge, making this scale critical for shaping both the feasibility and the impact of adaptive reuses.

Across the studied countries, city-scale office-to-residential adaptive reuse policies consistently pursue a set of shared objectives. Chief among these is the revitalization of underutilized districts through targeted housing initiatives, particularly in locations characterized by high office vacancy rates. Equally important is the optimization of accessibility, with conversions often concentrated in transit-rich, centrally located, or otherwise strategically significant zones. Another common priority is the careful balancing of residential density, aiming to avoid the overconcentration of housing in specific districts while ensuring that other areas remain socially and economically vibrant. In parallel, many strategies integrate explicit environmental goals, including the expansion of green spaces, the improvement of urban microclimates, and the promotion of low-carbon mobility options, thereby aligning adaptive reuse efforts with broader sustainability agendas.

In Germany, cities embed office-to-residential adaptive reuse within integrated urban development frameworks. Local administrations coordinate broader environmental improvements, invest in public infrastructure, support commercial activity, enhance transport connections, and expand green and recreational areas to strengthen the social fabric in targeted transformation zones (BMWSB, 2023). For example, municipal programs, in partnership with the *Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen* (BMWSB, Federal Ministry for Housing, Urban Development and Building), not only enable the repurposing of individual buildings but also invest in public infrastructure, green corridors, and transport upgrades in designated transformation zones. This dual approach seeks both to improve liveability and to stimulate local housing demand in areas where population growth has stagnated. The 2023 Transformations report highlights that approximately 12.5 million m² of office space, which was ca. 6% of the national stock was vacant, with rates reaching 20% in some eastern cities (BMWSB, 2025). To counter this, the *Wachstum und nachhaltige Erneuerung* (Growth and sustainable renewal) program allocated nearly €790 million in 2021 to support municipal regeneration and

adaptive reuse projects (BMWSB, 2023). All these efforts aim to increase the population on a city scale and, in doing so, to renovate old buildings.

In the French capital City of Paris, the adaptive reuse of offices is incorporated into city-scale design competitions and local urban planning revisions. Priority is given to centrally located or strategically connected districts, with the aim of preserving a balanced urban density and ensuring that new residential developments are embedded in a rich mix of public functions, including commercial, cultural, and recreational. Sustainability metrics, such as energy performance and climate resilience, are explicitly tied to city planning approvals. The Bioclimatic Local Urban Plan now sets binding targets for low-carbon design, while initiatives like *Réinventer Paris* (Reinventing Paris) ensure that conversion projects actively contribute to neighbourhood vitality and architectural quality (Grégoire, 2022; Ville de Paris, 2021).

In the United Kingdom, while national policies have liberalized adaptive reuse through extended permitted development rights, many cities, including London, apply local planning guidance to steer such projects toward areas with robust transport connections and established urban infrastructure. At the city level, the focus is on avoiding the creation of "dormitory districts" and ensuring that converted housing integrates into the wider economic and social fabric. In 2014 alone, 6.1 million ft² of office space was converted into approximately 7,600 new homes, and between 2010 and 2017, the extended permitted development regime generated between 86,000 and 95,000 units nationwide (Clifford, Ferm, Livingstone & Canelas, 2018b). However, subsequent studies found that only 22–30% of these units met national minimum space standards, raising significant concerns about housing quality (Clifford, Canelas, Livingstone & Ferm, 2020). In addition, it has been observed that office buildings repurposed within the scope of "permitted development rights" are concentrated in certain central areas of the city (Clifford, Ferm, Livingstone & Canelas, 2018a). This causes an uneven distribution of building renovations, population, and demographic structure within the city.

One of the important major cities of the United States, New York, uses a combination of zoning reform, financial incentives, and public-private partnerships to channel conversions into central business districts and transit-oriented corridors. These initiatives aim to consolidate infrastructure investments while also diversifying the housing supply in high-demand markets. Between 2010 and 2020, over 10 million ft² of office space was converted, and current estimates suggest up to 120 million ft² of additional offices could be suitable for reuse under proposed zoning reforms. Already announced projects are expected to

deliver approximately 3,600 new housing units, indicating the scale of potential impact if regulatory pathways are further streamlined (NYC DPC, 2023).

Australia, Melbourne's city scale strategy frames adaptive reuse as part of its climate-responsive urban design agenda. Conversions are concentrated in highly accessible central areas and integrated into policies that promote active transport, enhance public space, and improve environmental performance across the building stock. Melbourne's population has grown from only 1,000 residents in the central city in the early 1990s to over 180,000 today, with projections exceeding 308,000 by 2041. To meet these demands and reduce emissions, the city requires that around 80 buildings per year be retrofitted or converted to meet Green Star and NABERS performance standards, directly linking adaptive reuse to its net-zero by 2040 target (City of Melbourne, 2024).

Viewed collectively, these city-scale approaches demonstrate that office-to-residential conversions are most effective when aligned with holistic urban strategies that go beyond the building to address connectivity, liveability, environmental resilience, and socioeconomic balance at the metropolitan level.

Strategies and Approaches Implemented at Neighbourhood Scale

At the neighbourhood scale, office-to-residential conversions operate as targeted interventions designed to strengthen local communities and ensure that adaptive reuse contributes to more than just housing supply. Unlike citywide strategies that emphasize macro-level goals such as balanced density and climate adaptation, neighbourhood-focused policies attend to the social, economic, and spatial dynamics of specific districts. This scale highlights how conversions are embedded into the everyday fabric of urban life, shaping community vitality, local economies, and the distribution of amenities.

In Germany, neighbourhood-focused policies are often embedded in integrated urban development concepts. Local municipalities encourage adaptive reuse projects in declining districts where office vacancy has undermined community life. Alongside conversions, cities invest in schools, childcare, and green public spaces to ensure that new housing becomes a catalyst for wider neighbourhood revitalization. This approach is reinforced by the *Handlungsstrategie Leerstandsaktivierung* (2025 - vacancy activation strategy), which provides financial incentives for the conversion of vacant commercial buildings into housing, aiming to reduce structural vacancies, reactivate ground-floor retail, and enhance the overall attractiveness of neighbourhoods (BMWSB, 2025).

In France, especially in Paris, office-to-housing initiatives at the neighbourhood scale are closely linked with local urban planning revisions. Here, conversions are required to integrate ground-floor functions that support local services and commerce, maintaining lively streetscapes and ensuring that residents of reused buildings are embedded in socially complete neighbourhoods. This is reinforced by innovative competitions such as *Réinventer Paris* (Reinventing Paris) and *Quartiers d'innovation Urbaine* (Urban Innovation Districts), which promote mixed-use projects where housing, culture, and commerce reinforce one another at the community scale (Grégoire, 2022).

In the United Kingdom, neighbourhood-level outcomes have drawn substantial scrutiny. While national deregulation through permitted development rights facilitated widespread conversions, evidence from London and other cities indicates uneven neighbourhood impacts. Many projects concentrated in central locations, particularly avenues and city centres, reflecting a strong emphasis on location centrality and density management (Gibson, McCauley & Marston, 2015). Also, concerns are repeatedly raised about the limited access of new housing units to adequate social infrastructure and community facilities, alongside criticism of poor spatial quality in many schemes (Clifford, Ferm, Livingstone & Canelas, 2018a). Studies also highlight that inadequate transport infrastructure often undermines conversion outcomes, even where centrality is achieved, with access to public transit directly correlated to the quality and success of adaptive reuse projects (Clifford, Ferm, Livingstone & Canelas, 2018a; Clifford, Ferm, Livingstone & Canelas, 2018b). Based on the results of implementing the "Permitted development rights" scheme, a more restrictive and standard-requiring regulation was made.

In the United States, New York City links neighbourhood-scale conversions to community benefit agreements. Developers receiving tax incentives or zoning bonuses must provide affordable housing, ground-floor retail, or public amenities that directly serve the local community. In New York specifically, zoning reforms and incentive schemes like the 421-g Tax Program and Liberty Bonds helped transform the Financial District into a mixed-use neighbourhood, converting nearly 20 million square feet of office space into 17,000 homes since 1995. Analyses further highlight accessibility factors, particularly the balance of "live-work" conditions, proximity to transit networks, and the adequacy of local infrastructure, which play a decisive role in determining the overall success and quality of conversions (NYC DPC, 2023).

In Australia, Melbourne's neighbourhood-focused policies align adaptive reuse with its precinct structure planning. Converted buildings are concentrated in walkable mixed-use precincts, where they are tied to active transport infrastructure, local services, and climate-responsive streetscape improvements. By embedding conversions within precinct-level design, Melbourne ensures that neighbourhoods gain social amenities and environmental upgrades alongside new housing (City of Melbourne, 2024).

Together, these approaches reveal that neighbourhood scale conversion strategies are not merely about filling vacant offices with residents but about embedding adaptive reuse into the broader socio-spatial development of districts. By coupling housing creation with community infrastructure, environmental upgrades, and social diversity, these policies demonstrate how adaptive reuse can become a driver of resilient, equitable, and vibrant neighbourhoods.

Strategies and Approaches Implemented at Building Scale

At the building scale, adaptive reuse policies move from broad planning visions into concrete interventions that determine whether a specific office building can successfully be converted into housing. This level is where regulatory frameworks, technical feasibility, and design standards converge most strongly. Key issues typically addressed include fire safety, daylight and natural ventilation, energy efficiency, accessibility, seismic resilience, and minimum dwelling standards. Countries vary considerably in how they regulate and incentivize these requirements, but the goal is to ensure that conversions yield habitable, safe, and futureproof housing.

In Germany, building conversions are strictly governed by state-level building regulations. Authorities emphasize compliance with requirements regarding fire compartments, stairwell dimensions, and natural ventilation. Energy retrofitting is also critical, with federal programs' efficiency standards providing subsidies for façade insulation, triple glazing, and heating systems using renewable energy (BMWSB, 2025). This ensures that reused office buildings do not only meet safety codes but also advance national climate neutrality targets. Additionally, accessibility requirements -barrier-free entries, elevators, and adaptable apartment layouts- are rigorously enforced, reflecting Germany's long-term commitment to inclusive housing.

In France, building scale adaptation is tightly linked to performance-based standards, with a strong emphasis on carbon neutrality and energy efficiency. These frameworks demand substantial improvements in insulation, thermal bridges, and energy systems before approval is

granted, ensuring that conversions contribute to national climate targets. Conversions often require reconfiguring to provide sufficient daylight penetration and cross ventilation for apartments. Fire safety and seismic resilience are particularly critical in Paris and other dense urban contexts. At the same time, adaptive reuse is framed as a means of reducing the climate impact of construction by prioritizing the reuse of existing buildings rather than demolition and rebuilding (Grégoire, 2022; Ville de Paris, 2021).

The United Kingdom presents a distinctive case, where permitted development rights allow office-to-residential adaptive reuse without full planning permission, but this has led to controversies over housing quality. As a response, national regulations now enforce minimum space standards, natural light requirements, and fire safety provisions. According to the UK Government's research reports, only 22.1% of dwelling units created under permitted development complied with the Nationally Described Space Standards, compared to 73.4% of units delivered through full planning permission (Clifford, Canelas, Livingstone & Ferm, 2020). This finding clearly demonstrates that, in the absence of regulatory thresholds, office-to-residential conversion projects often result in significant quality and standard deficiencies compared to conventional housing developments. Because of that local councils have introduced design guidance to prevent the production of substandard units (Clifford, Canelas, Livingstone & Ferm, 2020). This highlights how, at the building scale, a regulatory gap initially created challenges, later filled by stricter codes and oversight mechanisms.

In the United States, building scale regulation is fragmented but often highly technical. New York City uses zoning overrides and building code amendments to facilitate conversions. Waivers are often granted for parking requirements and floor area restrictions, but projects must still comply with habitability standards such as minimum window-to-floor ratios, egress requirements, and HVAC upgrades. A critical determinant of feasibility lies in the age and structural design of office stock, where buildings constructed before 1961 are generally more suitable for conversion due to favourable parameters such as narrow floor plans, core placement, and window positioning, while newer post-1961 office towers often pose restrictive structural challenges (NYC DPC, 2023).

In Australia, the National Construction Code (NCC) sets the baseline requirements, demanding high performance in energy use, water efficiency, and indoor environmental quality. Conversion projects must also integrate fire safety upgrades and reconfigure deep office plans to ensure daylight and natural ventilation. Recent guidelines emphasize that the age of buildings significantly affects their conversion potential,

since older office stock often falls short of current standards for energy performance, safety, and accessibility. Residential codes require that habitable rooms provide natural light equivalent to at least 10% of the floor area, and natural ventilation equal to 5%, thresholds that many office buildings might fail to meet without major structural intervention (City of Melbourne, 2024).

Across these diverse contexts, a set of shared challenges and priorities emerges at the building scale. Structural adaptability is often the first hurdle, as many office floor plans are either too deep or too rigid to accommodate residential layouts without substantial redesign. Equally important are safety and resilience measures, where fire protection, seismic retrofitting, and egress planning form the non-negotiable basis for approvals. Beyond technical compliance, the question of habitability becomes central, where adequate daylight, natural ventilation, and minimum space standards are essential to ensuring that conversions produce homes of acceptable quality. At the same time, sustainability imperatives are increasingly integrated into building approvals, with energy retrofitting, climate adaptation, and performance ratings becoming prerequisites for public support or financial incentives.

Taken together, these factors demonstrate that while broader planning policies and neighbourhood strategies set the framework for adaptive reuse, the building scale is ultimately decisive in determining the feasibility and quality of conversion outcomes. Without resolving these building-level demands, office-to-residential projects risk producing substandard housing or failing to meet the expectations of long-term urban resilience.

DISCUSSION AND CONCLUSION

The cross-country review of office-to-residential adaptive reuse strategies reveal a wide spectrum of governance tools, ranging from regulation-heavy systems to incentive-driven models. These cross-national variations are comparatively synthesized across city-, neighbourhood-, and building-scale in Table 1, which highlights both convergences and divergences in policy approaches.

Table 1. Office-to-residential adaptive reuse strategies by country in different scales

Country	City Scale	Neighbourhood Scale	Building Scale
Germany	Promoting adaptive reuse in low-demand regions; investments in infrastructure and green corridors	Adaptive reuse projects in declining districts, combined with providing schools, childcare, and public green space	Strong fire and accessibility standards; energy efficiency goals; retrofits for energy & accessibility
France	Local urban plan revisions & design competitions; focusing on central areas with balanced density and functional diversity; pollution avoidance & safe environment.	Public functions on street levels; projects combining housing, culture, green space, and retail to sustain vibrant districts; locating projects in central, accessible areas	Performance-based standards; building carbon neutrality and energy efficiency; climate impact reduction.
United Kingdom	Liberalization of reuse by national "permitted development rights"; regional balanced distribution of projects	Concentration of projects in central locations; importance to providing public space, social infrastructure, and transportation.	Design guides on daylight, ventilation, and space-use requirements following the problems encountered.
United States	Projects in central business districts and transportation corridors using zoning reform, tax incentives, and public-private partnerships; evaluating impacts through pilot programs.	Providing live-work space balance, public transport access and neighbourhood infrastructure.	Basic standards such as for fire safety, mechanical systems, building envelope, daylighting; construction year-based assessment of buildings for suitability;
Australia	Climate-responsive urban planning; focusing on central districts; projects linked to public space and transit improvement	Projects tied to walkability, social infrastructure; Integrated with streetscape improvements, shading, green infrastructure.	Technical adaptations for fire safety, lighting and ventilation; energy efficiency-based standards; green buildings and carbon-reducing materials

The global review makes clear that office-to-residential conversion is no longer conceived simply as a technical fix to real estate imbalances, but as a multidimensional urban strategy. International cases show some recurring themes. In Germany, adaptive reuse is deployed not only to reactivate vacant buildings but also to respond to demographic shifts and population decline in certain regions, ensuring that housing interventions contribute to broader territorial balance. France, particularly Paris, illustrates how conversion is tied to neighbourhood-scale vitality, preserving street life, embedding commercial and cultural functions, and using design competitions to safeguard architectural quality. The United Kingdom demonstrates the risks of deregulation, where accelerated supply initially came at the expense of minimum habitability standards, prompting corrective measures to restore quality thresholds. The United States underscores the central role of financial incentives and local flexibility, with conversions used as vehicles for affordable housing and community benefits, though uneven results highlight the need for stronger coordination. Finally, Australia reflects how adaptive reuse can be aligned with climate-responsive urban policy, embedding performance standards for energy, daylight, and indoor quality into every project approval. These cases demonstrate that adaptive reuse is not a uniform practice but a context-sensitive process, where the balance between regulation, incentives, and design innovation determines long-term urban outcomes.

The Turkish context is marked by high housing demand, rapid urbanization, regional demographic disparities, and growing exposure to climate-related risks. These dynamics are well documented in national policy reports, which underline how rapid population growth and migration to urban areas have intensified the pressure on affordable housing supply and created uneven development patterns across regions (Ministry of Environment and Urbanization of the Republic of Turkey, 2021). At the same time, local assessments, such as the Istanbul Climate Change Action Plan, highlight the city's acute vulnerability and showing that unplanned urbanization exacerbates social inequalities and environmental risks (Istanbul Metropolitan Municipality, 2021).

A balanced scenario for Turkey must therefore adapt the most salient global lessons into a coherent national framework. At the building scale, robust minimum standards for safety, daylight, ventilation, and accessibility should be strictly enforced, preventing the pitfalls experienced in the early British approach. Energy retrofits and environmental performance measures should not be optional add-ons but central requirements, ensuring that every conversion contributes to Turkey's commitments on climate mitigation and resilience.

At the neighbourhood scale, adaptive reuse should be embedded within strategies that reinforce community life and social equity. Drawing from the French model, conversions must be accompanied by investments in ground-floor commerce, public amenities, and green infrastructure so that reused buildings do not create isolated residential enclaves but instead contribute to lively and socially complete districts. Mechanisms to secure a share of affordable housing—similar to practices in the United States—would also prevent conversions from serving only higher-income groups, thereby aligning them with broader goals of inclusivity.

At the city scale, conversions should be integrated into metropolitan planning systems. Germany's example highlights the potential of linking reuse to regional demographic policy—a lesson particularly relevant for Turkey, where some cities (e.g., Istanbul, Ankara) face pressures of overconcentration while others experience stagnation or outmigration. Conversion strategies should be aligned with transit-oriented planning, ensuring accessibility, and should help balance density across districts. Fiscal incentives such as tax relief, subsidized loans, or density bonuses can mobilize private investment, but they must remain conditional on meeting quality, social, and environmental benchmarks.

Viewed collectively, these cases demonstrate that adaptive reuse operates at the intersection of multiple priorities: housing demand, demographic restructuring, climate action, and the technical constraints of existing building stock. Heavy regulation ensures higher quality and social integration, but can be slow and resource-intensive; deregulated systems accelerate delivery but risk substandard outcomes; incentive-driven models mobilize capital but require robust oversight. Across contexts, recurring technical challenges such as deep floor plans that limit daylight and ventilation, outdated circulation systems, and the cost of energy retrofitting remain decisive at the building scale, regardless of policy design.

For Turkey, these experiences point to the need for an integrated and multi-scalar framework that aligns adaptive reuse with both housing and sustainability agendas. A balanced scenario emerges as the most viable path forward. This approach would integrate the speed and flexibility needed to address urgent housing shortages with the safeguards required to ensure long-term liveability and sustainability.

In summary, at the building scale, conversions must comply with minimum habitability standards, including daylight, ventilation, fire safety, and accessibility, while incorporating energy retrofits to align with climate commitments. At the neighbourhood scale, adaptive reuse

should be accompanied by investments in public amenities, green infrastructure, and social facilities to prevent mono-functional residential enclaves and to foster community vitality. At the city scale, conversions must be embedded in metropolitan development strategies that balance density, reinforce public transit, and integrate climate resilience objectives. Fiscal incentives can mobilize private investment, but they should be conditional on meeting strict quality and sustainability benchmarks. By adopting this balanced pathway, Turkey can transform office-to-residential conversions from a reactive housing solution into a strategic tool that advances resilience, inclusivity, and long-term sustainable development.

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MODIFIED LIFE CYCLE ASSESSMENT FRAMEWORK FOR ACOUSTIC PERFORMANCE ANALYSIS

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ABSTRACT

This study aims to provide a hybrid model for acoustic metamaterial design incorporating environmental life cycle assessment (LCA) methodology for noise reduction and environmental impact mitigation in open-plan offices with noisy acoustic environments. Acoustical monitoring and noise modeling of a perlit-based metamaterial is coupled with environmental LCA utilizing global warming potential (GWP) and particulate matters impact categories. The scope of study includes impact of material production, use, replacement and end-of-life phases. The impact categories are then monetarized according to MMG methodology to incorporate direct material and external environmental and health costs. The results displayed that the integration of two concepts may provide a comprehensive framework for material producers and designers. It was seen that there are potential overlapping impact categories which may provide a solid basis for inclusion of other impacts. In the end of the study, a solid foundation for future integration studies was laid and several research directions are introduced.

Keywords: Life Cycle Assessment, Acoustic Performance, Interior Finishing Materials, Material Characterization, Monetarization

INTRODUCTION

Over the past decade, the focus on sustainability in the built environment has shifted from building-use emissions to whole-life emissions. Recent studies displayed that the emissions originating from the use phase of the buildings may only represent 50% of all lifetime emissions (BPIE, 2022). The 'embodied' emissions that originate from the production phase is considered as a hidden source (Röck et al., 2020). The environmental impact of buildings and materials is being explored throughout their lifetime from cradle-to-grave. One prominent method for such an approach is environmental life cycle assessment (eLCA). The method is well-standardized for conduct in different scales, such as; ISO 14040 (ISO, 2006) for general LCA, EN 15978 (CEN, 2011) for building LCA and EN 15803 for the product-level LCA (CEN, 2012).

Recently, several guidelines have been published to localize the standards and lead the industry to practice. In the guide for whole life carbon assessment for the built environment (RICS, 2017), the scope and boundaries of building LCA have been properly drawn. While the minimum scope, which includes building envelope, structure, and foundation, is quite satisfactory, there is still a lack of inclusion of certain building materials that are; (i) hard to categorize or standardize, (ii) have less interest from the industry to publish environmental product declarations (EPD) (EPD Turkey, n.d.), (iii) have low quantities in buildings. This resulted in the omission of significant components such as internal finishing materials, appliances, mechanical and electrical installations (MEP), etc. (Kiamili, Hollberg, & Habert, 2020). It is claimed that the excluded components may represent a much higher ratio of all embodied emissions.

In this study, a methodological approach is proposed for considering the relationship between environmental life cycle impacts and the material selection process for interior spaces. In the literature, there are similar studies (Figure 1) but there is not one incorporating environmental and acoustical performance (Valencia-Barba, 2023). The focus is on developing interior finishing materials that satisfy both acoustic performance benchmarks and environmental expectations. The aim of the study is to explore the decision-making on material selection in the interior design of open-office spaces.

METHODOLOGY

The research methodology is based on ISO 14040 (ISO, 2006) and EN 15804 (CEN, 2012). The framework utilizes LCA to develop materials with higher acoustic performance and lower environmental impact. For

determining the acoustic performance benchmark, existing standards were utilized. Based on this benchmark, several variations of material characterization were performed, and each sample are evaluated in SimaPro LCA software. Then, a square test was conducted to see whether there is a relationship between environmental impact and acoustic performance.

The assessment of the environmental impacts of open-plan offices is a challenging topic in life cycle assessment (LCA) due to noise reduction requirements in interior spaces. This study intends to create hybrid modifications/systems/configurations of conventional LCA, using acoustical characterization data from the Image Source Model (ISM) and models of noise emissions, propagation, and exposure to incorporate the inventories and impacts of open-plan office noise. Additionally, based on the system and indicators considered LCA, the monetization of direct and external costs of low-noise office environments is included in order to extend environmental interpretation to a monetary perspective.

This study presents a hybrid model for acoustic metamaterial design incorporating LCA for noise reduction in open-plan offices with noisy acoustic environments where low-frequency sounds (HVAC, computer fans, etc.) are effective and medium- and high-frequency sounds. The hybrid model has been developed in three stages, as shown in Figure 1: in the first stage, an open-plan office noise inventory is created to use its outputs in metamaterial design in LCA. For this purpose, acoustic characterization data from the Image Source Model (ISM) and noise emission, propagation, and exposure are determined. In the second stage, four phases of LCA are implemented: (1) the process of providing raw materials, (2) the determination of metamaterial mixture ratios, dimensions, and form and the process of making/constructing the metamaterial, (3) the process of using it and (4) the process of demolition. In the last stage, the developed hybrid model is evaluated based on natural and external effects.

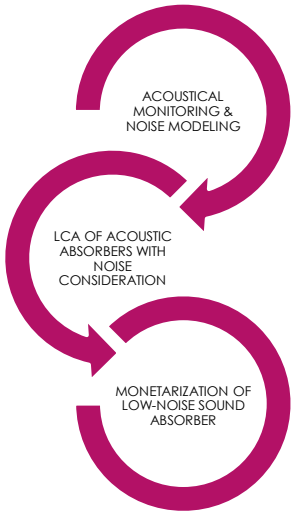


Figure 1. Steps of hybrid model development

For LCA, bio-based replacements for interior finishing materials were preferred for several reasons. Depending on the Layers of Brand framework (Brand, 1994), the interior building materials are more prone to rapid replacement (lifetime between 3-10 years) than façade materials (20 years), hence it is important to enable reuse and recyclability to decrease emissions in the end-of-life of materials (Durmisevic, 2016). When this is not considered, the amount of construction and demolition waste cannot be decreased. Moreover, emerging bio-based materials tend to display high performance, in addition to environmental impact, such as fire resistance, sound insulation, and indoor air quality. Then, existing EPD databases are utilized to pre-select low carbon bio-based materials such as perlite, hemp, and wood-based panels to develop sample materials.

The LCA study follows EN15804+A2 standard (CEN, 2012) and investigates the emissions that are emitted from the processes during the life cycle of a functional unit of 1 m^2 acoustic meta-material (AMM) that achieves an alpha value at different frequency spectrum. A cradle-to-gate (Module A to C) approach is followed, and life cycle phases are considered as given in Table 1.

Table 1. Life cycle scope

Production stage (A)			Construction stage (A)		Use (B)					End of Life (C)			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4
Raw material extraction	Transport	Manufacturing	Transport	Construction & Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction & Demolition	Transport	Waste processing	Disposal
X	X	X	?	-	X	-	-	X	-	X	X	X	X
					B6	Operational energy				included in LCA			X
					B7	Operational water				not declared			-

The life cycle inventory (LCI) is composed of two main aspects; (i) inventory of noise and (ii) inventory of environmental impacts. It is considered that the inventory and the impacts on the use phase is relevant for acoustics whereas embodied environmental impacts are considered in Module A-C.7

Inventory of noise in interior spaces: Acoustical monitoring & noise modeling

Acoustical monitoring and noise modeling constitute a multifaceted domain that encompasses the systematic analysis, measurement, and simulation of sound in various environments (ISO 1996-1:2016). These processes can be examined under several interrelated subtopics, each contributing to a holistic understanding of noise behavior and its implications. Acoustical mapping involves the spatial representation of sound pressure levels across geographical or architectural areas, enabling the identification of noise hotspots and the visualization of sound distribution patterns over time. Sound propagation monitoring focuses on tracking how sound waves travel through different media, influenced by factors such as air temperature, humidity, wind conditions, terrain variations, and structural barriers, all of which affect how sound energy attenuates or reflects across space (ANSI/ASA. ANSI S1.13-2020). Another essential aspect is sound absorption modeling, which evaluates the capacity of materials and surfaces—both natural and artificial—to absorb acoustic energy, thus playing a critical role in reducing reverberation, echo, and overall noise levels within indoor and outdoor environments (Aures, 1985). Complementing these physical aspects is the psychoacoustic response modeling of occupants, which delves into the subjective human perception of sound. This subtopic explores how individuals experience acoustic phenomena in terms of loudness,

sharpness, roughness, and annoyance, integrating behavioral and cognitive factors into the analysis (DIN 45631/A1, ECMA-418-1 and 418-2). Collectively, these subfields contribute to building a detailed inventory of noise, which serves as a foundational resource for sound management, regulatory compliance, urban planning, architectural acoustics, and the design of environments optimized for acoustic comfort and health.

Acoustical monitoring and mapping

Acoustical monitoring (mapping) in interior spaces refers to the systematic measurement and spatial visualization of sound behavior within an enclosed environment. This includes mapping sound pressure levels, reverberation, speech intelligibility, and noise distribution across a floor plan or three-dimensional model. The goal is to assess and optimize the acoustic performance of the space in terms of clarity, comfort, and compliance with noise control standards.

Open-plan offices, designed for flexibility and collaboration, often suffer from acoustic discomfort, such as excessive background noise, poor speech privacy, and distracting conversations. This impacts concentration, productivity, and employee well-being. Noise monitoring and mapping in these spaces is a critical approach to quantifying acoustic conditions, diagnosing problems, and guiding effective design or retrofitting interventions. Objectives of noise monitoring are (1) to identify noise sources and propagation paths (e.g., printers, HVAC, conversations), (2) to measure noise exposure at individual workstations and collaborative zones, (3) to map spatial distribution of noise levels and speech intelligibility, (4) to support acoustic zoning and layout decisions, (5) to evaluate effectiveness of interventions (e.g., partitions, ceiling panels, sound masking). The common noise sources, such as human speech (phones, casual chat, meetings), office equipment (printers, coffee machines), mechanical systems (HVAC, air purifiers), and External noise (street traffic, elevator shafts), have influenced the workers' performance in open-plan offices. Some tools, like ODEON and SPL mapping, can be used for the 3D simulation of open-plan acoustics and sound mapping and real-time workplace sound level tracking.

Sound Propagation Monitoring

Indoor sound propagation monitoring involves measurement, modeling, and analysis of how sound travels and behaves within enclosed environments such as offices, classrooms, theaters, auditoriums, hospitals, and residential buildings. Unlike outdoor environments, indoor spaces introduce complex reflections, reverberations, and modal behaviors due to the presence of walls, ceilings, furniture, and

architectural features. The goal is to ensure optimal acoustic performance, supporting speech clarity, music quality, noise control, and comfort.

Sound propagation monitoring in open-plan offices involves tracking and analyzing how sound waves travel and change within large, shared workspaces that lack full-height partitioning. The goal is to understand how speech, noise, and other acoustic signals behave as they reflect, diffract, and are absorbed by surfaces, furniture, and people. Unlike enclosed rooms, open offices introduce complex interactions between architecture, occupancy, and ambient conditions, making propagation monitoring critical for achieving acceptable acoustic comfort and intelligibility. Sound behavior in open-plan offices is as follows: Direct Sound travels unobstructed from source to listener; reflected sound bounces off floors, ceilings, desks, glass walls; diffused sound scatters by textured surfaces or acoustic treatments; diffracted sound bends around desks, screens, or columns and absorbed sound loss as heat when hitting carpets, panels, fabric-covered furniture. Open spaces often lack enough absorption and barriers, leading to longer propagation distances and poor speech privacy.

Sound Absorption Modeling: Metamaterial Design as Sound Absorber in Architectural Settings

Metamaterials are engineered structures with unique properties not typically found in natural materials. When applied to acoustics, acoustic metamaterials can manipulate sound waves in novel ways, making them promising candidates for sound absorption in architectural spaces such as theaters, offices, studios, or residential buildings. As key principles of acoustic metamaterials, (i) unlike traditional absorbers that require large thicknesses (e.g., porous materials or foam), metamaterials can be much thinner because they interact with sound at subwavelength scales; (ii) these materials can trap sound energy using small resonant elements (like membranes, cavities, or Helmholtz resonators); (iii) metamaterials can create frequency ranges (band gaps) where sound propagation is inhibited — ideal for selective noise control. To use of acoustic metamaterials, the main target is the frequency range since they often operate effectively within specific narrow frequency bands; tuning is required for broadband absorption. In terms of sound absorption performance, the combination of the membrane panel and the volume resonators would be the best among the types of metamaterials_ (1) Membrane-type acoustic metamaterials (MAMs), (2) Labyrinthine structures, and (3) Active metamaterials especially at low frequency range (100-500 Hz) Noise Reduction Coefficient (NRC) ~0.8.

Inventory of environmental impacts

The environmental impact indicators that were chosen in the CEN/TC 350 standards at product and building level formed the starting point for the selection of environmental indicators. In Table 2, the commonly used impact categories are listed.

Table 2. Environmental Impact Categories and Monetarization Values

Impact Category	Abbreviation	Unit	€/unit
Acidification	A	kg SO_2-eq	0.43
Eutrophication	EP	kg PO_4^{3-}-eq	20
Global warming	GWP	kg CO_2-eq	0.05
Photochemical oxidation	PO	kg NMVOC	0.48
Abiotic depletion, elements	ADE	kg Sb-eq	1.56
Abiotic depletion, fossil fuels	ADF	MJ	0
Ozone layer depletion	ODP	kg CFC11-eq	49.1

Monetarization of direct and external impacts

This study adopts the MMG method developed by OVAM (OVAM, 2017) which enables aggregating the environmental impact factors by means of monetary valuation. The environmental indicators were multiplied by a specific monetarization factor (i.e. €/kgCO_2-eq for global warming potential) for different regions. The resulting monetary value (€/m^2) expresses the environmental damage that is not reflected in product price but reflected to the society [x]. Depending on the previous studies, it was seen that Global Warming and Eutrophication impact categories constitutes between 90 and 95% of the total amount. Monetarization is considered as a means of combining several environmental indicators under a single score. It ensures that all indicators are taken into account and omission of any critical impact is avoided while the perspective of the local context is also included by using a regional environmental cost for each indicator.

The environmental assessment includes several impact categories provided in Table 2. To simplify the overall results into a single score, a monetarization approach is followed based on the MMG framework (OVAM, 2017). Besides the external impacts such as the cost related to environmental damage, the direct cost of the material is retrieved from the market.

RESULTS & DISCUSSION

In the end of first stage, a modified life cycle inventory (LCI) was developed which provides a brief list of acoustic and environmental parameters. A preliminary assessment was conducted between different sample variations based on the quantity of material used to maintain the acoustic benchmarks. Then in the second stage, life cycle impact assessment (LCIA) results were reported at the midpoint level (such as global warming potential, etc.) as required by EN 15804+A2. It is expected that, the environmental impact should decrease while acoustic performance increase, as both aspects benefit from cavities (less material) and bio-based elements (low embodied carbon intensity & more sound absorption).

This study integrates environmental and acoustic parameters under a single framework and apply it to interior finishing materials which is a less-explored domain under LCA literature. As the environmental expectations are rising from all sectors, the framework may be beneficial for material producers, interior designers and developers.

In case of Türkiye, this framework may have a direct relationship with the upcoming carbon border adjustment mechanism (CBAM) (EU, 2023), which introduces additional tax costs for materials that do not meet the required environmental standards in the EU. The integration of several characteristics of a meta-material can help material producers and designers in their decision-making processes.

CONCLUSION

Multi-disciplinary studies are encouraged by all initiatives related to the improvement of the built environment and interior spaces. This study provided a solid foundation for integration of different characteristics of open-plan office spaces. There are several limitations to explore such as the differences in terminology, impact categories, functional units, etc. On the other hand, the future research seems promising as new concepts and solutions may emerge from integration of other disciplines such as health, lighting and comfort.

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AN INVESTIGATION INTO IDENTIFYING GLARE ISSUES IN MUSEUM ARCHITECTURE

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ABSTRACT

This study examines glare problems frequently encountered in museums and evaluates studies in the literature that have addressed these issues. Lighting has an important role not only in ensuring the visibility of artifacts but also in protecting them, improving display methods, enhancing the spatial atmosphere, and enhancing the visitor experience. However, insufficient usage of daylight and planning of artificial lighting can negatively impact visual comfort, making it difficult to perceive artifacts. Therefore, a literature review was conducted to examine the causes of glare in museums and the methods used to analyze it. The findings reveal that glare can arise from both natural and artificial lighting conditions, as well as the material characteristics of artifacts and surfaces. The Daylight Glare Probability (DGP) method is used in the analysis of glare from natural light. The Unified Glare Rating (UGR) method is conducted to assess glare from artificial lighting; both methods allow for a numerical classification of visual comfort within a space. In addition, High Dynamic Range and Imaging Luminance Measuring Devices methods are available in the literature as tools for detecting glare from both types of lighting. Transferring the digital data obtained from these methods to simulation programs allows for the development of lighting setups for different environmental scenarios and the digital testing of proposed solutions. Consequently, the study provides an approach to examining the methods used to detect glare in museum lighting.

Keywords: Museum Lighting, Glare, Visual Comfort, Daylight Glare Probability (DGP), Unified Glare Rating (UGR)

INTRODUCTION

The main aim of the lighting control in museum buildings is to ensure the visibility of the exhibition issues, also playing a significant role in protecting them from light-induced disturbance, improving the spatial atmosphere, and enhancing the visitor experience. Lighting design keeps the objects from damage, enriching the exhibition experience with aesthetic and comfortable environments. However, insufficient amount and intensity of daylight and improper settlement of artificial lighting can create glare problems within the space, negatively impacting both visual comfort and security of the exhibition objects (Zhang et al., 2018).

Glare occurs when light from a light source either directly contacts the eye or reflects from the surfaces, creating an uncomfortable effect on the field of view. Glare problem not only negatively impacts visual perception but can also cause physical and mental discomfort in visitors, such as eyestrain, headaches, and loss of concentration (Boyce, P. R. 2014). Therefore, accurately detecting glare in museum lighting is essential for both preserving artifacts and enhancing the visitor experience. The increase in the number of museums and the increasing density of visitors in recent years has led to the increased importance of user-centered design decisions. Therefore, the balanced integration of natural and artificial lighting and the reliable identification of glare-causing factors are among the priorities of contemporary museum design. Analyzing glare problems not only contributes to the assessment of current spatial conditions but also to the development of qualified lighting solutions for the future.

In this context, the study, titled "An Investigation Into Identifying Glare Issues in Museum Architecture" is based on a comprehensive literature review compiling existing research on glare problems encountered in museum lighting and methods for identifying these problems. The literature review is based on international databases such as ScienceDirect, Google Scholar, and Scopus. Approximately five articles were reviewed during the research process, focusing on visual comfort issues and glare problems caused by lighting conditions in museums and exhibition spaces. The sources were categorized by keywords and examined under subheadings.

With the increasing use of natural lighting in museums today, a growing emphasis is being placed on studies that combine both natural and artificial lighting. The study examines the interaction between temporal variations in daylight and the intensity and non-uniform distribution of

artificial lighting, leading to glare problems, and explores holistic analyses of these problems using indices.

2. LITERATURE REVIEW

2.1. Museum Lighting and Architectural Priorities

Lighting design in museum buildings is important to control the exhibits from unwanted lighting levels and ensure visitors understand the concept of the exhibition. The percentage of museums in Turkey increased by 7.1% compared to the previous year, reaching 606, according to 2023 data. The total number of visitors welcomed during the year increased by 6.2%, reaching 55,752,208. (TÜİK, 2023) These data present the trend of public interest in cultural and historical heritage. The increase in visits to museums can be attributed to the increasing number of museums and to the different visual experiences offered to visitors, highlighting the importance of architectural design decisions, including lighting choices, affecting user experience. Proper lighting design ensures the preservation of artifacts while enhancing the atmosphere within the space, providing visitors with a high-quality experience.

In other words, the purpose of lighting is not only to meet basic visual needs; it is also to highlight the identity of the building and enhance the exhibition experience. There are two basic strategies for lighting in museums: natural and artificial lighting. Artificial lighting systems offer flexible solutions by controlling the intensity, angle of incidence, and color of light, providing visitors with a quality experience.

However, selecting inappropriate artificial lighting can create glare problems and make it difficult for visitors to perceive the works. Also, integration of only artificial lighting can deteriorate the natural ambiance of the space and create a monotonous atmosphere. Because of this, approaches accepting that integrating controlled natural lighting with artificial lighting create more qualified solutions come forward. Natural lighting is a beneficial approach to lighting design because it provides energy efficiency, adds dynamism to spaces, and supports the human body's circadian rhythm. However, disadvantages can be classified as: the difficulty in controlling daytime variability; the risk of irreversible damage to artifacts from solar irradiation (ultraviolet and infrared rays); and the glare problem, particularly on glass display cases and surfaces. If artifacts and surfaces within a museum are composed of light-resistant materials such as stone, ceramics, etc., natural light can be admitted in a controlled manner. However, if light-sensitive materials such as paper, wood, leather, etc. are present, utilizing natural light is inefficient. Considering these disadvantages, appropriate and controlled amounts of natural light

should be introduced to the space to reduce the risk of glare on artifacts and surfaces. Solar irradiation varies during the day. Therefore, varying the intensity of the artificial lighting depending on the time of day is important. Using diffused light instead of direct sunlight and opting for passive lighting systems facilitates the efficient use of natural light. Eventually, integrating natural and artificial lighting in a mutually supportive way protects the artifacts and improves visitors' visual comfort. However, for the success of this integration, the glare problem must be accurately diagnosed. Identifying the glare source is the first step toward a solution. Daylight Glare Probability (DGP) and Unified Glare Rating (UGR) methods allow glare to be measured numerically. At the same time, High Dynamic Range (HDR) and Imaging Luminance Measuring Devices (ILMD) techniques contribute to the detailed and simulated measurements. In this context, the primary objective of this study is to contribute to the use of accurate diagnostic methods in identifying glare problems and the development of solutions accordingly.

2.2. Glare Problems in Museums

Glare is one of the most significant visual problems encountered in museum lighting. It is a lighting problem that causes discomfort to the eye, whether it comes directly from the light source or is reflected from surfaces. Discomfort glare causes visual discomfort and distraction, while disability glare reduces contrast and makes it difficult to see details.

Glare problems, particularly on glass display cases, glossy surfaces, oil paintings, and photographic prints, negatively impact visitors' perception of the exhibited works (Dang et al., 2023). Inadequate lighting, causing glare encountered along the exhibition route, affects visual perception and negatively impacts the visitor experience by causing physical discomfort such as eye strain, headaches, and mental issues such as distraction and difficulty concentrating (Boyce, P. R. 2014). Therefore, glare control in museum lighting is a priority for both visual comfort and observing the exhibited objects clearly. Glare problems vary depending on their origins, caused by both natural and artificial lighting. Mostly glare from natural lighting occurs due to uncontrolled sunlight entering the exhibition spaces. Changing light angles acting on artifacts, particularly during the day, and the direct impact of light entering through glass facades on the visual field can cause visual discomfort. Significant differences between the optimal illumination level for the eye and the actual illumination level within the space can create discomfort for visitors and contribute to glare problems related to natural light.

Improperly planned artificial lighting, in particular, negatively impacts visitors' visual comfort and reduces the quality of perception along the exhibition route. Placing the light source directly, without any fixtures, diffusers, or shading elements, results in uneven light distribution and increases contrast by concentrating the light around the source. Furthermore, technical errors such as incorrect fixture and light color selection, and improper orientation angles make it difficult for visitors to perceive the works and can lead to discomfort such as eye strain, headaches, and distraction.

Glare encountered in museums is not solely dependent on lighting sources; the function of the museum and the characteristics of the works displayed within also directly affect glare. For example, in painting and photography exhibitions, glass frames, glossy varnished oil paintings, and photographic prints pose a risk due to reflection. Therefore, the Canadian Conservation Institute (1992) recommends that the light beam come at an angle of 60° to the horizontal. This creates a homogeneous image, improving the clarity of the artwork and reducing glare, especially in works protected by glass frames.(Figure 1a). An incident angle lower than 30° can create shadows on the artwork. The lines and paint marks may not be clearly observed (Figure 1b). Wide angles can also cause glare problems if the angle of incidence is not proper. When light interacts at angles higher than 30°, shadows from visitors and surrounding objects fall on the artwork, negatively impacting its visibility (Figure 1c) The study by Wahab & Zuhardi (2013) highlighted similar risks. Cerpentier et al. (2023) highlighted the benefit of adaptation of the lighting to the size and frame of the artwork in museums or exhibition halls, increasing visitor visual comfort. When this is not achieved, the contrast between the artifact and the background creates discomfort.



Figure 1a.



Figure 1b.

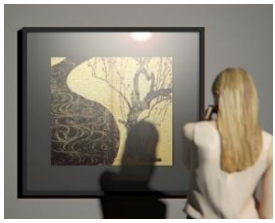
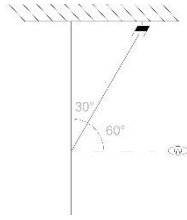


Figure 1c.



Drawing 1.

Figure 1. Lighting angle used for Paintings in museum exhibitions. From Light for pictures: The museum angle, by ERCO, n.d., ERCO

(https://www.erco.com/en/designing-with-light/mediaassetpool/light-studies/light-for-pictures- museum-angle-6475)

Similar glare problems often occur in sculpture and object exhibitions. Highly reflective surfaces such as polished marble, metal, glass, or lacquer used in such exhibitions directly reflect light and create a glare effect known as "veiling reflection". The light from the source diffuses across the surface, creating a translucent layer on it, reducing contrast, and obscuring the work's characteristics. Technically speaking, the reduced contrast created by the surface's reflective properties and the reflected light results in veiling reflection (Wahab & Zuhardi, 2013). The published technical guide "ANSI/IES RP-30-17: Recommended Practice for Museum Lighting" also refers to the issue of veiling reflection and highlights the potential glare risk associated with objects with highly reflective surfaces.

Glare problems, which arise from both natural and artificial light sources, often arise from technical errors in equipment selection and placement, as well as insufficient consideration of spatial conditions. Therefore, lighting designs that consider the angle of incidence of light and the surface characteristics of the exhibited artifacts yield more successful results.

2.3. Methods Used to Detect Glare Problems

Accurately identifying the factors that cause glare problems is the most fundamental step in the solution process. This identification process, when performed using the same method across all venue conditions, cannot yield reliable results. This is because the prevailing conditions in exhibition spaces can vary. Therefore, the preferred methods depend on the light source causing the glare and the characteristics of the exhibited works. While glare problems caused by natural light are generally assessed through changes in the angle of incidence of sunlight, glare caused by artificial lighting is associated with decisions made during the design and implementation processes.

The methods used to detect glare problems vary depending on the variety of contributing factors. While qualitative measurement methods, consisting of the analysis of visitors' sensations to lighting conditions, are preferred for detecting glare from natural light, quantitative studies called Daylight Glare Probability (DGP) are also possible. In artificial lighting, the Unified Glare Rating (UGR) method is an option for the measurement of contrast within a space. These methods become more reliable when supported by data obtained using High Dynamic Range (HDR) and Imaging Luminance Measuring Device (ILMD) techniques.

Transferring measurement results to simulation programs is also important for testing different conditions. The surface and material properties of the exhibited works also play a role in identifying glare problems. In an experimental study conducted by Sagawa et al. (2022), museum conditions were simulated by setting up a test room measuring 2900 mm wide, 3000 mm deep, and 2400 mm high. Indoor walls were painted white. In the experiments conducted on paintings with various surface properties, nine different painting surfaces were prepared by testing three Munsell shades (black, gray, and white) and three different varnish applications (unvarnished, single-coat, and double-coat). Munsell is a color system that quantitatively reveals the lightness and darkness of colors. The average reflectance values of the paintings prepared for the experiment were measured at nine points using a spectrophotometer, and the average gloss values were determined using a gloss meter. (Sagawa et al. 2022) The study concluded that lightening the surface color tone increases the glare effect, while unvarnished surfaces significantly prevent glare formation. A review of the literature reveals that luminance measurements are prominent for two-dimensional, highly reflective works. At the same time, simulation methods, which can also analyze formal features for three-dimensional objects, are appropriate. In addition to quantitative measurement methods,

qualitative assessments of visitors' glare perception are also available in the literature as a measurement technique.

2.3.1. Glare Detection Methods on Natural Lighting

The use of the complementary effect between qualitative and quantitative methods may support the detection of the glare from natural light. Qualitative approaches involve experiential analyses such as identifying low- and high-contrast areas within a space and observing visitors' responses to illuminance levels. Daylight Glare Probability (DGP), a quantitative method, allows for the numerical expression of the visual discomfort caused by glare on the human eye (Equation 1).

$$DGP = 5.87x10^{-5}E_v + 0.0918log\left(1 + \sum_i \frac{L_{si}^2\,\omega_{si}}{E_v^{1.87}P_i^2}\right) + 0.16$$

Equation 1. (Chien, S. & Ichinose, M. (2020). Determination of the simplified daylight glare probability (DGPs) criteria for daylit office spaces in Thailand. *Buldings, 10(10), 180.)*

The Daylight Glare Probability (DGP) method, developed by Wienold and Christoffersen (2006), considers the perceived illuminance level and the luminance value, solid angle, and Guth position index of the light source. This consideration allows light source intensity and position angle to be evaluated in terms of the current conditions of the space, and experimental studies have demonstrated a strong correlation between Daylight Glare Probability (DGP) values and user response. (Wienold & Christoffersen, 2005)

2.3.2. Glare Detection Methods on Artificial Lighting

Various measurement methods have been developed in the literature to determine the level of glare from artificial lighting quantitatively. The most common of these is the Unified Glare Rating (UGR). The UGR formula produces a glare rating, which is a psychological parameter intended to measure any adverse subjective discomfort response to a visual environment containing electric light sources (does not include daylight from windows or skylights) (CIE, 1995). The Unified Glare Rating (UGR) was developed by CIE Technical Committee 3-13 and was first defined in the report CIE 117-1995: Discomfort Glare in Interior Lighting (CIE, 1995). Subsequently, CIE 190:2010: Calculation and Presentation of Unified Glare Rating Tables for Indoor Lighting Luminaires was published to facilitate the creation of tables by luminaire manufacturers and lighting designers, and this method has been adopted as a standard in many regions (CIE, 2010; Abbasinejad, R., & Kacprzak, D. 2022).

UGR measures the discomfort glare effect caused by lighting with a special formula prepared by taking into account the position of the light sources, the brightness level, and the contrast values created by the surroundings (Equation 2).

$$UGR = 8 \cdot \lg \left[\frac{0{,}25}{L_b} \cdot \sum \frac{L_s^2 \cdot \Omega}{P^2} \right]$$

Equation 2. (ERCO. (n.d.). UGR method. In Lighting knowledge: Lighting design. Retrieved from: https://www.erco.com/en/designing-with-light/lighting-knowledge/lighting-design/ugr-method-7488/)

The equation of Unified Glare Rating includes variables named: background illuminance (Lb), determining the eye's visual adaptation; the average luminance of the luminaires (Ls); Ω, referring to the angle formed by the luminaire surface; and the Guth index (ρ), measuring the position of the luminaire due to the observer's viewing direction. The UGR value, calculated by formulating these parameters, quantifies the level of discomfort that occupants may experience within a space.

Due to the Hopkinson scale used to interpret UGR, it is stated that if UGR < 13, glare is either not perceived or is negligible, while if UGR > 19, visual comfort limits are exceeded (Chen, 2025). A value of 19 is considered the upper acceptable limit on the Hopkinson rating scale.

2.3.3. Imaging and Measurement Techniques

High Dynamic Range (HDR) imaging, a method used in glare analysis, is based on the principle of combining low dynamic range (LDR) images taken at different exposure values. LDR images have limited dynamic range because they can detect little difference between the lowest and highest light levels. Therefore, they can only capture either dark or bright areas; details are lost in dark areas, while highlights exhibit a glare effect. High Dynamic Range, on the other hand, achieves a wide brightness range by combining LDR images, encompassing both the darkest and brightest areas, and reveals the brightness distribution within a room with high accuracy and uniformity.

A number of studies in the literature have evaluated the potential, limitations, and applicability of the High Dynamic Range (HDR) imaging technique as a luminance mapping tool. Early work by Inanici (2006) demonstrated that combining photographs taken at different exposure values using Photosphere software produced luminance data with reasonable accuracy and repeatability when compared to physical

measurements. Later studies expanded this scope: Suk and Schiler (2012) integrated HDR images with Evalglare software for Daylight Glare Probability (DGP) analysis and highlighted discrepancies compared with Radiance-based simulations; Sawicki, Wolska, and Porsch (2019) showed that HDR, when combined with Imaging Luminance Measuring Devices (ILMD), improves the reliability of glare assessment; while Bishop and Chase (2023) discussed practical challenges of field applications. These findings suggest that HDR imaging not only enables precise mapping of spatial luminance distribution but also continues to evolve as a robust tool in glare analysis through integration with advanced software and complementary measurement techniques.

Another method is measurements using an Imaging Luminance Measuring Device (ILMD). These devices analyze ambient light distribution at the pixel level and record the corresponding numerical values using a camera-based system. The CIE 244:2021 report describes the elements, functions, and characterization methods of these devices, and also provides calibration processes and technical guidelines for their use (CIE, 2021). While traditional spot measurements only obtain data from a single point, Imaging Luminance Measuring Device (ILMD) tools allow for simultaneous measurement of the entire visual field, allowing for the generation of detailed luminance maps. Luminance maps are a visual representation of the luminance values measured at each point on the surface. These maps allow for comparison of luminance levels in different areas, thereby analyzing current conditions and contributing to improved visual comfort.

Sawicki, Wolska, and Porsch (2019) conducted a study on the contributions of ILMD to glare assessments. In this study, comparative measurements were made by varying the lighting conditions, light source positions, and sizes to test the reliability of the methods used in calculating the unified glare rating (UGR). In this context, ILMD-based measurements play a role not only in identifying glare problems but also in obtaining parameters such as light source luminance (L), the angle subtended by the luminaire surface (Ω), the Guth index (ρ), and the background illuminance (Lb) included in the UGR formula.

In conclusion, the HDR imaging technique and ILMD measurements used to detect glare problems allow for a comprehensive assessment of the lighting conditions of a space. The HDR technique combines images taken at different exposure values to obtain a wide luminance range, while ILMD devices create luminance maps by performing detailed measurements at the pixel level. A common feature of both methods is their contribution to the detection of glare problems by converting lighting conditions into numerical data. There are some limitations to the

methods. While the HDR technique is easy to adapt to fieldwork, obtaining accurate results requires technical expertise, such as selecting the appropriate equipment and exposure values. ILMD devices have high resolution and accuracy. However, their high cost is an important obstacle to the adoption of lighting imaging (Bishop & Chase, 2023). The preferred method for glare analysis is up to the scope of the study, the targeted accuracy level, available budget, and equipment resources.

2.3.4. Simulation Programs

The use of simulation tools is becoming increasingly important in lighting design or in improving existing systems, to ensure the appropriate display of artifacts and provide visitors with a comfortable visual experience.

The lighting simulation process consists of rendering method, computational algorithms, "input-output" categories. "Rendering methods" support visualizing light, while "computational algorithms" are concerned with the numerical calculation of lighting behavior. The "input and output" category encompass the definition of input of data as light sources, material properties, geometry, climate, and the resulting numerical or visual outputs. These simulation programs employ two distinct visualization approaches. Photo-realistic visualization is used for architectural presentations, focusing on visual aesthetics. However, it does not reveal the physical properties of light. Inversely, physics-based simulation uses numerical data for the calculation and simulation of light behavior in a realistic way (Davoodi, Johansson, & Enger, 2014).

Various simulation software programs have been developed with technological advancements. These programs allow researchers to select the most suitable program for their research purposes from among this variety. For example, DIALux and Relux are often preferred for quickly generating visuals for lighting projects. They offer practical solutions with energy analyses and basic UGR calculations. Radiance-based software is increasingly prominent in academic studies because it provides highly accurate simulations using numerical data. Integrated building simulation programs such as DesignBuilder allow researchers to evaluate daylight, energy consumption, and visual comfort on the same platform (DesignBuilder, n.d.). This diversity offers researchers the opportunity to compare different scenarios, corroborate analysis results with other software, and identify which research areas each program is most effective in.

Simulation programs have the advantage of testing different lighting scenarios before application by modeling the effects of natural and

artificial light within a space. They also contribute to improving visual comfort by calculating glare indices such as Unified Glare Rating (UGR) and Daylight Glare Probability (DGP) (Davoodi, Johansson, & Enger, 2014). In recent years, the High Dynamic Range (HDR) imaging technique and Evalglare software have been widely used in DGP calculations. In the HDR technique, wide brightness ranges are captured by combining photographs taken at different exposure values. When these images are imported into Evalglare, the luminance value, location, and solid angle magnitude of each pixel are calculated to identify potential glare sources.(Suk & Schiler, 2012). In a study by Suk and Schiler (2012), data obtained from HDR images were compared with Radiance-based simulation outputs, and discrepancies were identified between the methods. This may be due to both the HDR imaging technique's inability to accurately record high luminance values and the Evalglare software's underestimation of vertical illuminance values when processing this data. It is emphasized that Radiance-based simulations provide more consistent outputs; therefore, integrating illuminance values measured with luxmeters at eye level into the simulation software in DGP analyses would increase accuracy (Suk & Schiler, 2012).

Consequently, using the advantages of simulation programs and developing a combined approach will contribute to determining glare problems in museum lighting. Testing proposed solutions before implementation allows for the early identification of problems, providing more realistic decisions regarding time, visual comfort, and cost.

Table 1. Comparison of Simulation Programs

Program	Properties	Advantages	Disadvantages	Area of Usage
DIALux & Relux	-Fast visualization -Basic UGR and energy analyses	-User-friendly -Practical solutions	-Limited physical accuracy -Insufficient for in-depth analyses	-Architectural lighting projects -Early design stages
Radiance Based Softwares	-Physically-based simulation -High accuracy -DGP calculations	-High academic reliability -Detailed analysis	-More complex to use -Longer computation time	-Academic research -Detailed lighting analysis
DesignBuilder	-Integrated building simulation: daylight, energy, comfort	-Multi-parameter analysis -Combines energy, lighting,	-High license cost -Requires technical expertise	-Sustainability studies -Energy efficiency analysis

		and comfort		
HDR & Evalglare	-Glare analysis from HDR images -Pixel-based calculations	-Use of real environment images -Visual-oriented analysis	-Inconsistencies in some measurements	-Glare detection studies -Visual comfort assessment

CONCLUSION

This study examined glare problems that occur frequently in museums and techniques for their detection. According to the findings, glare prevention depends on the selection of appropriate analysis methods, architectural design, and lighting decisions. Daylight Glare Probability (DGP) and Unified Glare Rating (UGR) methods provide a quantitative representation of glare caused by different light sources. At the same time, High Dynamic Range (HDR) and Imaging Luminance Measuring Device (ILMD) techniques support this data, increasing the reliability of the analyses. However, as noted in the literature, inconsistencies can occur when transferring data obtained from these methods to simulation programs. The main reasons for this are that HDR images do not always accurately record high luminance values, and that software like Evalglare underestimates the vertical illuminance parameter (Suk & Schiler, 2012). Furthermore, difficulties in accurately transferring the colors of the space, the properties of the materials used, the reflectivity of the surfaces, and the positions of the displayed objects to the software can lead to differences between real-world conditions and the simulation environment. Furthermore, the variability of daylight due to season, time, and weather conditions limits the real-world experience of the results obtained. At this point, developing a hybrid approach is important because it allows for comparison between software. Using different detection methods together, taking into account object types, material properties, and spatial conditions, will yield more reliable results. This allows for the testing of different scenarios using simulation programs and the evaluation of proposed solutions before implementation. Potential risks and technical errors can be identified, resulting in savings in time, effort, and cost. In conclusion, evaluating glare problems in museum lighting from a holistic perspective has significant implications for both improving visual comfort and improving the clarity of exhibited works.

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REVIEW OF THE USE OF PHOTOBIOREACTOR TECHNOLOGY IN SUSTAINABLE ARCHITECTURE

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ABSTRACT

The rate of increase in energy consumption, carbon emissions, and resource usage has brought the integration of innovative approaches and strategies, such as biological systems, into architecture to the forefront. Photobioreactors (PBR) are living technologies that utilize the photosynthetic processes of microalgae to convert carbon dioxide, produce oxygen, and simultaneously generate biomass. These features make them systems that not only provide environmental benefits but also aesthetic and functional contributions. Photobioreactors, on the façade, roof, or designed as separate modules, provide benefits such as daylight, shading, and improved air quality control. Furthermore, they offer opportunities for circular resource utilization, such as wastewater treatment and reuse, and the utilization of biomass for energy production or various industrial products. Therefore, these systems, as a tool of sustainable architecture, can be considered holistic systems providing not only energy efficiency but also supporting and adapting to ecological cycles. They present a hybrid solution that contributes to the aesthetic, functional, and social dimensions of architecture. The literature contains studies exploring the advantages of microalgae in many different areas. This research aims to evaluate studies in the literature that utilize photobioreactor technology using different methods and, based on various application examples, to reveal the advantages and limitations of this technology. The study evaluates current design strategies and research areas for photobioreactors. This study brings together existing knowledge to provide a foundational framework for future research and highlights the potential of PBR technology in the construction sector. The review concludes that interdisciplinary collaboration, pilot-scale testing processes, studies, and applications show that with the practical integration of this technology, its widespread adoption in buildings has high potential to increase in the future.

Keywords: Photobioreactor (PBR), Microalgae, Sustainable Architecture, Energy Efficiency, Indoor Air Quality

INTRODUCTION

Today, rapidly increasing urbanization, growing population density, and rising energy demand have made the concept of sustainability a priority in the architectural discipline. Fossil fuel resources are the main cause of the escalation in carbon emissions, leading to climate change and the depletion of water resources. Therefore, the construction sector has a significant role in designing aesthetic and functional buildings and settlements, and in providing environmental sustainability. The operations of buildings account for 30% of global final energy consumption and 26% of global energy-related emissions (8% from direct emissions within buildings and 18% from indirect emissions related to electricity and heat production used in buildings) (IEA, 2023).This reality necessitates architects to consider not only visual and functional aspects but also environmental impacts in their design processes.

Sustainable architecture has goals such as increasing energy efficiency, using renewable resources, selecting materials compatible with ecological cycles, and creating healthy living spaces. In recent years, nature-integrated solutions, biomimicry, and the integration of renewable energy systems into buildings have come to the forefront. Photobioreactor (PBR) technology comes forward as a system offering innovative and multifaceted contributions to sustainable architecture. Photobioreactors are systems that allow microalgae to grow in a controlled environment. Microalgae absorb atmospheric CO_2 through photosynthesis, produce oxygen, and accumulate organic matter called biomass. This biomass can be used in various fields, such as biofuels, food additives, cosmetics, and pharmaceutical products. Microalgae also perform a natural purification process by consuming nitrogen, phosphorus, and other nutrients in wastewater. In this respect, FBR systems offer multifaceted benefits in terms of energy, water management, and environmental sustainability (Chisti, 2007; Quintana et al., 2011).

In architecture, photobioreactors are mostly integrated as transparent or semi-transparent building envelope components or separate standing modules. These systems control daylight, provide shading in interior spaces, and provide energy efficiency. Furthermore, improving indoor air quality through microalgae allows occupants to enjoy a healthier environment. Photobioreactor systems contribute to architectural aesthetics in terms of sustainability and ecological awareness, giving buildings an innovative identity.

The BIQ House project, built in Hamburg, Germany, is the first comprehensive application of photobioreactors in architecture. Microalgae panels integrated into the building's façade served shading and energy production functions. The resulting biomass met the energy requirements of the building. Also, pilot studies conducted in Singapore and South Korea have demonstrated the effectiveness of microalgae-based systems in terms of both energy efficiency and wastewater management. For example, Choe & Han (2022) showed via mock-up cultivation settings in South Korea that façade-integrated microalgae panels improve shading, reduce internal heat gain, and enhance spatial sustainability. Woo, Lee & Suk Lee (2022) modeled photobioreactor-integrated vertical louvers and found potential for reduced cooling loads while maintaining daylighting. Additionally, Park et al. (2019) implemented a pilot-scale cultivation using exhaust gas in Korea, showing that microalgae systems can produce biomass while mitigating emissions and improving environmental performance. These projects demonstrate the applicability of photobioreactors in architecture and their contribution to sustainable design.

Integration of photobioreactor technology into architecture in Türkiye is still at an early stage. However, considering the high isolation potential, rising energy costs, and water management challenges, PBR systems offer significant opportunities for the future. Photobioreactor applications in university campuses, libraries, office buildings, and public spaces are crucial for improving environmental performance and optimizing energy and water consumption. Besides the benefits such as reduction of energy consumption and carbon emissions, management of wastewater, improving indoor air quality, and creation of aesthetic buildings, limitations classified as high initial investment costs, maintenance requirements, and user awareness are disadvantages of this system. This study aims to evaluate current theoretical and practical studies aimed at improving the performance of photobioreactor systems in buildings, improving climatic conditions, improving indoor air quality, and increasing energy efficiency, based on existing literature and sample applications.

Photobioreactor systems offer innovative solutions that support ecological balance, increase energy efficiency, and improve user health in the cities of the future. In this context, the integration of microalgae into architecture creates a significant opportunity for the broader implementation of sustainable design approaches.

The study aims to evaluate how the ecological contributions of microalgae, classified as CO2 absorption, oxygen production, and biomass formation through their photosynthesis, can support building

energy efficiency and indoor air quality enhancement. The study is based on current literature covering the typologies of microalgae biotechnology and PBR systems, and theoretical, experimental, and simulation-based research obtained from academic sources such as ScienceDirect, Elsevier, and Frontiers was examined. In this context, the integration of PBRs into on-building facades, window systems, and interior applications was evaluated; their contributions to energy consumption, shading effect, and indoor air quality were discussed. As a method, applications at different scales (facade, window, interior) were analyzed through a literature review, and the CO_2 reduction rates, biomass production data, and energy simulation results obtained in experimental studies were comparatively examined. In the final stage, the findings were synthesized, and the ecological, energy, and indoor air quality contributions of PBR integration in architecture were presented within a holistic framework.

2.Microalgae and Photobioreactor

Like other photosynthetic organisms, microalgae convert solar energy into chemical energy. Algae are single-celled or multicellular microscopic organisms that constitute the primary producers of aquatic ecosystems. More than forty thousand species of microalgae have been identified worldwide, and most of them are highly nutritious. The large surface area of microalgae enables faster nutrient uptake and accelerates cell growth (Figure 1a) (Okomoda et al., 2021).

Many microalgae species are used in biofuel production due to their high lipid yields. Compared to other biofuels, microalgae-derived biofuels offer advantages such as non-seasonality, ease of large-scale biomass production, biological degradability, and renewability (Okomoda et al., 2021).

Algae used as biomass continue to grow through photosynthesis while simultaneously releasing the oxygen required for the respiration of living organisms into the atmosphere. The most critical process here is photosynthesis because the amount of carbon released during bioenergy production from biomass equals the amount of carbon absorbed by microalgae during their growth. As a result, atmospheric CO_2 levels and the greenhouse effect do not increase. Additionally, one-third of the world's plant biomass consists of microalgae. Therefore, the active use of algae in bioenergy production is of great importance (Kükdamar, 2017).



Figure 1a.

There are both open and closed culture environments for microalgae growth. Photobioreactors (PBRs) are closed systems that allow microalgae to grow in a controlled environment (Figure 1b). These systems allow microalgae to grow efficiently by controlling parameters such as light, carbon dioxide, temperature, and nutrients. PBRs provide higher yields and biomass quality compared to open pond types.



Figure 1b.

Photobioreactors are applied in buildings, in transparent or semi-transparent encapsulations integrated into the building envelope (Figure 1c). These systems filter sunlight, providing shading indoors and also contributing to cooling energy savings. Furthermore, improving indoor air quality through microalgae allows occupants to enjoy a healthier environment. Photobioreactor systems also contribute to architectural aesthetics in terms of sustainability and ecological awareness, giving buildings an innovative identity (Reynolds, 2014).



Figure 1c.

2.1. Literature Review :

Algae have a role in providing the carbon dioxide and oxygen balance through photosynthesis and also contribute to energy production. Therefore, the integration of algae with photobioreactor systems in buildings with high energy consumption and their applicability in urban areas have been extensively studied in the literature. Chew et.al. (2021) argue that the power needed to improve cities and achieve energy neutrality lies in the use of algae. They state that all countries should research and utilize algae species and technologies to identify the challenges of using algae and improve the quality of life of cities and people.

Kim (2013) investigated the performance in the carbon dioxide, oxygen, and renewable energy production of photobioreactor systems through experiments and simulations with the variation of algae species, climate characteristics, and façade orientations. The study concluded that the system is adaptable and customizable to different parameters. In their study, Haghir, Tashakori, Rezazadeh, and Ahmadi (2020) argue that equipping urban streets with microalgae bioreactor systems could be a solution for both visual appeal and for reducing urban air pollution. This study proposes implementing this system on the walls of Enghelab Street in Iran, and a prototype microalgae bioreactor is installed on a wall on that street for measurement. The study observed that the installed bioreactor absorbed an average of 22.55% of carbon dioxide per day over six days, which is considered a good indicator for reducing urban air pollution.

Microalgae absorb CO_2 through photosynthesis and produce oxygen, and this process can be used to improve indoor air quality.

Martokusumo, Koerniawan, Poerbo, Ardıani, and Krisanti (2017) aimed to reduce greenhouse gas emissions, energy consumption, and solar glare by using algae in buildings, which is one of the primary causes of energy consumption. In this context, in the new project of the ITB Innovation Park (IIP), the building's energy consumption and environmental impacts are being examined through modeling and a comprehensive literature review. A comparison of three types of building facades revealed that, the photobioreactor system did not significantly reduce the cooling load, but it positively influenced the building's indoor air quality through increased oxygen production.

Han et al. (2023) investigated the CO_2 absorption capacity of the microalgae species Spirulina maxima under conditions limited in $NaHCO_3$. Their results indicated that these microalgae could play a significant role in enhancing indoor air quality. Supporting this, Arora (2024) reviewed various approaches for integrating microalgae into building facades and concluded that such implementations not only improve indoor air quality but also provide additional benefits, including increased energy efficiency and aesthetic enhancement. Together, these studies highlight the potential of microalgae-based photobioreactor systems as a multifunctional tool for sustainable building design.

Kim et al. (2025) stated that integrating microalgae into building facades is effective in improving indoor air quality and that these systems offer potential for increasing energy efficiency.

Microalgae have significant potential in sustainable energy production due to their high biomass production capacity, rapid growth rate, and low environmental impact. Photobioreactors (PBRs) optimize biomass production by cultivating microalgae under controlled conditions and can utilize this biomass for biofuel production.

Microalgae are known as a source for bioenergy production, such as biodiesel and biogas. Bora et al. (2024) comparatively examined lipid accumulation and biomass yield of microalgae cultivated in conventional nutrient media versus nutrient-rich wastewater. Experimental results showed that using wastewater increased total biomass yield by approximately 18% and reduced nutrient input costs by 35%, demonstrating both economic and environmental advantages.

In their experimental study, Tripathi et al. (2025) used a two-staged photobioreactor (PBR) configuration under a laboratory environment to increase microalgal biomass production. The two-stage system

increased lipid content by 12–15% compared to single-stage systems, indicating a higher potential for bioenergy yield.

Furthermore, Gurreri et al. (2024) investigating industrial type PBR systems highlighted the benefit of continuous operation which could sustain a daily biomass production of 2.5 kg/m², while energy consumption per unit biomass was reduced by 20% compared to conventional methods.

2.2. Architectural Integration of Microalgae and Photobioreactors

Han et al. (2023) examined the CO_2 absorption performance of Spirulina maxima. They examined the ability of microalgae-based photobioreactors (PBRs) in indoor air quality enhancement in a $NaHCO_3$-limited environment with photobioreactor systems. Three scenarios with different nutrient types were created, classified as standard, 50% $NaHCO_3$, and no $NaHCO_3$, and cell growth was monitored for 30 days. In the study, researchers measured indoor CO_2 concentrations, up to 1100 ppm. Without $NaHCO_3$ in the environment, CO_2 levels decreased by 55%, while at very high CO_2 concentrations (10,000 ppm), the reduction reached up to 90%. Cell growth was higher in the environment without $NaHCO_3$ compared to other configurations. Computational fluid dynamics simulations with Ansys Fluent were conducted, validating the air diffusion and placement of sensors. These results suggest that optimizing both nutrient conditions and air flow can significantly enhance the effectiveness of microalgae-based CO_2 mitigation in indoor environments.

Kim, Parrow, and Kheirkhah Sangdeh (2025) experimentally investigated the carbon capture potential of integrating microalgae photobioreactors (PBRs) into building facades. The study specifically evaluated the performance of Chlorella and Chlorococcum species. Experimentally, the daily biomass production of Chlorella was measured at 175 mg/L-day, while that of Chlorococcum was 80 mg/L-day.

The research indicates that these systems, when combined with net-zero energy buildings, can contribute to sustainable urban development.

Arora et al. (2024) conducted a review study on building-integrated microalgae photobioreactors (PBRs). The study analyzes different façade integration designs considering light penetration, panel orientation, and microalgae growth conditions. Furthermore, the review emphasizes that PBR systems can utilize wastewater with nutrients, simultaneously supporting water purification and reducing operational costs. The shading effect provided by the panels helps with passive cooling.

Optimization studies showed that annual CO_2 sequestration varied between 84.87 kg and 770.13 kg depending on the PBR façade configuration. According to the literature review, PBR designs maintained daylight penetration above 50%. They also supported optimal indoor thermal comfort conditions. These findings indicate that, with proper design and configuration, microalgae photobioreactor façades can enhance carbon capture capabilities and maintain indoor environmental quality. Overall, FBR systems are identified as a versatile and effective solution for promoting sustainability and energy efficiency in buildings.

Hariyanto et al.'s (2022) study is an important study that comprehensively examines the effects of microalgae-based photobioreactors (PBRs) on indoor air quality. The study indicates that microalgae façades improve indoor air quality through CO_2 absorption and oxygen production, thereby improving the health and comfort of building occupants. The research, conducted using literature review and case studies, evaluated the role and potential of microalgae façades in building design. The findings demonstrate that microalgae façades increase comfort by improving indoor factors such as natural lighting, temperature, humidity, and acoustic comfort, while also contributing to building energy efficiency. These systems, which optimize air quality through CO_2 absorption and oxygen production, are emerging as a key tool in sustainable architecture. The research demonstrates the potential of microalgae-based systems to both improve indoor air quality and increase energy efficiency, highlighting the importance of their integration in future building designs.

The BIQ (Bio Intelligent Quotient) house is one of the primary projects with bioreactive façades. The BIQ house project team began with the idea that algae colonies are efficient carbon dioxide absorbers and biomass producers, reducing the negative impacts of climate change in cities while simultaneously generating on-site energy for the structures they adorn.

The bioreactive façade, called SolarLeaf, generates renewable energy from algae biomass and solar thermal heat. Specifically, the BIQ house in Hamburg features 200 m² of algae-filled bioreactive panels, which provide the building with all the energy it needs while reducing carbon dioxide (CO2) emissions by 6 tons per year. This pilot project exemplifies a building-integrated system that absorbs CO2 emissions while cultivating microalgae to produce biomass and heat as renewable energy sources. The photosynthetic environment is provided by glass photobioreactors installed on the southwest and southeast sides. This innovative system also highlights the full potential of this technology by

integrating additional functions such as dynamic shading, thermal insulation, and noise reduction. Thanks to this system, the BIQ house can operate as a carbon sink using algae to capture CO2 while simultaneously generating energy in a carbon-neutral manner. For these reasons, it represents a good practice for future building development to foster a low-carbon urban future and shape better cities to live and work in.

Strategically, algae can improve the sustainability and environmental health of all types of new or existing buildings (residential, public, commercial, industrial) as bioreactor systems, as they can naturally absorb CO2 due to their higher photosynthetic efficiency.

Pasikanti, V. (2023) systematically addressed the potential application of photobioreactors in real-world conditions by discussing the literature on microalgae biofuel production together with architectural applications.

The research analyzed variations with different microalgae species, bioreactor designs, and cultivation conditions with technical-economic analyses in three distinct geographical scenarios, supplemented by laboratory and field data, numerical modeling, and simulations. These scenarios represent different climates and building types in the UK, Europe, and India. Parameters such as CO_2 absorption, oxygen production, biomass production, and energy efficiency of microalgae PBRs in each scenario, indoor visual and climatic comfort factors such as natural lighting, indoor temperature, and humidity control were investigated.

The study shows that integrating microalgae PBRs into buildings offers environmental and energy benefits, including CO_2 absorption, biomass production, and passive heat management through shading and light filtering. Biomass can also be converted into biofuel, reducing fossil fuel use. However, challenges such as high initial costs, maintenance, energy grid integration, and performance uncertainties limit widespread adoption. Pasikanti (2023) suggests strategies like optimized reactor designs, sensor-based monitoring, dynamic control, and life cycle-based economic planning to address these issues. Overall, the thesis demonstrates that microalgae PBRs can enhance energy efficiency, support CO_2 absorption, and improve indoor air quality in future buildings.

Negev et al.'s (2019) experimental and numerical study is one of the pioneering studies that experimentally demonstrates the potential of microalgae photobioreactors (PBRs) to increase energy efficiency in buildings. This study was conducted in a field setting in Tel Aviv, Israel. It

evaluated the performance of microalgae PBR panels, called "Algae Window," integrated into building facades during the summer months. The primary objective of the research is to optimize energy consumption by reducing the heat load from facades through the photosynthetic activity of microalgae and thus reducing indoor cooling requirements. Microalgae PBR panels were integrated into building facades, and indoor and outdoor temperatures, solar radiation, indoor cooling load, and photosynthetic activity of microalgae cultures were measured in detail at different times and days. These measurements were systematically recorded to determine the heat absorption capacity of microalgae and its impact on building energy performance. The experimental process consisted of microalgae density, light penetration, and temperature tolerance monitoring. The research showed that microalgae PBR panels reduced the heat load on building facades by up to 15% in summer by filtering natural light and providing shading. These findings reveal that microalgae PBR panels are an effective tool for passive thermal management and can support energy savings in buildings. Therefore, this study highlights the benefit of integrating microalgae PBRs into architectural designs from both technical and biological perspectives, serving as a reference in the literature for its combined evaluation of energy savings, improvement of indoor air quality, and environmental benefits.

3. CONCLUSION

This study examined how photobioreactor (PBR) technology can be applied in sustainable building design. Microalgae-based PBR systems can capture CO_2 under controlled conditions, produce oxygen, generate biomass, and assist in wastewater treatment. These benefits can enhance building energy efficiency, reduce carbon emissions, and improve indoor air quality.

In architectural design, although PBR systems are integrated into building envelopes or interior spaces with typical transparent encapsulations, there is still potential for new technologies to be adopted to these configurations to enhance energy efficiency, water management, creating healthy indoor air. In addition to their functional benefits, photobioreactor panels give buildings a sustainable and ecological features and aesthetical apperiance, allowing designs to achieve a strong identity both visually and environmentally, such as The BIQ House in Hamburg, with microalgae panels integrated into its façade. Experimental studies conducted in Japan, China, and Europe have also demonstrated the effectiveness of PBR systems in energy production and wastewater management. These examples highlight

the potential of PBR technology to provide aesthetic value, energy savings, and environmental sustainability in buildings.

Although the application of this system can cause limitations such as high investment costs, maintenance, and specialized expertise requirements, its benefits in terms of energy savings, reduction of carbon emissions, and wastewater treatment make it an advantageous architectural configuration to be easily integrated into the built environment and buildings. User awareness and the aesthetic integration of the system into the building design are also crucial for its overall performance and widespread usage.

Therefore, the widespread adoption of photobioreactors, presenting advantages of biomass production, water recovery, energy consumption, and carbon emission reduction, improved indoor air quality, and design of an aesthetic building envelope, will support sustainable architecture in both environmental and economic dimensions.

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BIOMATERIALS AND INTERIOR ARCHITECTURE: THE CONNECTION BETWEEN SUSTAINABILITY, FUNCTIONALITY, AND AESTHETICS

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ABSTRACT

This study dives into how biomaterials are being woven into the fabric of interior design, highlighting their role in promoting sustainability, functionality, and a rich aesthetic experience. Sourced from renewable and often biodegradable materials, biomaterials are gaining recognition as dynamic elements that actively shape our indoor spaces, rather than just being passive building blocks. They bring a host of benefits to the table, such as regulating temperature and sound, improving air quality, and adding both tactile and visual appeal, all of which enhance environmental performance and the overall experience for occupants. However, there are still hurdles to overcome, including issues like limited durability, sensitivity to moisture, fire safety risks, high costs, and a lack of standardization that hinder their broader use. To get a clearer picture, a systematic review of literature from the last twenty years was carried out, examining peer-reviewed articles, conference papers, and academic books. The search was guided by keywords like "biomaterials," "sustainable interior design," "functional and aesthetic properties," and "healthy indoor environments." Additionally, ten case studies from residential, commercial, and public spaces were analyzed, focusing on material types, production methods, functional performance, aesthetic impact, and sustainability outcomes. A thematic analysis brought together the findings, emphasizing environmental impact, functional benefits, aesthetic qualities, and user well-being. The results show that biomaterials—such as mycelium composites, bamboo, cork, algal panels, and cellulose-based products—offer significant ecological, functional, and aesthetic benefits. They pave the way for low-carbon, renewable, and biodegradable design solutions while boosting user comfort and engagement through biophilic design principles. Incorporating biomaterials into design education not only raises awareness about choosing sustainable materials but also emphasizes their practical use. This study highlights how biomaterials can serve as powerful tools in modern interior design, effectively linking ecological responsibility with functionality and enhancing sensory experiences.

Keywords: Biomaterials, Sustainable Interior Design, Functional Performance, Aesthetic Experience, Design

INTRODUCTION

Materials have always played a crucial role in driving innovation and change in architectural design. In the past, decisions about design were mainly influenced by factors like structural strength, durability, and cost-effectiveness. But lately, with pressing global issues like climate change, resource depletion, and environmental pollution, the focus has shifted towards sustainability in material selection. This change means we now look at materials not just as structural elements but also as ecological, social, and experiential contributors (Ashby, 2021; Callister & Rethwisch, 2007). Nowadays, materials are far from being mere building blocks; they actively influence human health, environmental impact, and the overall experience of spaces.

The evolution of materials science clearly shows this shift. For a long time, materials were evaluated mainly on their "bulk" properties, focusing on large-scale factors like density, strength, hardness, and elasticity. However, since the late 20th century, advancements in technology have revealed that how materials perform is influenced not just by these macro-scale traits but also by their surface properties, microstructure, and even nanoscale features (Callister & Rethwisch, 2007). This deeper understanding has led to the need for considering environmental and functional aspects alongside traditional mechanical properties in design. In this light, eco-conscious material selection has become increasingly important, especially in the fields of architecture and interior design (Ashby, 2021).

In this ever-changing landscape, biomaterials—sourced from renewable natural resources, biodegradable, and generally safe for both human health and the environment—are stepping up as vital alternatives. When you stack them against traditional materials, biomaterials shine with their ecological benefits, like a smaller carbon footprint, recyclability, and support for circular design principles. Plus, they enhance our spaces by naturally regulating temperature, adding texture, scent, and visual variety.

This unique blend makes biomaterials a crucial choice in interior design, balancing sustainability, functionality, and aesthetics. The impact of biomaterials on interior performance is quite broad. They help create healthier living spaces with features like humidity control, improved air quality, and natural thermal and acoustic insulation (Miller, 2021; Wang, 2020). Green and White (2020) showed that natural fibers not only boost sound insulation but also foster warm and welcoming interiors. Their variety in texture and appearance also enhances how users perceive their surroundings (Smith & Jones, 2021). So, biomaterials bring not just

environmental benefits but also experiential and aesthetic value. However, there are some hurdles to the widespread use of biomaterials. Issues like moisture sensitivity, biological degradation, limited mechanical strength, fire safety, scalability, and cost can complicate their sustainable application (Lee & Park, 2022; Zhao, Chen, & Wu, 2021).

The literature suggests various solutions to tackle these challenges, such as hybrid materials, coating techniques, and industrial processing methods (O'Connor, 2018). Yet, the lack of sufficient standards and certification processes continues to be a major roadblock to the broader acceptance of biomaterials (Sydor et al., 2021).

Lately, there's been some exciting progress in experimental applications, especially with mycelium composites, plant-fiber-reinforced biopolymers, and natural fiber panels. These innovations have shown great promise, not just in terms of technical aspects like thermal and acoustic insulation and mechanical strength, but also in how they enhance our experience of space with their biophilic qualities and natural aesthetics (Almpani-Lekka et al., 2021; Sydor et al., 2021). It seems that biomaterials could not only serve as viable alternatives in the future but might also become a key player in sustainable interior design. However, the literature points out a couple of significant gaps. For one, while there's a lot of focus on the environmental perks of biomaterials, there's still a lack of research that dives into how they impact our interior experiences, aesthetic perceptions, and even user health (Miller, 2021). Additionally, the role of biomaterials in educational settings—specifically how design students gain material knowledge and embrace nature-integrated design approaches—hasn't been thoroughly investigated.

This makes biomaterials a timely and important area for both academic and practical exploration. This study aims to take a deep dive into the functional, aesthetic, and sustainable contributions of biomaterials in interior design. By reviewing existing literature and analyzing selected case studies, it will investigate production methods, applications, benefits, and limitations of these materials. The goal is to systematically uncover which design priorities biomaterials can address and the conditions under which they can be effectively utilized. In doing so, it highlights not just how biomaterials can tackle global environmental challenges but also their potential to redefine the landscape of interior design.

BACKGROUND

Materials science has long played a crucial role in shaping the core principles of architecture and interior design. In the past, research mainly

concentrated on the volumetric and structural aspects of materials. However, with the rapid pace of technological advancements, we've seen a shift towards focusing on surface, microstructural, and nanoscale properties when assessing performance (Callister, 2007). This evolution has broadened our understanding of materials, moving beyond just durability and structural integrity to also consider flexibility, energy efficiency, environmental impact, and lifespan.

As global discussions around the climate crisis, resource depletion, and environmental responsibility intensify, sustainability has emerged as a key theme in architecture and design. As a result, sustainable materials have become essential to modern design strategies. Among these, biomaterials have gained significant attention and are increasingly being studied as a vital category within sustainable materials. These materials are biodegradable, environmentally friendly, and primarily sourced from renewable resources, blending ecological responsibility with practical use and providing a viable alternative to traditional materials (Hench & West, 1996). Initially, biomaterials found their niche in biomedical applications, but their use in architecture and interior design has surged in recent years (Jones, 2014).

Research shows that biomaterials can enhance indoor environments by regulating humidity, improving air quality, and providing thermal insulation (Smith & Lee, 2018; Wang, 2020). These benefits directly impact the quality of life for users and align with human-centered design principles. In the realm of interior design, biomaterials stand out for their unique blend of aesthetic appeal, functionality, and sustainability.

The existing literature explores various types of biomaterials and their influence on interior performance from multiple angles. For example, mycelium-based panels offer lightweight and adaptable structures, allowing for a variety of geometric designs while promoting environmental sustainability through their low carbon footprints and biodegradability (Elsacker et al., 2020). Bamboo represents an excellent option for applications requiring both durability and flexibility. It not only boosts thermal and acoustic performance but also grows quickly and requires low energy for production (Giubilini & Nannipieri, 2019).

Table 1. Biomaterials: Applications and Contributions in Interior Design (1; Elsacker et al., 2020, 2; Giubilini & Nannipieri, 2019, 3; López et al., 2018, 4; Küçük et al., 2021, 5; Küçük et al., 2021, 6; Wan et al., 2022)

Material Type	Example Product / Application	Aesthetic Contribution	Functional Contribution	Sustainability / Environmental Contribution	S
Mycelium	Wall panel	Organic, natural texture; biophilic warmth	Lightweight, formable; adaptable to various geometries	Low carbon footprint, biodegradable	1
Bamboo	Furniture (chair, table)	Natural color and texture, warm and aesthetic	Durable, flexible; thermal and acoustic insulation	Fast-growing, renewable; low-energy production	2
Cork	Floor coverings, panels	Textural variety; natural warmth	Acoustic and thermal insulation	Recyclable, biodegradable, sustainable	3
Cellulose Nanocrystal	Furniture or surface panels	Textured and transparent surfaces, modern aesthetics	High mechanical strength; surface protection	Bio-based, recyclable, and low environmental impact	4
Chitosan	Antibacterial wall coating	Natural and transparent	Antibacterial; improves indoor hygiene	Bio-based, sustainable, eco-friendly	5
Algae-based materials	Lighting design, decorative panels	Innovative, lightweight visual effect	Lightweight, flexible, and adaptable	Renewable, low environmental impact	6

Biomaterials bring more to the table than just functional benefits; they also enhance the aesthetic appeal of our interiors. Take cork floor coverings and panels, for instance—they offer a delightful tactile experience and a natural look that adds warmth and softness, all while boosting acoustic and thermal comfort (López et al., 2018).

Then there are cellulose nanocrystals and chitosan-based materials, which not only look great but also pack a punch with their impressive mechanical strength and antibacterial properties (Küçük et al., 2021). Algae-based materials, known for being lightweight and flexible, present exciting possibilities in decorative and lighting applications, all while championing sustainability with their minimal environmental impact.

This variety showcases the many ways biomaterials contribute to interior design. The table below highlights key types of biomaterials found in the literature, along with examples of their applications and their contributions to aesthetics, functionality, and sustainability. As illustrated in the table, biomaterials offer a wealth of benefits in interior design—not just in terms of environmental sustainability, but also in aesthetics and functionality. Research underscores their ability to enhance acoustic comfort, improve air quality, and foster biophilic experiences for users.

While academic studies often zero in on technical performance, the aesthetic, user experience, and sustainability aspects are still somewhat overlooked (Almpani-Lekka et al., 2021; Vašatko et al., 2022). This study seeks to view biomaterials not just as a cutting-edge material choice but as a strategic asset that can transform the aesthetic, functional, and social dimensions of interior design, ultimately benefiting both design practice and academic inquiry.

METHODOLOGY

This study takes a qualitative research approach to explore how biomaterials function in interior design, with a keen eye on sustainability, aesthetic value, and their effects on human health. The main goal is to thoroughly assess how applicable and effective these materials are in interior spaces while also pinpointing any gaps in existing research. The review covers studies published from 2000 to 2025 in peer-reviewed journals, conference proceedings, and academic books. Key terms that guided the literature search included "biomaterials," "sustainable interior design," "aesthetic and functional properties," "eco-friendly materials," and "healthy indoor environments." This method not only bolsters the theoretical framework but also helps us grasp the complex effects of material choices in interior design. To ensure high-quality sources, databases like Scopus, Web of Science, ScienceDirect, and Google Scholar were utilized. The inclusion criteria focused on studies that discussed the production methods, applications, and functional performance of biomaterials in interiors. The selected literature provided insights not just into technical performance but also into aesthetic appeal, user experience, and sustainability aspects. This comprehensive approach allowed for a deeper understanding of the multifaceted impacts of biomaterials and helped in crafting effective interior design strategies. Alongside the literature review, case studies were examined to showcase real-world applications of biomaterials in interior spaces. Ten case studies were chosen from residential, commercial, and public environments across different regions. The selection criteria emphasized innovative uses of biomaterials, references to sustainability, and documented impacts on indoor environmental quality. Each case study

was analyzed in detail, focusing on material types, production methods, functional characteristics, aesthetic contributions, and design outcomes.

This approach offers essential insights into the pros and cons of using biomaterials in real-world settings. The data analysis utilized thematic analysis, which helps to categorize information into recurring themes and motifs for better understanding (Braun & Clarke, 2006). The main themes identified included sustainability of materials, their aesthetic contributions, functionality within interiors, and their effects on human health. Additionally, we looked into technical challenges, durability issues, biodegradability, and cost factors. By combining literature findings with case study examples, we created a solid framework to grasp the multifaceted role of biomaterials in interior design. This research method allows for a thorough assessment of how biomaterials can improve sustainable practices in interior design. The study methodically contrasts aesthetic and functional aspects while highlighting their potential for integration into future design strategies. We emphasize environmental impact, energy efficiency, and user well-being to stress the significance of making informed material choices.

The methodological design merges qualitative literature reviews with case study analyses, blending theoretical insights with practical applications (Creswell & Poth, 2018; Kozlowski, 2020; Zhao, Chen, & Wu, 2021). Data collection involved document analysis, project portfolios, and visual observations. Our evaluation framework covers three key areas: sustainability (environmental impact and lifecycle), functionality (material performance and user interaction), and aesthetics (visual and sensory experience) (Green & White, 2020; Smith & Jones, 2021). Lastly, the comparative analysis brings together literature and case study findings, uncovering patterns, differences, and connections across various projects and sources. This integration ensures both academic credibility and practical relevance for interior design professionals (Miller, 2021).

FINDINGS AND DISCUSSION

The biomaterials we looked at were assessed based on their aesthetic appeal, functionality, and environmental impact, all of which are essential elements of sustainable interior design. The findings show that these materials are not just notable for their natural origins; they also offer a rich variety of experiences, textures, and visual elements from both the designer's and user's viewpoints.

a. Sustainability and Environmental Impact

Research and case studies show that biomaterials offer some impressive environmental benefits. Materials like mycelium-based panels, bamboo, and bio-based polymers come from renewable sources and are biodegradable (Almpani-Lekka, Gkretsi, & Stavroulakis, 2021; Elsacker, Dueñas, & Vandelook, 2020). Compared to conventional materials such as plastics, metals, or concrete, these alternatives exhibit significantly lower embodied energy and contribute to the reduction of carbon footprints (Holt et al., 2021; Smith & Jones, 2020). For example, furniture made from mycelium composites is not only lightweight but also a low-carbon option (Jones, Bhat, & Williams, 2020). Additionally, materials like cork, bamboo, and algae-based panels are renewable and have a smaller environmental impact during their production (Liese, 2006; Pina & Silva, 2019; Dufresne, 2012). Using these materials aligns with the principles of a circular economy and helps lessen the ecological footprint of buildings (Rashdan & Ashour, 2024).

Table 2. Overview of Biomaterials: Functional, Aesthetic, and Environmental Roles in Interior Design (1; URL1, 2; URL2, 3; URL3, 4; URL4, 5;URL6, 6; URL6)

Material Type	Example Product / Application	Aesthetic Contribution	Functional Contribution	Sustainability / S Environmental Contribution	
Mycelium	Wall panels, furniture	Organic texture, warm and biophilic	Lightweight, moldable, adaptable to various geometries	Low carbon footprint, biodegradable, renewable	1
Bamboo	Furniture (chairs, tables), flooring	Natural color and texture, warm and visually appealing	Durable, flexible, provides thermal and acoustic insulation	Fast-growing, renewable, low-energy production	2
Cork	Flooring, wall panels	Textural variety, natural warmth	Acoustic and thermal insulation	Recyclable, biodegradable, sustainable	3
Coquim Coconut Fibre	Wall panels, furniture, interior decoration	Natural, fibrous, warm aesthetic	Lightweight, flexible, water retention, antifungal	Biodegradable, renewable, natural latex composite	4
Chitosan	Antibacterial wall coating	Natural, semi-transparent	Antibacterial, improves indoor hygiene	Bio-based, eco-friendly, biodegradable	5
Sensbiom 2 (Photochromic Bioplastic)	Decorative panels, lighting, installation	Dynamic, responsive visual effect	Changes color under UV exposure, interactive	Biodegradable, plant/mineral-based pigments	6

b. Functionality and Performance

Biomaterials offer distinct functional benefits in interior applications. Mycelium-based products assist in regulating humidity levels, while bamboo and natural fiber composites deliver enhanced durability and adaptability (Lee & Park, 2022; Faruk et al., 2012). Additionally, cellulose nanocrystals and chitosan are recognized for their antibacterial properties and extended lifespan, contributing positively to both health and longevity (Habibi, Lucia, & Rojas, 2010; Ravi Kumar, 2000).

Table 3. Case Studies of Biomaterials: Functional, Aesthetic, and Environmental Outcomes in Interior Applications (1; URL1, 2; URL2, 3; URL3, 4; URL4, 5;URL6, 6; URL6)

Case Study	Material Type	Application	Functional Outcomes	Aesthetic / Experiential Outcomes	Environmental Outcomes	S
Mushroom Mycelium Furniture Netherlands	Mycelium	Wall panels, seating	Lightweight, moldable, humidity regulation	Organic texture, biophilic warmth	Biodegradable, low carbon footprint	1
Bamboo Interior Elements Japan	Bamboo	Furniture, flooring	Durable, thermal/acoustic insulation	Warm, natural visual appeal	Fast-growing, renewable	2
Cork Acoustic Panels Spain	Cork	Wall panels	Acoustic insulation	Soft, tactile, natural aesthetics	Biodegradable, recyclable	3
Coquim Coconut Fibre Brazil	Wall panels, furniture, interior decoration	Natural texture, fibrous, warm aesthetic	Lightweight, flexible, water retention, antifungal	Soft, Organic texture, biophilic warmth	Biodegradable, renewable, natural latex composite	4
Chitosan Wall Coating South Korea	Chitosan	Wall finish	Antibacterial, indoor hygiene	Semi-transparent, subtle aesthetic	Biodegradable, eco-friendly	5
Sensbiom 2, Netherlands	Photochromic Bioplastic	Installation Decorative panels	Changes color under UV exposure, interactive	Dynamic, responsive visual effect	Biodegradable, plant/mineral-based pigments	6

Research demonstrates that biomaterials possess notable adaptability, granting substantial versatility in design applications. Configurations of renewable foams, mycelium composites, bamboo, and coconut fibre panels can be tailored to meet diverse spatial demands (Mohanty et al., 2018; Lee & Park, 2022), thereby directly impacting user comfort and contributing to improved interior performance.

For instance, mycelium panels can regulate humidity while maintaining structural lightness, and Coquim coconut fibre panels offer flexibility, water retention, and antifungal properties, making them suitable for wall coverings, furniture, and interior decoration. Bamboo provides durability,

thermal and acoustic insulation, and a natural aesthetic, reinforcing both functional and experiential outcomes in interior spaces.

The aesthetic and experiential qualities of biomaterials enhance user engagement with interiors. Materials such as mycelium, bamboo, cork, and Chitosan bring organic textures, tactile warmth, and subtle visual variations that align with biophilic design principles. Case studies illustrate that interactive materials, like Sensbiom 2 photochromic bioplastics, introduce dynamic visual effects by responding to UV exposure, adding both playful and functional dimensions to installations (Tablo 2.). This interactivity fosters user curiosity and can improve spatial satisfaction and emotional well-being.

Moreover, biomaterials support sustainable design objectives. Their renewable, biodegradable, and low-carbon properties contribute to reducing the environmental footprint of interior applications (Elsacker et al., 2020; Liese, 2006).

For example, integrating bamboo or cork panels into furniture or flooring not only ensures durability but also aligns with circular economy principles. The combination of functionality, aesthetic appeal, and environmental performance demonstrates that biomaterials are not just alternatives to conventional materials—they are strategic design tools capable of creating healthier, more sustainable, and more engaging interior environments.

c. Aesthetic and Experiential Dimension

Biomaterials really boost aesthetic appeal by adding a mix of visual and tactile elements. With their organic colors, textures, and surface variations, they help users feel more connected to nature, which aligns perfectly with biophilic design principles. Materials like mycelium and bamboo can act as eye-catching focal points, creating visual intrigue (Giubilini & Nannipieri, 2019; López, Martínez, & Sánchez, 2018).

Case studies show how well aesthetic and functional aspects can work together. For example, the rich textures and natural shapes of mycelium panels in the Netherlands not only enhance the user experience but also support sustainability goals (Jones, Bhat, & Williams, 2020; Elsacker et al., 2020; Mushroom Mycelium Furniture, Table 3). Bamboo interior elements in Japan combine natural color, texture, and warmth with durability and thermal/acoustic benefits, creating functional and visually pleasing surfaces (Bamboo Interior Elements, Table 3).

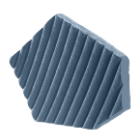
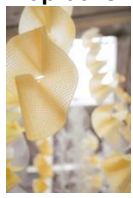
Cork acoustic panels in Spain provide soft, tactile surfaces that complement their acoustic insulation, illustrating how functional

performance and visual experience can coexist (Cork Acoustic Panels, Table 3). Coquim coconut fibre panels in Brazil add fibrous, warm textures that are lightweight, flexible, and moisture-regulating, enhancing both aesthetic and experiential qualities (Coquim Coconut Fibre, Table 3). Chitosan wall coatings in South Korea contribute subtle, semi-transparent finishes that combine antibacterial functionality with gentle visual enhancement (Chitosan Wall Coating, Table 3).

Finally, innovative materials such as Sensbiom 2 photochromic bioplastics in the Netherlands introduce dynamic, interactive color changes under UV exposure, creating visually engaging environments while maintaining biodegradable and eco-friendly properties (Sensbiom 2, Table 3).

Overall, these examples illustrate that biomaterials extend beyond mere functionality. By integrating organic textures, natural warmth, and interactive elements, designers can create interior environments that are visually compelling, experientially rich, and environmentally responsible, ultimately supporting user well-being and sustainability goals.

Table 4. Case Studies of Biomaterials: Functional, Aesthetic, and Environmental Outcomes in Design

Case Study	Material Type	Functional Outcomes	S
Mushroom Mycelium Furniture Netherlands	Mycelium 	 	1
Bamboo Interior Elements Japan	Bamboo 	 	2
Cork Acoustic Panels Spain	Cork 	 	3
Coquim Coconut Fibre Brazil	coconut fibre 	 	4
Chitosan Wall Coating South Korea	Chitosan 	 	5
Sensbiom 2, Netherlands	Photochromic Bioplastic 		6

This varied collection of organic materials goes beyond mere functionality; it also powerfully reflects the designer's goals. By thoughtfully selecting and integrating biomaterials, we can create interior spaces that are both contemporary and welcoming. For instance, the way light interacts with algae-based panels, or the unique textures of renewable foams can really elevate ordinary spaces, harmoniously linking architectural design with the natural environment. These engaging features not only enhance emotional ties but also support the well-being of those who use the space, emphasizing that interior design is about shaping experiences while fulfilling practical needs.

d. Education and Professional Applications

The variety of biomaterials provides valuable insights for both education and professional practice. By focusing on materials, curricula help students and designers see how different materials can offer aesthetic appeal, functionality, and sustainability (Wan, Li, & Chen, 2022). Using real-world case studies makes it easier to apply theoretical knowledge to hands-on projects.

In the professional realm, it's crucial to encourage collaboration among designers, manufacturers, and educators to enhance the practical use of biomaterials. Engaging in hands-on experiments and interdisciplinary workshops and getting familiar with new fabrication technologies allows everyone involved to make better material choices and adjust design strategies to meet changing sustainability goals. This collaborative approach fosters a culture of innovation that not only deepens expertise but also speeds up the adoption of fresh solutions tailored to the ever-evolving needs of interior spaces and user expectations.

e. Challenges and Limitations

Biomaterials are up against a few hurdles, like high costs, limited production capabilities, and a lack of standardization (Elsacker et al., 2020; Holt et al., 2021). Cultural acceptance and how users perceive these materials can really sway the choices made in material selection. On the bright side, technological advancements and digital fabrication techniques are helping to break down these barriers, paving the way for wider use (Sydor & Bonenberg, 2021)

Research shows that biomaterials can be seen as a unique category that offers sustainable, functional, and visually appealing options in interior design. When integrated thoughtfully, they can ensure environmental responsibility while keeping user comfort in mind. Plus, various case studies back up their real-world effectiveness and the

positive experiences they create. Even with ongoing challenges like high costs, production limits, and the lack of standardized practices, the field of biomaterials is progressing, thanks to technological advancements and digital fabrication methods that are making it easier for the industry to embrace them (Elsacker et al., 2020; Holt et al., 2021; Sydor & Bonenberg, 2021)

Understanding cultural perspectives and user expectations is also crucial for successful implementation, encouraging designers to find a balance between innovation and context sensitivity. Ultimately, the evidence suggests that biomaterials represent a distinct category that can deliver sustainability, functionality, and aesthetic appeal in interior design. When used thoughtfully, these materials not only meet practical and ecological needs but also elevate everyday experiences, as shown by a range of case studies.

CONCLUSION AND ACKNOWLEDGEMENTS

This research highlights how the use of biomaterials in interior design effectively addresses sustainability, practicality, and aesthetics. Numerous studies and literature demonstrate that biomaterials not only reduce environmental impact but also enhance user comfort, health, and overall well-being (Holt et al., 2021; Smith and Jones, 2020). Materials such as mycelium-based panels, bamboo, and algae are particularly notable for their minimal carbon footprint, renewability, and biodegradability, while enhancing the user experience and appearance of interior spaces (Elsacker et al., 2020; Giubilini and Nannipieri, 2019). At a functional level, biomaterials excel at improving thermal and acoustic insulation, managing moisture, and offering antibacterial benefits, all of which contribute to improved indoor quality. For example, cellulose nanocrystals and chitosan-based materials ensure both safety and performance (Habibi, Lucia, & Rojas, 2010; Ravi Kumar, 2000). This combination of functionality and user-centered design principles allows for a more holistic approach to interior spaces.

Biomaterials play a key role in improving thermal and acoustic insulation, managing moisture, and providing antibacterial properties, all of which contribute to a better indoor environment. For example, materials such as cellulose nanocrystals and chitosan not only ensure safety but also enhance performance (Habibi, Lucia, & Rojas, 2010; Ravi Kumar, 2000). This research demonstrates that incorporating biomaterials into interior design effectively addresses sustainability, functionality, and aesthetics. Numerous studies and real-world examples demonstrate that biomaterials can significantly reduce environmental impact while improving user comfort, health, and overall well-being (Holt et al., 2021;

Smith and Jones, 2020). Notable examples include mycelium panels, bamboo, and algae-based materials, which are known for their minimal carbon footprint, renewability, and biodegradability, enhancing the user experience and visual appeal of interior spaces (Elsacker et al., 2020; Giubilini and Nannipieri, 2019).

The study also highlights the strategic role of biomaterials in education and professional practice. Incorporating materials-focused curricula and case studies encourages informed material choices by enabling students to observe and understand aesthetic, functional, and sustainable properties.

Looking ahead, ongoing research on innovative production methods, combined with a growing awareness of material life cycles, promises to further expand the range of biomaterials available to designers. As industry and academia explore interdisciplinary solutions, new standards and guidelines are likely to emerge, increasing trust and acceptance of bio-based materials in both commercial and residential environments. This forward-thinking mindset not only fosters technical advancement but also reinforces the ethical imperative of designing with environmental responsibility in mind. By fostering a design culture that values experimentation, inclusivity, and ecological responsibility, the field of interior design is poised to meet the changing demands of users and the planet.

In summary, biomaterials effectively integrate sustainability, functionality, and aesthetics into interior design. Through informed and innovative applications, designers can create spaces that meet both environmental standards and user needs. As the industry progresses, the adoption of biomaterials will be a key strategy for achieving responsible, visually appealing, and dynamic interior environments.

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AN REVIEW ON THE LEGAL PROCESSES IN ENERGY RETROFITS IN TERMS OF THE SUSTAINABILITY OF HERITAGE BUILDINGS IN TURKIYE

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ABSTRACT

Retrofitting existing buildings can reduce energy use significantly and may even help reverse global warming. Consequently, laws aiming to ensure energy efficiency in new buildings have been extended to existing buildings, including historic buildings. Although heritage buildings were designed in accordance with passive design parameters, they still have potential for energy efficiency achievement with newly adopted strategies, with minimal intervention techniques not affecting the original historical value.

This study aims to present the existing international legislation for energy retrofitting in heritage buildings, to contribute to improving their applicability, and to provide suggestions for specific regional legislation to be prepared in the future for Türkiye.

From the 19th century onwards, conservation and energy legislation have been examined through a literature review, and the approaches of these laws towards energy retrofitting in heritage buildings have been evaluated. It has been determined that historic buildings are excluded from regional energy legislation in Türkiye. It was observed that decisions on this matter in Türkiye's conservation legislation are left to the opinion of the Cultural Heritage Conservation Boards, but the necessary standards for the decision-making processes to function properly have not been established.

Since 2010, specific legislations such as the ASHRAE, ICOMOS, and CIBSE Guidelines, focusing on energy retrofitting in heritage buildings, have been initiated. Among these, it has been concluded that ASHRAE Guide 34 can be considered a guiding framework in the process of developing original energy retrofitting legislation for heritage buildings in Türkiye.

Keywords: Energy efficiency, Heritage buildings, Conservation legislation, Energy Legislation

INTRODUCTION

Climate change is currently considered one of the most critical problems on a global scale, with its environmental, economic, and social dimensions. Fossil fuel use and human activities have caused atmospheric carbon dioxide concentrations to increase by 1.5 times and average global temperatures to rise by 1.1 °C compared to pre-industrial levels. The world population is estimated to reach 9.7 billion by 2050 and 10.9 billion by 2100. As a result, a 50–150% increase in carbon dioxide emissions, a 1.5–3 °C rise in global average temperatures, a sea level rise of up to 34 cm, a 50% increase in energy consumption, an increase in the frequency of extreme weather events, and water scarcity in some regions are expected by 2050 (IPCC, 2025; Kopp et al., 2014; OECD, 2021; United Nations, 2021).

One of the most fundamental strategies to combat climate change is energy efficiency. The buildings sector is responsible for approximately one-third of global energy consumption (Berg, Flyen, Godbolt, & Broström, 2017; Galatioto, Ricciu, Salem, & Kinab, 2019; Hong, Langevin, & Sun, 2018; Okutan, Kershaw, Fernandez, & Coley, 2018). 75% of the current building stock in the European Union is considered energy inefficient (Gremmelspacher, Pizarro, Jaarsveld, Davidsson, & Johansson, 2021). Retrofitting existing buildings could reduce energy use by 50–90% and even help reverse global warming (United Nations, 2021). Furthermore, it is estimated that by 2050, approximately 2 billion new homes will be built worldwide due to population growth (IPCC, 2025). All these reasons make it necessary to ensure energy efficiency in both existing building stock and newly constructed buildings.

Some of the existing buildings are cultural heritage buildings (Berg et al., 2017; Okutan et al., 2018). Although heritage buildings are designed in accordance with many passive design principles, they are inadequate according to today's energy performance criteria (Gremmelspacher et al., 2021; Li, Sun, Chen, & Yang, 2012). Therefore, energy retrofitting in heritage buildings is expected to yield effective results (Cho et al., 2020) and prevent the abandonment of these buildings (Gremmelspacher et al., 2021). However, when ensuring energy efficiency in heritage buildings, it is necessary to be much more sensitive than with existing buildings (Godwin, 2011) and to use different procedures (Cho et al., 2020; Santoli, 2015). Studies reveal that the issue is multidimensional, involving not only technical aspects but also the organization of legislations and implementation-monitoring mechanisms (European Committee for Standardization, 2017; Mazzarella, 2015; Santoli, 2015).

Mazzarella (2015) notes that, because buildings are one of the most significant energy consumers in Europe, numerous legislations have been enacted to reduce energy consumption in buildings. However, Mazzarella argues that these legislations exclude heritage buildings, while international legislations for the conservation of heritage buildings do not address energy efficiency. Mazzarella emphasizes that energy efficiency in cultural heritage buildings should be incorporated into policy at the European Union. De Santoli (2015) reports that a local guideline was prepared in Italy in 2014, aiming to ensure energy efficiency while fully respecting the cultural value of a building. Santoli notes that while this guideline has some shortcomings, it makes significant contributions to a harmonious and objective assessment of the relationship between energy efficiency and conservation criteria. In addition to Italy, some countries such as the United States and the United Kingdom have also developed their local legislation regarding energy efficiency in heritage buildings. Türkiye, due to its international responsibilities, needs to establish its local legislations to ensure energy efficiency in heritage buildings.

In this context, the purpose of this study is to present existing universal and local legislations for energy retrofits in heritage buildings through a literature review, contribute to improving their applicability, and offer suggestions for local legislations that should be developed specifically for Türkiye in the near future. Accordingly, this study will examine international conferences, summits, declarations, reports, protocols, agreements, charters, directives, and guidelines from the 20th century to the present, as well as local the Law, laws, presidential decrees, statutes, regulations, and directives.

THE LEGAL DEVELOPMENT PROCESS OF ENERGY EFFICIENCY AND CONSERVATION LEGISLATION

Milestones of International Conservation Legislation

Systematic methods on conservation of heritage buildings started to gain acceptance in the 20th century, particularly within Europe, and gradually began to spread on an international scale. During this period, science-based methods for conservation were developed and implemented through international conventions, charters, and the establishment of institutions (figure, 1).

The first significant step in this process was the Athens Charter (1931), which focused on the conservation of historical monuments. Subsequently, with the establishment of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1945, stronger institutional structures were established for the conservation of cultural

heritage at the international level (UNESCO, 2025). Today, UNESCO continues to be one of the most influential actors in the field of cultural heritage conservation in cooperation with the International Council on Monuments and Sites (ICOMOS).

The Venice Charter (1964) expanded the concept of conservation beyond the scale of historic monuments, considering buildings together with their environment. Moreover, the Charter mentioned that cultural value should be preserved not only for their artistic and aesthetic values but also for their significance as historical documents. Due to these enhancements, the World Heritage Convention (1972) introduced the "world heritage" concept at the international level, and the Declaration of Amsterdam (1975) highlighted the "integrity" concept.

The Granada Convention (1985) gained broad recognition, particularly in the context of structural strengthening. The Washington Charter (1987) contributed to the improvement of conservation at the urban scale, while the Nara Document on Authenticity (1994) emphasized the importance of regional and cultural differences in heritage conservation. The document emphasized that Japan's wooden and Europe's stone architecture could not be preserved using the same methods. Thereby, the significance of safeguarding authenticity was underlined.

In addition, Charter on the Built Vernacular Heritage (1999) contributed to the principle of sustainability by emphasizing that the adaptive reuse of heritage buildings is only appropriate when it ensures acceptable living standards. Since the last quarter of the 20th century, with the acceleration of the scientific and legal frameworks of conservation at the international level, numerous legal instruments have been enacted to address contemporary issues (figure, 2) (ICOMOS, 2025; Mazzarella, 2015; Young, 2016).

Most recently, the 2021 ICOMOS Policy Guidance for Heritage and Development Actors in the Context of the Sustainable Development Goals has emerged as one of the most comprehensive and up-to-date instruments in this field, highlighting energy efficiency and structural strengthening within the broader framework of cultural heritage sustainability (ICOMOS, 2025; Young, 2016).

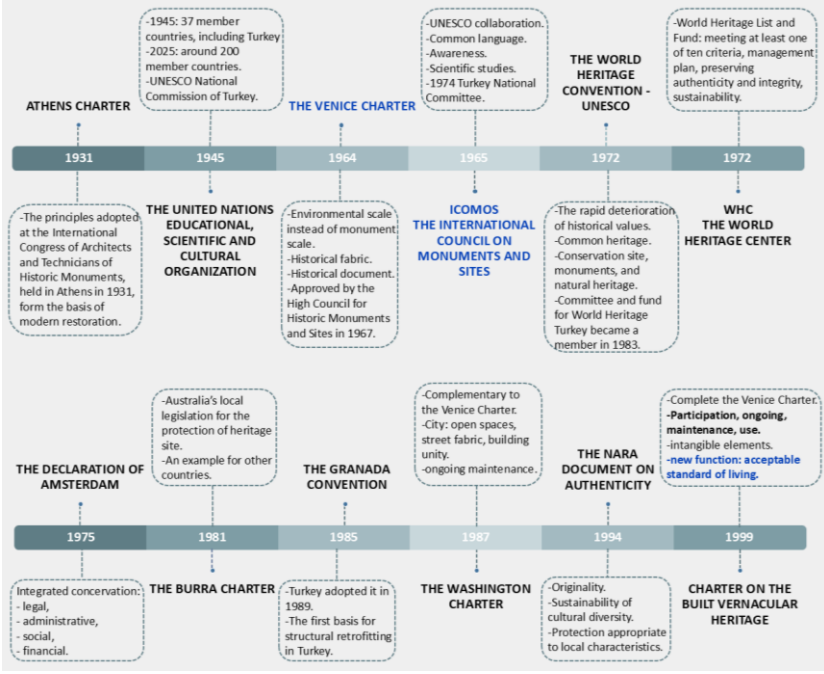


Figure 1. The Development Process of International Conservation Legislation

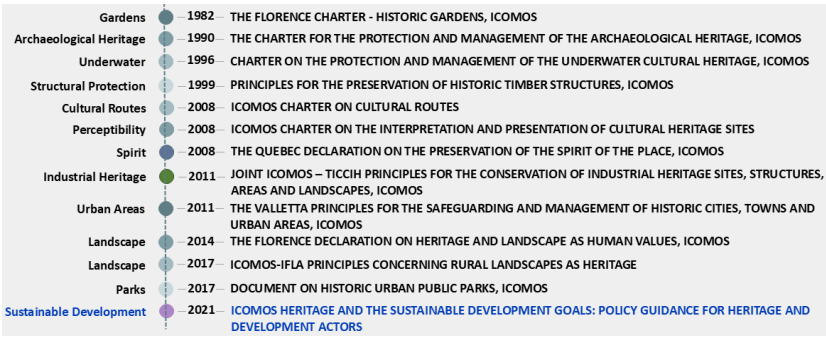


Figure 2. Selected Additional International Conservation Legislation

Milestones of Conservation Legislation in Türkiye

The first legal regulation concerning the conservation of heritage buildings in Türkiye was the *Âsâr-ı Atîka* Regulation of 1906, which addressed conservation at the scale of individual monuments (figure, 3). Subsequently, in 1933, the *Anıtlar Koruma Kurulu* was established, and in 1951, it was replaced by the *Gayrimenkul Eski Eserler ve Anıtlar Kurulu*.

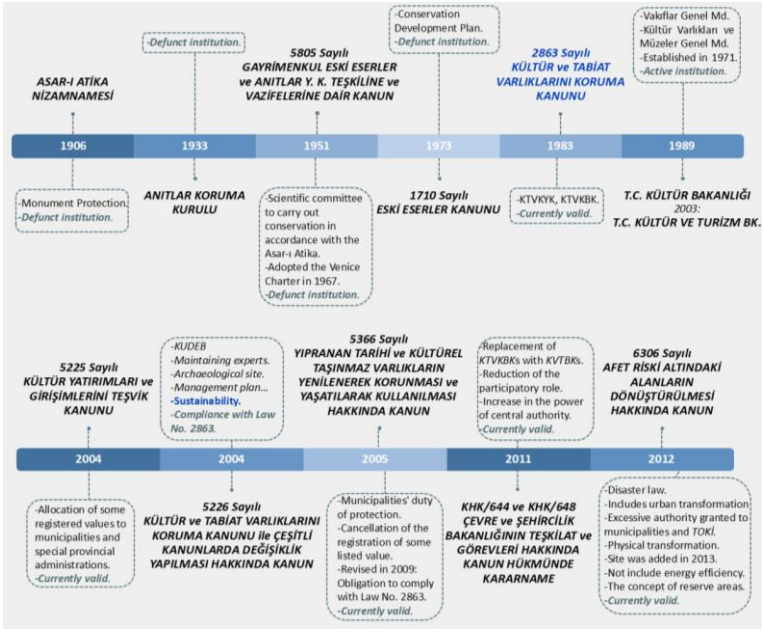


Figure 3. The Development Process of Conservation Legislation in Türkiye

A significant turning point in the concept of conservation occurred in 1973 with the enactment of the *Eski Eserler Kanunu*, which shifted conservation from the scale of historical monuments to that of archaeological and urban sites. In 1983, this law was replaced by Law No. 2863 on the *Kültür ve Tabiat Varlıklarını Koruma Kanunu*, which remains in force today. Within this framework, the *Kültür ve Tabiat Varlıklarını Koruma Yüksek Kurulu (KTVKYK)*, and the *Kültür ve Tabiat Varlıklarını Koruma Bölge Kurulları (KTVKBK)* were established as decision-making and implementing bodies (Kayasu, 2018). Law No. 2863 has been updated through various amendments over time, with new concepts such as site management being incorporated into the legislation. In 1989, the Ministry of Culture was established as the competent authority in this field.

Decree Law No. 644 - Çevre ve Şehircilik Bakanlığının Teşkilat ve Görevleri Hakkında Kanun Hükmünde Kararname (2011), which indirectly influenced conservation legislation, established the Ministry of Environment and Urbanisation, transferring the responsibility for the conservation of natural values to this ministry. As a result, the name of the *KTVKYK* was changed to the *Kültür Varlıklarını Koruma Yüksek Kurulu*

(KVKYK). The name of the *KTVKBK* was changed to the *Kültür Varlıklarını Koruma Bölge Kurulları (KVKBK)*. Most recently, in 2021, in order to strengthen Türkiye's institutional framework for addressing climate change, the ministry was redesigned and renamed as *The Ministry of Environment, Urbanization, and Climate Change*.

Milestones of International Energy Legislation

Since the last quarter of the 20th century, there has been a growing tendency to decrease the damaging impacts of human activities on the environment, to provide future generations access to conditions and resources equal to those of today (figure, 4). The issue of environment and sustainable development was addressed for the first time at a panel held in Switzerland in 1971, where it was stated that environmental problems are the result of poverty and underdevelopment. Then, the First United Nations Conference on the Human Environment, held in Stockholm in 1972, attracted considerable interest. At the conclusion of the conference, the Report of the United Nations Conference on the Human Environment was issued (United Nations, 2025).

The universal legal development concerning energy efficiency gained momentum following the oil crisis that emerged after the 1973 Yom Kippur War, with the oil embargo imposed by OPEC member Arab countries on the United States and several other nations. Although the primary objective during this period was to ensure economic security rather than sustainability, the concept of sustainable development began to gain international significance.

As a result of the United Nations General Assembly held in 1983, the report Our Common Future (1987) also known as the Brundtland Report, was published, marking a significant milestone. It is stated in the report that sustainable development is possible, ensuring the requirements of the present without preventing the capability of future generations to meet their own needs (Our Common Future, 1987).

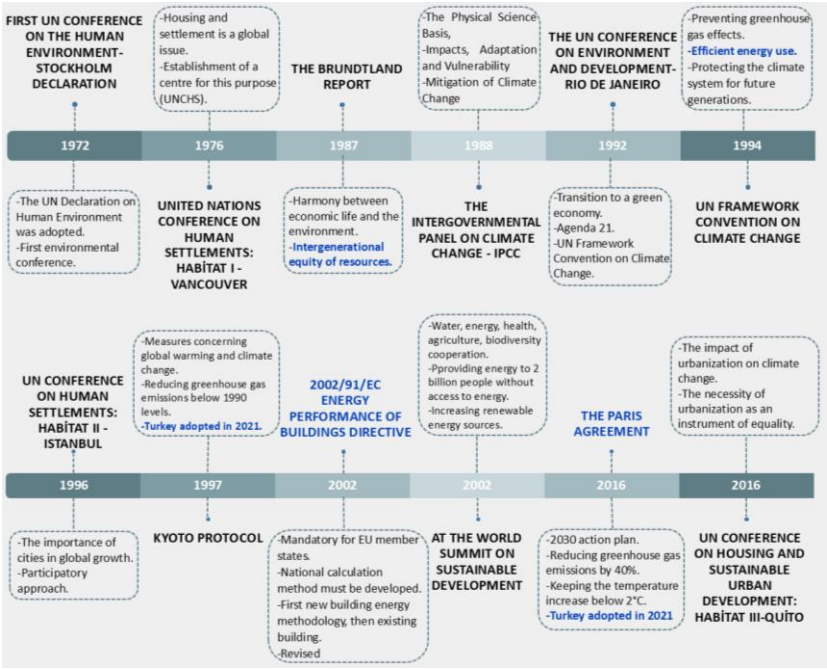


Figure 4. The Development Process of International Energy Legislation

Another international platform drawing attention to the impact of urbanization on climate change is the Habitat Conferences of the United Nations. At Habitat I, held in 1976, it was stated that 37.9% of the world's population lived in urban areas. This figure rose to 45.1% at Habitat II (1996) and to 54.5% at Habitat III (2016). Moreover, projections of these conferences point out that two-thirds of the world's population will be living in cities by 2050. Consequently, it is emphasized that both healthy urbanization and mitigating the unwanted effects of climate change are necessary (Meath, 2023; United Nations, 2025).

In addition, in 1988 the Intergovernmental Panel on Climate Change (IPCC) was established as a body of the United Nations with the aim of providing regular assessments on the scientific basis of climate change, its impacts and future risks, as well as options for adaptation and mitigation (IPCC, 2025; Meath, 2023; United Nations, 2025). The IPCC publishes reports approximately every 6–7 years under three main headings: *The Physical Science Basis*, *Impacts, Adaptation and Vulnerability*, and *Mitigation of Climate Change*.

The United Nations Conference on Environment and Development, focusing on sustainable development, was held in Rio de Janeiro in 1992

with the participation of 179 countries (117 heads of state). During this conference, several international agreements were signed, comprising the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change (UNFCCC), and Agenda 21 (Akgül, 2010). One of the significant results of the UNCED Conference was Agenda 21, suggesting new approaches to invest in the future for achieving overall sustainable development in the 21st century. The UN Framework Convention on Climate Change highlights main strategies as preventing the greenhouse effect, promoting energy efficiency, and slowing down or halting the adverse impacts of climate change, such as global warming (Ellison, Mosley, & Helman, 2017; United Nations, 2025).

The Kyoto Protocol was an important step taken to combat global warming and climate change by agreeing to reduce greenhouse gas emissions below 1990 levels (Kyoto Protocol, 1997; United Nations, 2025). Following the 2002 World Summit on Sustainable Development held in Johannesburg, South Africa, a 153-article document was published. The document addressed more effective strategies than those previously developed, including cooperation on issues such as water, energy, health, and biodiversity, access to energy in regions without electricity, and increasing the use of renewable energy sources (Koch, 2003; Nepsha et al., 2024; United Nations, 2025).

The Paris Agreement was adopted by 195 Parties at the UN Climate Change Conference (COP21) in Paris. The Paris Agreement is a milestone in the multilateral climate change process. The Agreement encompasses targets such as reducing greenhouse gas emissions by 2030 to keep the increase in global temperature well below 2°C, and to pursue efforts to limit it to 1.5°C (Dritsaki, Niklis, & Stamatiou, 2021; The Paris Agreement, 2015). By signing the Paris Agreement in 2021, Türkiye undertook to meet the 2050 targets. In this context, Türkiye announced at the 27th Conference of the Parties (COP 27) held in 2022 that it aims to achieve net-zero emissions by 2053. Türkiye has emphasized the importance of policies such as increasing energy efficiency to achieve this net zero target (T.C. Dışişleri Bakanlığı, 2022).

9 out of the 17 United Nations Sustainable Development Goals (2015) are directly related to the built environment. This is because today, approximately 40% of global carbon emissions and more than 30% of global final energy consumption originate from the built environment, which also consumes nearly half of the world's natural resources (Wbcsd, 2021). This situation has increasingly highlighted the importance of energy efficiency improvements in historic buildings. In recent years,

several regulations and standards have been developed to enhance the energy performance of historic buildings (figure, 5).

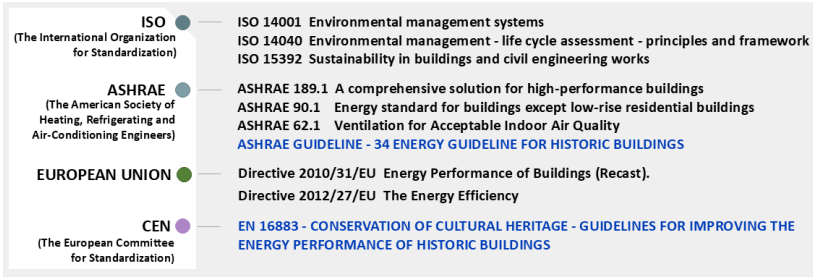


Figure 5. Selected Additional International Energy Legislation

In this regard, the American standard "ASHRAE Guideline 34 – Energy Guideline for Historic Buildings", together with the European Union's "EN 16883 – Conservation of Cultural Heritage - Guidelines for Improving the Energy Performance of Historic Buildings", are among the most important recent regulations addressing energy efficiency and cultural heritage conservation within an integrated framework (Dritsaki et al., 2021; Mazzarella, 2015).

Milestones of Energy Legislation in Türkiye

The first step taken in the field of energy in Türkiye (figure, 6) was the establishment of the *Elektrik İşleri Etüt İdaresi Genel Direktörlüğü* in 1935. In 1963, the Ministry of Energy and Natural Resources was founded, and within this framework, the aforementioned administration was affiliated with the ministry and renamed the *Elektrik İşleri Etüt İdaresi Genel Müdürlüğü* (Zeytinli, 2010).

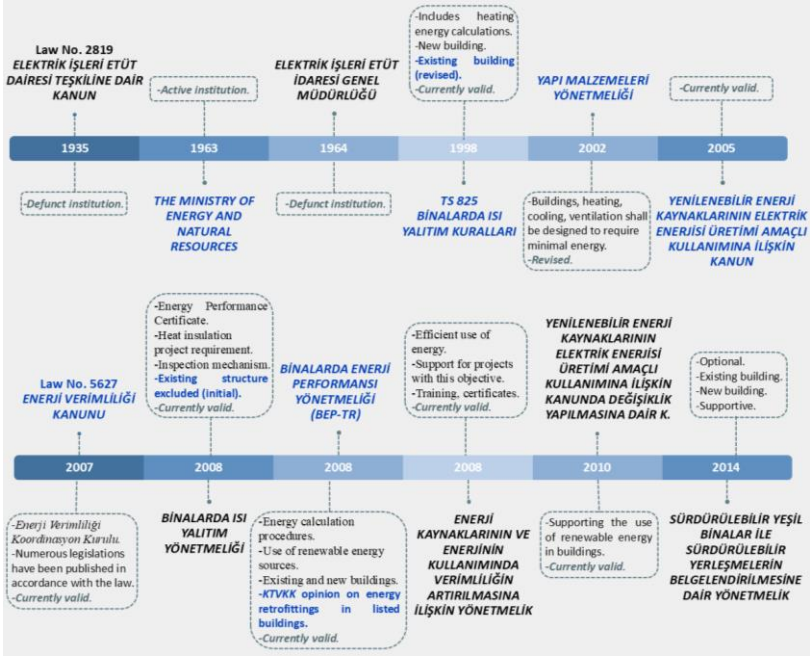


Figure 6. The Development Process of Energy Legislation in Türkiye

The first legal step toward energy efficiency was taken in 1981, when thermal insulation measures in new buildings were introduced into legislation. This process was followed in 1998 by the enactment of *TS 825-Binalarda Isı Yalıtım Kuralları Standardı*, which covered energy efficiency in new buildings. In later years, the scope of this standard was expanded to include existing buildings as well; however, it is noteworthy that heritage buildings were excluded from this framework.

The *Yapı Malzemeleri Yönetmeliği*, adopted in 2002, aimed at minimizing energy use in heating, cooling, and ventilation. In 2005, Law No. 5346 on the *Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına İlişkin Kanun* entered into force. Türkiye's fundamental legislation in the field of energy, however, is the *Enerji Verimliliği Kanunu* Law No. 5627, enacted in 2007. With this law, numerous regulations, circulars, and communiqués related to energy were put into practice.

Within this framework, in 2008, the *Binalarda Isı Yalıtım Yönetmeliği* (No. 27019) and the *Binalarda Enerji Performansı Yönetmeliği (BEP-TR, No. 27075)* were published. The Thermal Insulation Regulation made the Energy Performance Certificate mandatory for newly constructed buildings, and subsequent amendments enlarged this requirement to

include existing buildings as well. The *BEP-TR* Regulation, on the other hand, covers energy performance calculations, the applicability of renewable energy sources, and energy efficiency standards.

Since 2014, regulations concerning green building certification systems have been introduced in Türkiye; however, they have not yet become mandatory. In addition, various institutions and organizations, such as the Turkish branch of the International Solar Energy Society, which has been active since 1992, have also played a role in shaping the development of national energy policies.

In addition to the aforementioned legislation, the *Çevre Kanunu* is also of significant importance with its emphasis on a sustainable environment and sustainable development. This law provides a noteworthy legal framework both for the preservation of heritage buildings and for ensuring energy efficiency.

LEGAL INTERACTION BETWEEN CULTURAL HERITAGE CONSERVATION AND ENERGY EFFICIENCY

The national legislation on the conservation of heritage buildings has some statements as observed in Article 63 of The Basic Law (1982), titled Protection of Historical, Cultural and Natural Assets. This article states that the State will provide for the conservation of historical, cultural, and natural characteristics and values by taking supportive and incentive measures for this purpose. This provision makes the conservation of cultural and natural assets obligatory and places it under state guarantee. In this context, Law No. 2863 on the *Kültür ve Tabiat Varlıklarını Koruma Kanunu* was enacted to put the concept of conservation into practice within the framework of international charters and declarations signed by Türkiye (Ristawati, Salman, Fitriany, & Taskesen, 2025).

Initially adopted in 1983, this law has been supported and updated by subsequent regulations, such as Law No. 5226. In Article 3, titled *Definitions and Abbreviations*, the definition of a zoning plan includes the *phrase protection of cultural and natural assets in line with the principle of sustainability*. In contrast, the definition of an environmental planning project includes the phrase *meeting the needs of the area with facilities required by contemporary technological developments*. In conclusion, the fundamental national law in the field of heritage conservation, Law No. 2863, approaches energy efficiency mainly through general principles such as sustainable conservation, compliance with contemporary needs, and integration of technological

developments. However, it does not explicitly define energy efficiency as a direct field of application.

In addition, Article 9 of Law No. 2863, titled *Prohibition of Unauthorized Intervention and Use*, defines *major repair, construction, installation, drilling, partial or complete demolition, burning, excavation, or similar works* as structural and physical interventions, and stipulates that such interventions cannot be carried out without the approval of the Conservation Boards (*KVKYK* and *KVKBK*). It is observed that, through the principal decisions taken by the conservation boards, the construction of renewable energy facilities has been permitted in specific protected sites. With Principle Decision No. 658, it was stated that *in line with the principle of ensuring the conservation-use balance, wind power plants may be constructed in third-degree archaeological sites, provided that the conservation board approves them*. Principle Decision No. 688 declared that *in line with the growing global importance of utilizing resources that do not adversely affect the environment, proposals for the construction of wind power plants in natural sites may be evaluated by the conservation boards, based on the opinions of the relevant public institutions and organizations*. According to Principle Decision No. 728 *in first-degree natural sites, technical infrastructure services may be carried out in a manner deemed appropriate by the regional conservation board; applications related to the use of natural spring water shall be implemented due to university reports and the aspects of the Ministry of Environment and Forestry and the General Directorate of State Hydraulic Works; and applications related to the use of geothermal resources shall, in addition to these, be carried out with the aspects of the Ministry of Energy and Natural Resources (General Directorate of Mineral Research and Exploration) and the Ministry of Culture and Tourism's General Directorate of Investment and Enterprises, in a manner approved by the regional conservation board.* Through these principal decisions, the authority of conservation boards to permit energy production and infrastructure projects under specific conditions demonstrates that energy efficiency and the use of renewable energy have also become part of conservation policies in cultural heritage areas (Anadolu Agency, 2018).

Several regulations, such as *Koruma Amaçlı İmar Planları ve Çevre Düzenleme Projelerinin Hazırlanması, Gösterimi, Uygulaması, Denetimi ve Müelliflerine İlişkin Usul ve Esaslara Ait Yönetmelik* issued for the implementation of Law No. 2863, emphasize the principle of sustainable conservation. However, it does not include specific provisions regarding energy efficiency.

The most prominent legislation in which the concept of sustainability in conservation is emphasized is the *Mekansal Planlar Yapım Yönetmeliği*. Article 1 of this regulation defines its purpose as protecting and improving physical, natural, historical, and cultural values; to ensure the balance between conservation and use; to support sustainable development at national, regional, and urban levels; and to establish the procedures and principles for the preparation and implementation of spatial plans, which introduce land-use and construction decisions aimed at creating high-quality, healthy, and safe living environments. Article 14 of the Regulation states *ensuring the sustainable use of resources in planning*; Article 19 provides that *in environmental plans, ecological and economic decisions shall be evaluated together in line with the objective of sustainable development*; and Article 27 stipulates that *in conservation-oriented zoning plans, strategies specific to the area shall be developed to ensure the sustainable and livable preservation of the historical, cultural, and natural environment, and where necessary, goals, strategies, and implementation principles shall be set to make the activities and building stock within registered cultural properties and protected areas more resilient and secure against disasters such as earthquakes, floods, landslides, fires, and rockfalls*. As a summary, while the Regulation on the Preparation of Spatial Plans sets objectives such as sustainable development, disaster resilience, and efficient use of resources, it does not explicitly include the concept of energy efficiency.

In national conservation regulations, the concept of energy improvements in Türkiye is not explicitly addressed; rather, it is considered mainly from a sustainability perspective. However, in international legislation, energy efficiency is addressed in a more consistent manner, even if not fully comprehensive. In this context, the Venice Charter and the Valletta Principles are particularly prominent.

The Venice Charter (1964) presents several fundamental conservation principles, and scientific conservation methods comprising the necessity of using heritage for beneficial social purposes; the requirement to preserve heritage in situ and together with its surroundings whenever possible; the use of original materials in conservation; the allowance of reliable modern techniques when traditional methods are insufficient; interventions based on trustworthy documentation; permitting additions only when they do not harm the building's significant features or its relationship with the surroundings; preserving archaeological sites as they are; and ensuring that new applications are reversible. In this context, the Charter necessitates the development of intervention methods for energy efficiency that do not compromise the building's

exterior envelope or spatial integrity. It also requires that energy improvements be both scientifically grounded and reversible.

The Valletta Principles (2011) are among the first international documents to address energy efficiency in heritage areas explicitly. The principles state: *Changes in historic towns and urban areas must respect the natural balance; the depletion of natural resources, the waste of energy, and the disruption of natural cycles must be avoided. Interventions in historic towns and urban areas should not destroy the identity of cultural heritage and save their character, but also aim to improve energy efficiency and reduce pollutants. The renewable energy usage should be promoted. New constructions in historic areas must be energy-efficient. Urban planning considering green spaces and corridors; Pedestrian mobility supported by the restriction of vehicle traffic and the reduction of parking opportunities are the main strategies to prevent the heat island effect. Sustainable, non-polluting public transport systems should be implemented, and soft mobility options developed.* These principles provide an important example of how heritage buildings can be approached holistically and sustainably from the perspective of energy efficiency.

The legal framework for energy efficiency in Türkiye was established by the *Enerji Verimliliği Kanunu*. This law initially mandated energy performance certification for new buildings. Over time, amendments have also brought existing buildings into the scope of the law. This legislation explicitly excludes protected buildings and monuments. This demonstrates that energy legislation is sensitive to the conservation of cultural heritage but adopts a passive approach.

The *Binalarda Enerji Performansı Yönetmeliği*, issued based on Law No. 5627, stipulates in its provisional Article 3 that for existing buildings and those under construction that have not yet obtained a building occupancy permit, an Energy Performance Certificate must be issued within 10 years from the publication date of the Law. However, Article 2 explicitly states that energy efficiency applications for registered (heritage) buildings must be carried out in accordance with the opinions of the Conservation Boards (*KVKYK* and *KVKBK*), effectively exempting heritage buildings from the Energy Performance Certificate requirement.

Similarly, Article 8, additional paragraph of Law No. 5346 on the *Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına İlişkin Kanun* (2010) stipulates that: *The establishment of electricity generation facilities based on renewable energy sources is permitted in national parks, nature parks, natural monuments, protected*

natural areas, reserved forests, wildlife development areas, and special environmental protection zones, subject to the positive opinion of the relevant Ministry; in natural site areas, the approval of the relevant Conservation Regional Board is required (The Official Gazette, 2010).

Another national energy legislation, the *Yapı Malzemeleri Yönetmeliği*, explicitly exempts cultural heritage from its scope in Article 7. The relevant article states: *For building works identified and registered under Law No. 2863, and officially protected in accordance with the said Law for the conservation of cultural heritage -either as part of a specific environment or due to their special architectural and historical value- if the renovation is carried out using non-industrial processes, a performance declaration may not be required* (The Official Gazette, 1983).

The Energy Performance of Buildings Directive (2002/91/EC and revised 2010/31/EU) contains important procedures regarding energy efficiency on an uneversal scale. Under this directive, heritage buildings may be granted exemptions from energy performance requirements due to the risk of unacceptably altering the building's historical or architectural character, indicating that energy legislation demonstrates a principle of sensitivity toward the conservation of historic buildings at the global level. However, the directive does not provide a comprehensive strategy or implementation guide for how this sensitivity should be addressed.

With all these regulations, it is observed that national legislation for the cultural heritage conservation does not define energy efficiency directly or explicitly. Instead of it, it is mentioned indirectly within the principles such as sustainability, compliance with contemporary needs, and integration of technological developments. Although energy efficiency is not defined as a direct field of application, it can be said that the use of renewable energy sources is permitted to a limited extent under specific criteria. At the international level, it can be argued that energy efficiency and sustainability principles are integrated into heritage conservation legislation with a more balanced approach.

On the other hand, universal and national legislations on energy efficiency prioritize preserving the authenticity and historical character of heritage buildings. Accordingly, various exemptions have been granted to these buildings in energy efficiency practices, demonstrating that energy legislations are sensitive to the concervation of cultural heritage, but adopt a somewhat passive approach. Consequently, energy legislations do not offer a comprehensive strategy or implementation guide for addressing this sensitivity.

In this context, the first step taken in the field of heritage conservation is the ICOMOS Heritage and the Sustainable Development Goals: Policy Guidance for Heritage and Development Actors. However, instead of providing direct technical standards, this guidance recommends the development of energy efficiency standards specific to cultural heritage buildings (Kairiss, Geipele, & Olevska-Kairisa, 2023).

Conservation of Cultural Heritage: Guidelines for Improving the Energy Performance of Historic Buildings (EN 16883:2017) is the first comprehensive European guideline aimed at enhancing energy performance in historic buildings (Broström et al., 2021; Leijonhufvud, Buda, & Broström, 2021; Mazzarella, 2015; Mazzarella & Alfano, 2017). The document emphasizes that energy efficiency improvements must be carried out in a manner compatible with the original character, material properties, and cultural values of historic structures. Accordingly, it provides decision-making steps based on assessing the current energy performance, identifying potential improvement measures, and analyzing the impact of each measure on both energy efficiency and heritage value.

Energy Guideline for Historic Buildings (2019) under (ASHRAE Guideline 34) provides heritage-specific solutions for implementing energy improvements in historic buildings without compromising their original character, materials, or cultural values. The guideline primarily focuses on establishing the building's energy consumption profile and preserving passive energy-saving features. It recommends a staged approach, firstly implementation of low-impact and recyclable measures, followed by improvements to mechanical systems. As a guideline, it serves as a comprehensive and pioneering reference in the field of energy management for historic buildings, offering strategies and methods that can be applied at an international level.

Additionally, some countries, such as Belgium, the United Kingdom, and Italy, have developed their own regional legislation concerning energy efficiency improvements in heritage buildings. In this context, Türkiye must also urgently develop similar regional legislation aimed at the preservation of historic buildings and the enhancement of energy performance.

CONCLUSION

In recent years, ensuring energy efficiency in historic buildings has been regarded not only as a technical requirement but also as a strategic necessity for the preservation of cultural heritage and the achievement of sustainable development goals. In this context, academic research

has focused on energy efficiency potentials, from improvement measures that do not disturb the original values of heritage buildings to interventions that may be risky or potentially harmful, focusing on developing optimal solutions through cost-effectiveness analyses. However, the implementation of some improvement measures may be unacceptable due to the heritage value of the building. Therefore, guiding legal legislations in this field are of great importance.

At a global scale, it can be observed that energy regulations have long excluded heritage buildings without developing special procedures or standards that respect their original values. On the other hand, international heritage conservation regulations do not address energy efficiency directly but provide an indirect framework within the scope of the sustainability principle.

In this context, international guidelines prepared at a global scale, such as ASHRAE Guideline 34 (2019) and EN 16883 (2017), stand out as key reference documents emphasizing that energy improvements in historic buildings should be carried out in a manner consistent with the building's original character and cultural values. Some countries have also developed their national legislation based on these guidelines.

In the context of Türkiye, the energy efficiency potential of heritage buildings has not been sufficiently utilized. The existing legislation has not developed a comprehensive approach. The exclusion of heritage buildings from energy efficiency laws hinders the development of innovative solutions in this field. In contrast, the absence of the concept of energy efficiency in conservation legislation limits the contribution of current practices to sustainable development goals. Therefore, developing national procedures that integrate the preservation of heritage buildings with energy efficiency is important both for fulfilling international legislation and ensuring the sustainable maintenance of these buildings.

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SHIFTING PRIORITIES IN ARCHITECTURE: FROM ECONOMIC AND TECHNOLOGICAL OPTIMIZATION TO SOCIAL SUSTAINABILITY

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ABSTRACT

Architectural priorities have undergone a significant transformation from early approaches focused on economic and technological optimization to a more comprehensive, multidimensional framework. This evolution has included environmental priorities such as safeguarding ecological integrity and adopting regenerative strategies, and more recently, the social dimension, with participatory processes and cultural inclusivity recognized as indispensable for sustainable development. This paper examines this evolution by analyzing the shifting focus across three core axes: economic-technological, environmentally oriented, and social. It argues that environmental sustainability is fundamentally reliant on a strong social dimension, as it cannot be achieved without considering human attitudes and behaviors. The central contribution of this research is the development of the Approach-Action Network in the Sustainability Framework. This visual tool organizes various sustainability theories according to the key actions they prioritize and highlights their highlights in order. The framework demonstrates that a core, timeless hierarchy of actions exists, and that some actions are more foundational than others. The paper concludes that sustainability in architecture is not a fixed perspective offering purely technological and economic solutions, but a dynamic process that also prioritizes community and takes context into account. Therefore, for future architectural practice, the fundamental question should move beyond "which dimension to prioritize?" to "which actions are more important to fulfill?". Ultimately, the priority of architecture is to treat these dimensions not as separate objectives, but as dynamic processes that evolve in interaction with one another.

Keywords: Social Sustainability, Holistic Design, Community Engagement, Environmental Awareness, Sustainable Design Priorities

INTRODUCTION

In architectural discourse, the concept of sustainability has evolved from initial economic and technological priorities to a more comprehensive, multidimensional framework that increasingly integrates environmental and social concerns. To better understand this transformation, an analysis tracing the shifting focus across these three axes, economic-technological, environmental, and social, is essential. This paper examines these evolutions to propose a new framework, the Approach-Action Network in Sustainability Framework (Figure 1), which clarifies how different theories prioritize specific actions and how these dimensions intersect and reinforce one another.

After the 1970s, energy crises, material innovations, environmental policies, and computer-aided design tools brought measurable performance criteria to the forefront. Architecture is increasingly focused on reducing energy consumption and costs through technical and technological solutions, for example, by using high-performance facade systems.

However, it was not until the 1990s that this discourse was framed within a more holistic context. During this period, publications such as Brundtland's "Our Common Future" (Brundtland, 1987) introduced environmental and social dimensions as key components of sustainability, moving the debate beyond purely technical and economic considerations. This shift began to blur the distinction between architecture's technological function and its socio-ecological role.

Since the 2010s, sustainability has expanded further to encompass social justice, user participation, cultural continuity, and a sense of belonging. Social sustainability thus emerged as a critical concern, intersecting with technological optimization and environmental awareness. Architects increasingly aimed not only for efficiency but also for equity, cultural preservation, and community well-being, leading to a more holistic view of the building lifecycle—from design and construction to use and eventual deconstruction.

This paper analyzes the historical evolution of sustainability discourse, searching for sustainable approaches, their main goals, and limitations within each of the three dimensions. The aim is to interpret this evolution not only through technical progress but also in its social and cultural dimensions, thereby providing a comprehensive outlook that can inform future design approaches. The central contribution of this study is the development of the Approach-Action Network in Sustainability

Framework (Figure 1). This visual tool organizes diverse sustainability approaches based on the key actions they prioritize, serving as a dynamic roadmap for a more holistic practice. In this way, the framework suggests that the true priority is not to address every goal simultaneously, but to strategically sequence and prioritize actions.

The Rise Of Economic-Technological Optimization

In the 1970s, the oil crisis brought design approaches aimed at reducing energy consumption and optimizing costs to the forefront of architecture. Solutions that sought to lower the operating expenses of buildings and minimize resource use became a necessity due to rising energy prices and economic fluctuations. Among the architectural strategies of this period, building envelope optimization to reduce heat loss, natural lighting, and passive climate control were widely implemented.

David Harvey (Harvey, 1973, 2003) and Henri Lefebvre (Lefebvre, 1967, 2015) are two key figures who critiqued the capitalist dynamics of cities while discussing urban environmental issues within a Marxist framework. Green Marxism, meanwhile, offers a deep critique of capitalism by framing environmental issues within the context of social inequality and class struggle, merging Marxist theory with the environmental movement. As Naomi Klein highlights in her book *This Changes Everything* (2015), the climate crisis is directly linked to capitalism, and its solutions must be sought in models that restrain corporate dominance while supporting local economies and democracies.

Approaches that believe the ecological footprint of cities can be reduced by decreasing and optimizing the consumption of natural resources and energy by urban residents are mostly classified under the New Urbanism movement. This approach, which remains relevant today, can be traced particularly to the work of Herbert Girardet (Girardet, 1993), who focused on regulating energy and resource use in cities without disturbing ecological balance, and Peter Calthorpe (Calthorpe, 1997), who proposed a system that integrates low-carbon living with public transport, pedestrian-friendly design, density, and mixed use. In later phases, this movement also incorporated debates on diversity and environmental awareness.

Developed in Germany and the Netherlands in the 1980s, Ecological Modernization Theory is largely attributed to sociologist Joseph Huber, though in fact it was simultaneously and subsequently expanded by many other researchers (Gülçur, 2012). This theory argues that environmental protection and economic growth can occur simultaneously. As solutions, it proposes the development of clean

technologies, the greening of existing technologies, institutional and political adjustments to support these changes, and the promotion of environmental awareness to ensure broad societal participation. The concept of the Green Economy, which prioritizes environmental sustainability and social welfare, pursues comparable goals. Rather than a cyclical model, however, it emphasizes a more general framework that focuses on reducing energy consumption, lowering carbon emissions, and increasing energy efficiency—reinforced by stricter environmental legislation.

In this period, the widespread adoption of Computer-Aided Design (CAD) and energy simulation software made it possible to integrate energy performance analyses into the early stages of the design process. This development not only enabled cost-effective solutions but also facilitated the creation of integrated efficiency models through engineering innovations. Double-skin façade systems, integrated shading devices, automated ventilation control, and high-performance insulation materials were among the prominent technical solutions of the era.

At the architectural scale, green buildings that combined technology and environmental sensitivity were informed by Ecological Modernization Theory and the Green Economy approach, along with related or similar frameworks. Among the leading architects associated with these developments were Renzo Piano, whose projects include the California Academy of Sciences in San Francisco; Norman Foster, with works such as City Hall in London; and Ken Yeang, who particularly focused on high-rise buildings and articulated his approach in *The Green Skyscraper* (Yeang, 1999).

By the early 2000s, the concept of the Circular Economy came to the forefront. With the publication of *Cradle to Cradle: Remaking the Way We Make Things* by chemist Michael Braungart and architect William McDonough (McDonough & Braungart, 2002), the earlier "cradle-to-grave" model of take–make–dispose was reframed into a "cradle-to-cradle" approach, centered on reuse, repair, and recycling. Supported by policies in China and the European Union, the circular economy aimed not only at resource efficiency and waste reduction but also at fostering consumption awareness and raising social consciousness.

Another significant economic approach that emerged during this period was the Welfare Economy. It measures the overall welfare of society through factors such as access to healthcare and education, improved income distribution, social justice, better social services, and enhanced quality of life, aiming to enhance social welfare.

Table 1. Economic-Technological Sustainability Approaches and Their Prioritized Actions

		Actions and Sustainability Dimensions	Sustainability Approaches					
			Green Marxism	New Urbanism	Ecological Modernization	Green Economy	Circular Economy	Welfare Economy
	ECONOMICAL - TECHNOLOGICAL	utilization of technological advancements			x			x
		ensuring equitable income distribution	x					x
		improvement of social services						x
ECOLOGICAL		reduction of energy consumption		x		x		
		reduction of waste					x	
		reduction of carbon emissions			x	x		
		promotion of renewable energy and energy efficiency			x	x		
		conservation and efficient use of natural resources		x	x	x	x	
		balanced land use (urbanization– agriculture–natural areas)		x				
		enhancing environmental awareness and ecological literacy		x	x	x	x	
SOCIAL		achieving social justice	x					x
		supporting local democracies	x					
		fostering local participation and ownership		x				
		strengthening and enforcing the legal framework			x	x		
		raising consumer awareness				x	x	

The theoretical perspectives of economic–technological sustainability approaches discussed in the text are listed in Table 1 according to the actions they prioritize. This organization clarifies which priorities each approach focuses on, the common intersections they share, and the aspects in which they diverge.

As shown in the table, Ecological Modernization and the Green Economy are linked to a broad spectrum of actions and, by extension, to multiple dimensions of sustainability. In contrast, Green Marxism focuses on social justice and equitable income distribution, while New Urbanism emphasizes balanced land use and local participation. This visualization demonstrates that economic-technological optimization should not be understood as a one-dimensional strategy, but as a diverse field shaped by differing ideological commitments and practical orientations.

However, economic-technological approaches have also been subject to various criticisms. The Circular Economy has been criticized for its failure to challenge capitalism's underlying imperatives of consumption and growth; Green Marxism for attributing all problems solely to capitalism; the Green Economy for offering only limited improvements within the existing system; and the Welfare Economy for being difficult to

implement due to the large-scale transformations it requires. More broadly, these approaches have been questioned for their strong dependence on technological fixes, their neglect of social justice issues, and their tendency to propose short-term solutions.

When viewed in terms of energy savings, these technological and economic approaches undoubtedly provide measurable benefits. Yet attempting to solve problems rooted in industrialization and overconsumption with high-tech solutions that themselves require intensive industrial resources produces an inherent paradox. Moreover, considering the significant budgets required for these energy-saving measures, their impact on economic sustainability poses another challenge.Despite such criticisms, strategies developed under the primacy of technological and economic approaches, particularly those focused on energy efficiency and technological integration, helped lay the foundation for a more systemic and multidimensional understanding of sustainability in later years, where environmental and social goals are increasingly intertwined.

Environmentally-Oriented Approaches

In some eco-philosophical approaches, environmental issues have been addressed from a human-centered perspective, framed as problems defined and explained primarily through a human lens. In contrast to these weak anthropocentric approaches, the concept of *Deep Ecology*, a nature-centered (biocentric) view that rejects the idea of human superiority or privilege within nature, was first introduced by philosopher Arne Naess in 1973 (Naess, 1973). This approach calls for a reconfiguration of the human–nature relationship, emphasizing solutions such as enhancing ecological awareness, fostering environmental consciousness, and reestablishing social–ecological justice.

The perspective known as Ecocentric Ethics asserts that nature itself carries intrinsic worth and should be protected on moral grounds. It rejects the reduction of nature to a mere instrument for human use, emphasizing instead the inherent significance of ecosystems, species, and ecological functions. In this way, responsibility is shifted from human-centered needs toward maintaining the wholeness and balance of ecological systems. Although it may be less effective than Deep Ecology in offering radical or systemic transformations, ecocentric ethics provides a complementary perspective by emphasizing the necessity of safeguarding ecological processes and raising awareness about the efficient use and conservation of natural resources.

Emerging in the 1970s, Permaculture also emphasizes the efficient use of natural resources, addressing waste management and sustainable

agricultural policies while rethinking the human–nature relationship. In architecture, this is reflected in self-sufficient buildings, sustainable water management, green roofs, vertical gardens, passive climate control, and waste management systems, all of which embody ecological solutions that prioritize passive strategies.

Although more holistic approaches dominate contemporary discourse, Pastoral Ecology can still be considered a relevant ecological perspective when understood as an extension of earlier frameworks. It advocates an integrated management of agriculture, animal husbandry, and natural resources. Aldo Leopold, whose *A Sand County Almanac* (Leopold, 1949) played a pivotal role in laying the foundations of ecocentric ethics and who is recognized as a leading figure of environmental conservation, also stands among the precursors of pastoral ecology. Central to this approach is the idea that ecosystem management should remain adaptive and flexible in response to changing environmental conditions and emerging scientific knowledge, particularly within the context of sustainable agriculture.

Among environmentally focused theories, Ecophenomenology offers a distinctive framework. It challenges human-centered notions of nature by underlining the ways people experience and interpret their surroundings. In this view, nature is not a passive backdrop but an active presence that both shapes and is shaped by human existence. Thinkers such as Maurice Merleau-Ponty and Edward S. Casey developed this idea by linking the perception of space with environmental context.

Following this line, Juhani Pallasmaa in *The Eyes of the Skin* (Pallasmaa, 2011) reminds us that architecture mediates between humans and the world through sensory experience. Likewise, Christopher Day in *Places of the Soul* (Day, 2003) stresses that buildings should touch emotional and spiritual dimensions as well as physical needs, reinforcing the bond with nature. This orientation can also be traced in the works of Alvar Aalto, Peter Zumthor, and Kengo Kuma, who consistently aim to blend architecture with natural elements.

From the 1990s onward, sustainability debates have expanded beyond concerns of energy savings and cost efficiency to include ecosystem preservation, biodiversity protection, and carbon reduction. Since then, architecture and urban design have increasingly worked toward solutions that resonate with natural systems, use renewable resources, and lower ecological footprints.

Beyond technologically intensive projects, several architects have advanced sustainability through more ecological, low-tech, and

community-driven strategies. Hassan Fathy's *Architecture for the Poor* (Fathy, 1973) revived traditional construction methods and passive climate control using local materials in rural Egypt. Glenn Murcutt's modest houses in Australia embody a responsive, climate-sensitive minimalism that harmonizes with nature. Mike Reynolds' Earthship Biotecture pioneered self-sufficient dwellings integrating water recycling, renewable energy, and natural ventilation. Similarly, Balkrishna Doshi's Sangath in Ahmedabad employs subterranean structures and passive cooling techniques, while Francis Kéré uses local materials and natural ventilation in his projects across Burkina Faso. Together, these works exemplify ecologically grounded approaches that foreground local context, resource efficiency, and human–nature reciprocity.

Environmentally focused hybrid approaches have been characterized by integrated strategies that combine passive and active energy systems, water management, waste recycling, and the restoration of local ecosystems, where not only the building's performance but also its relationship with the surrounding environment has gained significance. By merging technical solutions with ecological sensitivity, these approaches expanded the discourse of sustainability; however, issues of social sustainability remained secondary, as aspects such as user participation and spatial sharing were often addressed only indirectly. Nevertheless, the environmental strategies developed during this period laid a strong foundation for the integrated models that, after 2010, came to explicitly incorporate the social dimension as well.

Table 2. Ecological Sustainability Approaches and Their Prioritized Actions

				Sustainability				
				Deep Ecology	Ecocentric Ethics	Permaculture	Pastoral Ecology	Ecophenomenology
ECOLOGICAL	ECON	Actions and Sustainability Dimensions	reduction of waste			x		
			conservation and efficient use of natural resources		x	x	x	
			protection of ecosystems		x			
			development of sustainable agricultural policies			x	x	
			preservation of biodiversity		x			
			re-establishing the human–nature relationship	x		x		x
	SOCIAL		enhancing environmental awareness and ecological literacy	x	x			x
			strengthening human experience of nature and spatial perception					x

Table 2 illustrates how ecologically oriented sustainability approaches are associated with the actions they prioritize. As seen in the table, Ecocentric Ethics and Permaculture intersect with a broad range of ecological strategies, from biodiversity protection to sustainable agriculture. Deep Ecology and Pastoral Ecology, on the other hand, highlight the re-establishment of the human–nature relationship and the safeguarding of ecosystems, while Ecophenomenology concentrates more on experiential and perceptual dimensions of environmental awareness. Taken together, these approaches demonstrate that ecological sustainability is not a singular path, but a spectrum of ethical, philosophical, and practical orientations.

While these approaches created an important paradigm shift by placing nature at the center, they were also criticized for not always adequately addressing the needs of growing populations, being applicable only at limited scales, and struggling to adapt to the comfort demands of contemporary life. Furthermore, Deep Ecology has been critiqued for neglecting economic and political roots; Ecophenomenology for remaining abstract and Western-centric; and Ecocentric Ethics for attributing absolute value to ecosystems in ways that complicate human-centered decision-making processes.

Overall, ecologically oriented approaches have broadened the sustainability discourse by shifting the focus from technological efficiency to ethical, philosophical, and experiential dimensions of the human–nature relationship, providing essential groundwork for more integrated sustainability models in architecture.

Strengthening The Social Dimension

Beyond economic and environmentally driven approaches, perspectives that place locality, community, and culture at their core have also gained importance. These approaches sometimes foreground local geographic features, natural resources, and local economies, and at other times emphasize social equity, justice, and cultural sustainability.

The concept of Bioregionalism, which entered sustainability debates in the 1970s, was articulated by Peter Berg and Raymond F. Dasmann (Berg & Dasmann, 1977) and continues to remain relevant today. At its core, this approach advocates for lifestyles grounded in the resources of the places where people live. Rooted in local knowledge and participatory engagement, bioregionalism aims to strengthen the link between ecology and culture. Its principles include the sustainable use of natural resources, the protection of biodiversity, balanced land-use

practices, the reinforcement of human–nature connections, and the promotion of living patterns that align with local ecosystems.

In architectural discourse, Victor Olgyay was among the early figures to stress climatic adaptation through his seminal work *Design with Climate* (Olgyay, 1963). He highlighted how solar orientation, natural ventilation, local material use, and other passive design strategies could reduce energy demand. Similarly, Ian L. McHarg in *Design with Nature* (McHarg, 1971) underscored the need for ecological compatibility, emphasizing that land-use planning and context-specific design must take a central role in both architectural and urban projects.

A parallel framework, Community-Based Natural Resource Management *(CBNRM),* also insists that sustainable resource management is only feasible when local communities are actively involved. It argues for legal and policy structures that enhance local governance capacities while ensuring social equity.

Some approaches examine the relationship between society and nature through the lens of justice. Ecofeminism, first articulated in Françoise d'Eaubonne's book *Le féminisme ou la mort* (*Feminism or Death*) (d'Eaubonne, 1974), draws a parallel between the exploitation of nature and the oppression of women, emphasizing the link between environmental issues and patriarchal structures. By associating women with nature, this perspective underlines that environmental justice and social justice are inseparable, and that achieving equality and justice in society is a prerequisite for addressing ecological problems.

Environmental Justice, advanced by Robert D. Bullard (Bullard, 1990), has approached environmental issues from a more anthropocentric perspective, framing them within the context of social justice. It emphasizes the unequal distribution of environmental burdens and argues for fairness and equity in how environmental risks and damages are borne across different social groups.

In contrast, Eco-Justice examines the rights of all living beings through the lens of ecological ethics. It asserts that nature possesses intrinsic value beyond human use, that ecosystems and all species must be protected, and that humans bear moral responsibilities toward the natural world.

A profound transformation, what Murray Bookchin himself calls a "utopia" in his book *Toward an Ecological Society* (Bookchin, 1979), is articulated through his proposal of Social Ecology. Bookchin argues that societies require not only revolutionary movements but also communities with cultural rootedness and a richness of everyday consciousness. He

advocates for modern technologies to be reinterpreted as "people's technologies" at a human scale, for social institutions based on mutual aid and solidarity, for decentralized democratic structures at the local level, and the recognition of humanity's embeddedness in nature, prioritizing a way of life aligned with ecological harmony (Bookchin, 1979).

Since the 1990s, sustainability has increasingly been understood not only in terms of energy efficiency and environmental performance, but also as encompassing social equity, cultural continuity, user participation, and community solidarity. In this regard, socially oriented integrated models have been developed, emphasizing user involvement in design processes, collective decision-making mechanisms, and the centrality of shared spaces in everyday life. Within this framework, the notions of Climate Justice and the Commons have also entered the discussion.

Among the theorists who approach environmental issues from a community-oriented perspective, Jane Jacobs, in her book *The Death and Life of Great American Cities* (Jacobs, 2017), draws attention to small-scale planning, the importance of neighborhood fabric, and the crucial role of community participation for sustainability. Similarly, in *The Nature of Design: Ecology, Culture, and Human Intention* (Orr, 2002), David Orr argues that the sustainability of nature cannot be ensured solely through technological or functional solutions; rather, the root causes of environmental problems also lie in the erosion of cultural values.

Several projects exemplify these ideas in practice. *Wohnprojekt Wien* (2013) in Vienna demonstrates a housing model with equal user participation, collective decision-making, and shared spaces. *Gleis 21* (2019), also in Vienna, highlights community involvement in the transformation of a former railway site, enriched with cultural and public programs. In Freiburg, the *Vauban* district integrates ecological and social goals through its car-free lifestyle, energy-positive buildings, and strong community ties. Similarly, Amsterdam's *SET Community Gardens* links urban agriculture with food security and social interaction.

These projects treat social sustainability not as an additional criterion but as a constitutive element of design. Shared kitchens, workshops, childcare facilities, community gardens, and cultural spaces not only optimize resource use but also foster a strong sense of belonging among community members. In this respect, integrated models that strengthen the social dimension represent the most inclusive and long-term approach to sustainability.

Table 3. Social Sustainability Approaches and Their Prioritized Actions

		Actions and Sustainability Dimensions		Sustainability Approaches				
				Community-Based Natural Resource Management	Ecofeminism	Environmental Justice	Eco-Justice	Social Ecology
ECOLOGICAL	ECON.		conservation and efficient use of natural resources	x				
			protection of ecosystems				x	
			preservation of biodiversity	x				
			re-establishing the human–nature relationship				x	x
	SOCIAL		enhancing environmental awareness and ecological literacy					x
			preservation of cultural diversity					x
			achieving social justice	x	x	x		x
			supporting local democracies	x				x
			fostering local participation and ownership	x				x
			promoting gender equality and strengthening human–nature relations		x			
			strengthening and enforcing the legal framework	x			x	

Table 3 illustrates how socially oriented sustainability approaches are positioned in relation to the actions they prioritize. For instance, Bioregionalism and CBNRM place strong emphasis on local governance, resource conservation, and biodiversity, while Ecofeminism links ecological concerns with gender equality and social justice. Environmental Justice foregrounds equity in the distribution of environmental burdens, whereas Eco-Justice underscores the intrinsic rights of ecosystems and all living beings. Social Ecology, meanwhile, integrates multiple dimensions, calling for decentralized democracies, cultural continuity, and the reinforcement of human–nature relationships.

Nevertheless, all three approaches have been subject to critique: Ecofeminism has been criticized for addressing cultural contexts only in a limited way; Environmental Justice for failing to offer solutions at a global scale; and Eco-justice for often subordinating human needs, thereby creating tensions in practical applications. Nonetheless, both bioregionalism and CBNRM have been criticized for their limited integration into global and economic systems, as well as for their insufficient engagement with modern technologies and international cooperation. It has also been argued that while social ecology strongly critiques the existing economic order, it does not provide sufficiently concrete alternatives; its call for the complete abolition of hierarchy renders it utopian and unrealistic; and, paradoxically, its emphasis on human social structures has been interpreted as retaining a degree of anthropocentrism.

Taken together, socially oriented approaches demonstrate that the durability of sustainable design depends on community engagement, cultural rootedness, and social equity as much as on ecological performance or technological innovation. By situating people and their collective practices at the heart of sustainability, these frameworks underline that architecture is not only a material practice but also a vehicle for fostering belonging, justice, and ecological responsibility. In this sense, the strengthening of the social dimension represents both a corrective to earlier technocentric models and a vital foundation for truly holistic sustainability.

THE APPROACH-ACTION NETWORK: A NEW FRAMEWORK

When examining the historical development of the sustainability discourse, it becomes evident that the axes of economic–technological optimization, environmentally oriented approaches, and integrated models that strengthen the social dimension should not be read merely as successive periods, but rather as intersecting and mutually reinforcing trajectories. While each approach emerged within its own contextual conditions and priorities, comprehensively achieving sustainability goals depends on bringing these axes together within a holistic framework.

The relationships among the approaches under these three main themes are schematically illustrated in Figure 1. The diagram visualizes the theoretical approaches positioned along the three axes (economic–technological, ecological, and social) as well as the hybrid models emerging at their intersections, together with their connections to key fields of action.

Figure 1 also shows the actions according to their relative priority levels within the sustainability framework. Some actions are preferred by more approaches and come to the fore. At the first priority level, the conservation and efficient use of natural resources and the enhancement of environmental awareness and ecological literacy emerge as the most central actions, lying at the intersection of ecological and social trajectories. At the second level, re-establishing the human–nature relationship and achieving social justice stand out as key actions that broaden sustainability beyond technical measures. Finally, at the third level, supporting local democracies, fostering local participation and ownership, and strengthening and enforcing the legal framework highlight that sustainable transformation cannot rely solely on design or technology, but must be reinforced through governance and active civic engagement.

The conservation and efficient use of natural resources is directly reflected in design through material selection, energy use, and land management in the production of buildings. Environmental awareness, on the other hand, reminds us that architecture is not only about producing physical space but also about serving as a tool for cultivating social consciousness. Designs that aim to transform users' everyday practices make the relationship with the environment visible and encourage ecological modes of behavior.

For instance, making the collection and reuse of rainwater visible through transparent channels, displaying real-time energy consumption on digital panels, or placing waste-sorting stations at the heart of shared spaces can embed environmental awareness into the routines of daily life. Such spatial strategies allow individuals to directly perceive their ecological impact, thereby encouraging behavioral change. Architecture can further reinforce this awareness by designing public spaces that foster environmental literacy.

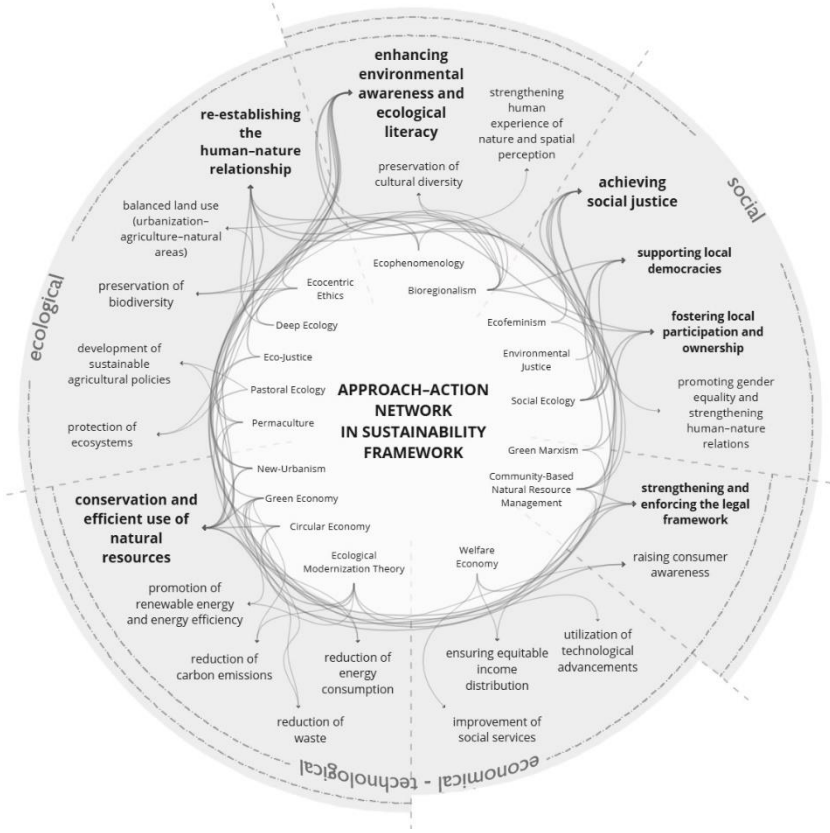


Figure 1. Approach-Action Network in the Sustainability Framework

Ecological centers, outdoor classrooms, community gardens, and ecomuseums serve as platforms where knowledge is shared and experiential learning is promoted. Within these environments, both children and adults engage with sustainable practices firsthand, contributing to ecological consciousness at a broader social scale. In this sense, environmental awareness operates not only at the individual level but also as a collective process of learning and transformation shaped by architectural design. Similarly, common spaces and places of encounter contribute to environmental awareness by strengthening social bonds. These spaces, where people can interact and share experiences in their daily lives, foster a sense of community and mediate the development of spatial belonging. Individuals whose sense of belonging is reinforced tend to adopt a more responsible and protective attitude toward their environment, which in turn contributes to the dissemination of sustainability consciousness at the societal level.

Ensuring social justice and re-establishing the bond with nature are the areas that demonstrate that architecture should not be limited to developing energy- and performance-based solutions alone, but must also prioritize social integration and ecological belonging. Ensuring social justice is directly linked to designing spaces that are accessible, equitable, and inclusive for all. Mixed-use environments, social housing policies, and collective living spaces bring together different socio-economic groups, thereby strengthening social cohesion and reinforcing the social dimension of sustainability. With the acceleration of urbanization, society's connection with nature has weakened, and the emotional ties with the natural environment have reached the breaking point. Functional ecological interventions such as the expansion of public green spaces, ecological corridors, permaculture practices, rain gardens, biophilic designs, and green infrastructure systems allow individuals to re-establish their relationship with the environment.

At the third level of priority, the emphasis lies on ensuring local participation and ownership, supporting local democracies, and strengthening and enforcing the legal framework. These actions demonstrate that sustainability can only be achieved through strong governance and active citizen participation. From neighborhood-scale planning meetings to local initiatives, from urban forums to design competitions, the strengthening of local participation and ownership reinforces individuals' bonds with architectural and urban spaces, while simultaneously enhancing their environmental awareness. Since local governments are the administrative bodies closest to citizens, they hold primary importance in decision-making processes.

Therefore, architecture must cultivate a holistic understanding of sustainability, balancing technology-driven efficiency with social justice and environmental awareness. In doing so, the spatial production of the future can serve a lasting transformation that simultaneously considers ecological, social, and economic dimensions.

CONCLUSION

In the fields of architecture and urban design, the discourse on sustainability within architecture and urban design has progressively unfolded through different priorities and approaches over time, developing along three central dimensions that can be defined as economic-technological optimization, environmentally oriented approaches, and interlinked models that strengthen the social dimension. Economic and technological approaches provided the initial groundwork for sustainability, emphasizing energy efficiency, cost

optimization, and engineering innovations. These were followed by environmentally oriented approaches, which expanded the scope of this paradigm with goals such as the preservation of ecosystems, the reduction of carbon emissions, and the establishment of resource cycles. In recent years, integrated models that strengthen the social dimension have highlighted that sustainability is not only a technical and environmental issue but is also directly connected to cultural continuity, social relations, and collective ways of living.

With this integrated perspective, the creation of sustainable living environments becomes possible not only through technological advances but also by strengthening the relationship between society and its environment. Architecture extends beyond the production of physical spaces; it plays a formative role in structuring social and environmental relations. In this context, it requires evaluating spaces in terms of the potential they provide for establishing social relationships and the spatial bonds they create. For this very reason, spatial belonging and environmental awareness are processes that should be addressed as interconnected. When architecture develops spatial strategies that are in harmony with nature, enhance environmental awareness, and uphold social justice, it can establish a lasting foundation for enduring urban settings.

The priorities of each approach have been shaped by their economic, technological, political, and cultural contexts; yet when considered in isolation, they fall short of sustainability's holistic goals. This recalls Maslow's hierarchy of needs: higher-level aims cannot be sustained without securing basic conditions. For instance, social interaction and belonging become meaningful only when grounded in safe, energy-efficient, and ecologically balanced spaces.

The congress theme, '*When everything is a priority, nothing is a priority,*' resonates strongly with sustainability debates. When all goals are addressed simultaneously and with the same level of priority, the design process risks losing focus. The way out of this trap is to establish a contextual framework of flexible, layered, and time-distributed priorities of actions. Developing strategies that integrate different approaches in a balanced way and adapt to changing conditions represents the true priority of sustainability in architecture.

In this regard, the Approach–Action Network in the Sustainability Framework constitutes the main contribution of this study. It demonstrates that a core, timeless hierarchy of actions exists, and that some actions are more foundational than others. Specifically, this study demonstrates that the conservation and efficient use of natural

resources, along with the enhancement of environmental awareness and ecological literacy, are the most foundational actions. Positioned at the core of the network, these actions form the intersection of ecological and social dimensions, indicating that a project's long-term sustainability is dependent on both its material efficiency and the cultivation of human consciousness.

Therefore, for future architectural practice, the fundamental question should move beyond "*which dimension to prioritize?*" to "*which actions are more important to fulfill?*" The true priority of architecture is to treat these dimensions not as separate objectives, but as dynamic processes that evolve in interaction with one another, and by providing the necessary actions to ensure sustainability, to enable the more inclusive management of a project's social, cultural, and environmental impacts.

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BIODEGRADABLE MATERIALS AND SUSTAINABLE ARCHITECTURE: PRIORITIES SHAPING THE FUTURE OF BUILDINGS

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ABSTRACT

Architecture today stands at a critical juncture where environmental responsibility must redefine design priorities. Global challenges such as climate change, resource depletion, and ecological degradation demand that architectural practice integrate sustainability at its core. Among various strategies, the adoption of biodegradable materials emerges as a pivotal approach to reducing the environmental footprint of buildings. Biodegradable materials—such as wood, bamboo, natural fibers, microbial-based biopolymers, and mycelium composites—decompose naturally without leaving toxic residues, thereby offering a viable alternative to conventional industrial building materials.

This paper investigates the role of biodegradable materials in shaping the future of sustainable architecture. It explores their potential to minimize waste, conserve resources, and contribute to healthier indoor environments, while also supporting circular economy principles through reuse and recycling at the end of their life cycle. By employing a mixed methodology that combines literature review and case study analysis, the study highlights how biodegradable materials have been successfully integrated into contemporary projects and evaluates their performance through life cycle assessment frameworks.

Findings reveal that biodegradable materials not only reduce embodied carbon and energy consumption but also open new design possibilities through innovative technologies such as biotechnology, Building Information Modeling (BIM), and AI-based environmental simulations. The paper argues that shifting architectural priorities toward environmental responsibility requires embracing these materials as central components of future practice. By aligning material innovation with sustainable design, architects can contribute to resilient, adaptive, and environmentally harmonious built environments that address the urgent challenges of our time.

Keywords: Biodegradable Materials, Sustainable Architecture, Environmental Responsibility, Energy Efficiency, Circular Economy

INTRODUCTION

Architecture has always been shaped by the ecological, social, and cultural conditions of its time. From local products based on available natural resources to the industrial goods developed during the Industrial Revolution, the built environment reflects humanity's evolving relationship with nature and technology. The expanding construction network that accompanied industrialization brought rapid urbanization and foregrounded the need for housing. Over the years, uncontrolled industrial growth has led to environmental problems, the climate crisis, rapid depletion of resources, and various other global challenges. Therefore, adopting biodegradable materials in the construction sector has emerged as one of the most promising ways to align architectural practice with the principles of sustainability and ecology for the future.

The construction industry is a significant contributor to global greenhouse gas emissions, resource depletion, and waste generation. According to recent studies, buildings account for nearly 40% of global energy consumption and over one-third of carbon emissions (Green & Brown, 2024). Although industrial construction materials such as concrete, steel, and plastics are technologically advanced and meet accepted building standards, their extraction, processing, and disposal leave an intensive ecological footprint, often causing long-term harm to both natural ecosystems and human health. These issues necessitate alternative materials that lower environmental costs while maintaining performance and compliance with standards. What distinguishes these materials from conventional industrial ones is their high potential for end-of-life recovery—through safe disposal, recycling, or reuse.

Biodegradable materials, defined as those capable of decomposing naturally without leaving harmful residues, address many of these concerns. Derived from renewable sources such as wood, bamboo, natural fibers, microbial biopolymers, and mycelium, these materials embody low environmental toxicity and a high potential for integration into sustainable construction. They provide insulation, structural efficiency, and aesthetic diversity while simultaneously offering environmental benefits such as carbon sequestration and waste minimization. Importantly, they align with circular-economy principles by enabling reuse, recycling, or safe reintegration into natural systems at the end of their life cycle (Williams, 2024).

Yet the adoption of biodegradable materials in architecture is not merely a technical substitution of one material for another. It represents a paradigmatic shift in architectural priorities—from a reliance on industrial permanence and predictability toward ecological

adaptability and responsibility. This shift requires rethinking traditional notions of durability, standardization, and design aesthetics. For instance, while conventional building materials often aim for maximum longevity regardless of environmental impact, biodegradable materials suggest a different design logic: one that balances structural stability with ecological impermanence, creating buildings that evolve with their environment rather than against it (Setyowati & Sugiharto, 2021).

The academic discourse on sustainable architecture has increasingly emphasized the importance of material choice. Life Cycle Assessment (LCA) studies demonstrate that biodegradable materials frequently outperform synthetic alternatives in terms of embodied energy and carbon emissions (Künzel et al., 2022). Research on microbial-based biopolymers and mycelium composites further indicates that scientific innovation can expand the possibilities for biodegradable construction components (Lee & Park, 2023). Meanwhile, advances in digital technologies such as Building Information Modeling (BIM) and AI-supported environmental simulations allow architects to model, test, and predict the performance of biodegradable materials at early design stages, thereby mitigating risk and enhancing adoption (Martin & Zhao, 2023). These findings underscore that the integration of biodegradable materials is not an isolated trend but part of a broader transformation in how architecture negotiates its responsibilities to the planet.

The successful implementation of biodegradable materials requires supportive cultural, economic, and institutional rules and frameworks. Green building certification systems can act as guides in material-innovation studies by incorporating this domain into their evaluation criteria.

This study adopts a mixed-methods approach that combines a comprehensive literature review with targeted case-study analysis. The rationale for this methodological choice lies in the study's dual aim: first, to establish a theoretical and empirical foundation for understanding biodegradable materials in sustainable architecture; and second, to demonstrate their real-world applications and performance through practical examples.

Key themes examined in the literature review include life-cycle assessment (LCA), sustainable architecture, ecological building criteria, environmental performance, health impacts, and innovations in materials science. Sources were selected for their relevance to architectural practice, sustainability frameworks, and recent developments in material ecology. This review provides the conceptual

basis necessary to situate biodegradable materials within broader debates on sustainability and architectural priorities.

The case-study analysis focuses on selected projects that incorporate biodegradable materials into design and construction processes. Chosen for their diversity of material use, geographic context, and scale—from bamboo gymnasiums in Southeast Asia to experimental mycelium structures in Europe—each case is examined in terms of material properties, design strategies, environmental performance, and cultural reception. Data for these case studies were gathered from academic publications, architectural project documents, and sustainability assessment reports.

THEORETICAL FRAMEWORK

The theoretical foundations of sustainable architecture are being reshaped through approaches such as ecology, the circular economy, and material production technologies. Although biodegradable materials reflect the practical implications of these frameworks, there remain limitations to be addressed in areas such as performance, durability, cost, and standardization. Nevertheless, these materials not only reduce environmental harm but also hold the potential to transform the future of architecture by contributing to ecological regeneration. This transformation points to a future in which the built environment is integrated with ecosystems, waste is treated as a resource, and a regenerative architectural culture is embraced. In this context, integrating material innovation with ecological performance stands out as a key strategy that will define the future of sustainable architecture.

Innovation in building materials is evolving beyond a sole focus on enhancing mechanical performance toward a multi-criteria "priorities" framework centered on safety, durability, low carbon emissions, indoor air quality, and cost. In addition to naturally biodegradable materials such as earth and stone, biodegradable materials that develop bio-based options—natural fiber composites or mycelium-derived biomaterials—introduce circularity advantages to construction materials and offer innovative solutions in building design and form.

To scale these innovations, buildings must be constructed in compliance with standards related to earthquakes, fire safety, and thermal insulation. In sum, an "innovative" material is one that, while evaluating technical risks, converts local resources into construction materials within the framework of established standards.

The concept of sustainable architecture is rooted in the broader paradigm of sustainable development, defined by the Brundtland

Report (1987) as development that meets present needs without compromising the ability of future generations to meet their own. In architectural discourse, sustainability transcends the simple reduction of energy use or incorporation of renewable technologies; it involves a holistic approach that considers environmental, social, and economic dimensions (Smith & Taylor, 2023). Architecture is thus understood not only as a technical practice but also as a cultural and ecological act that shapes human-environment interactions.

A central theoretical premise in sustainable architecture is the principle of *ecological responsibility*. This principle asserts that the built environment should minimize harm to ecosystems and actively contribute to ecological regeneration. Biodegradable materials directly align with this principle by allowing construction components to return safely to natural cycles after use, reducing long-term waste accumulation and environmental toxicity. In this way, biodegradable materials support the transition from a linear to a circular model of construction, consistent with contemporary theories of the circular economy (Williams, 2024).

Another relevant theoretical lens is material ecology, an emerging field introduced by Oxman (2010), which integrates material science, biology, and design. This framework emphasizes the interdependence of material properties, ecological performance, and design strategies. Biodegradable materials exemplify material ecology by demonstrating how material innovation can merge environmental performance with architectural creativity.

As embodiments of material ecology, biodegradable materials reveal how material innovation unites environmental performance and architectural creativity. Architectural practice must continually re-evaluate its goals in response to societal and environmental pressures. Historically, architectural priorities have oscillated between aesthetics, functionality, technology, and economy. Today, the pressing global climate emergency requires sustainability, and particularly material responsibility, to move to the forefront of architectural priorities.

Biodegradable materials represent a class of substances that can break down into natural, non-toxic components through biological processes, primarily mediated by microbial activity. This breakdown results in the release of harmless by-products such as carbon dioxide, water, and biomass, making these materials a vital solution for addressing the environmental issues posed by conventional plastics and other non-degradable materials (Hosni et al., 2019).

The growing demand for biodegradable materials is driven by the urgent need to reduce plastic pollution. Conventional synthetic plastics persist in the environment for extended periods, contributing to ecological degradation. In contrast, biodegradable materials decompose under specific environmental conditions, thus minimizing their environmental footprint (Schroeter et al., 2013; Kumar et al., 2011)

Biodegradable materials are designed to degrade through the action of microorganisms or under specific physical conditions within a desired timeframe (Monisha & Agarwala, 2022). These materials undergo chemical dissolution by bacteria or other biological means, with degradation occurring either aerobically with oxygen or anaerobically without oxygen (Rose et al., 2011). The primary driving forces behind biodegradable materials development include growing electronic waste problems, low recyclability of traditional materials, solid waste management challenges, decreasing landfill availability, and marine pollution from non-biodegradable plastics (Monisha & Agarwala, 2022; Bastioli, 1998). Biodegradable polymers constitute a family of materials offering alternatives to traditional non-biodegradable polymers when recycling is impractical or uneconomical (Bastioli, 1998). These materials, derived from natural and renewable sources, find applications in electronics, food, and biomedical industries (Monisha & Agarwala, 2022; Schaschke & Audic, 2014).

Biodegradable materials, by making an ecological contribution to industrial materials technology and by strengthening and extending the service life of traditional, nature-derived building materials, hold great potential for creating sustainable, environmentally friendly buildings. Biodegradable materials that meet life-cycle assessment and sustainability criteria can be mineralized into CO_2, water, and biomass under the action of microorganisms. This directly serves the question emphasized in the study's main title—"how priorities shape the future of buildings."

USE OF BIODEGRADABLE MATERIALS IN ARCHITECTURE

While biodegradability is often associated with natural materials, human-made materials can also be rendered biodegradable. Natural biodegradable building materials have been used since the advent of settled human life. However, with the emergence of industrial and contemporary materials, biodegradable options gradually lost their share of the construction market. Today, the escalating risks of the global climate crisis and concerns about humanity's future have brought natural materials back to the forefront. Initially, construction systems based on natural materials were enhanced to improve their

performance; subsequently, alternative biodegradable materials based on plastics and mycelium were developed. The plastics industry, in particular, has made rapid progress in this area. Biodegradable plastic materials are now being used in the construction of temporary shelters and urban pavilions.

Typologies of biodegradable materials in architecture include:

- **Natural Structural Materials:** Wood, bamboo, and straw—used traditionally but increasingly re-evaluated for their carbon sequestration potential and low embodied energy.
- **Natural Fibers:** Hemp, flax, jute,coconut, algea, cotton and kenaf—lightweight, renewable, and often used in composites for insulation or cladding.
- **Soil-Based Materials:** Adobe, rammed earth, and clay—biodegradable and regionally abundant, with historical precedent in vernacular architecture (Rodriguez & Lopez, 2023).
- **Bio-Polymers:** Materials derived from microbial or plant-based processes, including polylactic acid (PLA) and polyhydroxyalkanoates (PHA), offering biodegradable alternatives to petrochemical plastics (Lee & Park, 2023).
- **Fungal-Based Composites:** Mycelium, cultivated from fungal roots, used for insulation, packaging, 1162n deven structural blocks, representing one of the most innovative frontiers (Thompson & Becker, 2024).

This typology illustrates the breadth of biodegradable materials available, from ancient practices to cutting-edge innovations, highlighting their potential to reshape architectural practice.

When evaluated in terms of environmental performance, biodegradable building materials stand out as a strong alternative to industrial materials: they generally require less energy, enable reductions in construction and environmental waste across the construction–use–demolition phases, and support user health and comfort by improving indoor air quality. Accordingly, within sustainable architecture and construction practices, they provide benefits that are both environmental and human-centered.

Recent advances in biotechnology and materials engineering are expanding the architectural applications of biodegradable materials. For instance, microbial biopolymers can be engineered for structural use, combining biodegradability with mechanical strength (Lee & Park, 2023). In parallel, mycelium composites have been described as a "material revolution," offering lightweight, fire-resistant, and fully

compostable construction components (Thompson & Becker, 2024). Experimental research on algae-based bricks and panels further explores the integration of algae into building materials, enabling both carbon sequestration and renewable energy production during the building's lifespan. Complementing these material breakthroughs, the integration of artificial intelligence and Building Information Modeling allows architects to predict material degradation and optimize construction processes for biodegradable components (Martin & Zhao, 2023). Collectively, these innovations indicate that biodegradable materials are no longer restricted to vernacular or alternative practices but are entering mainstream architectural experimentation and practice.

The reviewed literature indicates a growing 1163 n deven 1163 s: biodegradable materials are not merely environmental alternatives but are central to the future of sustainable architecture. Their adoption represents a realignment of architectural priorities toward ecological responsibility, circularity, and innovation. As global climate concerns intensify, integrating biodegradable materials signals a shift in architectural practice—from merely reducing harm to actively contributing to environmental regeneration.

BIODEGRADABLE MATERIALS IN ARCHITECTURAL PRACTİCE

The use of biodegradable materials in architectural applications seeks to align environmental performance with design objectives. Within this framework, material choices must be assessed not only for renewability and circularity but also against criteria such as robustness, fire and moisture resistance, indoor environmental health, maintenance needs, and economic feasibility. These case studies exemplify the diversity of biodegradable materials in practice, demonstrating their feasibility, performance, and potential scalability.

Natural Structural Materials

Wood; wood is the oldest and most versatile representative of biodegradable materials at the architectural scale; it is used for structural framing, interior cladding, and wood-fiber insulation boards, among other applications.

Bamboo; among biodegradable materials, rapidly renewable bamboo is favored both for its capacity to serve as a natural structural element and for enabling lightweight, flexible design solutions.

Straw; thanks to its agricultural-residue origin, fibrous structure, and low embodied energy, straw is a strong candidate among biodegradable

materials. Whereas straw-bale construction was common in the past, today it is used in biodegradable architecture through varied construction techniques and material assemblies.

Natural Fibers

Hemp; hemp is widely used both in block production with lime or cement mixes and, as fibers bound with natural binders, in the form of insulation boards.

Flax; flax is valuable in biodegradable architecture for both its fiber and shive fractions: flax fibers are used in structural and insulating applications ranging from interior finishes and furniture components to fiber-reinforced composites.

Soil-Based Materials

Adobe; 1164n de is a 1164n de material obtained by enriching a local soil–water mix—usually with organic fibers—and sun-drying the units. It offers high thermal mass and vapor permeability. From a biodegradability standpoint, the fiber additives are biologically degradable, while the mineral soil matrix can return to 1164n dev in a non-toxic form.

Rammed Earth; a mixture of soil and clay, at an appropriate moisture content, is placed in formwork in layers and compacted with high energy to create block or monolithic walls. Being mineral-based, it does not biodegrade in the organic sense; however, it can return to the environment without leaving toxic residues. Its minimal waste generation and reliance on local resources align strongly with the aims of biodegradable architecture.

Clay; clay stands out as a binder in biodegradable architecture. Combined with fibrous additives it is used in plasters, and together with soil it is widely employed in the production of brick blocks due to its low cost and ready availability. It is also used as a cement additive to reduce carbon emissions.

Bio-Polymers

Polylactic Acid (PLA); PLA is a bio-based, industrially compostable thermoplastic produced by polymerizing lactic acid derived from starch- and sugar-rich sources such as corn and sugarcane. Its architectural relevance stems from low embodied energy/biogenic carbon content, broad processability (injection, extrusion, pressing, and especially FDM/FFF 3D printing), and rapid adaptability to design.

Applications are mostly non-load-bearing and limited to interiors and/or temporary structures.

Polyhydroxyalkanoates (PHA); PHA's are a family of bio-based polyesters produced by fermentation using plant sugars and starch hydrolysates (e.g., corn, sugarcane), molasses, whey, glycerol and other food/agricultural by-products, vegetable oils and fatty acids, 1165n deven waste frying oils—highly valuable from a waste-valorization standpoint. They can be used as binders in the production of insulation panels.

Fungal-Based Composites

Mycelium; Mycelium is a biocomposite formed by growing the hyphal network of fungi (e.g., *Pleurotus*, *Ganoderma*) within sterilized agricultural residues (such as straw, flax/hemp shives, or wood fiber). Growth occurs inside a mold; after reaching the target geometry, heat inactivation/drying is applied to halt biological activity. Experimental applications have been carried out in brick units and load-bearing structural assemblies.

Table 1 below compiles biodegradable materials—wood, bamboo, straw, natural fibers (hemp, flax, jute, kenaf), soil-based materials (adobe, rammed earth, clay), biopolymers (PLA, PHA), and mycelium composites—together with selected visual examples. For each material, the table details the raw-material source and production technique; product/element form (block, panel, board, composite); principal construction method; and the scale and domain of architectural use (structural system, envelope/wall, cladding, insulation, interior elements, and temporary structures/pavilions).

Natural Fibers with other materials					
Hemp		Flax			
4. *Zero Carbon Hemp House* United Kingdom, 2010' s		5. *Flax Chair Pavilion* Germany, 2024		Layered placement within formwork followed by high-energy compaction was employed in the production process. The resulting configuration serves as a load-bearing infill wall system, complemented by integrated thermal insulation boards to enhance energy efficiency	Shell/wall with thermal insulation; providing a breathable interior environment	It reintegrates into the environment without adverse effects
				Composite panel cladding Pressing/molding; surface finishing and module assembly	Temporary shell/wall, interior acoustic/cladding panels	Compostable; disintegrates and returns to the soil; very low waste. The fiber part is biodegradable; can be ground for partial recycling, and with bio-based resin the compostina potential is high

Soil-Based Materials					
Adobe		Rammed Earth			
Great Mosque of Djenné Mali, 13th c. (restored)		6. *Casa Entre Muros* Mexico, 2020		Masonry wall with timber reinforcement	Load-bearing walls in the inner and outer shell, Mosque structure	
				Monolithic wall/block. Layered placement within a mold + high-energy compaction	Load-bearing walls integrated into both the inner and outer shells are applicable across a wide range of building typologies, including residential and community structures	It returns to the soil; can be crushed and reused as infill; generates minimal waste

Typlogy	Mtr.	Nm.	Photo Location/Year	Construction Structure	Type of Building	Life Circle
Bio-Polymers	PLA	7. 3D Printed Canal House Amsterdam, Netherlands, 2016		Sheets/panels; 3D-printed shells; thin cladding pieces; 3D printing (FDM/FFF), injection/extrusion; modular assembly	Used in the building envelope and exterior cladding; applicable in temporary structures and non-load-bearing lightweight shells	Biodegradable through industrial composting; partially by recyclable grinding; energy recovery possible
	PHA	8. BioPolymer Pavilion Germany, 2021		Panelized elements with insulation core, composite cladding produced using a PHA (polyhydroxyalkanoate) binder	Exterior cladding Pressed/molded; fiber-reinforced composite; modular panel assembly	
Fungal-Based Composites	Mycelium	9. Hy-Fi Pavilion MoMA PS1, New York, 2014		Manufacturing of bricks, blocks, and lightweight panels	Temporary shell/wall; interior acoustic/cladding panels	Fully compostable; naturally breaks down and reintegrates into the soil, ensuring minimal residual waste
	Mycelium	10. The Growing Pavilion Eindhoven, Netherlands, 2019		In-mold cultivation; drying after growth for blocks and dry assembly; integration with a skeleton for temporary structures	Temporary shell/wall; interior acoustic/cladding panels	Fully compostable; naturally breaks down and reintegrates into the soil, ensuring minimal residual waste

Typlay	Mtr	Nm.	Photo Location/Year	Construction Structure	Type of Building	Life Circle
Bio-Polymers	PLA	7. 3D Printed Canal House Amsterdam, Netherlands, 2016		Sheets/panels; 3D-printed shells; thin cladding pieces. 3D printing (FDM/FFF), injection/extrusion; modular assembly	Used in the building envelope and exterior cladding; applicable in temporary structures and non-load-bearing lightweight shells	Biodegradable through industrial composting; partially recyclable by grinding; energy recovery possible
	PHA	8. Bio-Polymer Pavilion Germany, 2021		Panelized elements with insulation core, composite cladding produced using a PHA (polyhydroxyalkanoate) binder	Exterior cladding Pressed/molded; fiber-reinforced composite; modular panel assembly	
Fungal-Based Composites	Mycelium	9. Hy-Fi Pavilion MoMA PS1, New York, 2014		Manufacturing of bricks, blocks, and lightweight panels	Temporary shell/wall; interior acoustic/cladding panels	Fully compostable; naturally breaks down and reintegrates into the soil, ensuring minimal residual waste
	Mycelium	10. The Growing Pavilion Eindhoven, Netherlands, 2019		In-mold cultivation; drying after growth for blocks and dry assembly; integration with a skeleton for temporary structures	Temporary shell/wall; interior acoustic/cladding panels	Fully compostable; naturally breaks down and reintegrates into the soil, ensuring minimal residual waste

FINDINGS

One of the clearest findings is that biodegradable materials markedly reduce environmental impact compared to conventional industrial materials. Life Cycle Assessment (LCA) studies show that wood, bamboo, natural fibers, and new bio-based composites consistently have lower embodied energy and carbon footprints. In particular, wood and bamboo act as carbon sinks by storing atmospheric CO_2 during growth; when responsibly harvested and used in construction, this carbon remains locked in the built environment for decades, thereby reducing net greenhouse-gas loads (Künzel et al., 2022). In addition, the energy required to produce biodegradable materials is significantly lower than that for steel, aluminum, or concrete; for example, bamboo requires only a fraction of the energy input per unit volume (m^3) compared to reinforced concrete, making it one of the most energy-efficient structural materials (Yuan & Wang, 2023). At end-of-life, whereas synthetic materials can persist in landfills for centuries, biodegradable materials naturally reintegrate into ecosystems without leaving toxic residues—thereby mitigating waste accumulation, a major environmental problem associated with construction and demolition activities (Williams, 2024).

Biodegradable materials such as natural fibers, untreated wood, and clay are largely free from such toxic additives. Their use in interiors has been shown to improve air quality, regulate humidity, and provide thermal comfort. For example, hemp-lime composites regulate indoor humidity levels by absorbing and releasing moisture, creating stable and comfortable environments (Green & Brown, 2024). Additionally, clay plasters are known to filter indoor air pollutants, further enhancing occupant well-being.

Biodegradable materials align naturally with the principles of the circular economy, which prioritizes minimizing waste and continually reusing/recycling resources. Options such as mycelium, natural fibers, and biopolymers can safely break down within ecosystems, reducing the need for complex recycling infrastructure; at end of life they remain sustainable and help close the material loop. Even prior to decomposition, opportunities for reuse and recycling exist: for example, timber beams can be repurposed in new structures, and clay components can be reshaped and reintroduced into production through rehydration. Moreover, transforming agricultural residues or food by-products into biodegradable building components strengthens an innovative pipeline that converts waste streams into valuable inputs (Williams, 2024). Taken together, this shows that biodegradable materials not only substitute for unsustainable resources but also open

fundamentally new pathways for design and production in architectural waste management.

Technology plays a decisive role in supporting the viability of biodegradable materials. In particular, Building Information Modeling (BIM) reduces performance uncertainty and optimizes resource use by enabling the modeling and prediction of these materials' behavior across the full life cycle (Martin & Zhao, 2023). Artificial intelligence and predictive analytics can simulate material degradation, anticipate maintenance needs, and enable design-for-disassembly so that biodegradable components are integrated into the built environment in ways that maximize ecological benefits. Advances in biotechnology—such as microbial-based polymers and algae-enhanced bricks—are expanding the performance spectrum of biodegradable materials, achieving levels of strength, fire resistance, and versatility that were once considered unattainable (Lee & Park, 2023). This technological integration makes clear that biodegradable materials are not confined to tradition; rather, they are actively shaping the future of high-performance architecture.

Another key finding is that biodegradable materials connect architecture with local identities, economies, and cultures. In regions where wood, bamboo, or earth have been used historically, incorporating these materials into contemporary projects strengthens cultural continuity and supports local economies.

For example, bamboo construction in Southeast Asia not only provides ecological benefits but also sustains traditional craftsmanship, offering economic opportunities to local communities. Similarly, rammed earth and adobe housing projects revive vernacular knowledge, enhancing community resilience while reducing environmental costs (Setyowati & Sugiharto, 2021).

However, findings also reveal cultural barriers. In some contexts, natural materials are perceived as "primitive" or "temporary," creating resistance among clients or regulatory authorities. Overcoming these perceptions requires educational efforts, policy support, and demonstration projects that showcase the durability and sophistication of biodegradable architecture.

Despite their advantages, the findings also point to persistent limitations. In terms of durability, biodegradable materials may require protective treatments against moisture, pests, and fire; a lack of standardization—especially for newer materials such as mycelium—limits widespread adoption due to gaps in established building codes and regulations.

From a cost perspective, innovative biopolymers and fungal composites are often more expensive than conventional alternatives because production remains limited in scale. In terms of acceptance, client skepticism and professional inertia within construction cultures dominated by industrial materials slow down adoption (Saleh & Ahmed, 2022). Overcoming these challenges requires coordinated progress on multiple fronts: technological innovations to enhance performance, regulatory reforms that incorporate life-cycle–based criteria, and cultural transformation across design, education, and communication channels.

CONCLUSION

The findings indicate that biodegradable materials offer substantial benefits for sustainable architecture: reduced carbon footprints, improved indoor environments, alignment with circular economy principles, and integration into cultural and ecological contexts. They are supported by emerging technologies and incentivized by evolving policy frameworks. At the same time, challenges of durability, cost, and acceptance highlight that their integration into mainstream practice requires systemic transformation.

Ultimately, biodegradable materials do more than provide ecological alternatives to conventional construction—they reshape architectural priorities. By encouraging architects to design with impermanence, adaptability, and ecological cycles in mind, these materials redefine what it means for architecture to be sustainable.

This study, drawing on both the literature and selected case analyses, demonstrates the potential of biodegradable materials to redirect the course of sustainable architecture. In architectural production, adaptability and repairability are becoming design criteria as important as durability and permanence; rather than "resisting the passage of time," an ethic and aesthetic that centers on working with natural processes is coming to the fore. In this regard, biodegradable materials are more than a technical option—they are a concrete expression of the discipline's will to assume ecological responsibility.

Biodegradable materials open a regenerative horizon beyond sustainability: they reduce carbon emissions, support biodiversity and soil health, and return to nature at the end of their life cycle. This transformation requires the simultaneous updating of designers' interdisciplinary collaborations, policymakers' framing regulations, educators' curricula, and communities' value sets. The use of biodegradable materials signals an architectural mindset that chooses

renewal over consumption, continuity over limitation, and responsibility over negligence. Such an orientation advances a future architecture that is not merely "less harmful," but a practice that makes positive contributions to ecosystems.

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REEVALUATING ARCHITECTURAL PRIORITIES: UNVEILING THE LEGACY OF TRADITIONAL CONSTRUCTION IN ARDAHAN, TÜRKİYE

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ABSTRACT

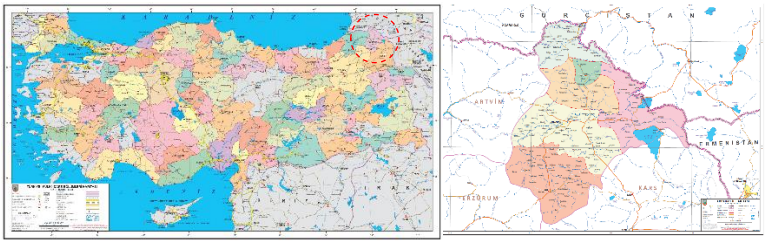
Ardahan, located in Turkey's northeastern border region, has long been a strategic settlement shaped by diverse cultural influences. Its urban fabric reflects a dual identity: the organic Ottoman-era texture clustered around Ardahan Castle and the grid-plan city introduced by the Russian Empire after the 1877–1878 Russo-Ottoman War. The Kura River, flowing through the city, has acted as a key geographical determinant of settlement patterns. Between 1878 and 1918, Ardahan, as part of the Kars Oblast under Russian administration, underwent significant urban and architectural changes. On the southern bank of the river, the Russians established a grid-plan district, constructing public buildings and residences in the Baltic architectural style with locally quarried basalt stone. These buildings combined local techniques—such as thick stone masonry walls, çakatura timber-lath infill partitions, and the distinctive peç heating system—with European façade ornamentation. While Ottoman-era structures were mainly religious and military, including mosques, baths, and the castle, Russian-period architecture emphasized administrative and residential types. Today, only a few examples remain. Among them, the Serhat Arslangörür House stands out as a rare detached garden residence, preserving its structural integrity despite later alterations. This paper examines Ardahan's architectural development within the theme of "priorities in architecture," focusing on how geography, climate, cultural traditions, and political authority shaped construction practices and spatial organization. Through the Serhat Arslangörür House case study, the study demonstrates how Ardahan's architecture embodies both local resilience and external influences.

Keywords: Ardahan Architecture, Baltic Architectural Influence, Russian Influence on Ardahan Architecture, Architectural Priorities, Traditional Construction

INTRODUCTION

The name of Ardahan appears in medieval Georgian sources such as Kartlis Çhovreba, where the region is mentioned under various historical forms, including Kaçta-Kalak, Hura, Artan, Artani, and Artaan (Kıldıroğlu, 2018). These records indicate that Ardahan was recognized as a strategic settlement long before the Ottoman or Russian periods in the Caucasus. Its geographical position in the upper basin of the Kura River made it an important center of political and cultural interactions throughout history.

Ardahan Province, located in Turkey's Northeastern Anatolia Region, is bordered by Kars to the south, Erzurum to the southwest, Artvin to the west, Georgia to the north, and Armenia to the east. It lies in one of Northeastern Anatolia's most mountainous and rugged parts. The city center of Ardahan is situated at an elevation of 1,860 meters above sea level, and the Kura River flows directly through it (Oral Patacı, 2020). Winding in a southwest–northeast direction and dividing into branches, the Kura River passes through the city's center, dividing it into northern and southern settlements (Karakoyun Yaşar & Kazaz, 2023).



(a) (b)

Figure 1. The location of Ardahan Province on the map of Turkey (a) and the provincial map of Ardahan (b). https://www.harita.gov.tr

The northern settlement of Ardahan developed during the Turkish-Islamic period, clustered around Ardahan Castle, in the district known as Kale or Halil Efendi. By contrast, The southern settlement was shaped under Tsarist Russia's rule. While some remnants of medieval Georgian architecture can still be found in the north, the urban fabric largely reflects Turkish-Islamic traditions, with mosques forming the majority of surviving structures. In the southern part, however, the Russian

administration established a grid-plan city and introduced a distinct architectural style reflecting local and imperial characteristics (Oral Patacı, 2020). In the 19th century, the Russian Empire applied grid-plan schemes in many of its oblasts (Rasimgil, 2017). This approach was also implemented in Ardahan, where administrative, military, and residential buildings were constructed in the southern district. The Russian occupation between 1878 and 1918, during which Ardahan was incorporated into the Kars Oblast, marked a decisive turning point in the city's architectural and urban character.

In the southern settlement, buildings lined up along streets and avenues, mainly consisting mainly of military structures, residences, and commercial establishments. While the military buildings have not survived, most existing ones have lost much of their originality. Urban development during the Republican period merged with the city fabric shaped under Tsarist rule (Oral Patacı, 2020).

From the Renaissance onward, European architecture witnessed successive stylistic shifts, with Baroque, Rococo, and later the Empire style under Napoleonic influence giving way to eclecticism in the 19th century. Eclecticism, as a mixed style, combined elements of Hellenistic, Roman, Gothic, Renaissance, Baroque, Rococo, and Empire architecture with features drawn from Chinese, Indian, Islamic, and Turkish traditions. To this amalgamation were added the characteristics of Baltic architecture, which developed in Scandinavian countries, and architectural features from Russia. With the expansion of Tsarist Russia, this approach began to be applied in planning new towns. After the Russo-Ottoman War of 1877–1878, Kars became one of the notable examples of this planning strategy. Similar influences of this urban approach and the Baltic architectural style are also evident in Ardahan (Gündoğdu, 2007).

ARCHITECTURAL STYLES INFLUENCING ARDAHAN

Before the Russian occupation, Ardahan's architectural character was largely shaped by the traditions of Turkish-Islamic culture. The urban fabric was concentrated around religious and communal structures such as mosques, baths, and the castle. The architectural style of this period reflected the organic urban pattern typical of Ottoman Anatolia. Local stone and timber were the primary construction materials, while residential buildings of the era generally consisted of detached houses with earthen roofs.

Following the Russo-Ottoman War of 1877–1878, Ardahan underwent a significant transformation under Russian administration. A new grid-plan

city was established on the southern bank of the Kura River, providing the framework for public and residential buildings. During this period, the prevailing architectural style in Ardahan shifted, and the influences of Baltic architecture began to emerge.

Architectural Style in the Pre-Russian Occupation Period

During the post-medieval Turkish-Islamic period, the urban center of Ardahan developed around Ardahan Castle, located in the northeastern part of the city. The earliest information about the city's construction in this era is in Seyahatname by Evliya Çelebi. According to his account, in the 17th century, the Halil Efendi Quarter, which surrounded what is now Ardahan Castle, consisted entirely of detached houses with earthen roofs. This northern settlement had small mosques, elementary religious schools (sıbyan mektebi), and some small inns, but there were no soup kitchens (aşevi) or madrasas. The Erzurum Provincial Yearbook (Salname) of 1871–72 records that at that time Ardahan, which was part of the Çıldır Sanjak, contained 59 mosques, 30 Islamic elementary schools, 100 madrasas, one bathhouse, four inns, 155 shops, and 2,007 households (Oral Patacı, 2020).

The oldest surviving Turkish-Islamic monument in Ardahan is Ardahan Castle. Built on a hill dominating the city, the castle was adapted to the topography and thus has an irregular quadrangular plan (Oral Patacı, 2020). Although its original construction date remains unknown, the castle was restored during the Ottoman period in the mid-16th century by Sultan Suleiman the Magnificent and has survived to the present day. Prehistoric excavations around the castle have revealed findings from the Bronze Age. On the western gate of the castle, there is an inscription measuring 65x71 cm, carved in relief with three lines of Nesih script on a hard red stone, placed in the final years of Suleiman's reign (Ardahan Governorship, n.d.). Ayaş Pasha, one of the prominent statesmen of the time, had the Great Mosque (Ulu Cami) built within the castle. Other functions, such as a bathhouse, also existed inside the castle, but neither the mosque nor the bathhouse has survived. It is believed that they were destroyed or plundered during wars and invasions.

The surviving Turkish-Islamic monuments in Ardahan today are mostly mosques. An examination of these few mosques reveals that their ceiling coverings, women's galleries, pulpits (minber), preaching platforms (vaiz kürsüsü), floors, and supporting columns were constructed of timber, while the walls were masonry with load-bearing functions. With these features, the historical mosques of Ardahan reflect an architectural tradition rooted in Central Asia, which continued through the Seljuk and Ottoman periods (Oral Patacı, 2020).

Architectural Style in the Russian Occupation Period

Following the Russo-Ottoman War of 1877–1878, the Treaty of San Stefano was signed on March 3, 1878, resulting in Kars, Doğubeyazıt, Batumi, and Ardahan coming under Russian control (Oral Patacı, 2020). Under the Tsarist administration, a new administrative unit was established in the region: the Karskaya Oblast, with its center in Kars. This oblast was divided into four sub-districts: Kars, Ardahan, Oltu, and Kağızman. The development of Kars and other surrounding centers after 1878 was primarily military. During this period, all of these towns became garrison centers (Türkan & Durak, 2016). The Tsarist Russian administration also implemented the 1855 Land Regulation (Arazi Nizamnamesi), systematically resettling groups such as Armenians, Greeks, Yazidis, and Assyrians from Anatolia, as well as Ukrainians, Molokans, Dukhobors, Germans, and Estonians from the Caucasus into the region (Oral Patacı, 2020). This policy created a multicultural structure in Ardahan, transforming it into a cosmopolitan area where diverse communities lived together.

As in other settlements under its control, the Tsarist administration introduced a new city plan in Ardahan. The 204th Russian Infantry Regiment in Ardahan indicates that the town had become a military center. While military buildings were constructed during this period, none have survived to the present day. Today, nearly all of the standing structures are residential houses. The contemporary urban fabric of Ardahan consists of interconnected streets and avenues. Along the main streets—such as Kongre Street, Atatürk Street, and İnönü Street—rows of shops, mansion-style civic buildings, and smaller residential houses were built (Oral Patacı, 2020).

After the French Revolution, Napoleon and his followers sought to reshape art and architecture in accordance with the Hellenistic and Roman traditions of antiquity. Instead of the curvilinear and fragmented asymmetry of Baroque, this style emphasized balance and order, with façades supported by columns, separated by cornices, and accentuated by triangular pediments. This approach remained influential for approximately 35–40 years.

By the mid-19th century, eclecticism had become a dominant trend worldwide and significantly influenced Ottoman architecture. Eclecticism combined selected elements from past architectural and decorative traditions into a unified whole, blending styles from the Far East, China, India, Islam, and the West. The style incorporated Western traditions such as Hellenistic, Roman, Romantic, Gothic, Renaissance, Baroque, Rococo, and Empire, alongside elements drawn from Chinese,

Indian, North African, Andalusian, Maghrebi, Turkish, and Islamic art. To this mixture were added features that emerged in Scandinavian countries—known as the "Baltic style"—which, combined with Central Russia's architectural traditions (notably Moscow, Kiev, and St. Petersburg), gave eclecticism a distinct character. With its growing power and territorial expansion, Tsarist Russia implemented this architectural approach in newly established cities and districts. During the years Ardahan was under Russian rule, this new understanding also came to the forefront, introducing the Baltic architectural style into the city (Gündoğdu, 2007).

CONSTRUCTION METHODS AND MATERIALS

The architectural character of the Ardahan and Kars region is primarily defined by the extensive use of basalt and andesite quarried locally. The area's geological structure consists largely of young volcanic layers formed by andesite and basalt lava, along with Neogene deposits in the basins. For this reason, the use of basalt and andesite became widespread in local architecture (Erdoğan, 2018). During the Tsarist Russian period, administrative, military, and residential buildings were typically constructed using cut basalt blocks in masonry techniques, with these stones providing both durability and a distinctive aesthetic quality.

The façades of buildings often featured carefully worked cut stones, while andesite and kevek stone—abundant in the region and easily shaped due to their porous texture—were commonly used as cladding materials. Cut basalt was combined with rubble stones and mortar on the rear and side elevations to form masonry walls (Gündoğdu, 2007). Façade organization emphasized cut andesite and ignimbrite stonework on the front elevations, while the sides and rear incorporated basalt and rubble stone. Because the walls were load-bearing, they were constructed thick, employing masonry and cladding techniques. Decorative elements were included on the front façades, while the side façades were left plain. Andesite and the volcanic red ignimbrite, both easy to work with, were frequently used in cladding and ornamental details (Oral Patacı, 2020).

Interior walls were thinner than the exterior walls and were constructed using a local technique known as çakatura. Also referred to as bağdadi, this method involved nailing thin wooden laths to both sides of a timber frame, filling the cavity, and finishing the surface with plaster. The term bağdadi originates from Baghdad, where the system is believed to have been developed, and it was often used for partitions and ceilings. Typically, laths were nailed 1–2 cm apart to the timber frame and covered with plaster, though the cavities could also be filled with

materials such as mudbrick, sand, gravel, or stone (Gökler, 2023). In the case of the Serhat Arslangörür House, these walls were filled with a mixture of small stones and sand.

The façades were enlivened with string courses and false columns, while elements such as corbels, jamb stones, keystones, and borders enhanced the plastic effect (Oral Patacı, 2020).

The harsh climatic conditions of the region also shaped architectural design. Due to heavy snowfall and long winters, porches with gable roofs were commonly added to building entrances. Windows were designed in rectangular form with double wooden frames, providing insulation against the cold. Double glazing reduced heat loss and improved interior comfort. Wooden flooring was generally preferred. Roofing solutions varied and included gable roofs, flat roofs, and hipped roofs (Oral Patacı, 2020). The Russians also sought stylistic diversity in using eaves, chimneys, and roof structures (Türkan & Durak, 2016).

A system known as the peç was employed for heating. Resembling a hybrid between a stove and a radiator, this installation consisted of metal doors and channels or pipes embedded within the walls, distributing heat throughout the interior (Erdoğan, 2018). In this system, smoke from the fire passed through pipes inside the walls, heating them before exiting through the chimney. The term PEÇ in Russian means stove or oven; in Russian-occupied Kars it was known as galanka (Rasimgil, 2017). Usually built of brick, these stoves also served as decorative features within rooms. Constructed most often at the intersection of two walls, they were sometimes elaborated with ornamental details. By projecting outward from the wall surface, they created a visually striking focal point within the interior (Erdoğan, 2018).

CASE STUDY: SERHAT ARSLANGÖRÜR HOUSE

The Serhat Arslangörür House provides a valuable example of the construction techniques and material characteristics of the Tsarist Russian period buildings in Ardahan. Built in 1906, this structure, reflecting Baltic architectural influence, is among the few surviving examples in Ardahan still used as residences today. Although a limited number of residential buildings from the Russian domination period remain in Ardahan, the Serhat Arslangörür House stands out as the only example that has preserved its structural integrity while continuing to serve as a dwelling. In this respect, it constitutes a significant case. The architectural style introduced by the Tsarist Russian period in Ardahan and Kars is clearly reflected in this house's façade, roof, spatial organization, construction technique, and materials.



(a) (b)

Figure 2. Exterior view of the residential section of the Serhat Arslangörür House (former annex) in its current state (a), and the rear façade of the section now used as commercial areas (former residential part) (b). Source: Photograph by the first author (2024).

Location and Significance

The Serhat Arslangörür House is located in the city center of Ardahan, on the main street, Kongre Street. Today, situated at one of the busiest points of the street, the building holds significance for urban memory. Figure 3 shows its central location and status as one of the rare surviving detached houses with a garden in Ardahan make it particularly important.



Figure 3. The location of the Serhat Arslangörür House in the city center of Ardahan Province. https://earth.google.com

According to information provided by Serhat Arslangörür, the house was originally built as a mansion by an Armenian family. Evidence for its construction date comes from an inscription stone once placed between the door and window on the street-facing façade. This

inscription indicated that the house was built in 1906. The stone was removed during later modifications, when the front façade was altered to create commercial shop units. It was subsequently embedded into the wall of a secondary structure in the garden built for storage purposes, to preserve it. The identity of the original owners remains unknown. According to Serhat Arslangörür, the property was purchased in 1948 by his father, Timur Arslan, from the politician Kahraman Arıklı (1893–1985). Since then, the house has been continuously used as a family residence by the Arslangörür family.

At the time of its construction, Kongre Street was predominantly lined with single- and two-story residential buildings. Today, the Serhat Arslangörür House is the only remaining residential structure on the street, which has since been entirely transformed into a commercial area. The street-facing façade of the house has been modified and divided into three separate commercial units. However, the portion of the building within the garden and the garden itself has preserved its integrity and continues to function as a residence. For this reason, the Serhat Arslangörür House was selected as a case study for this research.

Construction Techniques and Materials

The Serhat Arslangörür House reflects the architectural style influenced by Baltic architecture, which was introduced to the region during the Tsarist Russian period, particularly in its construction techniques and use of materials. The building is a two-story masonry structure. Its exterior walls were constructed mainly with cut basalt stone, with a thickness of approximately 70 cm. However, as shown in Figure 4(a), the load-bearing exterior walls at the rear of the building were constructed as rubble masonry walls. Unlike some other examples, stone ornamentation was applied not only on the street-facing façade but also on the garden-facing elevations. Figure 4(b) shows lintels and frames made of cut andesite stone above the window and door openings that remain visible today.



(a) (b)

Figure 4. The rubble masonry wall located on the rear façade of the building (a), lintels and frames made of finely cut andesite stones. (b).Source: Photograph by the first author (2024).

The interior walls, with a thickness of about 20 cm, were built using the çakatura (also known as bağdadi) construction technique. As seen in Figure 5(b), the interior walls in the lower floor, the çakatura walls consist of flat wooden laths nailed onto a timber frame, with the cavities filled with a mixture of small stones and sand. According to information provided by Serhat Arslangörür, the upper-floor walls were constructed using the same method, but instead of flat placement, the wooden laths were interwoven in a lattice-like form. All interior wall surfaces were finished with plaster.

The house's roof is a wooden hipped roof. Over time, it became deformed and was covered with sheet metal; however, the original roof was also covered with the same material. The chimneys were built of brick and enclosed with decorative sheet metal cladding, as seen in Figure 5(a). The original flooring of the building consisted of wooden coverings, and in the most recent restorations, this feature was preserved, with the floors once again finished in wood.



(a) (b)

Figure 5. Roof covering constructed in accordance with the original design and decorative sheet-metal chimney cladding (a), and the interior wall on the ground floor constructed with the çakatura/bağdadi technique, with the plaster removed (b). Source: Photograph by the first author (2024).

Spatial Layout and Usage

The original structural layout of the Serhat Arslangörür House consisted of a two-story main building facing Kongre Street and an annex/outbuilding located within the garden. The connection between these two structures was provided by a semi-open wooden passageway/bridge, covered with a roof but open on all sides. The annex section, smaller and narrower in plan compared to the main house, is the part that is still used as a residence today.

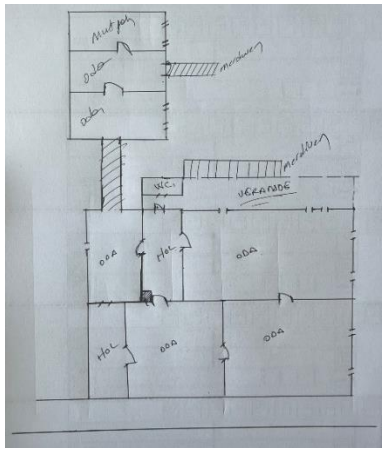


Figure 6. Sketch drawn by Serhat Arslangörür illustrating the spatial layout of the house after the renovations carried out in the 1960s. Source: Photograph by the first author (2024).

According to the original plan layout, the main entrance door on the left side of the façade facing Kongre Street opened into a hall. This main entrance was located on the upper floor of the building, accessible from the street by a staircase. The living room was to the right of the entrance hall, and further ahead was the kitchen. As seen in Figure 6, as in similar houses, circulation between the rooms was interconnected: from the living room to the bedroom, and from the bedroom to the sitting room. In the hallway to the right of the kitchen was a large PEÇ (heating stove), which provided heating for the entire house. Access to the lower floor was via a spiral staircase located in the kitchen. In its early use, this lower floor, which also contained a large stone fireplace, was believed to have been partly used as a wine cellar by Armenians.

Alterations and Transformations

After purchasing the house, Timur Arslan made various alterations in the 1960s. The wooden structure connecting the main house and the annex was enclosed with walls around its perimeter and beneath it, creating closed spaces. This way, the main building and the annex were combined into a single integrated structure. In addition, the portions of the street-facing façade that originally contained the living room and bedroom were modified and converted into commercial units. Following these alterations, no further changes were made to the house until the 1990s.



(a) (b) (c)

Figure 7. Stone cladding and wooden additions on the exterior façade for aesthetic purposes (a), wooden reinforcements and exposed load-bearing wall with removed plaster in the dining room interior (b), temporary reinforcements made in the basement (c). Source: Photograph by the first author (2024).

Later, in the 1990s, Serhat Arslangörür carried out a series of modifications and renovations. The parts designated for commercial use, the former annex, were separated by a wall, and the old main

house was completely transformed into commercial space. Meanwhile, the annex section was reconfigured by shifting the interior walls and opening a corridor slab, thus creating larger rooms and connecting it with the lower floor to form the present-day duplex detached residence. After being used in this way for a long period, some of the ceilings in the rooms suffered water damage due to heavy rains and gradually deteriorated. Renovations were undertaken inside and outside the house for aesthetic purposes and structural reinforcement. As seen in Figure 7(b), 10–15 cm thick wooden posts were placed in the corners of the rooms, with horizontal timber beams fixed on top to support the ceilings. The load-bearing exterior walls, originally built of rubble masonry, were clad with mosaic-patterned stone for decorative purposes, while wooden frames, which are seen in Figure 7(a), were added around the window and door openings. These wooden additions had no structural function. At the same time, the plaster on the dining room walls on the lower floor was removed, exposing the natural appearance of the rubble masonry walls as seen in Figure 7(b).

In the basement beneath the commercial areas, the ceiling-forming the slab of the ground floor-partially collapsed in some places. To support the slab, wooden and metal posts were installed as seen in Figure 7(c). Although these vertical and horizontal reinforcements provide a temporary solution, restoration or proper structural strengthening of these areas is necessary to prevent further collapse. Through such renovations, the Serhat Arslangörür House took on its present form. Figure 8 shows the commercial units created through all the alterations of the Serhat Arslangörür House, as well as the current condition of the staircase and kitchen area in the residential section.



(a) (b) (c)

Figure 8. The front façade of the building, currently divided into three commercial units (a), the wooden staircase located inside the section used as a residence today (b), and the kitchen area (c). Source: Photograph by the first author (2024).

CONCLUSION

This study examined the architectural development of Ardahan within the framework of "priorities in architecture," revealing the key factors that have shaped its urban environment. The findings clearly demonstrate the decisive role of climate and geography: harsh winter conditions necessitated thick masonry walls, the PEÇ heating system, and protective porches, while the abundance of basalt, andesite, and ignimbrite in the region directly influenced construction techniques and aesthetic choices.

Political authority also emerged as a critical force guiding architecture. During the Ottoman period, the Turkish-Islamic tradition prevailed, with a castle-centered urban fabric and religious buildings at its core. Under Russian occupation, however, new priorities associated with the Baltic style appeared, such as grid-planned urban layouts, cut-stone façades, ornamental details, and symmetrical arrangements. These transformations illustrate that architecture responded not only to natural and material-based necessities but also to geopolitical and cultural objectives.

The Serhat Arslangörür House embodies this layered identity. As one of the few surviving detached garden residences, it clearly demonstrates the manifestation of Baltic architectural influence in Ardahan and has retained its structural resilience despite later interventions.

By situating Ardahan within both its natural and historical contexts, this study has evaluated the continuity and transformation of architectural identity in a frontier city through the priorities of climate, materials, culture, and politics. Preserving such architectural examples is of great importance not only for the continuity of tangible heritage but also for understanding the complex dynamics that have shaped Ardahan's architectural identity.

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THE IMPACT OF BUILDING FORM COMPACTNESS AND ORIENTATION ON ENERGY EFFICIENCY IN DIFFERENT CLIMATE REGIONS

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ABSTRACT

A building's energy requirement refers to two main components of technical and architectural choices that can be applied during design planning process. Location, microclimate, shape, size and the direction of the building can all have a profound impact on the energy demand of the building. The form factor index and compression ratio of buildings (the ratio of the building envelope surface area to the heated internal volume (A/V), compared to its size-dependent index) regardless of thermal transfer can have a substantial effect on the cooling and heating demands. Compactness is the design performance indicator that affect heating load and overheating in building morphology. As a result, diverse cooling and heating energy requirements are simply divided. Compactness ratio represents 3D volume efficiency of a building, so the more compact the building is, the lower energy is required. This paper offers a deeper insight into the influence of form factor index on a building's heating demands. In this regard, the energy demand of a cubic building with 8 meters length and two stories with different orientations that receive solar radiations in different geographical latitudes and diverse climates but with the same technical characteristics is simulated by CASANOVA software. Moreover, the optimal solar orientation is determined as well as the cooling and heating energy demands are compared.

Keywords: Climatic Architecture, Energy Efficiency, Building Form, Compactness, Orientation

INTRODUCTION

The form and method of the building's settlement play a key role in their energy use. In the meantime, the usage of architectural solutions for exploitation of energy in the process of design and execution, causes the decrease of energy use in the stage of buildings keeping. One of Givoni's articles (1981) which emphasizes on deactivated energy concordant systems in architecture, states that the productivity of the building's energy depends not only on thermal indicators and capacities of used materials, but also it depends on the form, orientation, regulating transparent constructional mantle, the façade's paint and amount of solar radiation too.

In another research intermediated by Parasonis & Kezikas (2010) the possibility of decrease in the request of floored residential buildings' energy is pointed out. It means that in spite of no changes in the physical indicators of building, any changes in the form of the building results in energy loss. The usage of energy in buildings depending on volume and plan solutions, may be stated according to various standards which include: concerned national laws, international systems like assessing system of deactivated houses (Schneider ,2003), the American LEEDS system (the inducting system in energy and environmental design), the German DGNB system, the English BREEAM system (method of environmental evaluation) and etc. According to the energy output strategy in constructional systems, buildings must have the exigencies of near to zero standards of energy usage before 2020. Therefore, in volume designation of buildings the main emphasis is on architectural solutions which emphasize on high energy usage and the decrease of energy sources' usage.

Evaluation Criteria of Building's Geometrical Indexes

Generally architectural approaches depend on the building type, the building location and environment, aesthetical aspects and the functions which are linked with special parts and ratios of the volume. If the discussion for the request of energy use is proposed, the components and combinations in contact with compaction, attract more importance towards themselves. Because the ratio of surface totality which is on the outer side of the building and also the limited area of inner heating space is studied.

On the other hand, the life cycle of a building includes a lot of stages from building to maintenance and destruction. Therefore, in the stages of building and destruction, compaction directly effects the amount of energy used. Because the amount of building materials and following them the amount of energy needed for extraction, process,

transportation and using them in order to build depend on the maximum possibility of the building for maximum usage of the effective floor's ground surface. This means that creating maximum inner surfaces in the floors of the building with high volume but lesser outer surfaces results in high energy usage and a decrease in thermal loss. Hegger et al and some other scientists (2008) have studied the outer surfaces of many three-dimensional forms with the same volume which is shown in figure 1.

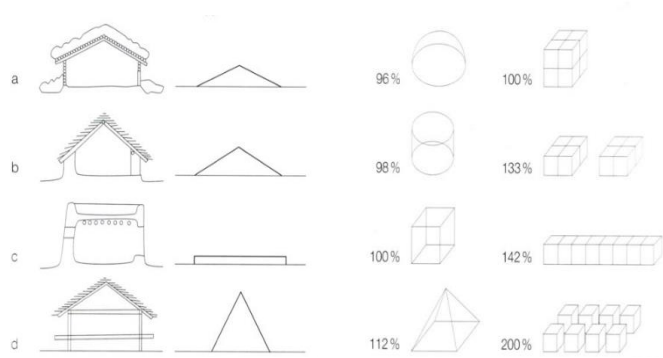


Figure 1. Typology of traditional buildings in cooperation with territorial areas (right) A: cold. B: temperate c: dry d: tropical; Transfer of thermal losses of three-dimensional forms with the same volume (left) (Hegger et al, 2008)

In order to distinguish the compactness amount there should be a standard for evaluation. So, the permissible compactness of existing approaches is compared with the maximum amount of compactness (square compaction). For this purpose, some strategies about this topic are pointed out. For example, Aksoy & Inally (2006) point out the issue of volume as Shape Factor (SF) in order to study the effects of form on the amount of energy needed which expresses the length ratio to the depth of a one floored building. Whereas Bostancioghlu who have studied the effects of shape, energy and the expenses of life cycle by comparing rectangular buildings such as H like and star shaped with the same measurements attracts the attention towards outer walls (façade) area ratio comparing to main floor's ground area. However, the A/S ratio stated by Gonzalo and Habermann (2008) or Hegger et al's A/V (exterior surface area to the internal volume) ratio, generally is considered more than other ideas and more widely because of linked amounts with volume study. Nevertheless, both of them emphasize on the importance of building's outer covering's surface ratio in contact with the linked inner volume.

On the other hand, very small structures (like individual up-country houses have a considerable amount of outer surface in comparison with volume, comparing to larger buildings. For instance, a compactness equal with 0.7 is considered as a high limit in small residential buildings (in the central Europe climate) which with the aim of reaching standards of a deactivated house can possibly be uneconomical (or including extra costs) (Ruckert et al., 2010). On the contrary as buildings become bigger, more flexibility is created in resulting a compactness ratio which stops the exorbitant decrease of thermal function. Therefore, the more a building is compacted the less energy it will need. Moreover, building's outer covering surface is more vital comparing to the building's inner volume (A/V) or the same compactness amount for checking the energy balance. So, evaluation of building's volume compactness amount must happen without any changing tools and any capability of relocating or removal of other good architectural aspects.

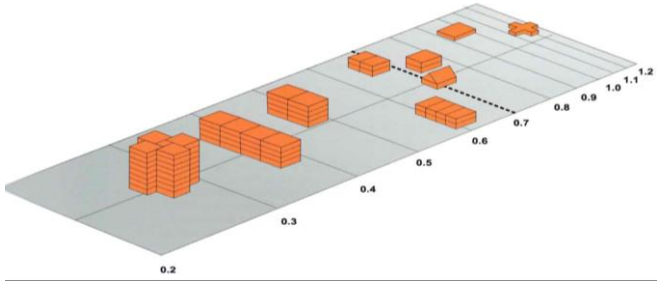


Figure 1. The compactness ration of different types of buildings: The compactness ratio with economical costs in small buildings with less than 0.7(m2/m3). (Hopfe, 2015)

Building Orientation

The way a building is placed facing the direct solar radiation, plays and important part in the thermal need of the building and also in the organization of building's inner spaces (Depecker et al., 2001). In the North Pole, the south front is known as the most important constructional front which produces energy by interacting with the energy of direct solar radiation. So, the more constructional elongation is vertical to magnetic south the more solar energy is produced. With the deviation of main constructional direction from the magnetic south to the west or the east, the solar inception decreases. But the evaluation of amount of received solar radiation with other factors effective on the energy request of building fitting with the desired climate should be considered. By knowing this determining, the optimal azimuth (in order to have optimal placement) for the main zone of the building will depend on the climate too.

Research Methodology

This research is intended to focus on building physics and energetic contribution of the given cubic form-as the simplest architectural form-than other aspects like aesthetical issues, so a two floored cubic building with equal known constructional elements and in different geographical areas with various climates chosen, is studied for its thermal and no thermal energy requests siding with the request for initial energy and final no thermal energy with solar energy usable in different azimuths(0 to 45 eastern degree and also 0 to 45 western degree) with 15 degree steps by using an energy simulator software named Casanova in order to specify the optimal azimuth of assumed places for receiving optimal solar radiation with the least amount of thermal loss.

The validated CASAnova simulation program, is an educational software which is provided by division of building physics & solar energy of Siegen University, Germany available as free software through its official website (URL 1). This program is one of the simplest, fastest and most powerful programs which starts with building form setting within related constructional details for different locations around the world. Other programs like Design Builder might be compared with this program but with more details and complexity and without considering to the compactness and form comparison. Furthermore, CASAnova presents professional energetic contribution of the designed forms to compare with other forms and to make a better decision for form selection as well. CASAnova is used for heating and cooling energy demand as well as the temperature behavior in buildings can be used intuitively in order to understand the relations between building geometry, orientation, thermal insulation, glazing, solar heat gains, heating demand, heating and primary energy as well as overheating in summer. Casanova has an ability for adjustment and changing more than 20 different parameters. The calculation of heating demand - shown in the diagrams and the tables- is based on the European norm EN 832. Casanova uses building shapes of rectangular form for which in a monthly balance transmission and ventilation losses as well as solar and internal gains are calculated. Heating demand is the difference between energy losses and energy gains of the building. Finding optimum azimuth for energy efficiency for all of the selected cities for minimum energy loss (hearing or cooling within the optimum solar gain) can be developed for similar cases.

Case Studies

A two-story cubic building with 8 meters long and an infrastructure 68 square meters big, 102.4 heated floor area surface, with an inner air volume of 409.6 cubic meters big which holds a 0.75 compactness amount and in 9 different geographical locations around the world. The cities' selection is based on choosing cities from different climates and both hemispheres to compare their energy demands regarding energy losses and energy gains. The cities are: Delhi (India), Los Angeles (US), Tokyo (Japan), Seville (Spain), Rome (Italy), Freiburg (Germany), Murmansk (Russia), Nairobi (Kenya) and Sydney (Australia) with the same constructional materials and elements is studied. The details about climate type of the mentioned cities are as following:

-Delhi: Delhi is located in the central of India and has extreme climate situation with very hot in summers and cold in winters. Most of the months, you can experience hot and humid temperature in the capital city. Delhi climate is an overlap between monsoon-influenced humid subtropical (Köppen climate classification Cwa) and semi-arid (Köppen climate classification BSh), with high variation between summer and winter temperatures and precipitation (URL 2, URL 3).

- Los Angeles: The Climate of Los Angeles is a year-round mild-to-hot and mostly dry climate for the LA metropolitan area in California. The climate is classified as a Mediterranean climate, which is a type of dry subtropical climate. It is characterized by seasonal changes in rainfall—with a dry summer and a winter rainy season. Under the modified Köppen climate classification, the coastal areas are classified as Csb, and the inland areas as Csa (URL 4).

-Tokyo: The former city of Tokyo and the majority of mainland Tokyo lie in the humid subtropical climate zone with hot humid summers and generally mild winters with cool spells. Annual rainfall averages nearly 1,530 millimeters (60.2 in), with a wetter summer and a drier winter (URL 5).

-Seville: Seville has a subtropical Mediterranean climate (Köppen climate classification Csa), featuring very hot, dry summers and mild, wet winters. Like most Mediterranean climates, Seville has a drier summer and wet winter (URL 6).

-Rome: Rome and its metropolitan area has a Mediterranean climate (Köppen climate classification: Csa), with mild winters and warm to hot summers. According to Troll-Paffen climate classification, Rome has a warm-temperate subtropical climate (URL 7).

-Freiburg: Temperatures in the winter tend to be mild, while summer temperatures are moderate. The Köppen Climate Classification subtype for this climate is "Cfb". (Marine West Coast Climate). The average temperature for the year in Freiburg is 50.0°F (10°C) (URL 8).

-Murmansk: Climate Murmansk features a subarctic climate (Köppen Dfc), with long and cold winters and short, cool summers. In the city, freezing temperatures are routinely experienced from October to May. Average temperatures exceed 0 degrees Celsius only from May through October (URL 9).

-Nairobi: Temperatures in the winter tend to be mild, while summer temperatures are moderate. The Köppen Climate Classification subtype for this climate is "Cfb". (Marine West Coast Climate). The average temperature for the year in Nairobi is 67.0°F (19.4°C) (URL 10).

Sydney: Sydney enjoys a sunny climate with mild winters and warm summers, perfect for making the most of the outdoors. Plan ahead with this information on temperature and rainfall. During summer, average temperatures range from 18.6 - 25.8°C (65.5 - 78.4°F), and average humidity spikes to 65% (URL 11).

The given form for all the 9 selected cities is the same. But latitudes, longitudes and climates are different. In other words, needed information regarding energy efficiency under the effect of building compactness and orientation provided enough in case studies part and tables. For more details, see table 1 and table 2.

Table 1. Building Specifications

Space, Quantity, Ratio	**Value (Unit)**
Ground Area	64m^2
Heated Floor Area	102.4 m^2
Total Volume	512m^3
Air Volume	409.6m^3
Compactness (A/V)	0.75 (m^{-1})

Windows Characteristics		
Windows Location	Windows Area (m^2)	Fraction of Wall (%)
North	3.2	5
South	25.6	40
East	3.2	5
West	3.2	5

Table 2. Geographical and Energetic Specifications of Selected Case Studies

Location	Latitude	Azimuth Deviation from the South	Primary Energy Demand (kWh/m²a)		Heat Energy Demand (kWh/m²)	End Energy Demand for Cooling (kWh/m²)	Cooling Demand (kWh/m²)	Usable Solar Gain	
			Heating (kWh/m²)	Cooling (kWh/m²)				Absolute (kWh/m²)	Specific (kWh/m²)
1-New Delhi (India)	28° 36' N	0°	13.4	156.2	0.7	52.1	130.1	1847	18.0
		15° E	13.4	161.4	0.7	53.8	134.5	1853	18.1
		30° E	13.5	167.5	0.8	53.8	139.6	1837	17.9
		45° E	13.7	172.3	1.0	57.4	143.6	1797	17.5
		15° W	13.6	152.7	0.9	50.9	127.2	1818	17.8
		30° W	13.9	151.6	1.1	50.5	126.3	1766	17.2
		45° W	14.3	151.5	1.4	50.5	126.3	1711	17.7
		30° W	13.9	151.6	1.1	50.4	126.3	1766	17.2
2- Los Angles (USA)	34° 02' N	0°	17.8	15.7	4.4	5.2	13.0	5080	49.6
		15° E	17.4	18.5	4.1	6.2	15.4	5138	50.2
		30° E	17.6	22.8	4.2	7.6	19.0	5126	50.1
		45° E	18.1	28.1	4.7	9.4	23.4	5070	49.5
		15° W	18.6	14.5	5.1	4.8	12.1	4977	48.6
		30° W	19.8	15.0	6.1	5.0	12.5	4843	47.3
		45° W	21.0	15.9	7.1	5.3	13.3	4713	46.0
		13° W	18.5	14.6	5.0	4.9	12.1	4995	48.8
3-Tokyo (Japan)	35° 41' N	0°	72.0	18.5	50.0	6.2	15.4	5535	54.1
		15° E	70.8	19.2	49.1	6.4	16.0	5640	55.1
		30° E	71.4	20.6	49.6	6.9	17.1	5593	54.6
		45° E	73.1	22.2	51.0	7.4	18.5	5444	53.2
		15° W	74.4	18.7	52.1	6.2	15.6	5312	51.9
		30° W	77.6	19.3	54.7	6.4	16.1	5030	49.1
		45° W	80.6	19.9	57.3	6.6	16.6	4760	46.5
		19° E	70.8	19.5	49.0	6.5	16.2	5648	55.2
4-Seville (Spain)	37° 23' N	0°	25.4	59.3	10.9	19.8	49.4	4926	48.1
		15° E	25.1	62.6	10.6	20.9	52.1	4970	48.5
		30° E	26.0	68.0	11.3	22.7	56.7	4886	47.7
		45° E	27.6	73.2	12.7	24.4	61.0	4725	46.1
		15° W	26.9	58.5	12.1	19.5	48.7	4778	46.7
		30° W	29.0	59.9	13.9	20.0	49.9	4561	44.5
		45° W	31.4	61.7	15.9	20.6	51.4	4327	42.3
		9° W	26.1	58.5	11.4	19.5	48.8	4853	47.4
5-Rome (Italy)	41° 53' N	0°	51.4	34.9	32.7	11.6	29.1	6134	59.9
		15° E	50.5	37.5	31.9	12.5	31.2	6224	60.8
		30° E	51.5	42.3	32.8	14.1	35.2	6144	60.0
		45° E	53.5	47.3	34.5	15.8	39.4	5962	58.2
		15° W	53.9	34.9	34.8	11.6	29.1	5903	57.6
		30° W	57.4	36.4	37.8	12.1	30.4	5573	54.4

	45° E	61.3	37.9	41.1	12.6	31.6	5219	51.0
	12° E	50.6	36.7	32.0	12.2	30.6	6215	60.7
6-Feiburg 48° 04' N	0°	145.9	4.5	112.2	1.5	3.7	6705	65.5
	15° E	144.4	5.2	111.0	1.7	4.3	6844	66.8
	30° E	144.6	6.5	111.1	2.2	5.4	6842	66.8
	45° E	146.3	8.1	112.6	2.7	6.7	6701	65.4
	15° W	148.5	4.5	114.5	1.5	3.7	6467	63.2
	30° W	151.8	4.8	117.2	1.6	4.0	6179	60.3
	45° E	155.1	5.0	120.0	1.7	4.2	5894	57.6
	14° E	144.4	5.1	111.0	1.7	4.2	6839	66.8
7-Murmansk 68° 57' N	0°	369.6	0.2	300.5	0.1	0.2	8260	80.7
	15° E	367.7	0.2	298.9	0.1	0.2	8428	82.3
	30° E	367.2	0.2	298.5	0.1	0.2	8479	82.8
	45° E	367.3	0.2	298.7	0.1	0.2	8466	82.7
	15° W	372.2	0.2	302.8	0.1	0.2	8027	78.4
	30° W	375.4	0.2	305.5	0.1	0.2	7748	75.7
	45° E	378.9	0.2	308.4	0.1	0.2	7444	72.7
	29° E	367.0	0.2	298.4	0.1	0.2	8487	82.9
8-Nairobi (Kenya) 01° 17' S	0°	13.2	6.7	0.5	2.2	5.6	1485	14.5
	15° E	13.2	9.1	0.5	3.0	7.6	1486	14.5
	30° E	13.2	12.8	0.5	4.3	10.7	1495	14.6
	45° E	13.1	16.5	0.5	5.5	13.8	1516	14.8
	15° W	13.2	6.3	0.5	2.1	5.2	1486	14.5
	30° W	13.2	7.6	0.5	2.5	6.4	1489	14.5
	45° W	13.1	9.4	0.5	3.1	7.9	1496	14.6
	9-12°W	13.2	6.2	0.5	2.1	5.1	1486	14.5
9-Sydney 33° 52' S	0°	30.9	13.3	15.4	4.4	11.1	3246	31.7
	15° E	31.1	16.4	15.6	5.5	13.7	3228	31.5
	30° E	31.2	21.4	15.7	7.1	17.8	3228	31.5
	45° E	30.5	27.0	15.1	9.0	22.5	3315	32.4
	15° W	30.9	13.0	15.4	4.3	10.9	3249	31.7
	30° W	31.0	14.8	15.6	4.9	12.3	3233	31.6
	45° W	31.2	17.0	15.7	5.7	14.1	3222	31.5
	12° W	30.8	12.9	15.4	4.3	10.7	3250	31.7

Considering two cities including Delhi with exceedingly warm climate and Murmansk with extremely cold climate allocate the most requirement to cooling and heating energy among 9 considered cities sequentially. So, receives and heat losses of these two cities presented in optimal orientation of the building with charts and analytical more-detailed diagrams. As previously mentioned, according to square cube dimensions with 8-meter length, compression measure equals 0.75 which is corresponding with compacting square cube reference. This value is also 25% higher than the best compression ratio for the spherical form of the cubic volume. (See figure 3)

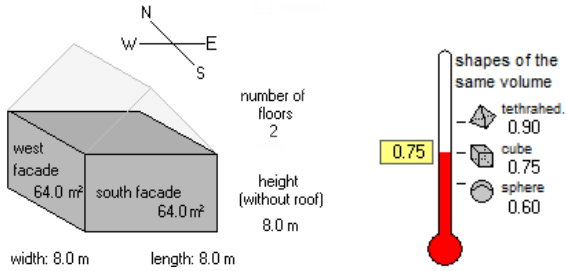
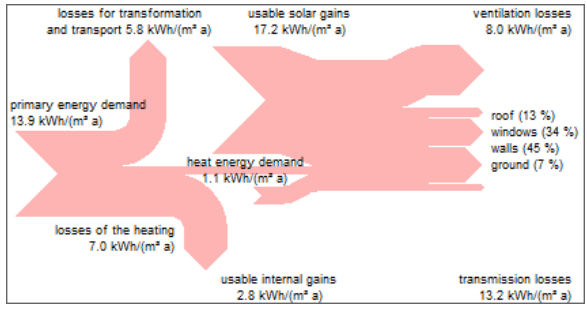


Figure 3. Schematic diagram of two-story cube-shaped structure (8*8*8 m) [left] and Comparison of the supposed cube compression with the reference forms of the pyramid, cube and butter with the same volume's [right]

Murmansk's annual heating energy and heating losses' requirement is about 271 and 4 times more than New Delhi respectively; So that the annual heating of each square meter of this building volume in New Delhi is only 1.1 KWh/m^2 which it requires the minimum energy while Murmansk with 298 KWh/m^2 usage, require increasing insulating layers and usage of heavier materials with exceeding thermal mass. On the contrary, the demand for Delhi's cooling energy is 505 times higher than Murmansk. In overall, difference in thermal demand (includes heating/ cooling) of these two cities is 246.9 KWh/m^2 which means Murmansk's energy supply is harder and more costly that New Delhi. (See figure 4, figure 5)



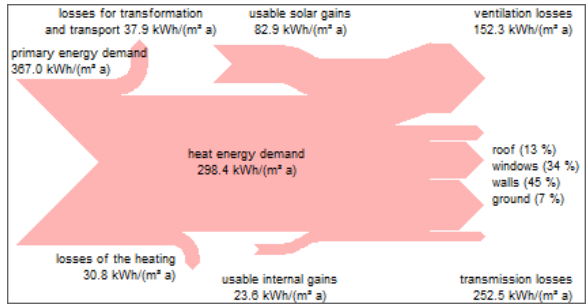
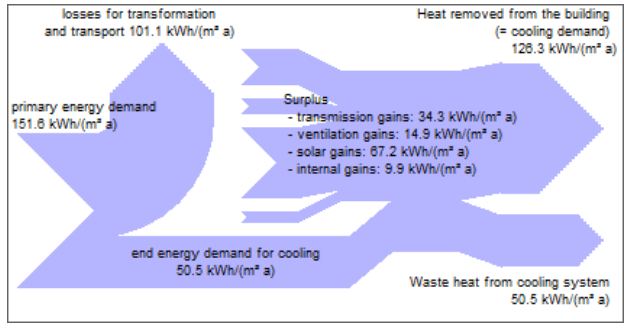


Figure 4. Comparative diagrams of heating energy required between New Delhi of India (left) and Murmansk of Russia (right)



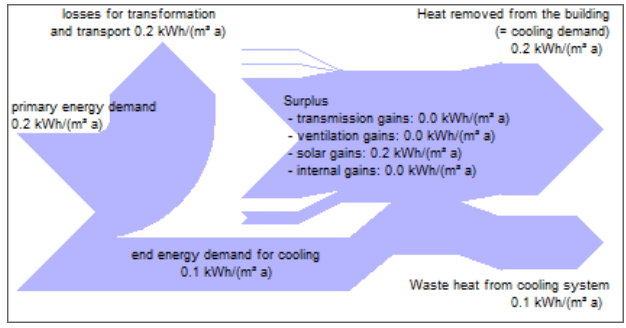
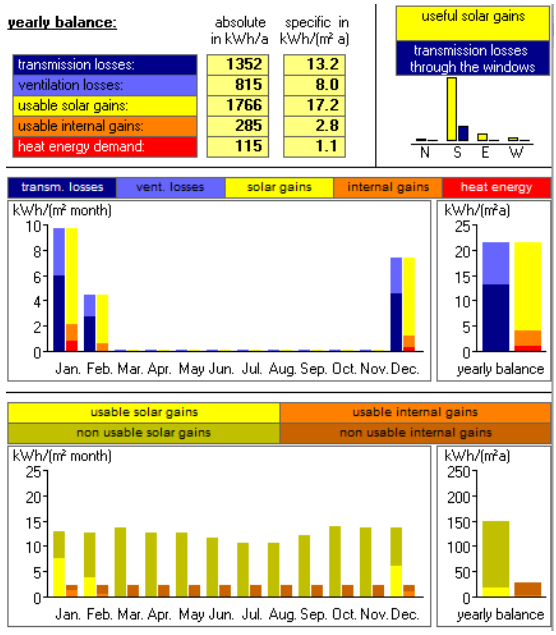


Figure 5. Comparative diagrams of cooling energy required between New Delhi of India (left) and Murmansk of Russia (right)

Although windows' heating losses in Murmansk is about 19 times higher than New Delhi, the amount of solar power available in Murmansk is 4.8 times higher than Delhi for every m^2; which can play a significant role in supplying the high energy demand of Murmansk. (See figure 6)

Although the average monthly warming day in New Delhi throughout the year except from December to February is high, the annual average of this equals 18 h/d (hours per day), while in Murmansk, except for July with a very little value, this amount is close to zero; And so, the total annual cooling rate of New Delhi is much higher than Murmansk. (See figure 7)



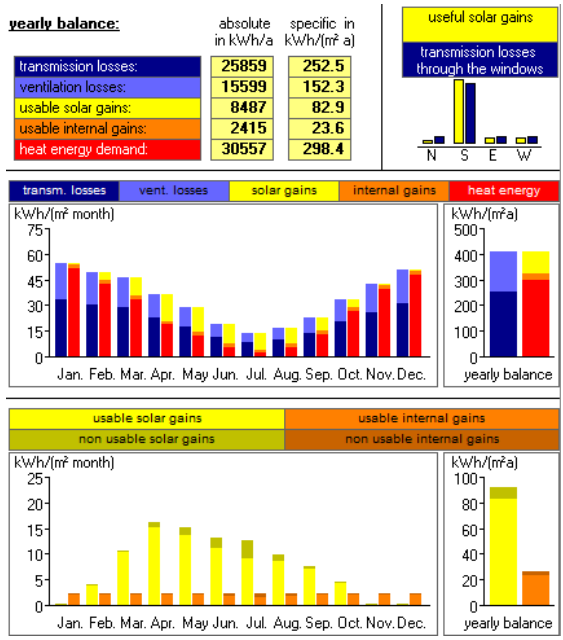


Figure 6. Comparative diagrams of heat losses/ heating energy requirement/ usable solar receipts in New Delhi (up) and Murmansk of Russia (down)

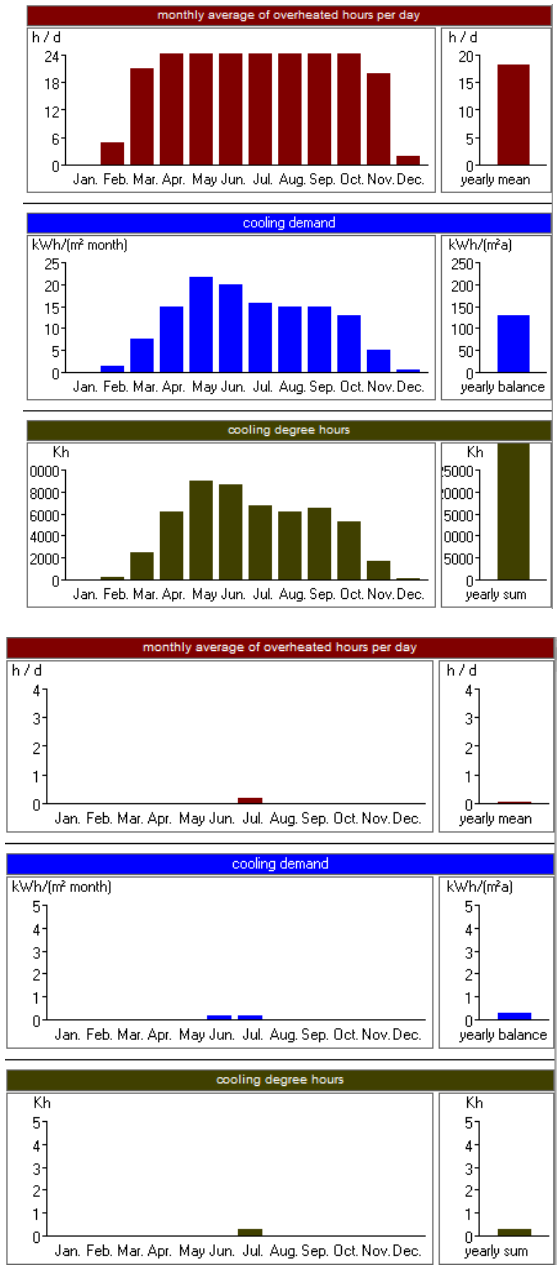


Figure 7. Comparative diagrams of the warm days of the year/ cooling energy requirement/ annual cooling degree in New Delhi (up) and Murmansk of Russia (down)

DISCUSSION AND RESULTS

In spite of the fact that the constructional compactness is 0.75 in 9 different geographical zones, because of being placed in 9 various climates and variable intensity of solar radiation, a changeable energy request is mentioned. On the other hand, the optimal intensity of solar radiation with the minimum thermal loss is produced with the help of optimized azimuth. The resulting studies show the orientation up to 30 degrees to the east (for warm or bowed to be warm climates) and 30 degrees to the west for cold climates. And for energy request in climates like the New Delhi in India, the need for thermal energy is at its minimum while there is a higher request for non-thermal energy. However, the non-thermal climate of Murmansk in the northern part of Russia with non-thermal need of 300 kilowatt hours per square meter, is the highest amount and with 0.2-kilowatt hour per meter has the least amount of need for non-thermal energy between the mentioned 9 cities. In general, despite the fact that even cubic forms, due to their optimum compression ratio, lead to lower energy losses, due to the variable thermal energy demand of buildings associated with their performance, the amount of solar power used should be increased. This is accomplished with two variables of the optimal orientation of the sun-linked building with the local climate, on the one hand, and pulling the southern side of the building along with improving the insulation of the outer walls.

CONCLUSION

This paper seeks to provide a deeper understanding about the effect of the compactness index with various azimuths on the thermal demand of a building. Therefore, the energy requirement of a two-story, 8-meter-long, cubic building with various building orientations for solar reception in different latitudes from countries located in the Mediterranean Sea to near the North Pole, including various climates and the same technical characteristics, is compared analytically with simulated computer software, while determining the optimal solar azimuth of the building, their heating/cooling energy requirement is determined. This research shows that choosing the appropriate building form and orientation can have a significant impact on reducing energy consumption. More compact forms and appropriate orientation not only reduce energy consumption but also increase thermal comfort for users. In other words, buildings with higher compactness ratios generally release less heat through the envelope. Also, the use of simulation tools is essential to predict the energy performance of buildings in the early stages of design. By understanding these factors, architects and builders can better design structures that not only meet energy efficiency goals but

also adapt to the unique challenges posed by their specific environments.

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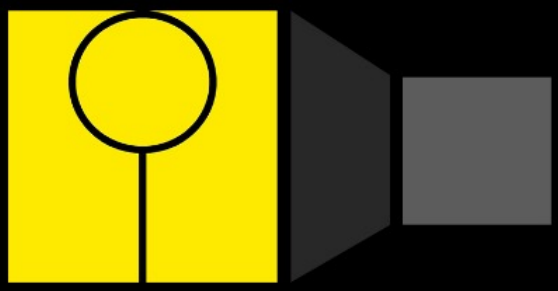
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